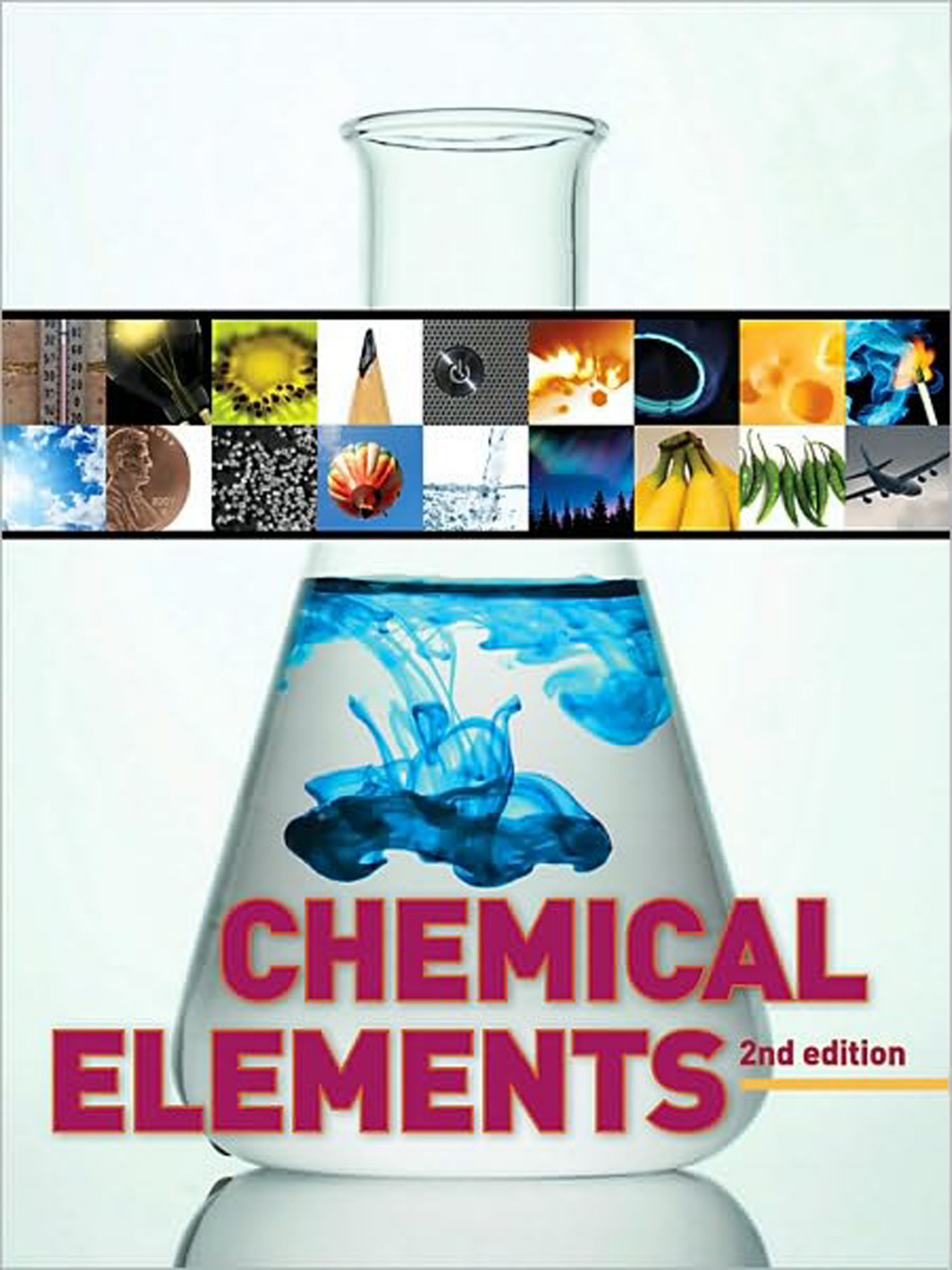

CHEMICAL ELEMENTS

2nd edition

Chemical Elements

2nd Edition

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2nd Edition

David E. Newton
Kathleen J. Edgar, Editor

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Main–Group Elements

Atomic number	86	[222]	Atomic weight
Symbol	Rn		
Name	radon		

Transition Metals

Period	1 I A	2 II A	3 III B	4 IV B	5 V B	6 VI B	7 VII B	8	9 VIII B
1	1 1.00794 H hydrogen								
2	3 [6.941] Li lithium	4 9.012182 Be beryllium							
3	11 22.98976928 Na sodium	12 24.3050 Mg magnesium							
4	19 39.0983 K potassium	20 40.078 Ca calcium	21 44.955912 Sc scandium	22 47.867 Ti titanium	23 50.9415 V vanadium	24 51.9961 Cr chromium	25 54.938045 Mn manganese	26 55.845 Fe iron	27 58.933195 Co cobalt
5	37 85.4678 Rb rubidium	38 87.62 Sr strontium	39 88.90585 Y yttrium	40 91.224 Zr zirconium	41 92.90638 Nb niobium	42 95.96 Mo molybdenum	43 [98] Tc technetium	44 101.07 Ru ruthenium	45 102.90550 Rh rhodium
6	55 132.9054519 Cs cesium	56 137.327 Ba barium	57–71 * lanthanoids	72 178.49 Hf hafnium	73 180.94788 Ta tantalum	74 183.84 W tungsten	75 186.207 Re rhenium	76 190.23 Os osmium	77 192.217 Ir iridium
7	87 [223] Fr francium	88 [226] Ra radium	89–103 † actinoids	104 [261] Rf rutherfordium	105 [262] Db dubnium	106 [266] Sg seaborgium	107 [264] Bh bohrium	108 [277] Hs hassium	109 [268] Mt meitnerium

*Lanthanoids	57 138.90547 La lanthanum	58 140.116 Ce cerium	59 140.90765 Pr praseodymium	60 144.242 Nd neodymium	61 [145] Pm promethium	62 150.36 Sm samarium
†Actinoids	89 [227] Ac actinium	90 232.03806 Th thorium	91 231.03588 Pa protactinium	92 238.02891 U uranium	93 [237] Np neptunium	94 [244] Pu plutonium

Color Key

- alkali metals
- alkaline earth metals
- transition metals
- inner-transition metals
- metalloids
- other metals
- other non-metals
- halogens
- noble gases
- under review
- not yet discovered

Main–Group Elements

10	11 I B	12 II B	13 III A	14 IV A	15 V A	16 VI A	17 VII A	18 VIII A
								2 4.002602 He helium
			5 10.811 B boron	6 12.0107 C carbon	7 14.0067 N nitrogen	8 15.9994 O oxygen	9 18.9984032 F fluorine	10 20.1797 Ne neon
			13 26.9815386 Al aluminum	14 28.0855 Si silicon	15 30.973762 P phosphorus	16 32.065 S sulfur	17 35.453 Cl chlorine	18 39.948 Ar argon
28 58.6934 Ni nickel	29 63.546 Cu copper	30 65.38 Zn zinc	31 69.723 Ga gallium	32 72.64 Ge germanium	33 74.92160 As arsenic	34 78.96 Se selenium	35 79.904 Br bromine	36 83.798 Kr krypton
46 106.42 Pd palladium	47 107.8682 Ag silver	48 112.411 Cd cadmium	49 114.818 In indium	50 118.710 Sn tin	51 121.760 Sb antimony	52 127.60 Te tellurium	53 126.90447 I iodine	54 131.293 Xe xenon
78 195.084 Pt platinum	79 196.966569 Au gold	80 200.59 Hg mercury	81 204.3833 Tl thallium	82 207.2 Pb lead	83 208.98040 Bi bismuth	84 [209] Po polonium	85 [210] At astatine	86 [222] Rn radon
110 [271] Ds darmstadtium	111 [272] Rg roentgenium	112 [285] Cn copernicium	113 [284] Uut ununtrium	114 [289] Uuq ununquadium	115 [288] Uup ununpentium	116 [293] Uuh ununhexium	117 Uus ununseptium	118 [294] Uuo ununoctium

Inner–Transition Metals

63 151.964 Eu europium	64 157.25 Gd gadolinium	65 158.92535 Tb terbium	66 162.500 Dy dysprosium	67 164.93032 Ho holmium	68 167.259 Er erbium	69 168.93421 Tm thulium	70 173.054 Yb ytterbium	71 174.9668 Lu lutetium
95 [243] Am americium	96 [247] Cm curium	97 [247] Bk berkelium	98 [251] Cf californium	99 [252] Es einsteinium	100 [257] Fm fermium	101 [258] Md mendelevium	102 [259] No nobelium	103 [262] Lr lawrencium

Contents

Contents: Elements by Atomic Number

Elements are listed in order by atomic number. Volume numbers appear in ***bold-italic type*** followed by the page numbers.

Contents: Elements by Family Group

Bold-Italic type indicates volume numbers.

LANTHANOIDS

ACTINOIDS

Reader's Guide

Many young people like to play with Lego blocks, erector sets, and similar building games, including virtual games found on the Internet. It's fun to see how many different ways a few simple shapes can be put together.

The same can be said of chemistry. The world is filled with an untold number of different objects, ranging from crystals and snowflakes to plant and animal cells to plastics and medicines. Yet all of those objects are made from various combinations of only about 100 basic materials: the chemical elements.

Scientists have been intrigued about the idea of an "element" for more than 2,000 years. The early Greeks developed complicated schemes that explained everything in nature using only a few basic materials, such as earth, air, fire, and water. The Greeks were wrong in terms of the materials they believed to be "elemental." But they were on the right track in developing the concept that such materials did exist.

By the 1600s, chemists were just beginning to develop a modern definition of an element. An element, they said, was any object that cannot be reduced to some simpler form of matter. Over the next 300 years, research showed that about 100 such materials did exist. These materials range from such well-known elements as oxygen, hydrogen, iron, gold, and silver to substances that are not at all well known, elements such as neodymium, terbium, rhenium, seaborgium, darmstadtium, and copernicium.

By the mid-1800s, the search for new chemical elements had created a new problem. About 50 elements were known at the time. But no one yet knew how these different elements related to each other, if they did at all. Then, in one of the great coincidences in chemical history, that question was answered independently by two scientists at almost the same time, German chemist Lothar Meyer (1830–1895) and Russian chemist Dmitri Mendeleev (1834–1907). (Meyer, however, did not publish his research until 1870, nor did he predict the existence of undiscovered elements as Mendeleev did.)

Meyer and Mendeleev discovered that the elements could be grouped together to make them easier to study. The grouping occurred naturally when the elements were laid out in order, according to their atomic weight. Atomic weight is a quantity indicating atomic mass that tells how much matter there is in an element or how dense it is. The product of Meyer and Mendeleev's research is one of the most famous visual aids in all of science, the periodic table. Nearly every classroom has a copy of this table. (A copy is available in this book just before the table of contents.) It lists all of the known chemical elements, arranged in rows and columns. The elements that lie within a single column or a single row all have characteristics that relate to each other. Chemists and students of chemistry use the periodic table to better understand individual elements and the way the elements are similar to and different from each other.

About *Chemical Elements, 2nd Edition*

Chemical Elements, 2nd Edition is designed as an introduction to the chemical elements. This new edition, presented in full color, updates the earlier three-volume set, providing new information about the elements as well as many new photographs.

Students will find *Chemical Elements* useful in a number of ways. First, it is a valuable source of fundamental information for research reports, science fair projects, classroom demonstrations, and other activities. Second, it provides more detail about elements and compounds that are only mentioned in other science textbooks or classrooms. Third, it is an interesting source of information about the building blocks of nature for those who simply want to know more about the elements.

Elements with atomic numbers 1 through 100 are presented in separate entries. The transfermium elements (elements 101 through 112) are covered in one entry, which also discusses six additional elements (113, 114, 115, 116, 118, and 122) that have yet to be confirmed by the International Union of Pure and Applied Chemistry (IUPAC).

Entry Format

Chemical Elements is arranged alphabetically by element name. All entries open with an overview section designed to introduce students to the basics of the element. Each entry then contains specific information in the following categories:

- Discovery and Naming
- Physical Properties
- Chemical Properties
- Occurrence in Nature
- Isotopes
- Extraction
- Uses
- Compounds
- Health Effects

In addition, the first page of each entry features a Key Facts section in the margin. Here, the element's chemical symbol, atomic number, atomic mass, family, and pronunciation are shown. A diagram of an atom of the element is also shown at the top of the page. In the diagram, the atom's electrons are arranged in various "energy levels" outside the nucleus. Inside the nucleus, the number of protons and neutrons is indicated.

Entries are easy to read and written in a straightforward style. Difficult words are defined within the text. Each entry also includes a "Words to Know" sidebar that defines technical words and scientific terms. This enables students to learn vocabulary appropriate to chemistry without having to consult other sources for definitions.

Special Features

Chemical Elements, 2nd Edition includes a number of special features that help make the connection between the elements, minerals, people who discovered and worked with them, and common uses of the elements. These features include:

- Nearly 300 photographs and illustrations, most in color, showcasing various elements, the products in which they are used, and the places in which they are found. Such imagery brings the elements to life. Black-and-white images of historical figures are also included.

- Sidebars discussing fascinating supplemental information about scientists, theories, uses of elements, and more.
- Extensive cross-references. Other elements mentioned within an entry appear in bold type upon first mention, serving as a helpful reminder that separate entries are written about these other elements.
- A periodic table (positioned right before the table of contents) that includes the following for each element: name, symbol, atomic number, and atomic mass. A color key also informs students about the various groupings of the elements.
- Three tables of contents—alphabetically by element name, by atomic number, and by family group. This presentation provides varied access to the elements.
- A timeline in each volume. This section details the chronology of the discovery of the elements.
- A cumulative Words to Know section in each volume. This section collects all the glossary terms used in the individual entries.
- A Where to Learn More section at the back of each volume. This bibliography provides information on books, periodicals, Web sites, and organizations that may be useful to those interested in learning more about the chemical elements.
- A comprehensive index that quickly points readers to the elements, minerals, and people mentioned in *Chemical Elements, 2nd Edition.*

A Note about Isotopes and Atomic Weights

Various authorities list slightly different isotopes for some elements. One reason is that the discovery of a new isotope may not yet have been confirmed by other researchers, so its existence is uncertain. Lists of isotopes may change also because new isotopes are being discovered from time to time. The number of isotopes, with a known half life, listed in this book is based on information available from the Lawrence Berkeley National Laboratory in Berkeley, California. The list is up to date as of December 2009. All stable isotopes exist in nature. Some radioactive isotopes also exist in nature, but the vast majority has been prepared synthetically in the laboratory.

The atomic weight information presented in the entries and periodic table is the latest available (at press time) from the International Union of

Pure and Applied Chemistry (IUPAC), the governing body that officially confirms and names any new elements. The IUPAC lists the atomic weight in brackets when an element does not have any stable nuclides. For example, the atomic weight of actinium is listed as [227]. This represents the mass of its longest-lived isotope.

Special Thanks

The project editor wishes to thank graphic artist Christine O'Bryan for the amazing job she did colorizing the atom diagrams and updating the periodic table. Thanks also to Robyn Young for working her magic in acquiring new images for this edition. Also thanks to Lemma Shomali for lending her content expertise to this set. All your efforts are greatly appreciated.

Comments and Suggestions

We welcome your comments on this work as well as suggestions for future science titles. Please write: Editors, *Chemical Elements, 2nd Edition*, U•X•L, 27500 Drake Rd., Farmington Hills, MI, 48331-3535; call toll-free: 800-347-4253; send fax to 248-699-8066; or send e-mail via http://www.gale.com.

Timeline: The Discovery of Elements

Assigning credit for the discovery of a new element is often a difficult and complicated process. First, many elements were in use well before recorded history. In some cases, these elements were known in the form of their compounds, but not as pure elements. Elements that fall into this category include carbon, copper, gold, iron, lead, mercury, silver, sulfur, tin, and, perhaps, zinc.

In addition, the discovery of an element has seldom been a single, clear-cut event that occurs in such a way that everyone agrees that "X" should receive credit for discovering the element. Instead, the first step in the process of discovery is often the recognition that a new substance has been found—a new mineral, rock, compound, or other material—that has properties different from anything previously known. This discovery may lead a chemist (or a number of chemists) to suspect the existence of a new element.

The next step may be to isolate the element, either in its pure form or, more commonly, as a compound, such as the oxide or sulfide of the new element. Finally, someone is able to prepare a pure sample of the element, which the world then sees for the first time. An example of this sequence of events can be seen in the elements that make up groups 1 and 2 of the periodic table. Most of those elements were known in one form or another for centuries. But it was not until the early 1800s that Sir Humphry Davy found a method for isolating the pure elements from their oxides.

The process becomes even more complicated when a truly new element is discovered which, sometime later, is found not to be a single element, but a mixture of two or more new elements. The story of the discovery of the rare earth elements is probably the best example of this process.

This sequence of events often takes place over an extended period of time, many years or even decades. For that reason, assigning a specific date to the discovery of an element can also be difficult. Does one choose the date and person when a new compound of the element is discovered, when the pure element itself is prepared, when the discoverer publicly announces his or her discovery, or when official confirmation of the discovery is announced?

For all these reasons, the dates and names listed below must be considered as somewhat ambiguous. For more detailed information about the discovery of each element, the reader should refer to the entry for that element in the main body of this set of books.

About 800 CE Persian natural philosopher Abu Musa Jābir ibn Hayyān al azdi (better known as Geber) is credited with discovering **antimony, arsenic,** and **bismuth**.

About 800 CE Indian metallurgist Rasaratna Samuchaya is perhaps the first person to recognize **zinc** as an element.

1250 German natural philosopher Albertus Magnus is credited as being the first European to discover **arsenic**.

About 1450 The apocryphal Basilius Valentinus (Basil Valentine) is the first European to mention elemental **antimony** and **bismuth**.

1526 Swiss physician Auroleus Phillipus Theostratus Bombastus von Hohenheim (Paracelsus) is acknowledged as the modern discoverer of **zinc**.

1669 German physician Hennig Brand discovers **phosphorus**.

1735 Swedish chemist Georg Brandt discovers **cobalt**.

1735–1748 Spanish military Leader Don Antonio de Ulloa discovers **platinum**.

1751 Swedish mineralogist Axel Fredrik Cronstedt discovers **nickel**.

1755 Scottish physician and chemist Joseph Black recognizes the presence of a new element in magnesia alba, later found to be **magnesium**.

1766 English chemist and physicist Henry Cavendish discovers **hydrogen**.

1771 Swedish chemist Carl Wilhelm Scheele discovers **oxygen**, but does not publish his discovery until 1777.

1772 Scottish physician and chemist Daniel Rutherford discovers **nitrogen**.

1774 Swedish chemist Carl Wilhelm Scheele discovers **chlorine**.

1774 Swedish mineralogist Johann Gottlieb Gahn discovers **manganese**.

1774 English chemist Joseph Priestley discovers **oxygen** and, because he announces his results almost immediately, is often credited as the discoverer of the element.

1781 Swedish chemist Peter Jacob Hjelm discovers **molybdenum**.

1782 Austrian mineralogist Baron Franz Joseph Müller von Reichenstein discovers **tellurium**.

1783 Spanish scientists Don Fausto D'Elhuyard and Don Juan José D'Elhuyard and Swedish chemist Carl Wilhelm Scheele discover **tungsten**.

1787 Scottish military surgeon William Cruikshank and Irish chemist and physicist Adair Crawford independently announce the probable existence of a new element, later found to be **strontium**.

1789 German chemist Martin Klaproth recognizes the presence of **uranium** in pitchblende, but does not isolate the element.

1789 German chemist Martin Klaproth discovers **zirconium**. The element is not isolated until 1824.

1791 English clergyman William Gregor discovers an oxide of **titanium**. German chemist Martin Klaproth makes a similar discovery four years later. The element is not isolated until 1910.

1794 Finnish chemist Johan Gadolin discovers **yttrium**.

1797 French chemist Louis-Nicolas Vauquelin discovers **chromium**.

1798 French chemist Louis-Nicolas Vauquelin discovers **beryllium**.

1801 English chemist Charles Hatchett discovers **niobium**.

1801 Spanish-Mexican metallurgist Andrés Manuel del Río discovers **vanadium**.

1802 Swedish chemist and mineralogist Anders Gustaf Ekeberg discovers **tantalum**.

1803 English chemist and physicist William Hyde Wollaston discovers **palladium**.

1803 Swedish chemists Jöns Jakob Berzelius and Wilhelm Hisinger and German chemist Martin Klaproth discover the black rock of Bastnas, Sweden, which led to the discovery of several elements. Berzelius and Hisinger originally assume the rock is a new element, which they name **cerium**.

1803 English chemist Smithson Tennant discovers **osmium** and **iridium**.

1804 English chemist and physicist William Hyde Wollaston discovers **rhodium**.

1807–1808 English chemist Sir Humphry Davy isolates a number of elements in a pure form for the first time, including **potassium, sodium, magnesium, barium, calcium**, and **strontium**.

1808 French chemists Louis Jacques Thênard and Joseph Louis Gay-Lussac discover **boron**. Davy isolates the element a few days after its discovery has been announced.

1811 French chemist Bernard Courtois discovers **iodine**.

1817 Swedish chemist Johan August Arfwedson discovers **lithium**.

1817 German chemists Friedrich Stromeyer, Karl Samuel Leberecht Hermann, and J. C. H. Roloff independently discover **cadmium**, a name chosen by Stromeyer.

1818 Swedish chemists Jöns Jakob Berzelius and J. G. Gahn discover **selenium**.

1823 Swedish chemist Jöns Jakob Berzelius discovers **silicon**.

1825 Danish chemist and physicist Hans Christian Oersted discovers **aluminum**.

1825 French chemist Antoine-Jérôme Balard and German chemist Leopold Gmelin independently discover **bromine**.

1829 Swedish chemist Jöns Jakob Berzelius discovers **thorium**.

1830 Swedish chemist Nils Gabriel Sefström rediscovers **vanadium**.

1838 Swedish chemist Carl Gustav Mosander discovers that **cerium** contains a new element, which he names **lanthanum**. His lanthanum is later found to consist of four new elements.

1842 Swedish chemist Carl Gustav Mosander discovers that the earth called yttria actually consists of two new elements, **erbium** and **terbium**.

1844 Russian chemist Carl Ernst Claus discovers **ruthenium**.

1860 German chemists Robert Bunsen and Gustav Kirchhoff discover **cesium**.

1861 German chemists Robert Bunsen and Gustav Kirchhoff discover **rubidium**.

1861 British physicist Sir William Crookes discovers **thallium**.

1863 German chemists Ferdinand Reich and Hieronymus Theodor Richter discover **indium**.

1868 Pierre Janssen and Norman Lockyer discover **helium** in the spectrum of the sun.

1875 Paul-Émile Lecoq de Boisbaudran discovers **gallium**.

1878 Swiss chemist Jean-Charles-Galissard de Marignac, Swedish chemist Lars Fredrik Nilson, and French chemist Georges Urbain all receive partial credit for the discovery of **ytterbium**.

1878–1879 Swedish chemist Per Teodor Cleve discovers **holmium** and **thulium**.

1879 Swedish chemist Lars Fredrik Nilson discovers **scandium**.

1880 French chemist Paul-Émile Lecoq de Boisbaudran discovers **samarium**.

1880 French chemist Jean-Charles-Galissard de Marignac discovers **gadolinium**.

1885 Austrian chemist Carl Auer von Welsbach discovers **praseodymium** and **neodymium**.

1885 German chemist Clemens Alexander Winkler discovers **germanium**.

1886 French chemist Henri Moissan discovers **fluorine**.

1886 French chemist Paul-Émile Lecoq de Boisbaudran discovers **dysprosium**.

1894 English chemists Lord Rayleigh and Sir William Ramsay discover **argon**.

1895 English chemist Sir William Ramsay and Swedish chemists Per Teodor Cleve and Nils Abraham Langlet independently discover **helium** in the mineral clevite, the first discovery of the element on Earth's surface.

1896 French chemist Eugène-Anatole Demarçay discovers **europium**.

1898 English chemists Sir William Ramsay and Morris Travers discover **krypton, neon**, and **xenon**.

1898 French physicists Marie and Pierre Curie discover **polonium** and **radium**.

1898 German physicist Friedrich Ernst Dorn discovers **radon**.

1899 French chemist André Debierne discovers **actinium**.

1906 French chemist Georges Urbain and Austrian chemist Carl Auer von Welsbach independently discover **lutetium**.

1908 Japanese chemist Masataka Ogawa discovers **rhenium**, but erroneously assigns it to atomic number 43, instead of its correct atomic number of 75. He names the element nipponium, but his research is forgotten and ignored for many years.

1911 French chemist Georges Urbain and Russian chemist Vladimir Ivanovich Vernadskij independently discover **hafnium**. Their research is unconfirmed because of World War I (1914–1918).

1917 Three research teams, consisting of German physicists Lise Meitner and Otto Hahn, Polish-American physical chemist Kasimir Fajans and German chemist O. H. Göhring, and English physicists Frederick Soddy and John A. Cranston, independently and almost simultaneously discover **protactinium**.

1923 Dutch physicist Dirk Coster and Hungarian chemist George Charles de Hevesy rediscover **hafnium** and are generally recognized as discoverers of the element.

1925 German chemists Walter Noddack, Ida Tacke, and Otto Berg rediscover and name **rhenium**.

1937 Italian physicist Emilio Segré and his colleague Carlo Perrier discover **technetium**.

1939 French chemist Marguerite Perey discovers **francium**.

1940 Dale R. Corson, Kenneth R. Mackenzie, and Emilio Segré discover **astatine**.

1940 Edwin M. McMillan and Philip H. Abelson prepare **neptunium**.

1940 University of California at Berkeley researchers Glenn Seaborg, Arthur C. Wahl, J. K. Kennedy, and E. M. McMillan prepare **plutonium**.

1944 University of California at Berkeley researchers Glenn Seaborg, Albert Ghiorso, Ralph A. James, and Leon O. Morgan prepare **americium**.

1944 University of California at Berkeley researchers Glenn Seaborg, Albert Ghiorso, and Ralph A. James prepare **curium**.

1945 Oak Ridge National Laboratory researchers Jacob A. Marinsky, Lawrence E. Glendenin, and Charles D. Coryell discover **promethium**. The element had probably been found as early as 1942 by Chien Shiung Wu, Emilio Segré, and Hans Bethe.

1949 University of California at Berkeley researchers Stanley G. Thompson, Albert Ghiorso, and Glenn Seaborg prepare **berkelium**.

1950 University of California at Berkeley researchers Glenn Seaborg, Albert Ghiorso, Kenneth Street Jr., and Stanley G. Thompson prepare **californium**.

1952 A team of University of California at Berkeley researchers led by Albert Ghiorso prepares **einsteinium** (#99) and **fermium** (#100).

1955 University of California at Berkeley researchers Glenn Seaborg, Albert Ghiorso, Bernard G. Harvey, Gregory R. Choppin, and Stanley G. Thompson prepare **mendelevium** (#101).

1958 University of California at Berkeley researchers Glenn Seaborg, Albert Ghiorso, Tørbjorn Sikkeland, and J. R. Walton prepare **nobelium** (#102).

1961 University of California at Berkeley researchers Albert Ghiorso, Tørbjorn Sikkeland, Almon E. Larsh, and R. M. Latimer prepare **lawrencium** (#103).

1964 A research team at the Joint Institute for Nuclear Research at Dubna, Russia, led by Russian physicist Georgy Nikolaevich Flerov, produces **rutherfordium** (#104).

1968 A research team at the Joint Institute for Nuclear Research at Dubna, Russia, led by Russian physicist Georgy Nikolaevich Flerov, produces **dubnium** (#105).

1974 A research team at the University of California at Berkeley led by Albert Ghiorso produces **seaborgium** (#106).

1981 A research team led by Peter Armbruster and Gottfried Münzenberg at the Gesellschaft für Schwerionenforschung (Institute for Heavy Ion Research) in Darmstadt, Germany, produces **bohrium** (#107).

1982 The Heavy Ion Research team in Darmstadt produces **meitnerium** (#109).

1984 The Heavy Ion Research team in Darmstadt produces **hassium** (#108).

1994 The Heavy Ion Research team in Darmstadt, under the leadership of Sigurd Hofmann, produces **darmstadtium** (#110) and **roentgenium** (#111).

1996 The Heavy Ion Research team in Darmstadt, under the leadership of Sigurd Hofmann, produces **copernicium** (#112).

1999 Researchers at the Joint Institute for Nuclear Research announce the discovery of element #114, ununquadium.

2000 Researchers at the Joint Institute for Nuclear Research announce the discovery of element #116, ununhexium. This and all subsequent discoveries have not been confirmed nor a name approved for the possible new elements as of early 2010.

2002 Researchers at the Joint Institute for Nuclear Research at Dubna and the Lawrence Livermore National Laboratory in California announce the discovery of element #118, ununoctium.

2003 Researchers at the Joint Institute for Nuclear Research at Dubna and the Lawrence Livermore National Laboratory in California announce the discovery of element #113 ununtrium and element #115 ununpentium.

2008 Researchers at the Hebrew University at Jerusalem, under the leadership of Amnon Marinov, report the discovery of single atoms of element #122, unbibium, in naturally occurring deposits of **thorium**. Although unconfirmed as of early 2010, this report would be the first discovery of a new element in nature since 1939 (**francium**).

2009 The International Union of Pure and Applied Chemistry (IUPAC) officially recognizes element 112, Copernicium (Cn), and adds the name to the standard periodic table.

2009 A team of researchers at the Lawrence Berkeley National Laboratory confirm the production of #114, ununquadium.

Words to Know

A

Abrasive: A powdery material used to grind or polish other materials.

Absolute zero: The lowest temperature possible, about -459°F (-273°C).

Actinoid family: Formerly Actinide family; elements in the periodic table with atomic numbers 90 through 103.

Alchemy: A kind of pre-science that existed from about 500 BCE to about the end of the 16th century.

Alkali: A chemical with properties opposite those of an acid.

Alkali metal: An element in Group 1 (IA) of the periodic table.

Alkaline earth metal: An element found in Group 2 (IIA) of the periodic table.

Allotropes: Forms of an element with different physical and chemical properties.

Alloy: A mixture of two or more metals that has properties different from those of the individual metals.

Alpha particles: Tiny, atom-sized particles that can destroy cells.

Alpha radiation: A form of radiation that consists of very fast moving alpha particles and helium atoms without their electrons.

Amalgam: A combination of mercury and at least one other metal.

Amorphous: Without crystalline shape.

Anhydrous ammonia: Dry ammonia gas.

Antiseptic: A chemical that stops the growth of germs.

Aqua regia: A mixture of hydrochloric and nitric acids that often reacts with materials that do not react with either acid separately.

B

Battery: A device for changing chemical energy into electrical energy.

Biochemistry: The field of chemistry concerned with the study of compounds found in living organisms.

Biocompatible: Not causing a reaction when placed into the body.

Bipolar disorder: A condition in which a person experiences wild mood swings.

Brass: An alloy of copper and zinc.

Bronze: An alloy of copper and tin.

Bronze Age: A period in human history ranging from about 3500 to 1000 BCE, when bronze was widely used for weapons, utensils, and ornamental objects.

Buckminsterfullerene: Full name for buckyball or fullerene; also see Buckyball.

Buckyball: An allotrope of carbon whose 60 carbon atoms are arranged in a sphere-like form.

C

Capacitor: An electrical device, somewhat like a battery, that collects and then stores up electrical charges.

Carat: A unit of weight for gold and other precious metals, equal to one fifth of a gram, or 200 milligrams.

Carbon arc lamp: A lamp for producing very bright white light.

Carbon-14 dating: A technique that allows archaeologists to estimate the age of once-living materials by using the knowledge that carbon-14 is found in all living carbon materials; once an organism dies, no more carbon-14 remains.

Cassiterite: An ore of tin containing tin oxide, the major commercial source of tin metal.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Chalcogens: Elements in Group 16 (VIA) of the periodic table.

Chemical reagent: A substance, such as an acid or an alkali, used to study other substances.

Chlorofluorocarbons (CFCs): A family of chemical compounds consisting of carbon, fluorine, and chlorine that were once used widely as propellants in commercial sprays but regulated in the United States since 1987 because of their harmful environmental effects.

Corrosive agent: A material that tends to vigorously react or eat away at something.

Cyclotron: A particle accelerator, or "atom smasher," in which small particles, such as protons, are made to travel very fast and then collide with atoms, causing the atoms to break apart.

D

Density: The mass of a substance per unit volume.

Diagnosis: Finding out what medical problems a person may have.

Distillation: A process by which two or more liquids can be separated from each other by heating them to their boiling points.

"Doped": Containing a small amount of a material as an impurity.

Ductile: Capable of being drawn into thin wires.

E

Earth: In mineralogy, a naturally occurring form of an element, often an oxide of the element.

Electrolysis: A process by which a compound is broken down by passing an electric current through it.

Electroplating: The process by which a thin layer of one metal is laid down on top of a second metal.

Enzyme: A substance that stimulates certain chemical reactions in the body.

F

Fabrication: Shaping, molding, bending, cutting, and working with a metal.

Fission: The process by which large atoms break apart, releasing large amounts of energy, smaller atoms, and neutrons in the process.

Fly ash: The powdery material produced during the production of iron or some other metal.

Frasch method: A method for removing sulfur from underground mines by pumping hot air and water down a set of pipes.

Fuel cell: Any system that uses chemical reactions to produce electricity.

Fullerene: Alternative name for buckyball; also see Buckyball.

G

Galvanizing: The process of laying down a thin layer of zinc on the surface of a second metal.

Gamma rays: A form of radiation similar to X rays.

Global warming: A phenomenon in which the average temperature of Earth rises, melting icecaps, raising sea levels, and causing other environmental problems. Causes include human-activities, including heavy emissions of carbon dioxide (CO_2).

H

Half life: The time it takes for half of a sample of a radioactive element to break down.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Heat exchange medium: A material that picks up heat in one place and carries it to another place.

Hydrocarbons: Compounds made of carbon and hydrogen.

Hypoallergenic: Not causing an allergic reaction.

I

Inactive: Does not react with any other element.

Inert: Not very active.

Isotope: Two or more forms of an element that differ from each other according to their mass number.

L

Lanthanoid family: Formerly Lanthanide family; the elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Liquid air: Air that has been cooled to a very low temperature.

Luminescence: The property of giving off light without giving off heat.

M

Machining: The bending, cutting, and shaping of a metal by mechanical means.

"Magic number": The number of protons and/or neutrons in an atom that tend to make the atom stable (not radioactive).

Magnetic field: The space around an electric current or a magnet in which a magnetic force can be observed.

Malleable: Capable of being hammered into thin sheets.

Metalloid: An element that has characteristics of both metals and non-metals.

Metallurgy: The art and science of working with metals.

Metals: Elements that have a shiny surface, are good conductors of heat and electricity, and can be melted, hammered into thin sheets, and drawn into thin wires.

Micronutrient: A substance needed in very small amounts to maintain good health.

Misch metal: A metal that contains different rare earth elements and has the unusual property of giving off a spark when struck.

Mohs scale: A way of expressing the hardness of a material.

Mordant: A material that helps a dye stick to cloth.

N

Nanotubes: Long, thin, and extremely tiny tubes.

Native: Not combined with any other element.

Neutron radiography: A technique that uses neutrons to study the internal composition of material.

Nickel allergy: A health condition caused by exposure to nickel metal.

Nitrogen fixation: The process of converting nitrogen as an element to a compound that contains nitrogen.

Noble gases: Elements in Group 18 (VIIIA) of the periodic table.

Non-metals: Elements that do not have the properties of metals.

Nuclear fission: A process in which neutrons collide with the nucleus of a plutonium or uranium atom, causing it to split apart with the release of very large amounts of energy.

Nuclear reactor: A device in which nuclear reactions occur.

O

Optical fiber: A thin strand of glass through which light passes; the light carries a message through a telephone wire.

Ore: A mineral compound that is mined for one of the elements it contains, usually a metal element.

Organic chemistry: The study of the carbon compounds.

Oxidizing agent: A chemical substance that gives up or takes on electrons from another substance.

Ozone: A form of oxygen that filters out harmful radiation from the sun.

Ozone layer: The layer of ozone that shields Earth from harmful ultraviolet radiation from the sun.

P

Particle accelerator ("atom smasher"): A device used to cause small particles, such as protons, to move at very high speeds.

Periodic law: A way of organizing the chemical elements to show how they are related to each other.

Periodic table: A chart that shows how chemical elements are related to each other.

Phosphor: A material that gives off light when struck by electrons.

Photosynthesis: The process by which plants convert carbon dioxide and water to carbohydrates (starches and sugars).

Platinum family: A group of elements that occur close to platinum in the periodic table and with platinum in the Earth's surface.

Polymerization: The process by which many thousands of individual tetrafluoroethlylene (TFE) molecules join together to make one very large molecule.

Potash: A potassium compound that forms when wood burns.

Precious metal: A metal that is rare, desirable, and, therefore, expensive.

Proteins: Compounds that are vital to the building and growth of cells.

Pyrophoric: Gives off sparks when scratched.

R

Radiation: Energy transmitted in the form of electromagnetic waves or subatomic particles.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Radioactive tracer: An isotope whose movement in the body can be followed because of the radiation it gives off.

Radioactivity: The process by which an isotope element breaks down and gives off some form of radiation.

Rare earth elements: Elements in the Lanthanoid family.

Reactive: Combines with other substances relatively easily.

Refractory: A material that can withstand very high temperatures and reflects heat back away from itself.

Rodenticide: A poison used to kill rats and mice.

Rusting: A process by which a metal combines with oxygen.

S

Salt dome: A large mass of salt found underground.

Semiconductor: A material that conducts an electric current, but not nearly as well as metals.

Serendipity: Discovering something of value when not seeking it; for example, making a discovery by chance or accident.

Silver plating: A process by which a very thin layer of silver metal is laid down on top of another metal.

Slag: A mixture of materials that separates from a metal during its purification and floats on top of the molten metal.

Slurry: A soup-like mixture of crushed ore and water.

Solder: An alloy that can be melted and then used to join two metals to each other.

Spectra: The lines produced when chemical elements are heated.

Spectroscope: A device for analyzing the light produced when an element is heated.

Spectroscopy: The process of analyzing light produced when an element is heated.

Spectrum (plural: spectra): The pattern of light given off by a glowing object, such as a star.

Stable: Not likely to react with other materials.

Sublimation: The process by which a solid changes directly to a gas when heated, without first changing to a liquid.

Superalloy: An alloy made of iron, cobalt, or nickel that has special properties, such as the ability to withstand high temperatures and attack by oxygen.

Superconductivity: The tendency of an electric current to flow through a material without resistance.

Superconductor: A material that has no resistance to the flow of electricity; once an electrical current begins flowing in the material, it continues to flow forever.

Superheated water: Water that is hotter than its boiling point, but which has not started to boil.

Surface tension: A property of liquids that makes them act like they are covered with a skin.

T

Tarnishing: Oxidizing; reacting with oxygen in the air.

Tensile: Capable of being stretched without breaking.

Thermocouple: A device for measuring very high temperatures.

Tin cry: A screeching-like sound made when tin metal is bent.

Tin disease: A change that takes place in materials containing tin when the material is cooled to temperatures below 55°F (13°C) for long periods of time, when solid tin turns to a crumbly powder.

Tincture: A solution made by dissolving a substance in alcohol.

Tinplate: A type of metal consisting of a thin protective coating of tin deposited on the outer surface of some other metal.

Toxic: Poisonous.

Trace element: An element that is needed in very small amounts for the proper growth of a plant or animal.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

Transfermium element: Any element with an atomic number greater than 100.

Transistor: A device used to control the flow of electricity in a circuit.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Transuranium element: An element with an atomic number greater than 92.

U

Ultraviolet (UV) radiation: Electromagnetic radiation (energy) of a wavelength just shorter than the violet (shortest wavelength) end of the visible light spectrum and thus with higher energy than visible light.

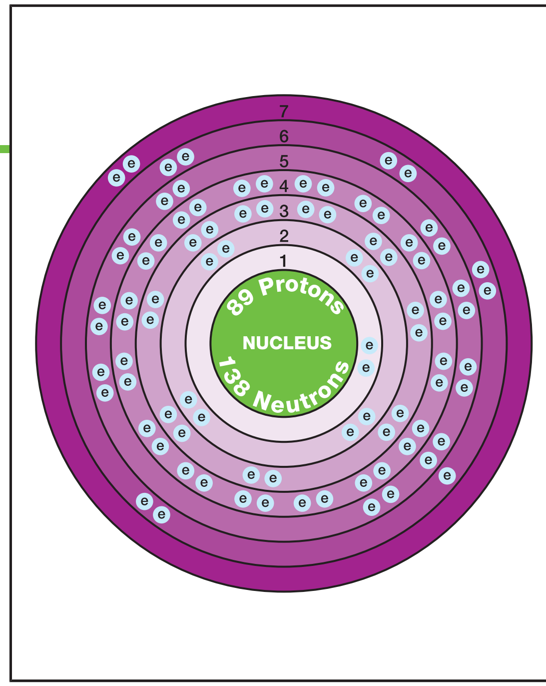
V

Vulcanizing: The process by which soft rubber is converted to a harder, long-lasting product.

W

Workability: The ability to work with a metal to get it into a desired shape or thickness.

Actinium



Key Facts

Symbol: Ac

Atomic Number: 89

Atomic Mass: [227]

Family: Group 3 (IIIB); transition metal

Pronunciation: ack-TIN-ee-um

Overview

Actinium is the third element in Row 7 of the periodic table, a chart that shows how the chemical elements are related to each other. Some chemists place it in Group 3 (IIIB), with scandium and yttrium. Other chemists call it the first member of the actinoids. The actinoids are the 15 elements that make up Row 7 of the periodic table after radium. They have atomic numbers from 89 to 103 and are all radioactive. A radioactive atom is unstable and tends to throw off particles and emit energy in order to become stable. Either way of classifying actinium is acceptable to most chemists.

Actinium has chemical properties like those of **lanthanum** (number 57), the element just above it in the periodic table. Actinium is also similar to **radium**, the element just before it (number 88) in Row 7.

Naturally occurring actinium is very rare in Earth's crust. It can be made in the lab by firing neutrons at radium, but it has very few important uses.

Discovery and Naming

Four new elements, all radioactive, were discovered between 1898 and 1900. A radioactive element is one that gives off radiation in the form

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Ore: Mineral compound that is mined for one of the elements it contains, usually a metal element.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

of energy or particles and may change into a different element. The first two of these elements—**polonium** and radium—were discovered by French physicists Marie Curie (1867–1934) and Pierre Curie (1859–1906). The third, actinium, was discovered in 1899 by a close friend of the Curies, French chemist André-Louis Debierne (1874–1949). Debierne suggested the name actinium for the new element. The name comes from the Greek words *aktis* or *aktinos,* meaning "beam" or "ray." The fourth element discovered in this series was **radon**, a gas given off during the radioactive decay of some heavier elements. It was found in 1900 by German chemist Friedrich Ernst Dorn (1848–1916).

Actinium was discovered a second time in 1902. German chemist Friedrich O. Giesel (1852–1927) had not heard of Debierne's earlier discovery. Giesel suggested the name emanium, from the word emanation, which means "to give off rays." Debierne's name was adopted, however, because he discovered actinium first.

Physical and Chemical Properties

Only limited information is available about actinium. It is known to be a silver metal with a melting point of 1,920°F (1,050°C) and a boiling point estimated to be about 5,800°F (3,200°C). The element has properties similar to those of lanthanum. Generally speaking, elements in the same column in the periodic table have similar properties. Few compounds of actinium have been produced. Neither the element nor its compounds have any important uses.

Occurrence in Nature

Actinium is found in **uranium** ores. An ore is a mineral mined for the elements it contains. Actinium is produced by the radioactive decay, or breakdown, of uranium and other unstable elements. Actinium can also be artificially produced. When radium is bombarded with neutrons, some of the neutrons become part of the nucleus. This increases the atomic weight and the instability of the radium atom. The unstable radium decays, gives off radiation, and changes to actinium. Actinium metal of 98 percent purity—used for research purposes—can be made by this process.

Isotopes

Thirty-four isotopes of actinium are known, all of which are radioactive. The isotope that occurs in nature is actinium-227. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation.

The half life of actinium-227 is 21.77 years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. For example, suppose 1.0 gram of actinium-227 is formed by the breakdown of another element. After 21.77 years, only 0.5 gram of actinium-227 would remain. This is known as the half life.

Extraction

Actinium is rarely, if ever, extracted from natural sources.

Uses

There are no practical commercial uses of actinium. Actinium of 98 percent purity is prepared for research studies.

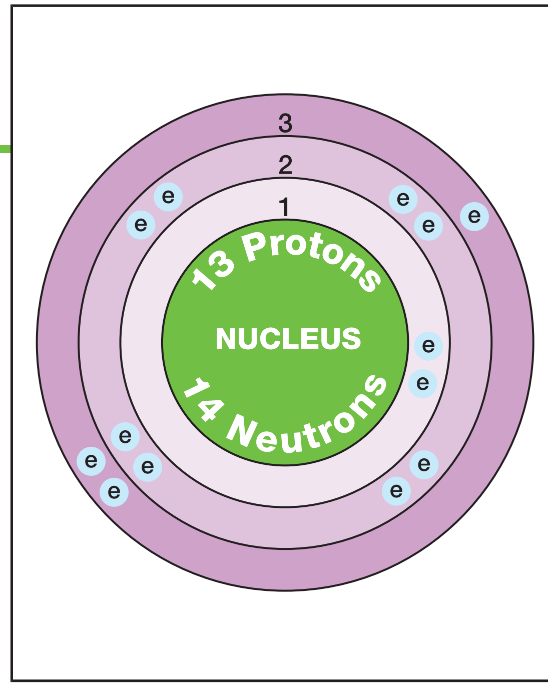
Compounds

The few compounds of actinium that are known are used solely for research purposes.

Health Effects

Like all radioactive materials, actinium is a health hazard. If taken into the body, it tends to be deposited in the bones, where the energy it emits damages or destroys cells. Radiation is known to cause bone cancer and other disorders.

Aluminum



Key Facts

Symbol: Al

Atomic Number: 13

Atomic Mass: 26.9815386

Family: Group 13 (IIIA); aluminum

Pronunciation: uh-LOO-min-um

Overview

Aluminum is found in Row 3, Group 13 of the periodic table. The periodic table is a chart that shows how the chemical elements are related to each other. Elements in the same column usually have similar chemical properties. The first element in this group is **boron**. However, boron is very different from all other members of the family. Therefore, group 13 is known as the aluminum family.

Aluminum is the third most abundant element in Earth's crust, exceeded only by **oxygen** and **silicon**. It is second to silicon as the most abundant metallic element. It is somewhat surprising, then, that aluminum was not discovered until relatively late in human history. Aluminum occurs naturally only in compounds, never as a pure metal. Removing aluminum from its compounds is quite difficult. An inexpensive method for producing pure aluminum was not developed until 1886.

Today, aluminum is the most widely used metal in the world after **iron**. It is used in the manufacture of automobiles, packaging materials, electrical equipment, machinery, and building construction. Aluminum is also ideal for beer and soft drink cans and foil because it can be melted and reused, or recycled.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Discovery and Naming

Aluminum was named for one its most important compounds, alum. Alum is a compound of **potassium**, aluminum, **sulfur**, and oxygen. Its chemical name is potassium aluminum sulfate, $KAl(SO_4)_2$. In North America, aluminum is spelled with one *i* and is pronounced uh-LOO-min-um. Elsewhere in the world, a second *i* is added—making it aluminium—and the word is pronounced al-yoo-MIN-ee-um.

No one is sure when alum was first used by humans. The ancient Greeks and Romans were familiar with the compound alum. It was mined in early Greece where it was sold to the Turks. The Turks used the compound to make a beautiful dye known as Turkey red. Records indicate that the Romans were using alum as early as the first century BCE.

These early people used alum as an astringent and as a mordant. An astringent is a chemical that causes skin to pull together. Sprinkling alum over a cut causes the skin to close over the cut and start healing. A mordant is used in dyeing cloth. Few natural dyes stick directly to cloth. A mordant bonds to the cloth and the dye bonds to the mordant.

Over time, chemists gradually began to realize that alum might contain a new element. In the mid-1700s, German chemist Andreas Sigismund Marggraf (1709–1782) claimed to have found a new "earth" called alumina in alum. But he was unable to remove a pure metal from alum.

The first person to accomplish that task was Danish chemist and physicist Hans Christian Oersted (1777–1851). Oersted heated a combination of alumina and potassium amalgam. An amalgam is an alloy of a metal and mercury. In this reaction, Oersted produced an aluminum amalgam—aluminum metal in combination with **mercury**. He was unable, however, to separate the aluminum from the mercury.

Pure aluminum metal was finally produced in 1827 by German chemist Friedrich Wöhler (1800–1882). Wöhler used a method perfected by English chemist Sir Humphry Davy (1778–1829), who succeeded in isolating several elements during his lifetime. Wöhler heated a mixture of aluminum chloride and potassium metal. Being more active, the potassium replaces the aluminum, as shown by the following equation:

$$3K + AlCl_3 \rightarrow 3KCl + Al$$

The pure aluminum can then be collected as a gray powder, which must be melted to produce the shiny aluminum that is most familiar to consumers.

After Wöhler's work, it was possible, but very expensive, to produce pure aluminum. It cost so much that there were almost no commercial uses for it.

Before chemists developed inexpensive ways to produce pure aluminum, it was considered a somewhat precious metal. In fact, in 1855, a bar of pure aluminum metal was displayed at the Paris Exposition. It was placed next to the French crown jewels!

A number of chemists realized how important it was to find a less expensive way to prepare aluminum. In 1883, Russian chemist V. A. Tyurin found a less expensive way to produce pure aluminum. He passed an electric current through a molten (melted) mixture of cryolite and **sodium** chloride (ordinary table salt). Cryolite is sodium aluminum fluoride (Na_3AlF_6). Over the next few years, similar methods for isolating aluminum were developed by other chemists in Europe.

The most dramatic breakthrough in aluminum research was made by a college student in the United States. Charles Martin Hall (1863–1914) was a student at Oberlin College in Oberlin, Ohio, when he became interested in the problem of producing aluminum. Using homemade equipment in a woodshed behind his home, he achieved success by passing an electric current through a molten mixture of cryolite and aluminum oxide (Al_2O_3).

Hall's method was far cheaper than any previous method. After his discovery, the price of aluminum fell from about $20/kg ($10/lb) to less than $1/kg (about $.40/lb). Hall's research changed aluminum from a semi-precious metal to one that could be used for many everyday products.

Physical Properties

Aluminum is a silver-like metal with a slightly bluish tint. It has a melting point of 1,220°F (660°C) and a boiling point of 4,221–4,442°F (2,327–2,450°C). The density is 2.708 grams per cubic centimeter. Aluminum is both ductile and malleable. Ductile means capable of being pulled into thin wires. Malleable means capable of being hammered into thin sheets.

Aluminum is an excellent conductor of electricity. **Silver** and **copper** are better conductors than aluminum but are much more expensive. Engineers are looking for ways to use aluminum more often in electrical equipment because of its lower costs.

Chemical Properties

Aluminum has one interesting and very useful property. In moist air, it combines slowly with oxygen to form aluminum oxide:

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

The aluminum oxide forms a very thin, whitish coating on the aluminum metal. The coating prevents the metal from reacting further with oxygen and protects the metal from further corrosion (rusting). It is easy to see the aluminum oxide on aluminum outdoor furniture and unpainted house siding.

Aluminum is a fairly active metal. It reacts with many hot acids. It also reacts with alkalis. An alkali is a chemical with properties opposite those of an acid. Sodium hydroxide (common lye) and limewater are examples of alkalis. It is unusual for an element to react with *both* acids and alkalis. Such elements are said to be amphoteric.

Aluminum also reacts vigorously with hot water. In powdered form, it catches fire quickly when exposed to a flame.

Occurrence in Nature

The abundance of aluminum in Earth's crust is estimated to be about 8.8 percent. It occurs in many different minerals. Bauxite, a complicated mixture of compounds consisting of aluminum, oxygen, and other elements, is the primary commercial source for aluminum.

As of 2008, large reserves of bauxite were found in Australia, China, Brazil, Guinea, Jamaica, Russia, and Venezuela. Bauxite production statistics for the United States were not reported to protect trade secrets.

According to the U.S. Geological Survey (USGS), in 2008 China led world smelter production of aluminum, followed by Russia, Canada, the United States, Australia, Brazil, and India.

Isotopes

Only one naturally occurring isotope of aluminum exists: aluminum-27. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Aluminum also has 14 radioactive isotopes. A radioactive isotope gives off either energy or subatomic particles in order to reduce the atomic mass and become stable. When the emission produces a change in the number of protons, the atom is no longer the same element. The particles and energy emitted from the nucleus are called radiation. The process of decaying from one element into another is known as radioactive decay.

No radioactive isotope of aluminum has any commercial use.

Extraction

Aluminum production is a two-step process. First, aluminum oxide is separated from bauxite by the Bayer process. In this process, bauxite is mixed with sodium hydroxide (NaOH), which dissolves the aluminum oxide. The other compounds in bauxite are left behind.

The aluminum oxide is then treated with a process similar to the Hall method. There is not enough natural cryolite to make all the aluminum needed, so synthetic (artificial) cryolite is manufactured for this purpose. The chemical reaction is the same with synthetic cryolite as with natural cryolite.

Uses

Aluminum is used as pure metal, in alloys, and in a variety of compounds. An alloy is made by melting and then mixing two or more metals. The mixture has properties different from those of the individual

The aluminum used for beer and soft drink cans can be recycled. IMAGE COPYRIGHT 2009, KATHY BURNS-MILLYARD. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

metals. Aluminum alloys are classified in numbered series according to the other elements they contain.

The 1000 classification is reserved for alloys of nearly pure aluminum metal. They tend to be less strong than other alloys of aluminum, however. These metals are used in the structural parts of buildings, as decorative trim, in chemical equipment, and as heat reflectors.

The 2000 series are alloys of copper and aluminum. They are very strong, are corrosion (rust) resistant, and can be machined, or worked with, very easily. Some applications of 2000 series aluminum alloys are in truck paneling and structural parts of aircraft.

The 3000 series is made up of alloys of aluminum and **manganese**. These alloys are not as strong as the 2000 series, but they also have good machinability. Alloys in this series are used for cooking utensils, storage tanks, aluminum furniture, highway signs, and roofing.

Alloys in the 4000 series contain silicon. They have low melting points and are used to make solders and to add gray coloring to metal. Solders are low-melting alloys used to join two metals to each other. The 5000, 6000, and 7000 series include alloys consisting of **magnesium**, both magnesium and silicon, and **zinc**, respectively. These alloys are used in ship and boat production, parts for cranes and gun mounts, bridges, structural parts in buildings, automobile parts, and aircraft components.

Aluminum is often used in construction. Here, a modern office building with an aluminum facade (exterior) is shown. IMAGE COPYRIGHT 2009, BALONCICI. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

The largest single use of aluminum in the United States is in the transportation industry (37 percent). Car and truck manufacturers like aluminum and aluminum alloys because they are very strong, yet lightweight. Companies are using more aluminum products in electric cars. These cars must be lightweight in order to conserve battery power. Aluminum producers also plan to make a wider variety of wheels for both cars and trucks.

Another major use of aluminum is in packaging (23 percent). Aluminum foil, beer and soft drink cans, paint tubes, and containers for home products such as aerosol sprays are all made from aluminum.

Aluminum is also used for building and construction (13 percent). Windows and door frames, screens, roofing, and siding, as well as the construction of mobile homes and structural parts of buildings rely on aluminum.

Aluminum is also used in a staggering range of products, including electrical wires and appliances, automobile engines, heating and cooling systems, bridges, vacuum cleaners, kitchen utensils, garden furniture, heavy machinery, and specialized chemical equipment.

Compounds

A relatively small amount of aluminum is used to make a large variety of aluminum compounds. These include:

Aluminum foil is widely used in packaging products, including candy. IMAGE COPYRIGHT 2009, DANIEL ZUCKERKANDEL. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

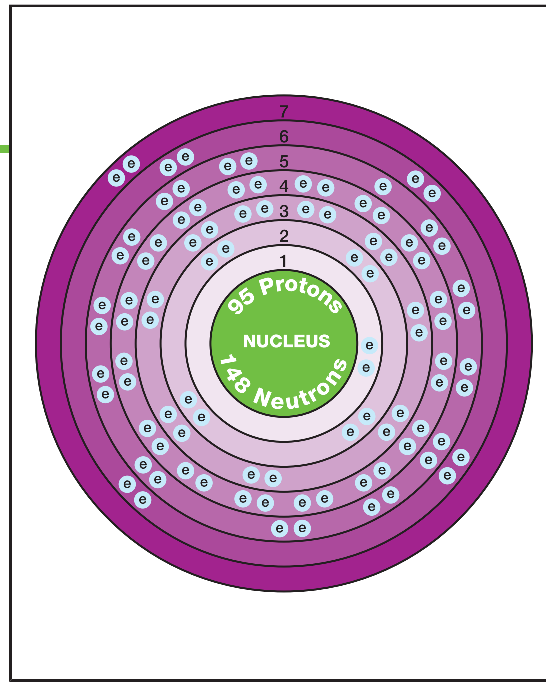
- aluminum ammonium sulfate ($Al(NH_4)(SO_4)_2$): mordant, water purification and sewage treatment, paper production, food additive, leather tanning
- aluminum borate ($Al_2O_3 \bullet B_2O_3$): production of glass and ceramics
- aluminum borohydride ($Al(BH_4)_3$): additive in jet fuels
- aluminum chloride ($AlCl_3$): paint manufacture, antiperspirant, petroleum refining, production of synthetic rubber
- aluminum fluorosilicate ($Al_2(SiF_6)_3$): production of synthetic gemstones, glass, and ceramics
- aluminum hydroxide ($Al(OH)_3$): antacid, mordant, water purification, manufacture of glass and ceramics, waterproofing of fabrics
- aluminum phosphate ($AlPO_4$): manufacture of glass, ceramics, pulp and paper products, cosmetics, paints and varnishes, and in making dental cement
- aluminum sulfate, or alum ($Al_2(SO_4)_3$): manufacture of paper, mordant, fire extinguisher system, water purification and sewage treatment, food additive, fireproofing and fire retardant, and leather tanning

Health Effects

Aluminum has no known function in the human body. There is some debate, however, as to its possible health effects. Some health scientists suspect that aluminum may be associated with Alzheimer's disease. This is a condition that most commonly affects older people, leading to forgetfulness and loss of mental skills. It is still not clear whether aluminum plays any part in Alzheimer's disease.

Breathing aluminum dust may also cause health problems. It may cause a pneumonia-like condition called aluminosis.

Americium



Overview

Americium is called an actinoid or transuranium element. It occurs in Row 7 of the periodic table, a chart that shows how the chemical elements are related to each other. The actinoids are named after element 89, actinium. The term transuranium means “beyond uranium” in the periodic table. **Uranium** has an atomic number of 92. Any element with an atomic number larger than 92, therefore, is called a transuranium element.

Discovery and Naming

Americium was discovered as a by-product of military research during World War II (1939–45). The U.S. government maintained a major research site at the University of Chicago during the war. Work there led to the development of the first atomic bomb. During that research, a team from the University of California, consisting of Glenn Seaborg (1912–1999), Albert Ghiorso (1915–), Ralph A. James, and Leon O. Morgan, discovered a new element, which would eventually be named americium.

Americium was first produced in a nuclear reactor. A nuclear reactor is a device in which elements are bombarded by neutrons, sometimes

Key Facts

Symbol: Am

Atomic Number: 95

Atomic Mass: [243]

Family: Actinoid; transuranium element

Pronunciation: am-uh-REE-see-um

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Alpha radiation: A form of radiation that consists of very fast moving alpha particles and helium atoms without their electrons.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear reactor: A device in which nuclear reactions occur.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive: Having a tendency to give off radiation.

Transuranium element: An element with an atomic number greater than 92.

forming new elements. The name, americium, in honor of the American continent, was chosen because the new element occurs just below **europium** (named for Europe) in the periodic table.

Physical Properties

Enough americium has been produced to determine a few of its properties. It is a silvery-white metal with a melting point of about 2,150°F (1,175°C) and a density of about 13.6 grams per cubic centimeter. A number of its compounds have been produced and studied, but only one isotope has considerable practical use outside the laboratory.

Occurrence in Nature

All of the transuranium elements, including americium, are synthetically produced. None exist in nature.

Isotopes

Americium has 25 isotopes, all of which are radioactive. The most stable is americium-243. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary.

Each variation is an isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation.

The half life of a radioactive element is the time it takes for half of a sample of the element to break down. The half life of americium-243 is 7,370 years. For example, suppose a laboratory made 10 grams of americium-243. At the end of 7,370 years (one half life), only half would remain. The other half would have changed into a new element.

Extraction

Americium does not occur naturally.

Uses

Americium-241 is the only isotope of americium of any practical interest. When it decays, it gives off both alpha rays and gamma rays. Alpha rays do not travel very far in air, but gamma rays are very penetrating, much like X rays. The gamma rays from americium-241 are used in portable X-ray machines that can, for example, be taken into oil fields to help determine where new wells should be dug.

Americium-241 is also used to measure the thickness of materials. For instance, a small piece of americium-241 can be placed above a conveyor belt carrying newly made glass. A Geiger counter, a device for counting alpha radiation, is placed below the conveyor belt. If the glass is always the same thickness, the same amount of alpha radiation gets through to the detector. If the glass is thicker than normal, less alpha radiation gets through. If the glass is thinner than normal, more radiation gets through. The detector will register if the glass being produced is too thick or too thin.

One of the simplest and cheapest safety devices found in homes and other buildings is a battery-operated smoke detector. And americium is an important part of it. A small piece of americium oxide made with the americium-241 isotope is sealed inside the smoke detector. The americium-241 gives off alpha particles. The alpha particles strike air molecules, causing them to break apart. The pieces formed in this process—ions—are electrically charged.

The electrically charged ions help carry a current from one side of the detector to the other. The current continues to flow as long as nothing other than air is inside the detector. If smoke enters the detector, the smoke particles absorb some of the alpha particles so that the current is interrupted. When this happens, a buzzer or other sound is set off.

Common smoke detectors include an americium oxide made with the americium-241 isotope. IMAGE COPYRIGHT 2009, DANNY E. HOOKS. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

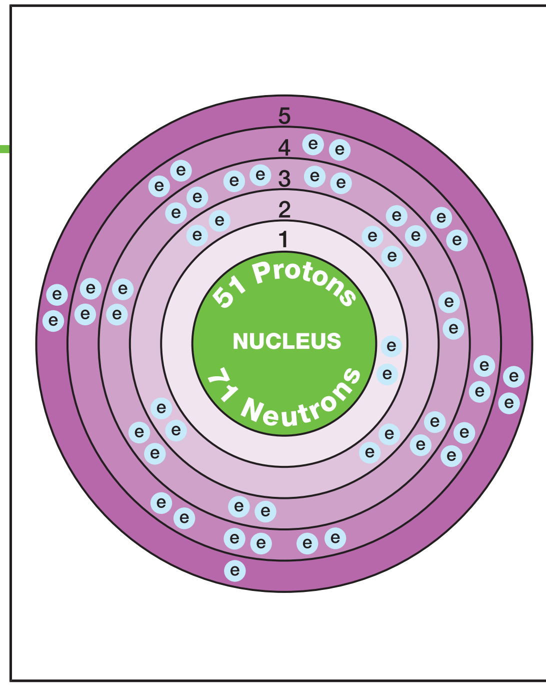
Compounds

There are no commercial uses of americium compounds.

Health Effects

Americium is an extremely toxic element. If swallowed, it is deposited in the bones. There, the radiation it gives off kills or damages cells, causing cancer. People are normally in no danger from smoke detectors containing americium-241. (Indeed, countless lives are saved each year because of smoke detectors.) The amount of this isotope in a smoke detector is very small. One gram of americium oxide made with americium-241 will make 5,000 smoke detectors.

Antimony



Key Facts

Symbol: Sb

Atomic Number: 51

Atomic Mass: 121.760

Family: Group 15 (VA); nitrogen

Pronunciation: AN-ti-moh-nee

Overview

Antimony compounds have been used by humans for centuries. Women of ancient Egypt used stibic stone, antimony sulfide (Sb_2S_3), to darken the skin around their eyes. Antimony was also used in making colored glazes for beads and glassware. The chemical symbol for antimony was taken from the ancient name for the element, stibium. Not recognized as a chemical element until the Middle Ages, antimony became a common material used by alchemists.

Alchemy was a kind of pre-science that existed from about 500 BCE to about the end of the 16th century. Alchemists wanted to find a way of changing **lead**, **iron**, and other metals into **gold**. They also wanted to find a way of having eternal life. Alchemy contained too much magic and mysticism to be a real science, but alchemists developed a number of techniques and produced many new materials that were later found to be useful in modern chemistry. Antimony was one of these materials.

Antimony is a metalloid. A metalloid is an element that has characteristics of both metals and non-metals. The metalloids can be found on either side of the staircase line on the right side of the periodic table (with the exception of **aluminum**, which is not considered a metalloid).

WORDS TO KNOW

Alchemy: A kind of pre-science that existed from about 500 BCE to about the end of the 16th century.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Aqua regia: A mixture of hydrochloric and nitric acids that often reacts with materials that do not react with either acid separately.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Metalloid: An element that has characteristics of both metals and non-metals.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Solder: An alloy that can be melted and then used to join two metals to each other.

Toxic: Poisonous.

Tracer: A radioactive isotope whose presence in a system can be easily detected.

Antimony is primarily used in alloys, ceramics and glass, plastics, and flame retardant materials. Flame retardant materials do not burn with an open flame. Instead, they smolder or do not burn at all.

Discovery and Naming

Compounds of antimony were known to ancient cultures. They have been found, for example, in the colored glazes used on beads, vases, and other glassware. But these compounds were not widely used until the Middle Ages when they became popular among alchemists. They thought that antimony could be used to convert lead into gold. It was during this period that records about the properties of antimony begin to appear.

The element was probably first named by Roman scholar Pliny (23–79 CE), who called it stibium. Muslim alchemist Abu Musa Jabir Ibn Hayyan (c. 721–c. 815) probably first called it antimony—*anti* ("not") and *monos* ("alone"). The name comes from the fact that antimony does not occur alone in nature.

Alchemists used secret codes to write about much of their work, so modern scholars do not know a great deal about how antimony was used. The first detailed reports about antimony were published in 1707 when French chemist Nicolas Lemery (1645–1715) published his famous book, *Treatise on Antimony.*

Antimony samples. ©RUSS LAPPA/SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Physical Properties

Antimony is a silvery-white, shiny element that looks like a metal. It has a scaly surface and is hard and brittle like a non-metal. It can also be prepared as a black powder with a shiny brilliance to it.

The melting point of antimony is 1,170°F (630°C) and its boiling point is 2,980°F (1,635°C). It is a relatively soft material that can be scratched by glass. Its density is 6.68 grams per cubic centimeter.

Chemical Properties

Antimony is a moderately active element. It does not combine with **oxygen** in the air at room temperature. It also does not react with cold water or with most cold acids. It does dissolve in some hot acids, however, and in aqua regia (a mixture of hydrochloric and nitric acids). It often reacts with materials that do not react with either acid separately.

Occurrence in Nature

Antimony is rarely found in its native (as an element) state. Instead, it usually occurs as a compound. The most common minerals of antimony are stibnite, tetrahedrite, bournonite, boulangerite, and jamesonite. In most of these minerals, antimony is combined with **sulfur** to produce some form of antimony sulfide (Sb_2S_3).

In 2008, the largest producers of antimony were China, Bolivia, South Africa, Russia, and Tajikistan. The United States produced some antimony concentrate at a mine in Nevada and some antimony metal and oxide in Montana. According to the U.S. Geological Survey (USGS), other states with antimony resources include Alaska and Idaho.

The abundance of antimony is estimated to be about 0.2 parts per million, placing it in the bottom fifth among the chemical elements found in Earth's crust. It is more abundant than **silver** or **mercury**, but less abundant than **iodine**.

Isotopes

There are two naturally occurring isotopes of antimony: antimony-121 and antimony-123. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty-three radioactive isotopes of antimony are also known. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Two of antimony's radioactive isotopes are used commercially as tracers. These isotopes are antimony-124 and antimony-125. A tracer is an isotope injected into a living or non-living system. The movement of the isotope can then be followed as it moves through the system. For example, a small amount of antimony-124 could be injected into an oil pipeline. The presence of the isotope can be detected by means of an instrument held above the pipeline. The radiation given off by the isotope causes a light to flash or a sound to occur in the instrument.

Lead-antimony alloys are used for fishing tackle. IMAGE COPYRIGHT 2009, SASHA RADOSAVLJEVICH. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

The movement of the isotope through the pipeline can be followed in this way. If the pipeline has a leak, the tracer will escape from it. Its movement through the soil can be detected.

Extraction

Antimony can be recovered from stibnite with hot iron:

$$2Fe + Sb_2S_3 \rightarrow Fe_2S_3 + 2Sb$$

Some of the antimony produced in the United States is recycled from old lead storage batteries used in cars and trucks.

Uses

Antimony is used to make alloys with a number of different metals. An alloy is made by melting and mixing two or more metals. The properties of the mixture are different than those of the individual metals. One of the most common of these alloys is one made with lead. Lead-antimony alloys are used for solder, ammunition, fishing tackle, covering for electrical cables, alloys that melt at low temperatures, and batteries.

The manufacture of lead storage batteries, like the ones used in cars and trucks, account for about one-fifth of all the antimony used each year. A small amount of antimony is also used in making transistors, which are found in such consumer electrical devices as computer games, pocket calculators, and portable stereos. A transistor is a solid-state (using special properties of solids, rather than electron tubes) electronic device used to control the flow of an electric current.

Other minor uses of antimony include the manufacture of glass and ceramics and the production of plastics. In glass and ceramics, a small amount of antimony insures that the final product will be clear and colorless. In the production of plastics, antimony is used as a catalyst. A catalyst is a substance that increases the rate of a chemical reaction. The catalyst does not undergo any change itself during the reaction.

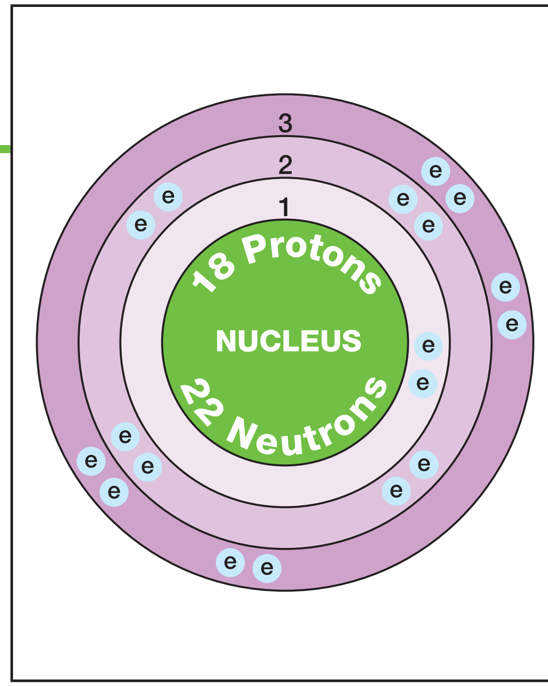
Compounds

Commercially, antimony trioxide (Sb_2O_3) is the most important compound of antimony. It is used primarily in the manufacture of flame-retardant materials. It is usually sprayed on or added to a fabric to make it flame retardant.

Health Effects

Antimony and its compounds are dangerous to human health. In low levels, these materials can irritate the eyes and lungs. They may also cause stomach pain, diarrhea, vomiting, and stomach ulcers. At higher doses, antimony and its compounds can cause lung, heart, liver, and kidney damage. At very high doses, they can cause death.

Argon



Key Facts

Symbol: Ar

Atomic Number: 18

Atomic Mass: 39.948

Family: Group 18 (VIIIA); noble gas

Pronunciation: AR-gon

Overview

Argon is a noble gas. The noble gases are the six elements in Group 18 (VIIIA) of the periodic table. The periodic table is a chart that shows how the chemical elements are related to each other. The noble gases are sometimes called inert gases because Group 18 (VIIIA) elements react with very few other elements. In fact, no compound of argon had been made until 2000. In that year, researchers at the University of Helsinki, in Finland, made the first compound of argon by reacting the element with hydrogen fluoride. The compound formed was argon hydrofluoride (HArF).

Argon was discovered in 1894 by English chemist John William Strutt, most commonly known as Lord Rayleigh (1842–1919), and Scottish chemist William Ramsay (1852–1916). It was the first of the noble gases to be isolated.

Rayleigh and Ramsay discovered argon by the fractional distillation of liquid air. Fractional distillation is the process of letting liquid air slowly warm up. As the air warms, different elements change from a liquid back to a gas. The portion of air that changes back to a gas at –302.55°F (–185.86°C) is argon.

WORDS TO KNOW

Inert: Not very active.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Noble gas: An element in Group 18 (VIIIA) of the periodic table.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Argon is used to provide an inert blanket for certain industrial operations. An inert blanket of gas prevents any chemicals in the operation from reacting with **oxygen** and other substances present in air. Argon is also used in making "neon" lamps and in lasers.

Discovery and Naming

Argon was discovered in 1894. However, English scientist Henry Cavendish (1731–1810) had predicted the existence of argon many years earlier. When Cavendish removed oxygen and **nitrogen** from air, he found that a very small amount of gas remained. He guessed that another element was in the air, but he was unable to identify what it was.

When Ramsay repeated Cavendish's experiments in the 1890s, he, too, found a tiny amount of unidentified gas in the air. But Ramsay had an advantage over Cavendish: he could use spectroscopy, which did not exist in Cavendish's time. Spectroscopy is the process of analyzing light produced when an element is heated. The spectrum (plural: spectra) of an element consists of a series of colored lines and is different for every element.

Ramsay studied the spectrum of the unidentified gas. He found a series of lines that did not belong to any other element. He was convinced that he had found a new element. Meanwhile, Rayleigh was doing similar work and made his discovery at about the same time Ramsay did. The two scientists decided to make their announcement together. The name argon comes from the Greek word *argos,* "the lazy one." The name is based on the fact that argon does not react with other elements or compounds.

The discovery of argon created a problem for chemists. It was the first noble gas to be discovered. Where should it go in the periodic table?

At the time, the table ended with Group 17 (VIIA) at the right. Ramsay suggested that the periodic table might have to be extended. He proposed adding a whole new group to the table. That group would be placed to the right of Group 17 (VIIA).

Ramsay's suggestion was accepted, but it created an interesting new problem for chemists. If there was a new group in the periodic table, where were the other elements that belonged in the group?

Fortunately, chemists had a good idea what these missing elements might look like. All of the elements in a single group are very much like each other. Chemists looked for more inactive gases. Within the next five years, they had found the remaining members of the group: **helium**, **krypton**, **neon**, **radon**, and **xenon**.

The symbol *A* was used for argon until the 1950s when chemists agreed to use the two letter symbol *Ar* for the element.

Physical Properties

Argon is a colorless, odorless, tasteless gas. Its density is 1.784 grams per liter. The density of air, for comparison, is about 1.29 grams per liter. Argon changes from a gas to a liquid at –302.55°F (–185.86°C). Then it changes from a liquid to a solid at –308.7°F (–189.3°C).

Chemical Properties

Argon is chemically inactive. On rare occasions, and under extreme conditions, it forms weak, compound-like structures.

Occurrence in Nature

Argon is the third most abundant gas in Earth's atmosphere, following nitrogen and oxygen. Its abundance is about 0.93 percent. It is also found in Earth's crust to the extent of about 4 parts per million.

Extraction

Argon can be produced from liquid air by fractional distillation. It can also be produced by heating nitrogen gas from the atmosphere with hot **magnesium** or **calcium**. The magnesium or calcium combines with nitrogen to form a nitride:

$$3Mg + N_2 \rightarrow Mg_3N_2$$

A little argon always occurs as an impurity with nitrogen. It remains behind because it does not react with magnesium or calcium.

Argon also occurs in wells with natural gas. When the natural gas is purified, some argon can be recovered as a by-product.

Isotopes

Three isotopes of argon exist naturally. They are argon-36, argon-38, and argon-40. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fifteen radioactive isotopes of argon are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

No radioactive isotopes of argon have any practical application. One non-radioactive isotope is used, however, to find the age of very old rocks. This method of dating rocks is described in the **potassium** entry.

Uses

Argon is used in situations where materials need to be protected from oxygen or other gases. One example is an incandescent lightbulb, which consists of a metal wire inside a clear glass bulb. An electric current passes through the wire, causing it to get very hot and give off light.

Oxygen will combine with the hot metal very easily, forming a compound of the metal and oxygen. This compound will not conduct an electric current very well, thereby causing the lightbulb to stop giving off light.

Argon, however, is used to prevent this from happening. Because argon is inert, it will not react with the hot wire, leaving the metal hot for very long periods of time. The lightbulb will stop giving off light only when the metal breaks. Then it can no longer carry an electric current.

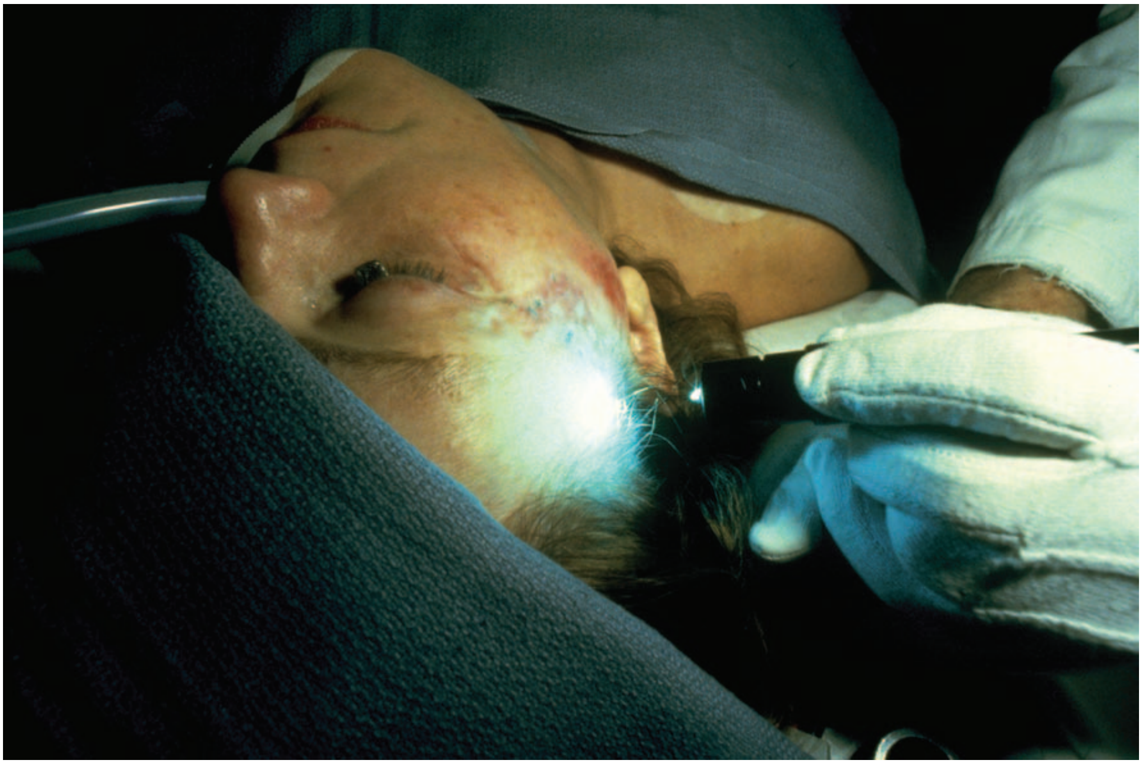
Argon is also used in welding. Welding is the process by which two metals are joined to each other. In most cases, the two metals are heated to very high temperatures. As they get hot, they melt together.

Argon is used in various types of lightbulbs, including incandescent and compact fluorescent (shown here). IMAGE COPYRIGHT 2007, R. MACKAY. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

However, as the metals get hot, they begin to react with oxygen. In this reaction, a compound of metal and oxygen is formed. It becomes very difficult to join the two metals if they have formed compounds, but introducing argon into the welding environment prevents the metals from reacting with oxygen.

Argon is also used in compact fluorescent lightbulbs (CFLs), argon lasers, and argon-dye lasers. A laser is a device that produces very bright light of a single color (frequency). An argon laser is used to treat skin conditions. The laser shines a blue-green light on the affected area of the skin. The energy from the laser is absorbed by hemoglobin and converted to heat. (Hemoglobin is the protein pigment in red blood cells. It transports oxygen to the tissues and carbon dioxide from them.) The blood vessels are damaged, but then sealed, prompting them to decompose and be reabsorbed into the body. Unwanted growths are flattened and dark spots are lightened, with only a small risk of scarring.

An argon-dye laser is used in eye surgery. The color of light produced by the laser can be adjusted with high precision. It can be made to produce light ranging across the green-to-blue color range. Each shade of green or blue has a slightly different frequency. It can penetrate more or less deeply in the eye. The laser can be adjusted to treat a very specific



Argon is used in lasers, such as the one shown here removing a birthmark. © ALEXANDER TSIARAS/PHOTO RESEARCHERS, INC.

part of the eye. The argon dye laser is used to treat tumors, damaged blood vessels, conditions involving the retina, and other kinds of eye problems.

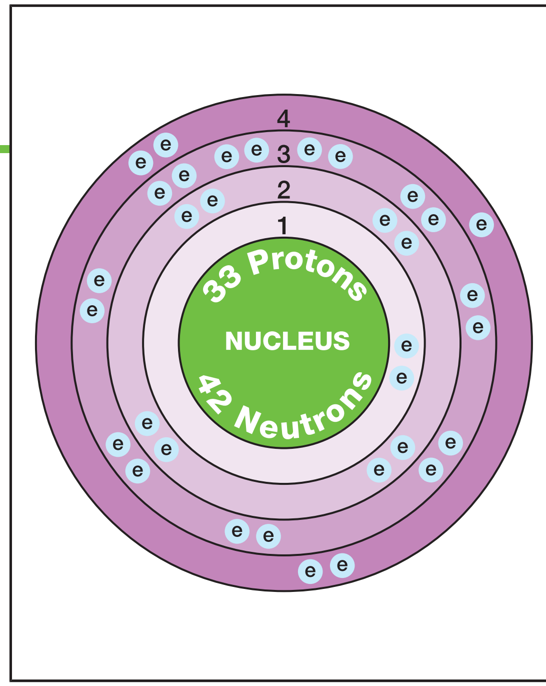
Compounds

Only one compound of argon has been produced, argon hydrofluoride (HArF).

Health Effects

Argon is not known to have any positive or negative effects on the health of plants or animals.

Arsenic



Overview

Arsenic compounds have been known since at least the days of Ancient Greece and Rome (about 2,000 years ago). The compounds were used by physicians and poisoners. The compound most often used for both purposes was arsenic sulfide (As_2S_3).

Arsenic was first recognized as an element by alchemists. Alchemy was a kind of pre-science that existed from about 500 BCE to about the end of the 16th century. People who studied alchemy—alchemists—wanted to find a way of changing **lead**, **iron**, and other metals into **gold**. They were also looking for a way to have eternal life. Alchemy contained too much magic and mysticism to be a real science, but alchemists developed a number of techniques and produced many new materials that were later found to be useful in modern chemistry.

A small amount of arsenic is used in alloys. An alloy is made by melting and then mixing two or more metals. The mixture has properties different from those of individual metals. The most important use of arsenic in the United States is in wood preservatives.

Key Facts

Symbol: As

Atomic Number: 33

Atomic Mass: 74.92160

Family: Group 15 (VA); nitrogen

Pronunciation: AR-se-nick

WORDS TO KNOW

Alchemy: A kind of pre-science that existed from about 500 BCE to about the end of the 16th century.

Allotropes: Forms of an element with different physical and chemical properties.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Metalloid: An element that has properties of both metals and non-metals.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Sublimation: The process by which a solid changes directly to a gas when heated, without first changing to a liquid.

Toxic: Poisonous.

Discovery and Naming

Arsenic can be produced from its ores very easily, so many early craftspeople may have seen the element without realizing what it was. Since arsenic is somewhat similar to **mercury**, early scholars probably confused the two elements with each other.

Credit for the actual discovery of arsenic often goes to alchemist Albert the Great (Albertus Magnus, 1193–1280). He heated a common compound of arsenic, orpiment (As_2S_3), with soap. Nearly pure arsenic was formed in the process.

By the mid-17th century, arsenic was well known as an element. Textbooks from the period often listed methods by which the element could be made from its compounds.

Physical Properties

Arsenic occurs in two allotropic forms. Allotropes are forms of an element with different physical and chemical properties. The more common form of arsenic is a shiny, gray, brittle, metallic-looking solid. The less common form is a yellow crystalline solid. It is produced when vapors of arsenic are cooled suddenly.

When heated, arsenic does not melt, as most solids do. Instead, it changes directly into a vapor (gas). This process is known as sublimation. However, under high pressure, arsenic can be forced to melt at about

1,500°F (814°C). Arsenic has a density of 5.72 grams per cubic centimeter.

Chemical Properties

Arsenic is a metalloid. A metalloid is an element that has properties of both metals and non-metals. Metalloids occur in the periodic table on either side of the staircase line that starts between **boron** and **aluminum**.

When heated in air, arsenic combines with **oxygen** to form arsenic oxide (As_2O_3). A blue flame is produced, and arsenic oxide can be identified by its distinctive garlic-like odor.

Arsenic combines with oxygen more slowly at room temperatures. The thin coating of arsenic oxide that forms on the element prevents it from reacting further. Arsenic does not dissolve in water or most cold acids. It does react with some hot acids to form arsenous acid (H_3AsO_3) or arsenic acid (H_3AsO_4).

Occurrence in Nature

Arsenic rarely occurs as a pure element. It is usually found as a compound. The most common ores of arsenic are arsenopyrite (FeAsS), orpiment (As_2S_3), and realgar (As_4S_4). These compounds are obtained as a by-product of the mining and purification of **silver** metal.

The abundance of arsenic in Earth's crust is thought to be about 5 parts per million. That places it among the bottom third of the elements in abundance in Earth's crust.

In 2008, the world's largest producers of arsenic trioxide were China, Chile, Morroco, and Peru. According to the U.S. Geological Survey (USGS), the United States has not produced arsenic compounds or metal since 1985. About $7 million of arsenic was used in the United States in 2008.

Isotopes

One naturally occurring isotope of arsenic exists: arsenic-75. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-four radioactive isotopes of arsenic are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the isotopes of arsenic have any important commercial use.

Extraction

The process of recovering arsenic from its ores is a common one used with metals. The ore is first roasted (heated in air) to convert arsenic sulfide to arsenic oxide. The arsenic oxide is then heated with charcoal (pure carbon). The carbon reacts with the oxygen in arsenic oxide, leaving behind pure arsenic:

$$2As_2O_3 + 3C \rightarrow 3CO_2 + 4As$$

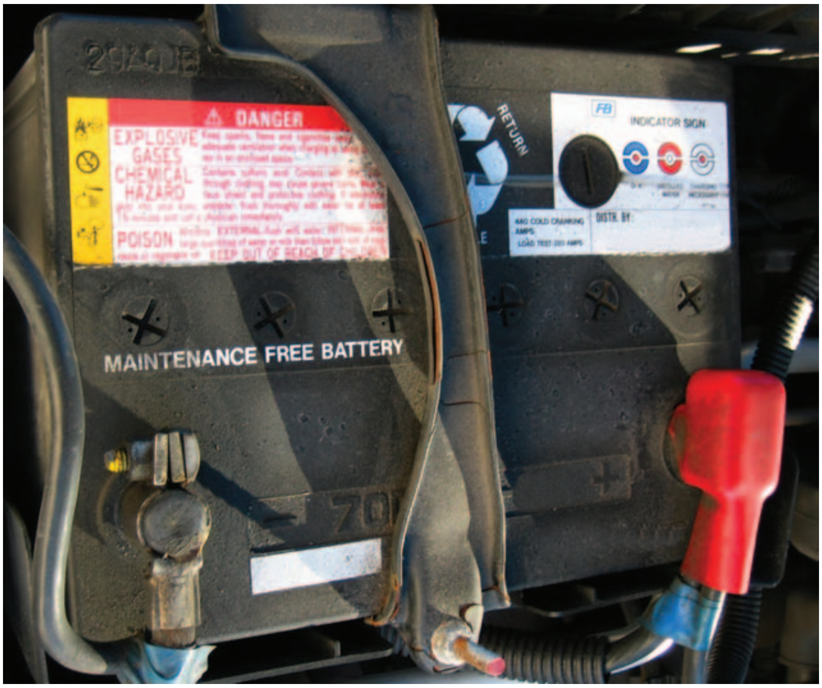
Uses

Arsenic is used most commonly in the form of its compounds. A much smaller amount of the element itself is used in alloys. For example, certain parts of lead storage batteries used in cars and trucks contain alloys of lead and arsenic. Arsenic has also been used to make lead shot in the past. The amount of arsenic used in these applications is likely to continue to decrease. It is too easy for arsenic to get into the environment from such applications.

Some arsenic is used in the electronics industry. It is added to **germanium** and **silicon** to make transistors. A compound of arsenic, **gallium** arsenide (GaAs), is also used to make light-emitting diodes (LEDs). LEDs produce the lighted numbers in hand-held calculators, clocks, watches, and a number of other electronic devices.

Compounds

Arsenic has a fascinating history as a healer and killer. Early physicians, such as Hippocrates (c. 460–370 BCE) and Paracelsus (1493–1541), recommended arsenic for the treatment of some diseases. In more recent times, compounds of arsenic have been used to treat a variety of diseases, including syphilis and various tropical diseases.



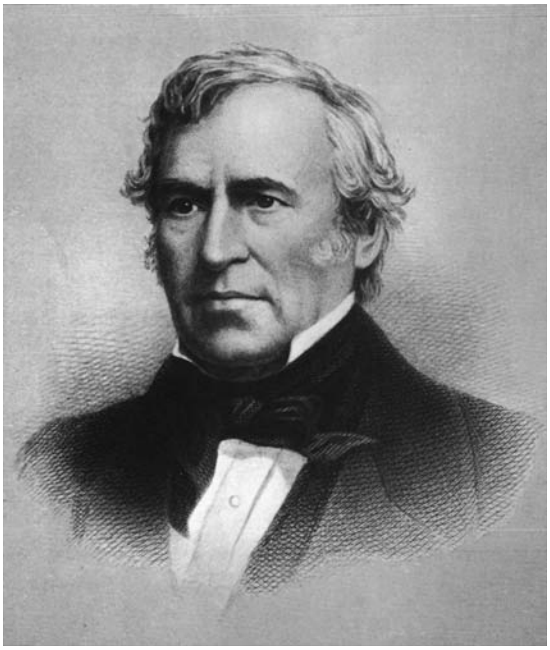
Common lead storage batteries used in cars and trucks contain alloys of arsenic. IMAGE COPYRIGHT 2009, ALBERT LOZANO. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Arsenic has a special place in the history of modern medicine. In 1910, German biologist Paul Ehrlich (1854–1915) invented the first drug that would cure syphilis, a sexually transmitted disease. This drug, called salvarsan, is a compound of arsenic. Its chemical name is arsphenamine.

Compounds of arsenic have long been used for less happy purposes. Especially during the Middle Ages, they were a popular form of committing murder. At the time, it was difficult to detect the presence of arsenic in the body. A person murdered with arsenic was often thought to have died of pneumonia.

The toxic properties of arsenic compounds made them useful as rat poison. However, they are seldom used for this purpose today. Safer compounds are used that do not present a threat to humans, pets, and the environment.

For many years, the most important application of arsenic was the preservation of wood. When arsenic compounds are added to wood, they kill the insects that attack and eat the wood. In the first years of the 21st century, more than 90 percent of all the arsenic produced in the



For years, historians wondered whether Zachary Taylor, the 12th president of the United States, was poisoned.
LIBRARY OF CONGRESS.

United States was used for this purpose. The most common compound used for this purpose was chromated copper arsenate (CCA). Wood preserved with CCA is referred to as pressure-treated wood. Wood treated with CCA is now recognized as a health hazard. Many authorities believe that humans and other animals exposed to pressure-treated wood may develop health problems because of arsenic present in the wood. For this reason, the U.S. Environmental Protection Agency (EPA) issued a ban on the use of CCA for treating wood, effective December 31, 2003. Pressure-treated wood may no longer be used for residential construction, although its use for industrial production is still permitted.

Health Effects

Arsenic and its compounds are toxic to animals. In low doses, arsenic produces nausea, vomiting, and diarrhea. In larger doses, it causes abnormal heart beat, damage to blood vessels, and a feeling of "pins and needles" in hands and feet. Small corns or warts may begin to develop on the palms of the hands and the soles of the feet. Direct contact with the skin can cause redness and swelling.

Long term exposure to arsenic and its compounds can cause cancer. Inhalation can result in lung cancer. If arsenic is swallowed, cancer is likely to develop in the bladder, kidneys, liver, and lungs. In large doses, arsenic and its compounds can cause death. In fact, for years, historians wondered whether the 12th president of the United States, Zachary Taylor (1784–1850), had been murdered—poisoned by arsenic.

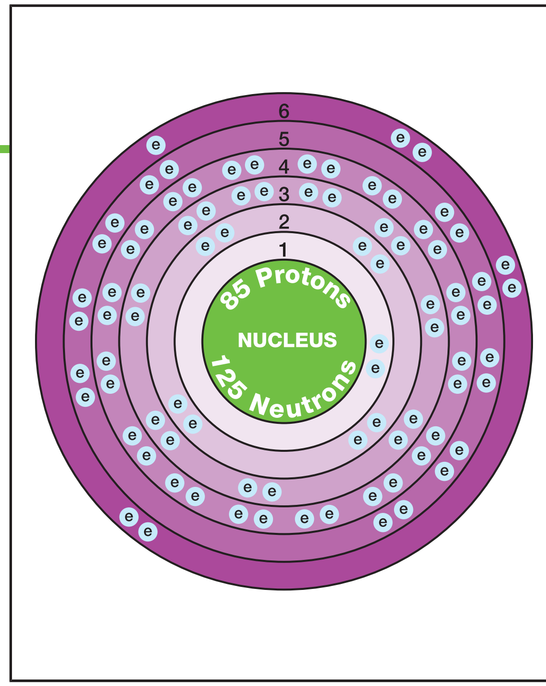
On July 9, 1850, Taylor died in office. He had served as president for a little more than 16 months. The cause of death was widely reported as gastroenteritis (an inflammation in the stomach and intestines). He had become sick after eating a mixture of cherries and buttermilk. But many wondered whether Taylor's enemies had actually poisoned the former war hero.

On June 17, 1991, Taylor's remains were exhumed (removed from his grave) from a cemetery in Louisville, Kentucky. The late president's descendents agreed with historians that the possibility of poisoning existed. Samples of Taylor's hair and fingernails were taken to Oak Ridge National Laboratory, in Oak Ridge, Tennessee, for analysis.

Scientists used a process that measured the amount of arsenic in the tissue samples. Most human bodies *do* contain traces of arsenic. So the key issue was whether there would be more arsenic in the tissue samples than would be normal for someone who had been dead for 141 years. If there were, that would mean Taylor was probably poisoned; if not, death by natural causes was more likely.

The Kentucky medical examiner came to a conclusion. He said the amount of arsenic found in Taylor's samples was several hundred times less than what could be expected had the president been poisoned by arsenic. So although some people still wonder whether Taylor was poisoned, arsenic was not the chemical element used.

Astatine



Overview

Astatine is a member of the halogen family, elements in Group 17 (VIIA) of the periodic table. It is one of the rarest elements in the universe. Scientists believe that no more than 25 grams exist on Earth's surface. All isotopes of astatine are radioactive and decay into other elements. For this reason, the element's properties are difficult to study. What *is* known is that it has properties similar to those of the other halogens—**fluorine**, **chlorine**, **bromine**, and **iodine**. Because it is so rare, it has essentially no uses.

Key Facts

Symbol: At

Atomic Number: 85

Atomic Mass: [210]

Family: Group 17 (VIIA); halogen

Pronunciation: AS-tuh-teen

Discovery and Naming

The periodic table is a chart that shows how the chemical elements are related to each other. The periodic table was first constructed by Russian chemist Dmitri Mendeleev (1834–1907) in the early 1870s.

Mendeleev's periodic table contained some empty boxes. At first, no one was sure what these empty boxes meant. By the early 1900s, however, chemists had decided that the empty boxes must be spaces for elements that had not yet been discovered. A search began for elements to fill the half dozen or so boxes that still remained in the periodic table.

WORDS TO KNOW

Cyclotron: A particle accelerator, or "atom smasher," in which small particles, such as protons, are made to travel very fast and then collide with atoms, causing the atoms to break apart.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactivity: The tendency for an isotope to break apart and give off some form of radiation.

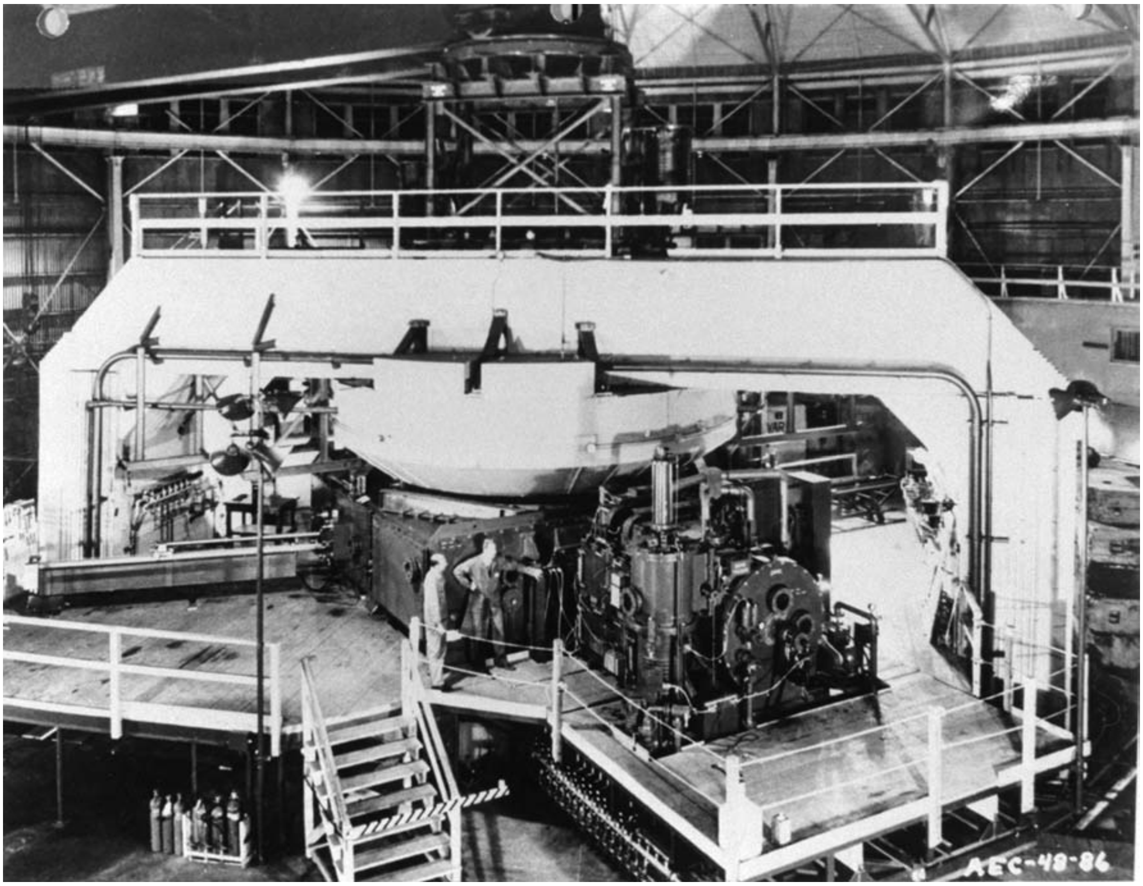
Two of the most troubling empty boxes were elements 85 and 87. During the first third of the 20th century, chemists worked very hard to find these two missing elements. Along the way, a number of incorrect answers were proposed. For example, American chemist Fred Allison (1882–1974) announced in 1931 that he had discovered elements 85 and 87. He proposed the names virginium and alabamine for these two elements. (Allison was born in Virginia and worked at the Alabama Polytechnic Institute.) Unfortunately for Allison, other chemists could not repeat his experiments successfully. They decided his results must have been incorrect.

In 1940, three chemists working at the University of California at Berkeley found evidence of element 85. Dale R. Corson, Kenneth R. Mackenzie, and Emilio Segrè (1905–1989) found evidence of element 85 at the end of an experiment they were conducting with a cyclotron. A cyclotron is a particle accelerator, or atom smasher. In a cyclotron, small particles, such as protons, are made to travel at high speeds. The particles collide with atoms, causing the atoms to break apart into other elements.

Segrè's team suggested the name astatine for element 85 because there are no stable isotopes for the element. In Greek, the word for "unstable" is *astatos.*

Physical and Chemical Properties

The properties of astatine are not well known. The element breaks down too fast to allow experiments that take more than a few hours. Much of what is known about astatine comes from experiments conducted at the Argonne National Laboratory, outside Chicago, Illinois, and the Brookhaven



Overhead view of a cyclotron chamber. LIBRARY OF CONGRESS.

National Laboratory, in Upton, New York. Those experiments show that astatine is chemically similar to the other halogens above it in Group 17 of the periodic table. As chemists would expect, it acts more like a metal than iodine, the element just above it in the table. One of the few properties that have been determined for astatine is its melting point, found to be 576°F (302°C). Its boiling point is estimated to be about 639°F (337°C).

Occurrence in Nature

Astatine is produced in Earth's crust when the radioactive elements **uranium** and **thorium** decay. It can be made artificially only with great difficulty. By one estimate, no more than a millionth of a gram of astatine has ever been produced in the lab.

Isotopes

All 43 of astatine's isotopes are radioactive. That means they break down spontaneously and are transformed into other elements. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The isotopes with the longest half life are astatine-209, astatine-210, and astatine-211. The numbers after the names here are the atomic weights of the isotopes. These isotopes have half lives of 5.4 to 8.1 hours. The half life of a radioactive isotope is the time it takes for half of a sample of the element to break down. In 5.4 hours, only half of a sample of astatine-209 will still be astatine-209. Another 5.4 hours later, only 25 percent of it will remain.

Extraction

Astatine does not occur naturally.

Uses

Astatine is far too rare to have any uses. Some research suggests a possible medical use, however. Astatine is similar to the elements above it in Group 17 (VIIA) of the periodic table, especially iodine. One property of iodine is that it tends to collect in the thyroid gland. The thyroid is a gland at the base of the neck that controls many body functions.

Some researchers think that astatine will behave like iodine. If so, it could be used to treat certain diseases of the thyroid, such as thyroid cancer. When swallowed, the astatine would go to the thyroid. There, the radiation it gives off would kill cancer cells in the gland.

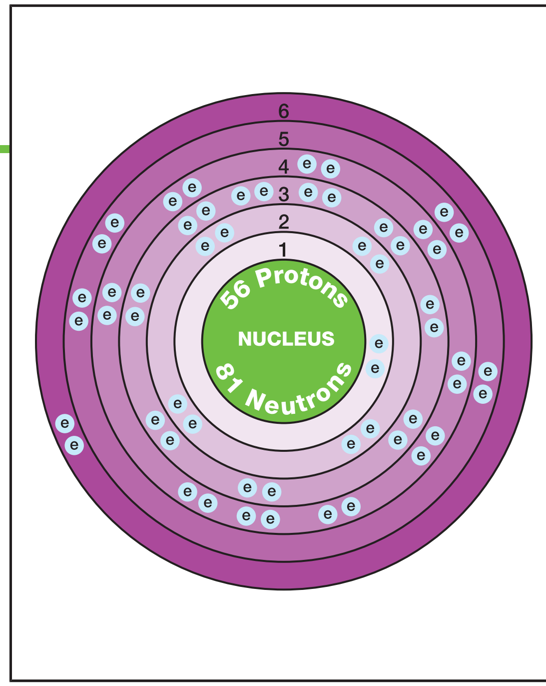
Compounds

There are no known commercial uses for astatine compounds.

Health Effects

As a radioactive element, astatine would pose a serious health hazard. However, because it can be produced only artificially—and with great difficulty at that—hardly anyone would ever be exposed to it.

Barium



Key Facts

Symbol: Ba

Atomic Number: 56

Atomic Mass: 137.327

Family: Group 2 (IIA); alkaline earth metal

Pronunciation: BARE-ee-um

Overview

Barium was first isolated in 1808 by English chemist Sir Humphry Davy (1778–1829). In 1807 and 1808, Davy also discovered five other new elements: **sodium**, **potassium**, **strontium**, **calcium**, and **magnesium**. All of these elements had been recognized much earlier as new substances, but Davy was the first to prepare them in pure form.

Barium had first been identified as a new material in 1774 by Swedish chemist Carl Wilhelm Scheele (1742–1886). The form with which Scheele worked, however, was a compound of barium, barium sulfate ($BaSO_4$). Barium sulfate is, in fact, the most common naturally occurring ore of barium. It is generally known as barite or barytes.

Barium is a member of the alkaline earth metals. The alkaline earth metals make up Group 2 (IIA) of the periodic table. The other elements in this group are **beryllium**, magnesium, calcium, strontium, and **radium**. These elements tend to be relatively active chemically and form a number of important and useful compounds. They also tend to occur abundantly in Earth's crust in a number of familiar minerals such as aragonite, calcite, chalk, limestone, marble, travertine, magnesite, and dolomite. Alkaline earth compounds are widely used as building materials.

WORDS TO KNOW

Alkaline earth metal: An element found in Group 2 (IIA) of the periodic table.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radiation: Energy transmitted in the form of electromagnetic waves or subatomic particles.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

Barium itself tends to have relatively few commercial uses. However, its compounds have a wide variety of applications in industry and medicine. Barium sulfate is used in X-ray studies of the gastrointestinal (GI) system. The GI system includes the stomach, intestines, and associated organs.

Discovery and Naming

The first mention of barium compounds goes back to the early 17th century. Early records mention a "Bologna stone," named for the city of Bologna, Italy. The Bologna stone glowed in the dark.

For more than 100 years, researchers labored without being able to identify the elements in the stone. In 1774, Scheele announced the presence of a new element in the Bologna stone. Today, scientists know that the stone was a form of barite. Five years later, Scheele demonstrated that barite was also present in heavy spar. This dense transparent mineral closely resembles ordinary spar, a compound of calcium.

Physical Properties

Pure barium is a pale yellow, somewhat shiny, somewhat malleable metal. Malleable means capable of being hammered into thin sheets. It has a melting point of about 1,300°F (700°C) and a boiling point of about 2,700°F (1,500°C). Its density is 3.6 grams per cubic centimeter.

When heated, barium compounds give off a pale yellow-green flame. This property is used as a test for barium.

Chemical Properties

Barium is an active metal. It combines easily with **oxygen**, the halogens, and other nonmetals. The halogens are Group 17 (VIIA) of the periodic table and include **fluorine**, **chlorine**, **bromine**, **iodine**, and **astatine**. Barium also reacts with water and with most acids. It is so reactive that it must be stored under kerosene or some similar petroleum-based liquid to prevent it from reacting with oxygen and moisture in the air. Of the alkaline earth family, only radium is more reactive.

A barium X ray shows a patient with diverticulosis (an intestinal disorder).
PHOTOGRAPH BY MICHAEL ENGLISH. CUSTOM MEDICAL STOCK PHOTO.

Occurrence in Nature

Barium is the 14th most abundant element in Earth's crust. Its abundance is estimated to be about 0.05 percent.

The most common sources of barium are barite and witherite. Witherite is an ore containing barium carbonate ($BaCO_3$). In 2008, the world's major sources of barite were China, India, the United States, Morocco, Iran, Mexico, and Turkey. Most of the barite processed in the United States came from Nevada and Georgia.

Isotopes

There are seven naturally occurring isotopes of barium: barium-130, barium-132, barium-134, barium-135, barium-136, barium-137, and barium-138. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-nine radioactive isotopes of barium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the isotopes of barium has any practical commercial application.

Extraction

Pure barium is produced by reacting barium oxide (BaO) with **aluminum** or **silicon**:

$$3BaO + 2Al \rightarrow 3Ba + Al_2O_3$$

Uses

Barium metal has relatively few uses because it is so active. This activity makes it an excellent "getter" or "scavenger" when removing unwanted oxygen from sealed glass containers. (Oxygen can interfere with the operation of a vacuum tube, for example.) By adding a small amount of barium to the tube, the free oxygen inside will be "soaked up." The oxygen reacts with the barium to form barium oxide.

Compounds

Compounds of barium, especially barite ($BaSO_4$), are critical to the petroleum industry. Barite is used as a weighting agent in drilling new oil wells. A weighting agent is a material that adds body to petroleum.

Drilling for oil used to produce huge gushers. A gusher is when oil sprays out of the well into the air. Gushers are undesirable, because they waste oil and can burn for months if ignited.

Gushers are caused by the pressure of oil rushing into a newly drilled hole in the ground. This pressure pushes the oil upward much too rapidly. Barite is added to the hole as it is drilled. There, it tends to mix with oil in the ground and form a very dense mixture that comes out much more slowly and under control. Nearly 95 percent of the barite used in the United States was used by the petroleum industry in 2008.

Use in Medicine Perhaps the best known use of barium compounds is in medicine. Doctors often want to know what is happening inside a patient's body. One way to find out, of course, is through surgery. But surgery is a drastic procedure. It can cause new problems for the patient.

As a result, medical researchers have developed procedures that are less extreme. One such method is called radiography.

Radiography is a technique in which X rays are passed through the body. X rays are high energy light waves. They can pass through skin and tissue, but are absorbed by bones. So X rays are a good way of finding out if a bone is broken, for example.

Any type of light appearing on film from an X ray produces a black area, or exposure. The X rays pass through soft issues, exposing the film. Bones look greyish white on the film, depending on how much energy gets through.

Radiography can also be used for studying parts of the body where bones are *not* involved. For example, a doctor might want to study a person's stomach. Since there are no bones in the stomach, some other method must be used to see inside the stomach.

Barium sulfate is often used in such cases. Barium sulfate has some of the same properties as bony material. Therefore, since X rays will not pass through barium sulfate, this compound can be used to examine certain soft tissues.

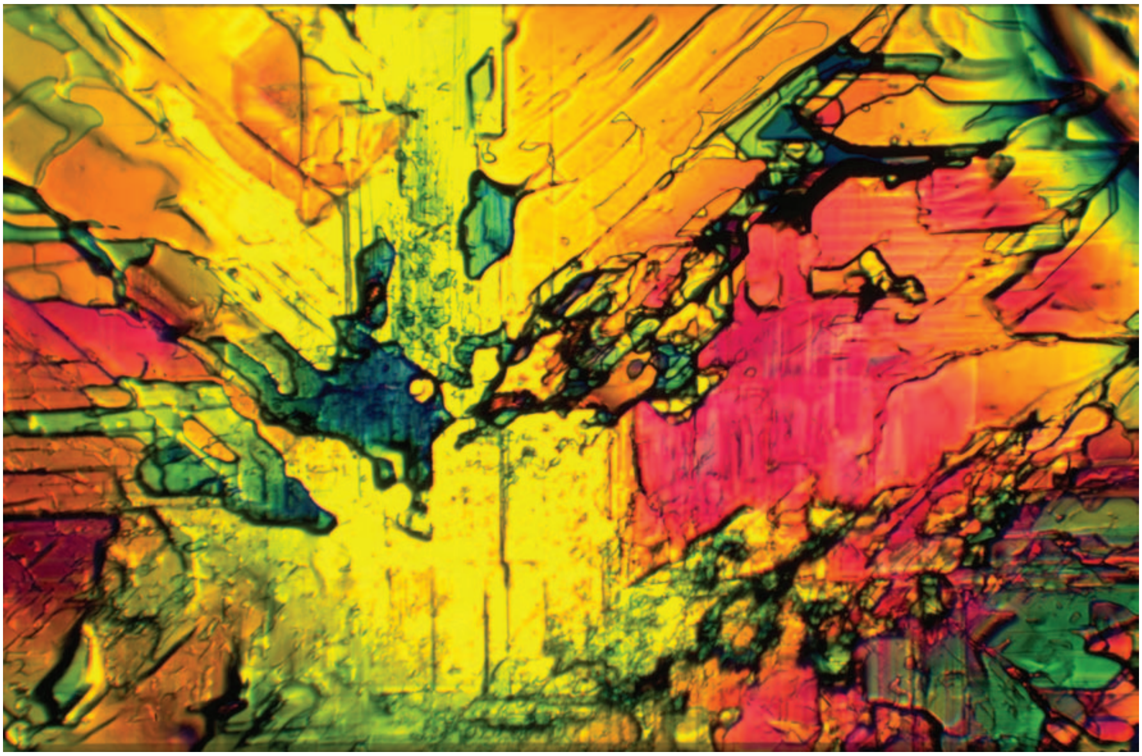
Radiography using barium sulfate is called a barium swallow or a barium enema. Barium sulfate is mixed with water into a slurry (mixture) that looks and tastes like ground-up chalk. The patient swallows the dense mixture. A doctor or nurse then holds a fluoroscope over the patient's abdomen. The fluoroscope emits X rays that show up on a television screen.

The barium sulfate-water mixture slowly travels down the patient's throat, into the stomach, through the intestines, and out through the bowels. As the barium sulfate coats the lining of the digestive tract, a doctor can see if anything is wrong.

How can a toxic compound like barium sulfate be used for this procedure? Barium sulfate does not dissolve in water. So it cannot enter the bloodstream. If it cannot get into the blood, it has no toxic effects. The barium sulfate is eliminated through the bowels a few hours after the procedure.

Other Compound Uses Other uses of barite and other barium compounds include:

- barium sulfate (barite): used to add body to or as a coating for paper products; as a white coloring agent in paints, inks, plastics,



Since barium sulfate does not dissolve in liquids, it is often used to analyze the stomach. A patient swallows a water-barium sulfate mixture, and an X ray shows the path of the barium sulfate, highlighting any abnormalities. © LUIS DE LA MAZA/PHOTOTAKE NYC.

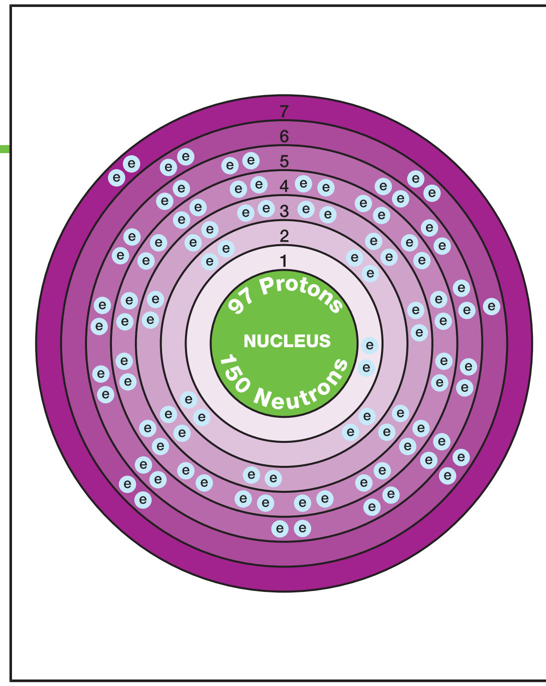
and textiles; in the manufacture of rubber products; in the production of batteries; in medical applications

- barium carbonate ($BaCO_3$): used in the production of chlorine and sodium hydroxide; as rat poison; in special types of glass
- barium oxide (BaO): used to remove water from solvents; in the petroleum industry
- barium nitrate ($Ba(NO_3)_2$): used in fireworks; as rat poison; in special ceramic glazes.

Health Effects

Barium and all of its compounds are very toxic.

Berkelium



Overview

In the period between 1940 and 1961, 11 transuranium elements were discovered by researchers from the University of California at Berkeley (UCB). The term transuranium element refers to elements beyond **uranium** (atomic numbers greater than 92) in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. All transuranium elements are unstable or radioactive. Radioactive elements emit energy or particles as they decay into more stable atoms. One of these elements was berkelium.

Key Facts

Symbol: Bk

Atomic Number: 97

Atomic Mass: [247]

Family: Actinoid; transuranium element

Pronunciation: BER-klee-um

Discovery and Naming

In 1949, element number 97 was produced in a particle accelerator on the UCB campus. A particle accelerator is sometimes called an atom smasher. It is used to speed up very small particles and atoms, which then collide with atoms of such elements as **gold**, **copper**, or **tin**. These atoms are called targets. When the particles strike target atoms precisely, the atom is converted into a new element.

The UCB researchers fired alpha particles—**helium** atoms without their electrons—at **americium** atoms in their particle accelerator. The result was a new element—number 97.

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive: Having a tendency to give off radiation.

Transuranium element: An element with an atomic number greater than 92.

helium + americium → new element (atomic number 97)

The new element was given the name berkelium by the UCB research team, in honor of the city of Berkeley, California, where the research was done.

Physical and Chemical Properties

Berkelium exists in such small amounts that very little is known about its properties. Scientists have found that it exists in two forms, known as the alpha form and the beta form. The melting points of these two forms of berkelium are 1920°F (1050°C) and 1810°F (986°C), respectively. The two forms have densities of 14.78 and 13.25 grams per cubic centimeter, about 14 times the density of water.

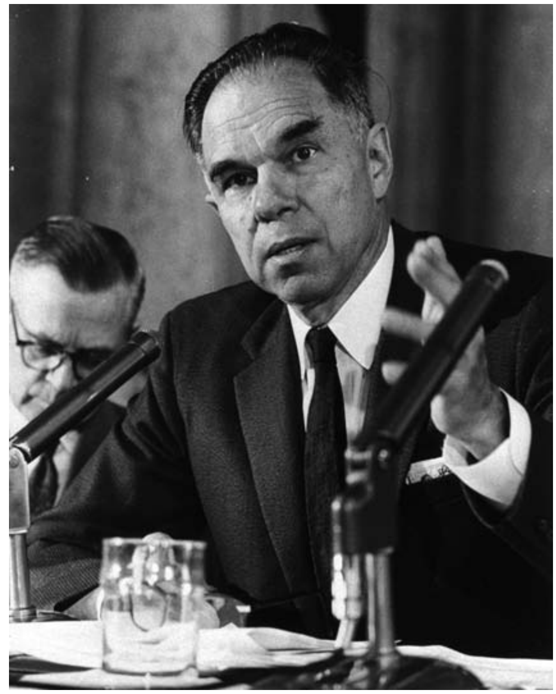
Occurrence in Nature

Berkelium does not occur in nature. It is made artificially.

Isotopes

All 17 known isotopes of berkelium are radioactive. The most stable is berkelium-247. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation.

Berkelium-247 has a half life of 1,380 years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. After 1,380 years, only half of a 10-gram sample (5 grams) of berkelium-247 would be left. The other half would have changed into a different element. After another 1,380 years, half of the remaining berkelium-247 would have changed, leaving 2.5 grams behind.



Dr. Glenn T. Seaborg helped synthesize berkelium at UCB. LIBRARY OF CONGRESS.

Extraction

Berkelium does not occur in nature. Therefore, it is not extracted.

Uses

Berkelium has no commercial uses.

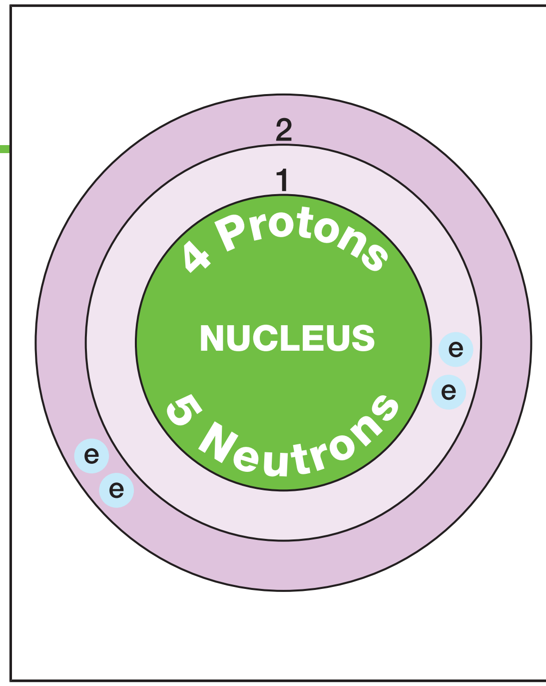
Compounds

No compounds of any practical importance have been prepared.

Health Effects

The health effects of berkelium have not been studied in detail. Since it is radioactive, scientists assume that it is harmful to human health.

Beryllium



Overview

Beryllium is the lightest member of the alkaline earth metals family. These metals make up Group 2 (IIA) of the periodic table. They include beryllium, **magnesium**, **calcium**, **strontium**, **barium**, and **radium**. Elements in the same column of the periodic table have similar chemical properties. The periodic table is a chart that shows how the chemical elements are related to each other.

Beryllium was discovered by French chemist Louis-Nicolas Vauquelin (1763–1829) in 1798. Vauquelin suggested the name glucinium, meaning "sweet tasting," for the element because the element and some of its compounds have a sweet taste. The name beryllium was adopted officially in 1957.

Beryllium-**copper** alloys account for much of all the beryllium produced. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals.

Key Facts

Symbol: Be

Atomic Number: 4

Atomic Mass: 9.012182

Family: Group 2 (IIA); alkaline earth metal

Pronunciation: buh-RIL-lee-um

Discovery and Naming

A common compound of beryllium, beryl, was known in ancient Egypt, but nothing was known about the chemical composition of this mineral until the end of the 18th century. In 1797, French mineralogist

WORDS TO KNOW

Alkaline earth metal: An element found in Group 2 (IIA) of the periodic table.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

René-Just Haüy (1743–1822) completed studies on beryl and emerald. Emerald is a naturally occurring green gemstone. Haüy was convinced that these two minerals were nearly identical. He asked a friend, Vauquelin, to determine the chemical composition of the two minerals.

When Vauquelin performed his chemical analysis, he found a new material that had been overlooked because it is so much like **aluminum**. His data proved that the material was *not* aluminum. He suggested calling the new element glucinium. Scientists referred to the element by two different names, beryllium and glucinium, for 160 years. The name beryllium comes from the mineral, beryl, in which it was first discovered.

Physical Properties

Beryllium is a hard, brittle metal with a grayish-white surface. It is the least dense (lightest) metal that can be used in construction. Its melting point is 2,349°F (1,287°C) and its boiling point is estimated to be about 4,500°F (2,500°C). Its density is 1.8 grams per cubic centimeter, about twice that of water. The metal has a high heat capacity (it can store heat) and heat conductivity (it can transfer heat efficiently).

Beryllium is transparent in X rays. X rays pass through the metal without being absorbed. For this reason, beryllium is sometimes used to make the windows for X-ray machines.

Chemical Properties

Beryllium reacts with acids and with water to form **hydrogen** gas. It reacts with **oxygen** in the air to form beryllium oxide (BeO). The beryllium oxide then forms a thin skin on the surface of the metal that prevents the metal from reacting further with oxygen.

Occurrence in Nature

Beryllium never occurs as a free element, only as a compound. The most common ore of beryllium is beryl. Beryl has the chemical formula $Be_3(Al_2(SiO_3))_6$.

In 2008, the major beryl producer in the world was the United States, followed by China and Mozambique. In the United States, beryl was produced by only one mine in Utah. Some plants also converted beryl into beryllium and its compounds.

Beryllium is relatively common in Earth's crust. Its abundance is estimated at 2 to 10 parts per million.

Isotopes

Only one naturally occurring isotope of beryllium exists: beryllium-9. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Eight radioactive isotopes of beryllium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the isotopes of beryllium has any commercial use.

Extraction

Beryllium ores are first converted to beryllium oxide (BeO) or beryllium hydroxide ($Be(OH)_2$). These compounds are then converted to beryllium chloride ($BeCl_2$) or beryllium fluoride (BeF_2). Finally, the pure metal is isolated by: (1) an electric current:

$$\mathbf{BeCl_2 \quad \text{electric current}\rightarrow Be + Cl_2}$$

or, (2) reaction with magnesium metal at high temperature:

$$\mathbf{BeCl_2 + Mg \rightarrow MgCl_2 + Be}$$

Uses

By far the greatest use of beryllium metal is in alloys. Beryllium alloys are popular because they are tough, stiff, and lighter than similar alloys. For example, an alloy of beryllium and aluminum called Beralcast was released in 1996. Beralcast is three times as stiff and 25 percent lighter than pure aluminum. It is used in helicopters and satellite guidance systems.

Other popular alloys of beryllium are those with copper metal. Copper-beryllium alloys contain about 2 percent beryllium. They conduct heat and electricity almost as well as pure copper but are stronger, harder, and more resistant to fatigue (wearing out) and corrosion (rusting). These alloys are used in circuit boards, radar, computers, home appliances, aerospace applications, automatic systems in factories, automobiles, aircraft landing systems, oil and gas drilling equipment, and heavy machinery.

Gemstones Beryllium is also associated with gemstones. A gemstone is a mineral that can be cut and polished for use in jewelry. Some typical gemstones are jade, sapphire, diamond, ruby, amethyst, emerald, spinel, moonstone, topaz, aquamarine, opal, and turquoise. Gemstones are often used as birthstones, which honor the month in which a person is born. (For instance, the birthstone for April is a diamond.)

Gemstones are valued for their beautiful colors and crystal forms. Light reflects off them in brilliant patterns. The crystal forms are the result of very exact arrangements of atoms in the gemstone. Its perfection contributes to its beauty and its monetary value.

But gemstone color is due to very small impurities in the mineral. For example, the mineral known as corundum is colorless when pure. But a very small amount of **chromium** produces a bright red color. The corundum is now a ruby. A touch of **iron** or **titanium** produces shades of yellow, green, purple, pink, or blue that turn it into a sapphire.

Two gemstones are made primarily of beryl. They are emeralds and aquamarines. In emeralds, traces of chromium produce a brilliant green color. In aquamarines, iron is the impurity. It gives the beryl a beautiful blue color.

Compounds

Some of the beryllium used in the United States is in the form of beryllium oxide (BeO). Beryllium oxide is a white powder that can be made into many different shapes. It is desirable as an electrical insulator because

Emeralds are one of the two gemstones that are made primarily of beryl. Their green color is due to traces of chromium. IMAGE COPYRIGHT 2009, TERRY DAVIS. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

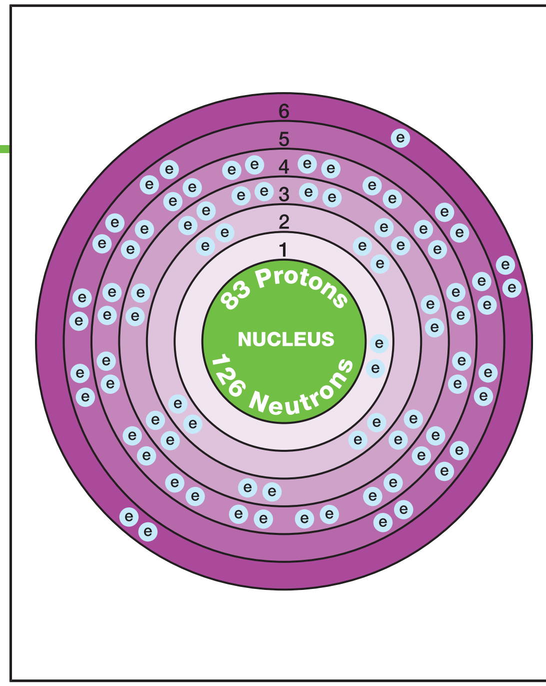
it conducts heat well, but an electrical current poorly. It is used in high-speed computers, auto ignition systems, lasers, microwave ovens, and systems designed to hide from radar signals.

Health Effects

Beryllium is a very toxic metal. It is especially dangerous in powder form. The effects of inhaling beryllium powder can be acute or chronic. Acute effects are those that occur very quickly as the result of large exposures. Chronic effects are those that occur over very long periods of time as the result of much smaller exposures. Acute effects of inhaling beryllium powder include pneumonia-like symptoms that can result in death in a short time. Chronic effects include diseases of the respiratory system (throat and lungs), such as bronchitis and lung cancer.

These effects can be avoided fairly easy. Workers can wear masks over their faces to filter out beryllium particles. Filtering devices in factories where beryllium is used also prevent beryllium from getting into the air.

Bismuth



Key Facts

Symbol: Bi

Atomic Number: 83

Atomic Mass: 208.98040

Family: Group 15 (VA); nitrogen

Pronunciation: BIZ-muth

Overview

Early chemists had difficulty separating similar elements from each other. Elements with similar properties can be told apart only with tests not available before the 18th century.

Chemists also believed that metals grew in the earth, in much the same way that plants grow. Unattractive metals, like **lead**, were thought to be young or immature metals. More attractive metals, like **tin**, were thought to be partially grown. The most mature metals were **silver** and **gold**. This made identification very difficult. Were chemists looking at "older lead" or a "younger tin?"

Bismuth is one of the elements often confused with other elements. Old manuscripts show that bismuth was often confused with lead, tin, **antimony**, or even silver.

Bismuth was used in early alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The first printing presses (dating back to the 1450s) used type made of bismuth alloys.

WORDS TO KNOW

Alchemy: A kind of pre-science that existed from about 500 BCE to about the end of the 16th century.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radiation: Energy transmitted in the form of electromagnetic waves or subatomic particles.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

Discovery and Naming

As with **arsenic** and antimony, it is difficult to say who exactly discovered bismuth. The name bismuth was probably taken from two German words, *weisse masse,* meaning "white mass." The phrase describes how the element appears in nature. Later the name was shortened to *wismuth,* and then to *bisemutum,* before bismuth came into common use.

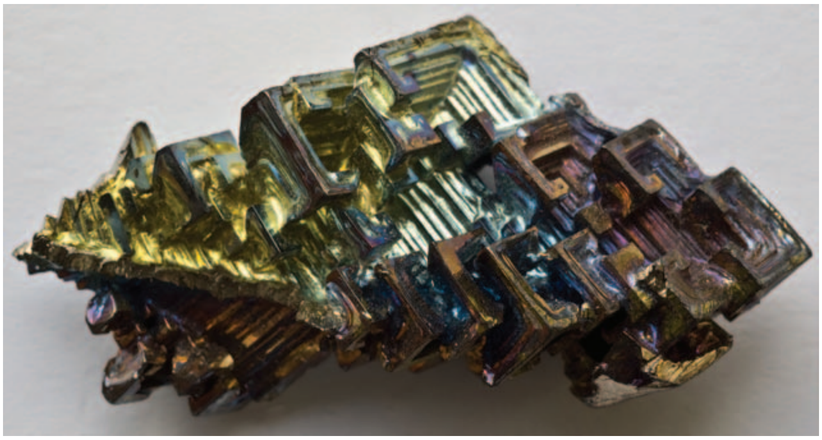
In 1753, French scholar Claude-Françoise Geoffrey wrote a book summarizing everything that was known about bismuth at the time.

Physical Properties

Bismuth is a soft, silvery metal with a bright, shiny surface and a yellowish or pinkish tinge. The metal breaks easily and cannot be fabricated (worked with) at room temperature. Its melting point is 520°F (271°C) and its boiling point is 2,840°F (1,560°C). Its density is 9.78 grams per cubic centimeter.

Bismuth expands as it solidifies (changes from a liquid to a solid). Most materials contract (have a smaller volume) as they solidify. Few elements behave like bismuth.

This property makes bismuth useful for producing type metal. An alloy of bismuth is melted and poured into molds that have the shape of letters and numbers. As the type cools, it solidifies and expands to fill all the corners of the mold. The type formed is clear, crisp, and easy to read. Computer typesetting, however, has largely replaced bismuth metal typesetting.



Bismuth crystals. IMAGE COPYRIGHT 2009, JENS MAYER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Chemical Properties

Bismuth combines slowly with **oxygen** at room temperature. Bismuth oxide (Bi_2O_3) gives the metal its pinkish or yellowish tinge. At higher temperatures, the metal burns to form bismuth oxide. Bismuth also reacts with most acids.

Occurrence in Nature

The abundance of bismuth in Earth's crust is estimated to be about 0.2 parts per million, making it a relatively rare element. This puts it in the bottom quarter of the elements according to their abundance in the earth.

Bismuth is seldom found in its elemental state (as a pure metal) in the earth. Its compounds are generally found along with ores of other metals, such as lead, silver, gold, and **cobalt**. The most important mineral of bismuth is bismuthinite, also known as bismuth glance (Bi_2S_3).

As of 2008, the largest producers of bismuth in the world were China, Mexico, Peru, and Canada. Bismuth is produced in the United States as a by-product of lead refining.

Isotopes

There is only one naturally occurring isotope of bismuth: bismuth-209. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fifty-nine radioactive isotopes of bismuth are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of bismuth have any commercial applications.

Extraction

Bismuth metal is usually separated from ores of other metals by the Betterton-Kroll process. **Calcium** or **magnesium** is added to the molten (melted) ore, forming an alloy with bismuth. Later, the bismuth can be separated from the calcium or magnesium to make the pure metal.

In 2008, the price of bismuth ranged from approximately $9.75 to $13.25 per pound.

Uses

The primary use of bismuth metal is in making alloys. Many bismuth alloys have low melting points. The metal itself melts at 520°F (271°C), but some bismuth alloys melt at temperatures as low as 160°F (70°C). This temperature is below the boiling point of water. These alloys are used in fire sprinkler systems, fuel tank safety plugs, solders, and other applications.

Interest in using bismuth as a substitute for lead in alloys has increased. Lead is toxic to humans and other animals so scientists are trying to find ways to replace lead in most applications. For example, an alloy containing 97 percent bismuth and 3 percent tin is popular as shot used in waterfowl hunting. Bismuth is also being used in place of lead in plumbing applications and in coloring paints, ceramics, and glazes.

Compounds

About a third of bismuth produced in the United States is made into drugs, pharmaceuticals, and other chemicals. The most widely used compound is bismuth subsalicylate ($Bi(C_7H_5O_3)_3$), the active ingredient in many over-the-counter stomach remedies. An over-the-counter drug is one that can be sold without a prescription.

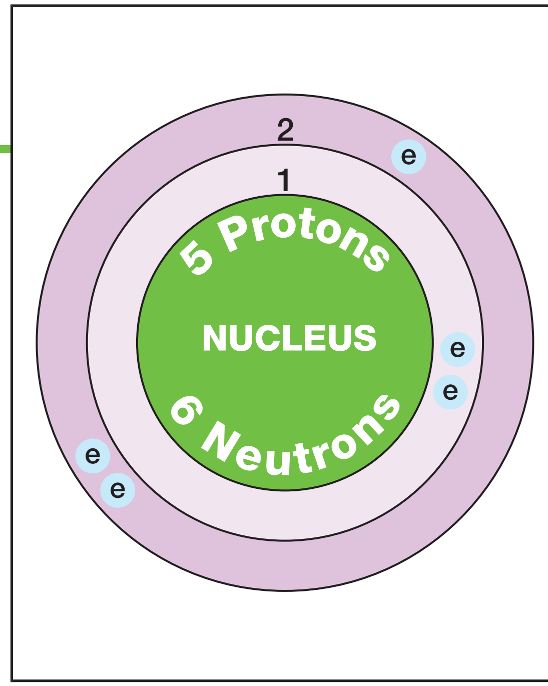
Other compounds used in medicine include bismuth ammonium citrate ($Bi(NH_4)_3(C_6H_5O_7)_2$), bismuth citrate ($BiC_6H_5O_7)_2$), bismuth subgallate ($Bi(OH)_2OOCC_6H_2(OH)_3$), and bismuth tannate. These compounds are used to treat a large variety of problems, including burns, stomach ulcers, and intestinal disorders, and in veterinary applications.

Bismuth compounds are also widely used in various cosmetics. Bismuth oxychloride (BiOCl) is a lustrous white powder added to face powder. Bismuth subcarbonate [$(BiO)_2CO_3$] and bismuth subnitrate [$4BiNO_3(OH)_2 \bullet BiO(OH)$] are also white powders used to give a pearl-like luster to lipstick, eyeshadow, and other cosmetics.

Health Effects

Bismuth and its compounds are not thought to be health hazards. In fact, bismuth compounds are used in medications. A relatively new bismuth compound is used to treat ulcers, a common stomach problem.

Boron



Overview

Boron is the first element in Group 13 (IIIA) of the periodic table. The periodic table is a chart that shows how the chemical elements are related to each other. The elements in this group are usually referred to as the aluminum family.

Boron is quite different from other members of the family. One difference is that boron is not a metal. All other members of the family (**aluminum**, **gallium**, **indium**, and **thallium**) are metals.

Compounds of boron have been used for centuries. Borax, a boron compound, has long been used to make glass and glazes. The element itself was not identified until 1808.

The most important use of boron is still in glass manufacture. Agricultural products, fire retardants, and soaps and detergents are all made of boron compounds.

Key Facts

Symbol: B

Atomic Number: 5

Atomic Mass: 10.811

Family: Group 13 (IIIA)

Pronunciation: BOR-on

Discovery and Naming

The first mention of boron compounds is found in a book by Persian alchemist Rhazes (c. 865–c. 925). Alchemists studied the nature of

WORDS TO KNOW

Abrasive: A powdery material used to grind or polish other materials.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Alpha radiation: A form of radiation that consists of very fast moving alpha particles and helium atoms without their electrons.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Refractory: A material that can withstand very high temperatures and reflect heat away from itself.

matter before modern chemistry was born. Rhazes classified minerals into six classes, one of which was the *boraces,* which included borax.

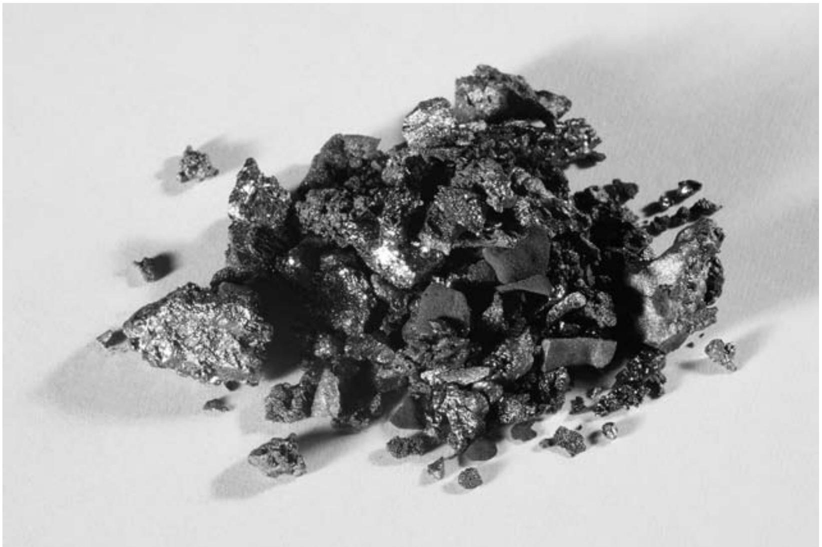
Borax was widely used by crafts people. It reduces the melting point of materials used to make glass. It was also used to melt the ores of metals and to isolate the metals from those ores.

In 1808, English chemist Humphry Davy (1778–1829) had just learned how to isolate the most active metals, such as **sodium** and **potassium**. He was also working on a method to remove boron from its compounds.

News of Davy's success had traveled to France, where emperor Napoleon Bonaparte (1769–1821) grew concerned about the scientific reputation of his country. He ordered larger and better equipment built for his scientists. He wanted them to surpass Davy in his work on metals. This equipment was designed especially for two French chemists, Louis Jacques Thênard (1777–1857) and Joseph Louis Gay-Lussac (1778–1850).

Thênard and Gay-Lussac found a new way to separate boron from its compounds. They heated boracic acid (also known as boric acid, H_3BO_3) with potassium metal to produce impure boron. Thênard and Gay-Lussac were given credit for discovering the new element. In 1892, French chemist Henri Moissan (1852–1907) produced boron that was 98 percent pure.

The names borax and boracic acid probably originated as far back as the time of Rhazes as *buraq* (in Arabic) or *burah* (in Persian).



One of the forms of boron.

Physical Properties

One of the unusual properties of boron is the many physical forms, called allotropes, in which it occurs. Allotropes are forms of an element with different physical and chemical properties. One form of boron consists of clear red crystals with a density of 2.46 grams per cubic centimeter. A second form consists of black crystals with a metallic appearance and a density of 2.31 grams per cubic centimeter. Boron can also occur as a brown powder with no crystalline structure. The density of this powder is 2.350 grams per cubic centimeter.

All forms of boron have very high melting points, from 4,000 to 4,200°F (2,200 to 2,300°C).

One property of special importance is boron's ability to absorb neutrons. Neutrons are subatomic particles with no charge that occur in the nucleus of nearly all atoms. Boron atoms are able to absorb a large number of neutrons. This makes boron useful in the control rods of nuclear reactors.

A nuclear reactor is a device for generating energy from nuclear fission reactions. Nuclear fission is the process in which large atoms are split, releasing large amounts of energy and smaller atoms. In a nuclear reactor, it is essential that just the right number of neutrons are present. Too many neutrons can cause a fission reaction to get out of control. Too few neutrons and a fission reaction stops.

Control rods are long tubes packed with boron (or some other element). The rods can be raised and lowered in the reactor. As the rods are lowered into the core, the boron absorbs neutrons, slowing the reaction.

Chemical Properties

Boron combines with **oxygen** in the air to form boron trioxide (B_2O_3). Boron trioxide forms a thin film on the element's surface that prevents further reaction with oxygen.

Boron is not soluble in water. It normally does not react with acids. In powder form, it reacts with hot nitric acid (HNO_3) and hot sulfuric acid (H_2SO_4). It also dissolves in molten (melted) metals.

Occurrence in Nature

The abundance of boron in Earth's crust is estimated to be about 10 parts per million. That places it in about the middle among the elements in terms of their abundance in the earth.

Boron never occurs as a free element but always as a compound. The most common minerals of boron are borax, or sodium borate ($Na_2B_4O_7$); kernite (another form of sodium borate); colemanite, or **calcium** borate ($Ca_2B_6O_{11}$); and ulexite, or sodium calcium borate ($NaCaB_5O_9$). These minerals usually occur as white crystalline deposits in desert areas. As of 2008, Turkey was the largest producer of boron ore. Other major producers of boron materials are Argentina, Chile, Russia, China, Bolivia, and Kazakhstan. Production statistics for the United States were not released in order to protect trade secrets.

Isotopes

Two naturally occurring isotopes of boron exist: boron-10 and boron-11. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. Boron-10 is the isotope with high neutron-absorbing tendencies described earlier under "Physical Properties."

A lake in Bolivia containing borax in its natural state is shown. IMAGE COPYRIGHT 2009, LAURA HART. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Nine radioactive isotopes of boron are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of boron have any important commercial uses.

Extraction

Boron is still produced by a method similar to that used by Thênard and Gay-Lussac. Boric oxide is heated with powdered **magnesium** or aluminum:

$$2Al + B_2O_3 \quad \text{heat}\rightarrow Al_2O_3 + 2B$$

The element can also be obtained by passing an electric current through molten (melted) boron trichloride:

$$2BCl_3 \quad \text{electrical current}\rightarrow 2B + 3Cl_2$$

Uses

Boron is used to make certain types of alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different

Experimental Cancer Treatment

Boron is also associated with cancer treatment, an area dominated by radiation. Radiation can kill living cells. Light, X rays, radio waves, and microwaves are all forms of radiant energy. These forms of radiation differ from each other in the amount of energy they carry with them. X rays carry a great deal of energy; light waves, less energy; and radio waves, very little energy.

The bad news about high-energy radiation is that it can kill healthy cells. A person exposed to high levels of X rays will become ill and may die. Because the X rays kill so many cells, the person's body cannot survive. Essential body functions stop, and death occurs.

The good news is that high-energy radiation can be used to kill cancer cells. Cancer cells are abnormal cells that reproduce faster than normal cells. The rapidly dividing cells form tumors, crowd organs, and shut down some organ functions. Radiation is one way to kill cancer cells.

The problem lies in killing only the cancer cells. The radiation has to be "targeted" at the cancer (bad) cells, and not the healthy (good) cells. Scientists think that using boron may be one way of achieving this goal. The experimental procedure called boron neutron capture therapy (BNCT) is one method for targeting cancer cells.

With BNCT, a person with cancer receives an injection of boron-10. The boron tends to go directly to cancer cells. Scientists currently do not know why boron favors cancer cells. But it does.

The patient's body is then bombarded with neutrons that pass through tissue without harming healthy cells. They then collide with boron atoms. The boron is converted into **lithium** atoms, alpha particles, and gamma rays. An alpha particle is a **helium** atom without electrons. Gamma radiation is very high-energy radiation that can kill cells.

The lithium atoms and alpha particles travel only a short distance. They do not leave the cancer cell but have enough energy to kill the cell. Since they do not leave the cell, they pose no threat to healthy cells nearby.

BNCT is not fully developed. But it holds great promise as a cancer treatment. It is currently being used primarily to treat two forms of cancer: glioblastoma, a very dangerous form of cancer that can not be treated by other means, and malignant melanoma, a very serious form of skin cancer.

from those of the individual metals. The most important of these alloys commercially are used to make some of the strongest magnets known. The rare earth magnets, for example, are made from boron, **iron**, and **neodymium**. These magnets are used for microphones, magnetic switches, loudspeakers, headphones, particle accelerators, and many other technical applications.

The use of boron in nuclear power plants was described earlier under "Physical Properties."

Compounds

The most important boron compound is sodium borate ($Na_2B_4O_7$), used in the manufacture of borosilicate glass, glass fiber insulation, and textile glass fiber. The addition of sodium borate to glass makes it easier to work while it is molten. The final glass is not attacked by acids or water, is very strong, and resists thermal shock. Resistance to thermal shock means the glass can be heated and cooled very quickly without breaking. The Pyrex glass used in kitchenware and chemistry laboratories is a form of borosilicate glass. High quality optical glass, like that used in telescopes, is also made from borosilicate glass.

Glass fiber insulation is made by forcing borosilicate glass through narrow openings. The glass comes out as a thin fiber and is then spun into insulation. These fibers trap air. Since neither the borosilicate fibers nor air is a good conductor of heat, it makes excellent insulation. Much of the insulation used in private homes, office buildings, and other structures is made of borosilicate fibers.

Fibers made from borosilicate glass are also used in making cloth. Borosilicate fibers are blended with other synthetic fibers to make durable fabric for automobile seat covers and other long-wear applications.

Boron also forms important compounds with two other elements, **carbon** and **nitrogen**. Boron carbide (B_4C) and boron nitride (BN) are important compounds because of their hardness. In fact, boron nitride may be the hardest substance known. Both compounds have very high melting points: 4,262°F (2,350°C) for boron carbide and more than 5,432°F (3,000°C) for boron nitride.

These properties make boron carbide and boron nitride useful as abrasives and refractories. An abrasive is a powdery material used to grind or polish other materials. A refractory material is one that can withstand very high temperatures by reflecting heat. Refractory materials line ovens to maintain high temperatures.

Boron carbide and boron nitride are used in high-speed tools, military aircraft and spacecraft, heat shields, and specialized heat-resistant fibers. They also are found in face powders, cream make-ups, and lipsticks.

Small amounts of boron compounds are also used to control the growth of weeds in agriculture, and as insecticides, fertilizers, and flame retardants. A flame retardant is a material that prevents another material from catching fire and burning with an open flame.

Health Effects

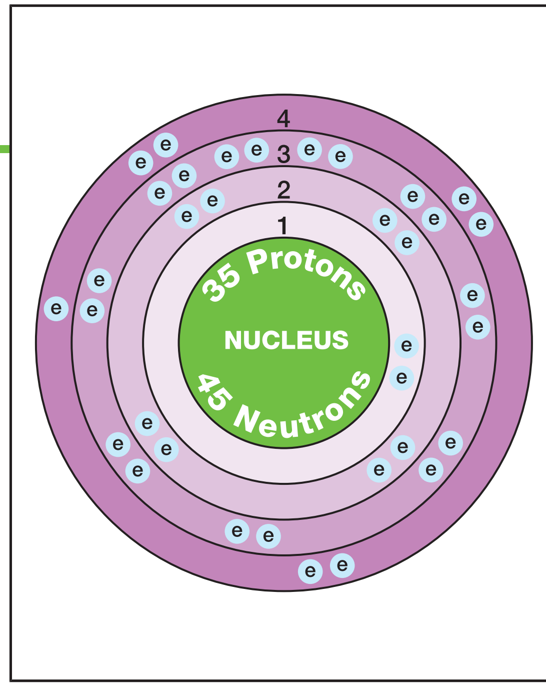
The role of boron in human health is not well understood. There is growing evidence that very small amounts of boron may be required to maintain healthy bones, especially in women. Studies suggest that a lack of boron may lead to arthritis and other disorders of the skeleton. Boron may also be necessary for healthy brain functions, such as memory and hand-eye coordination.

No specific recommendations have been made by health authorities. But some experts believe boron should be included in the daily diet. Most people get boron from fruits, green vegetables, nuts, and beans in their normal diet.

Boron is also an essential trace mineral in plants. A trace mineral is an element needed in minute amounts for the good health of an organism. Boron is critical to production of certain essential plant proteins and to help plants extract water from the soil. Low levels of boron show up as yellowing, blackening, twisting, or crumpling of leaves.

Few studies have been conducted on the harmful effects of exposure to boron and its compounds. Some evidence suggests that the element and its compounds may cause irritation of the eyes, skin, and respiratory system. No serious long-term problems, such as cancer, have yet been associated with exposure to boron or its compounds.

Bromine



Overview

Bromine is a member of the halogen family. Halogens are the elements that make up Group 17 (VIIA) of the periodic table. The periodic table is a chart that shows how elements are related to one another. The word halogen means "salt-former." **Fluorine**, **chlorine**, bromine, **iodine**, and **astatine** form salts when chemically combined with a metal.

Bromine was discovered, at almost the same time in 1826, by two men, German chemist Carl Löwig (1803–1890) and French chemist Antoine-Jérôme Balard (1802–1876). Although Balard announced his discovery first, Löwig had simply not completed his studies of the element when Balard made his announcement.

The vast majority of all bromine produced comes from the United States, Israel, and China. In 2008, Israel produced about 182,000 short tons (165,000 metric tons) and China contributed 149,000 short tons (135,000 metric tons). Statistics for the United States were not released in order to protect trade secrets.

The largest single use of the element is in the manufacture of flame retardants. Flame retardants are chemicals added to materials to prevent burning or to keep them from burning out of control. Other major uses

Key Facts

Symbol: Br

Atomic Number: 35

Atomic Mass: 79.904

Family: Group 17 (VIIA); halogen

Pronunciation: BRO-meen

WORDS TO KNOW

Density: The mass of a substance per unit volume.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

are in the manufacture of drilling fluids, pesticides, chemicals for the purification of water, photographic chemicals, and as an additive to rubber.

Discovery and Naming

Compounds of bromine had been known for hundreds of years before the element was discovered. One of the most famous of these compounds was Tyrian purple, also called royal purple. (Tyrian comes from the word Tyre, an ancient Phoenician city.) Only very rich people or royalty could afford to buy fabric dyed with Tyrian purple. It was obtained from a mollusk (shellfish) found on the shores of the Mediterranean Sea (a large body of water bordered by Europe, Asia, and Africa).

In 1825, Löwig enrolled at the University of Heidelberg in Germany to study chemistry. He continued an experiment he had begun at home in which he added chlorine to spring water. The addition of ether to that mixture produced a beautiful red color. Löwig suspected he had discovered a new substance. A professor encouraged him by suggesting he study the substance in more detail.

As these studies progressed, Balard published a report in a chemical journal that announced the discovery of the new element bromine. The element had all the properties of Löwig's new substance. The two chemists had made the discovery at nearly the same time. Balard, however, is credited as the discoverer of bromine, because scientists acknowledge the first person to *publish* his or her findings.

In Greek, the word *bromos* means "stench" (strong, offensive odor). Bromine lives up to the description. The odor is intense and highly irritating to the eyes and lungs.

Chemists found that bromine belonged in the halogen family. They knew that it had properties similar to other halogens and placed it below fluorine and chlorine in the periodic table.

A laboratory vessel holds the solid, liquid, and gaseous states of bromine. © CHARLES D. WINTERS, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Physical Properties

Only two liquid elements exist—bromine and **mercury**. At room temperature, bromine is a deep reddish-brown liquid. It evaporates easily, giving off strong fumes that irritate the throat and lungs. Bromine boils at 137.8°F (58.8°C), and its density is 3.1023 grams per cubic centimeter. Bromine freezes at 18.9°F (–7.3°C).

Bromine dissolves well in organic liquids—such as ether, alcohol, and carbon tetrachloride—but only slightly in water. Organic compounds contain the element **carbon**.

Chemical Properties

Bromine is a very reactive element. Although it is less reactive than fluorine or chlorine, it is more reactive than iodine. It reacts with many metals, sometimes very vigorously. For instance, with **potassium**, it reacts explosively. Bromine even combines with relatively unreactive metals, such as **platinum** and **palladium**.

Occurrence in Nature

Bromine is too reactive to exist as a free element in nature. Instead, it occurs in compounds, the most common of which are **sodium** bromide (NaBr) and potassium bromide (KBr). These compounds are found in seawater and underground salt beds. These salt beds were formed in regions where oceans once covered the land. When the oceans evaporated (dried up), salts were left behind—primarily sodium chloride (NaCl), potassium chloride (KCl), and sodium and potassium bromide. Later, movements of Earth's crust buried the salt deposits. Now they are buried miles underground. The salts are brought to the surface in much the same way that coal is mined.

Bromine is a moderately abundant element. Its abundance in Earth's crust is estimated to be about 1.6 to 2.4 parts per million. It is far more abundant in seawater where its occurrence is estimated to be about 65 parts per million.

In some regions, the abundance of bromine is even higher. For example, the Dead Sea (which borders Israel and Jordan), has a high level of dissolved salts. The abundance of bromine there is estimated to be 4,000 parts per million. The salinity, or salt content, is so high that nothing lives in the water. That fact explains how the Dead Sea got its name.

Isotopes

Two naturally existing isotopes of bromine exist: bromine-79 and bromine-81. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-four radioactive isotopes of bromine are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

No isotope of bromine has any important commercial use.

Extraction

The method used by Löwig and Balard to collect bromine continues to be used today. Chlorine is added to seawater containing sodium bromide or potassium bromide. Chlorine is more active than bromine and replaces bromine in the reaction:

$$\mathbf{Cl_2 + 2NaBr \rightarrow 2NaCl + Br_2}$$

Uses and Compounds

The most important use of bromine today is in making flame retardant materials. Many materials used in making clothing, carpets, curtains, and drapes are flammable, and if a flame touches them, they burn very quickly. Chemists have learned how to make materials more resistant to fires by soaking them in a bromine compound. The compound coats the fibers of the material. The bromine compound can also be chemically incorporated into the material.

The bromine compounds used in flame retardants are often complicated. One such compound is called tris(dibromopropyl)phosphate ($(Br_2C_3H_5O)_3PO$). However, this compound has been found to be a carcinogen (cancer-causing substance). Its use, therefore, has been severely restricted.

Bromine is also used in drilling wells. Calcium bromide ($CaBr_2$), sodium bromide ($NaBr$), or zinc bromide ($ZnBr_2$) is added to a well to increase the efficiency of the drilling process.

Bromine is also important in the manufacture of pesticides, chemicals used to kill pests. For many years, one of the most popular bromine-based pesticides was methyl bromide (CH_3Br). Methyl bromide is sprayed on the surface or injected directly into the ground to control pests.

The problem with using methyl bromide is that some of the chemical always evaporates into the air. It then escapes into Earth's stratosphere, where it damages the ozone layer. Ozone (O_3) gas filters out a portion of the ultraviolet (UV) radiation from the sun. UV radiation causes skin cancer, sunburn, and damage to plants and fragile organisms.

Bromine compounds increase the efficiency of the drilling process in oil rigs.
IMAGE COPYRIGHT 2009, BRAM VAN BROEKHOVEN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Because of the damage it causes to the environment, many countries have banned the production and/or use of methyl bromide as a pesticide. The U.S. ban on methyl bromide became effective on January 1, 2005. Some exceptions to the ban exist, permitting the pesticide's use for certain specialized purposes.

Ethylene dibromide ($C_2H_4Br_2$) is a bromine compound added to leaded gasoline. The lead in "leaded gasoline" is tetraethyl lead ($Pb(C_2H_5)_4$). It helps fuels burn more cleanly and keeps car engines from "knocking." "Knocking" is a repetitive metallic banging sound that occurs when there are ignition problems with a car's engine. "Knocking" reduces the efficiency of a car engine.

But leaded gasoline gives off free lead as it burns. Free lead is a very toxic element that causes damage to the nervous system. Ethylene dibromide is added to react with free lead and convert it to a safe compound.

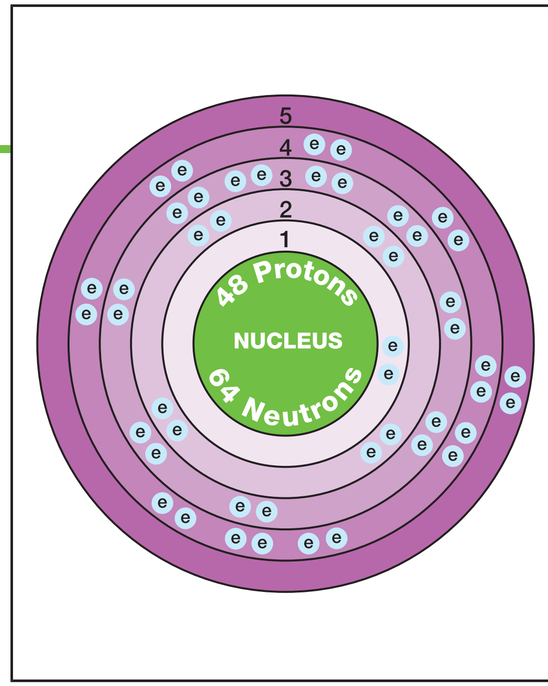
Ethylene dibromide does not completely solve the problem. Some free lead still escapes into the atmosphere. Leaded gasoline has been banned in the United States for many years but is still used in some countries.

Bromine is also used as a disinfectant for swimming pools and water used in industrial cooling towers. It kills disease-causing bacteria as effectively as chlorine, which was once the most popular disinfectant for these purposes. But it adds less odor to water than chlorine and is less likely to irritate a person's skin, eyes, and nose. Today, many individuals and companies have switched from chlorine to bromine for disinfecting the water in swimming pools and cooling towers.

Health Effects

Bromine is toxic if inhaled or swallowed. It can damage the respiratory system and the digestive system, and can even cause death. It can also cause damage if spilled on the skin.

Cadmium



Key Facts

Symbol: Cd

Atomic Number: 48

Atomic Mass: 112.411

Family: Group 12 (IIB); transition metal

Pronunciation: CAD-mee-um

Overview

Cadmium is a transition metal. The transition metals are the elements found in Rows 4 through 7 between Groups 2 and 13 in the periodic table, a chart that shows how elements are related to each other. Cadmium was discovered by German chemist Friedrich Stromeyer (1776–1835) in 1817. It is found most commonly in ores of **zinc**.

Cadmium is a soft metal that is easily cut with a knife. It resembles zinc in many of its physical and chemical properties. However, it is much less abundant in Earth's crust than zinc.

Among the most important uses of cadmium in the United States is in the production of nicad (**nickel**-cadmium), or rechargeable, batteries. It is also used in pigments, coatings and plating, manufacture of plastic products, and alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals.

Caution must be used when handling cadmium and its compounds, as they are toxic to humans and animals. They present a threat to the environment because they are used for so many applications.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

In addition to being a professor at Göttingen University, Stromeyer was a government official responsible for inspecting pharmacies in the state of Hanover, Germany. On one inspection trip, he found that many pharmacies were stocking a compound of zinc called zinc carbonate ($ZnCO_3$) instead of the usual zinc oxide (ZnO).

Stromeyer was told that the supplier had problems making zinc oxide from zinc carbonate and had offered the substitution. The normal process was to heat zinc carbonate to produce zinc oxide:

$$\mathbf{ZnCO_3 \quad heat\rightarrow ZnO + CO_2}$$

The supplier explained that zinc carbonate turned yellow when heated. Normally, a yellow color meant that **iron** was present as an impurity. The supplier found no iron in his zinc carbonate, but it was still yellow. Pharmacies would not buy yellow zinc oxide, so the supplier sold white zinc carbonate instead.

Stromeyer analyzed the odd yellow zinc carbonate. What he discovered was a new element—cadmium. The cadmium caused the zinc carbonate to turn yellow when heated. The name cadmium comes from the ancient term for zinc oxide, *cadmia.* Zinc oxide is still available in pharmacies today. It is sold under the name of calamine lotion. Calamine lotion is a popular remedy for stopping the itch of sunburn or bug bites.

Physical Properties

Cadmium is a shiny metal with a bluish cast (shade) to it. It is very soft and can almost be scratched with a fingernail. Its melting point is

Cadmium samples. © RICH TREPTOW, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

610°F (321°C) and its boiling point is 1,410°F (765°C). The density of cadmium is 8.65 grams per cubic centimeter.

An interesting property of cadmium is its effect in alloys. In combination with certain metals, it lowers the melting point. Some common low-melting-point alloys are Lichtenberg's metal, Abel's metal, Lipowitz' metal, Newton's metal, and Wood's metal. The Wood's metal alloy melts at 158°F (70°C), and is used in fire sprinkler systems as a plug. When the temperature rises above 158°F (70°C), the plug melts and falls out. This opens up the water line and activates the sprinkler. Out sprays the water!

Chemical Properties

Cadmium reacts slowly with **oxygen** in moist air at room temperatures, forming cadmium oxide:

$$2Cd + O_2 \rightarrow 2CdO$$

Cadmium does not react with water, although it reacts with most acids.

Occurrence in Nature

The abundance of cadmium in Earth's crust is estimated to be about 0.1 to 0.2 parts per million. It ranks in the lower 25 percent of the elements in terms of abundance in the earth.

The only important ore of cadmium is greenockite, or cadmium sulfide (CdS). Most cadmium is obtained as a by-product of zinc refinement.

As of 2008, China, Korea, Canada, Kazakhstan, Japan, Mexico, Russia, and the United States were among the largest producers of cadmium.

Isotopes

Seven naturally occurring isotopes of cadmium exist. They are cadmium-106, cadmium-108, cadmium-110, cadmium-111, cadmium-112, cadmium-114, and cadmium-116. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-five radioactive isotopes of cadmium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One isotope of cadmium, cadmium-109, is sometimes used to analyze metal alloys. It provides a way of keeping track of the alloys in stock and sorting different forms of scrap metal from each other.

Extraction

Most cadmium is obtained as a by-product from zinc refinement. Cadmium and zinc melt at different temperatures, providing one way of separating the two metals. As a liquid mixture of zinc and cadmium is cooled, zinc becomes a solid first. It can be removed from the mixture, leaving liquid cadmium behind.

In 2008, American consumption of cadmium metal totaled approximately \$3.87 million.

Uses

At one time, the most important use of cadmium was in the electroplating of steel. Electroplating is a process by which a thin layer of one metal is deposited on the surface of a second metal. An electric current is passed through a solution containing the coating metal. The metal is electrically deposited on the second metal. A thin layer of cadmium protects steel from corrosion (rusting).

Since the 1960s, the use of cadmium for electroplating has dropped significantly due to environmental concerns. Discarded electroplated steel puts cadmium into the environment. Alternative coating methods are usually used now.

Much of the cadmium produced worldwide is used in nickel-cadmium (nicad or Ni-Cd) batteries. Nicad batteries can be used over and over. When a nicad battery has lost some or all of its power, it is inserted into a unit that plugs into an electrical outlet. Electricity from the outlet recharges the battery.

Nicad batteries are used in a large variety of appliances, including compact disc players, cell phones, pocket recorders, handheld power tools, cordless telephones, laptop computers, camcorders, and scanner radios. A few automobile manufacturers have explored the possibility of using nicad batteries in electric cars. For example, the Mitsubishi Corporation of Japan built and marketed an experimental car called the Libro EV that operated on either traditional lead batteries or on nicad batteries.

Nicad (nickel-cadmium) batteries can be recharged in a plug-in unit such as this one.

Compounds

A popular use of cadmium compounds is as coloring agents. The two compounds most commonly used are cadmium sulfide (CdS) and cadmium selenide (CdSe). The sulfide is yellow, orange, or brown, while the selenide is red. These compounds are used to color paints and plastics. There is concern about possible environmental effects of using cadmium for this purpose, and scientists have been attempting to find substitutes for these compounds. Some satisfactory alternatives have been found.

Health Effects

Cadmium enters the human body as the result of cigarette smoking, eating certain foods (such as shellfish, liver, and kidney meats), coal burning, and drinking contaminated water. Those most at risk for high intake of cadmium are people who work directly with the metal. Manufacturing plants where batteries are made use cadmium as a fine powder where it can easily be inhaled. Workers must be careful in handling cadmium.

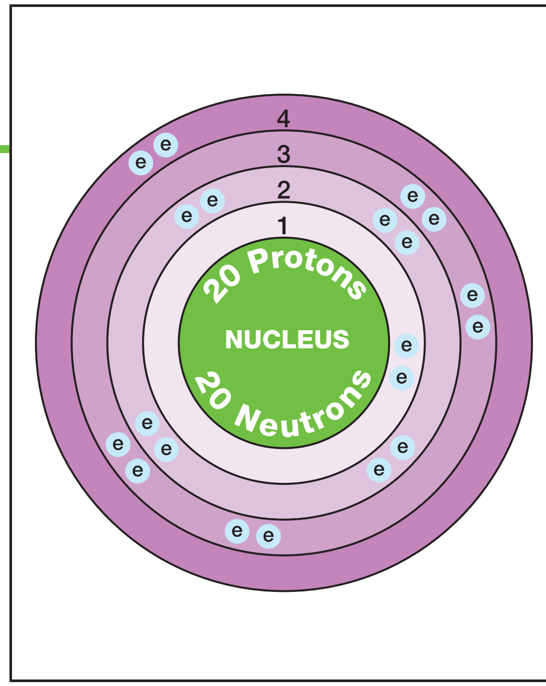
There is growing concern about the dangers of cadmium in the environment. Some rechargeable batteries are made with cadmium and nickel. Cadmium can escape from landfills (where trash is buried) and get into the ground and groundwater. From there, it can become part of the food and water that humans and other animals ingest.

Low levels of cadmium cause nausea, vomiting, and diarrhea. Inhaled, cadmium dust causes dryness of the throat, choking, headache, and pneumonia-like symptoms.

The effects of extensive cadmium exposure are not known, but are thought to include heart and kidney disease, high blood pressure, and cancer. A cadmium poisoning disease called *itai-itai,* Japanese for "ouch-ouch," causes aches and pains in the bones and joints. In the 1970s, a number of cases of *itai-itai* were reported in Japan when waste from a zinc refinery got into the public water supply. Those wastes contained cadmium compounds.

In 2010, product testing revealed that high levels of cadmium were being used in some children's jewelry made in Asia. In response, various U.S. stores pulled those products off their shelves, and a recall was initiated.

Calcium



Key Facts

Symbol: Ca

Atomic Number: 20

Atomic Mass: 40.078

Family: Group 2 (IIA); alkaline earth metal

Pronunciation: CAL-cee-um

Overview

Calcium is an alkaline earth metal. The alkaline earth metals make up Group 2 (IIA) of the periodic table, a chart that shows how the elements are related. They also include **beryllium**, **magnesium**, **strontium**, **barium**, and **radium**. The alkaline earth metals are more chemically active than most metals. Only the alkali metals in Group I (IA) are more reactive.

Calcium compounds are common and abundant in Earth's crust. Humans have used calcium compounds for thousands of years in construction, sculpture, and roads.

Calcium metal was not prepared in a pure form until 1808 when English chemist Humphry Davy (1778–1829) passed an electric current through molten (melted) calcium chloride.

Metallic calcium has relatively few uses. However, calcium compounds are well known and widely used. They include chalk, gypsum, limestone, marble, and plaster of paris.

Discovery and Naming

It is impossible to say when humans first knew about or used compounds of calcium. Whenever they used limestone to build a structure, they were

WORDS TO KNOW

Alkaline earth metal: An element found in Group 2 (IIA) of the periodic table.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Calx: The original term for calcium.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

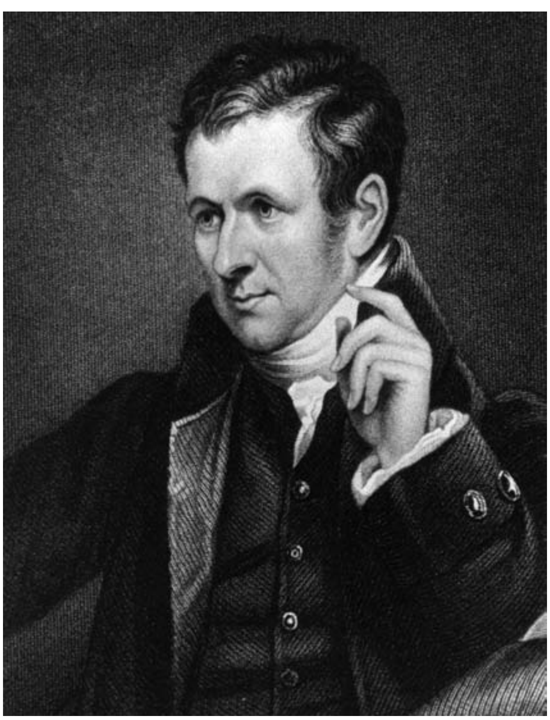
Periodic table: A chart that shows how the chemical elements are related to each other.

Quarry: A large hole in the ground from which useful minerals are taken.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

using a compound of calcium. Limestone is the common name for calcium carbonate ($CaCO_3$). Whenever humans built a statue or monument out of marble, they were using calcium carbonate in another form. Ancient Egyptians and early Greeks used mortar, a cement-like material that holds stones and bricks together. Early mortar was made by roasting or heating limestone for long periods of time. Water was then mixed with the powder, which would then dry to form a strong bond.



Humphry Davy. LIBRARY OF CONGRESS.

Another calcium compound used by early civilizations was plaster of paris. Plaster of paris is made by heating gypsum, or calcium sulfate ($CaSO_4$), to remove the water that makes it crystallize. Water was added and it hardened into a brittle, cement-like substance. Until recently, it was most often used to make casts to protect broken bones. However, it has largely been replaced by fiberglass, which is lighter, yet stronger. The first mention of plaster of paris to protect broken bones can be found in a book written by Persian pharmacist Abu Mansur Muwaffaw in about 975 CE.

By the 1700s, chemists had learned a great deal about calcium compounds. They knew that limestone, gypsum, marble, and many other commonly occurring compounds all contain a

Element Discoverer: Humphry Davy

Born in 1778, Humphry Davy grew up in Cornwall, England, in a poor family. His father, who died when Davy was a boy, had lost money in unwise investments. So Davy worked to help his mother pay off the debts. He disliked being a student, although he liked reading about science.

With no money for further education, Davy began to work for a surgeon-pharmacist. He also started learning about geography, languages, and philosophy on his own. Davy even dabbled in poetry. At 19, he decided to concentrate on chemistry and eventually became a major contributor to the field of electrochemistry, the science involving the relation of electricity to chemical changes.

Davy discovered nitrous oxide after testing the effects of hydrogen and carbon dioxide on himself. (He liked to use himself as a human guinea pig.) Nitrous oxide is a gas that consists of nitrogen and oxygen. He discovered that its effects often made him feel very happy or very sad. The feeling of happiness eventually gave nitrous oxide another name: laughing gas. Most importantly, Davy recognized that it could be used as an anesthetic. An anesthetic is a chemical used to dull pain during surgery.

In 1808, Davy invented the carbon arc lamp. He had proposed using carbon as the electrode material instead of metal. (Electrodes are conductors used to establish electrical contact with a nonmetallic part of a circuit.) With carbon electrodes, he made a strong electric current leap from one electrode to the other. This created an intense white light. Davy's invention marked the beginning of the era of electric light. Arc lamps are still used today.

In addition, Davy built a large battery that he used to break down substances that most scientists thought were pure elements. In 1807, he discovered the element potassium by using a process known as electrolysis. Electrolysis is a reaction in which electric current is used to bring about chemical changes. Less than a week later, Davy also isolated the element sodium by the same procedure. Then in 1808, he isolated calcium, magnesium, barium, and strontium. Davy was only 29 by the time he had discovered all of these elements.

Davy went on to make other major discoveries and inventions. During his lifetime, Davy was awarded many honors and medals. He died of a stroke in 1829.

common element. They called the element calx. That word comes from the Latin term for lime. In 1807, Davy isolated the new element.

Davy invented a method for extracting elements from compounds that were difficult to separate by usual methods. He first passed an electric current through the compound, causing it to melt. The electric current then caused the compound to break apart into the elements of which it is made.

One of the compounds he used this method on was calx (calcium oxide; CaO), producing pure calcium metal for the first time. Davy suggested the name calcium for the new element. He chose the name by adding the suffix *-ium* to the word calx; *-ium* is the ending used for almost all metallic elements. Using the same method, Davy was also able to produce free **sodium**, **potassium**, strontium, magnesium, and barium.

Physical Properties

Calcium is a fairly soft metal with a shiny silver surface when first cut. The surface quickly becomes dull as calcium reacts with oxygen to form a coating of white or gray calcium oxide.

Calcium's melting point is 1,560°F (850°C) and its boiling point is 2,620°F (1,440°C). It has a density of 1.54 grams per cubic centimeter.

Chemical Properties

Calcium is a moderately active element. It reacts readily with oxygen to form calcium oxide (CaO):

$$\mathbf{2Ca + O_2 \rightarrow 2CaO}$$

Calcium reacts with the halogens—**fluorine**, **chlorine**, **bromine**, **iodine**, and **astatine**. The halogens are the elements that make up Group 17 (VIIA) of the periodic table. Calcium also reacts readily with cold water, most acids, and many non-metals, such as **sulfur** and **phosphorus**. For example, calcium reacts with sulfur:

$$\mathbf{Ca + S \rightarrow CaS}$$

Occurrence in Nature

Calcium is the fifth most common element in Earth's crust. Its abundance is estimated to be about 3.64 percent. It is also the fifth most abundant element in the human body.

Calcium does not occur as a free element in nature. It is much too active and always exists as a compound. The most common calcium compound is calcium carbonate ($CaCO_3$). It occurs in the minerals aragonite, calcite, chalk, limestone, marble, and travertine, and in oyster shells and coral.

Shellfish build their shells from calcium dissolved in the water. When the animals die or are eaten, the shells sink. Over many centuries, thick layers of the shells may build up and be covered with mud, sand, or other materials. The shells are squeezed together by the heavy pressure of other materials and water above them. As they are squeezed together, the layer is converted to limestone. If the limestone is squeezed even more, it can change into marble or travertine.

Calcium can be found in oyster shells. IMAGE COPYRIGHT 2009, PACK-SHOT. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Isotopes

Five naturally occurring stable isotopes of calcium exist: calcium-40, calcium-42, calcium-43, calcium-44, and calcium-46. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fourteen radioactive isotopes of calcium are also known, one of which, calcium-48, exists in nature. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Two radioactive isotopes of calcium are used in research and medicine. Calcium-45 is used to study how calcium behaves in many natural processes. For example, it can be used to see how various types of soil behave with different kinds of fertilizers. The calcium-45 is used as a tracer in such studies. A tracer is a radioactive isotope whose presence in a system can easily be detected. The isotope is injected into the system at some point. Inside the system, the isotope gives off radiation. The radiation can be followed by detectors placed around the system.

Calcium-45 can also be used as a tracer in the study of glassy materials, detergents, and water purification systems.

Both calcium-45 and calcium-47 can be used to study how calcium is used in the body. A doctor may think that a person's body is not using calcium properly in making bones or regulating nerve messages. The doctor can use calcium-45 or calcium-47 to find out more about this problem. The radioactive isotope is injected into the person's bloodstream. Then its path can be followed by the radiation it gives off. The doctor can then tell if the calcium is being used normally in the body.

Extraction

Pure calcium metal can be made by the same method used by Davy. An electric current is passed through molten calcium chloride:

$$CaCl_2 \xrightarrow{\text{electric current}} Ca + Cl_2$$

There is not much demand for pure calcium. Most calcium is used in the form of limestone, gypsum, or other minerals that can be mined directly from the earth.

Uses

Calcium metal has relatively few uses. It is sometimes used as a "getter." A getter is a substance that removes unwanted chemicals from a system. Calcium is used as a getter in the manufacture of evacuated glass bulbs. Calcium is added to the bulb while it is being made. It then combines with gases left in the glass in the final stages of manufacture. Calcium is also used as a getter in the production of certain metals, such as **copper** and steel. The calcium removes unwanted elements that would otherwise contaminate the metal.

Calcium is also used to make alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. An alloy of calcium and **cerium** is used in flints found in lighters (the parts of a lighter that create sparks).

Compounds

The starting point for the manufacture of most calcium compounds is limestone. Limestone occurs naturally in large amounts in many parts

Calcium carbonate ($CaCO_3$) can be seen in the White Cliffs of Dover in Great Britain.

of the world. It is usually mined from open-pit quarries. A quarry is a large hole in the ground from which useful minerals are taken.

Limestone is first heated to obtain lime, or calcium oxide (CaO):

$$\mathbf{CaCO_3 \quad heated \rightarrow CaO\ (lime) + CO_2}$$

Lime is one of the most important chemicals in the world. It usually ranks in the top 10 chemicals produced in the United States.

Lime is used in the production of metals. It is used during the manufacture of steel to remove unwanted sand, or silicon dioxide (SiO_2), present in iron ore:

$$\mathbf{CaO + SiO_2 \rightarrow CaSiO_3}$$

The product formed in this reaction, calcium silicate ($CaSiO_3$), is called slag.

Another important use of lime is in pollution control. Many factories release harmful gases into the atmosphere through smokestacks. Lining a smokestack with lime allows some of these gases to be captured. The lime is known as a scrubber. Lime captures one harmful gas, sulfur dioxide (SO_2), which is a contributor to acid rain (a form of precipitation that is significantly more acidic than neutral water, often produced as the result of industrial processes):

$$\mathbf{CaO + SO_2 \rightarrow CaSO_3}$$

Calcium sulfite ($CaSO_3$) is a solid that can be removed from the inside of the smokestack.

Lime is also used in water purification and waste treatment plants. When calcium oxide combines with water, it forms slaked lime, or calcium hydroxide ($Ca(OH)_2$):

$$\mathbf{CaO + H_2O \rightarrow Ca(OH)_2}$$

Slaked lime traps impurities present in the water as it forms. It carries the impurities with it as it sinks to the bottom of the tank.

At one time, lime was used as a source of light in theaters. When lime is heated to a high temperature, it gives off an intense white light. Pots of hot lime were often used to line the front of the stage. The light the pots gave off helped the audience see the performers. As a result, the performers were said to be "in the limelight." That phrase is still in use today, but lime is no longer used as a source of light in theaters.

Lime is used to make more than 150 different industrial chemicals. Some examples of these chemicals with their uses are:

- calcium alginate: thickening agent in food products such as ice cream and cheese products; synthetic fibers
- calcium arsenate ($Ca_3(AsO_4)_2$): insecticide
- calcium carbide (CaC_2): used to make acetylene gas (for use in acetylene torches for welding); manufacture of plastics
- calcium chloride ($CaCl_2$): ice removal and control of dust on dirt roads; conditioner for concrete; additive for canned tomatoes; provides body for automobile and truck tires
- calcium cyclamate ($Ca(C_6H_{11}NHSO_4)_2$): sweetening agent (cyclamate), no longer permitted for use in the United States because of suspected cancer-causing properties
- calcium gluconate ($Ca(C_6H_{11}O_7)_2$): food additive; vitamin pills
- calcium hypochlorite ($Ca(OCl)_2$): swimming pool disinfectant; bleaching agent; deodorant; algicide and fungicide (kills algae and fungi)
- calcium permanganate ($Ca(MnO_4)_2$): liquid rocket propellant; textile production; water sterilizing agent; dental procedures
- calcium phosphate ($Ca_3(PO_4)_2$): supplement for animal feed; fertilizer; commercial production of dough and yeast products; manufacture of glass; dental products

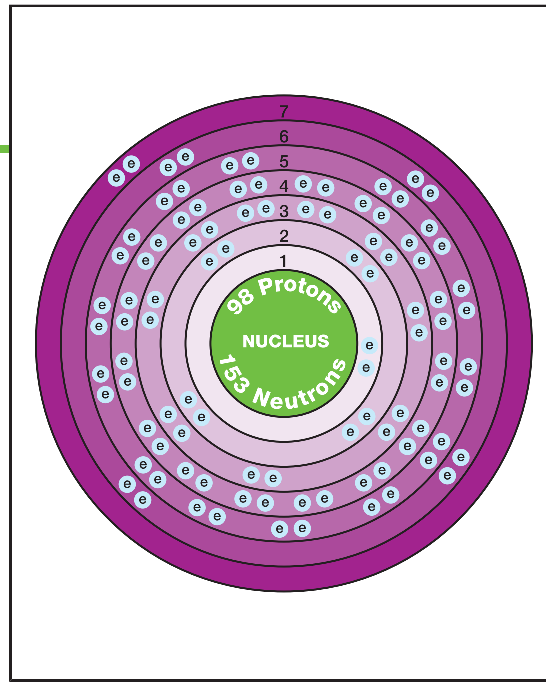
- calcium phosphide (Ca_3P_2): fireworks; rodenticide (kills rats); torpedoes; flares
- calcium stearate ($Ca(C_{18}H_{35}O_2)_2$): manufacture of wax crayons, cements, certain kinds of plastics, and cosmetics; food additive; production of water resistant materials; production of paints
- calcium tungstate ($CaWO_4$): luminous paints; fluorescent lights; X-ray studies in medicine.

Health Effects

Calcium is essential to both plant and animal life. In humans, it makes up about 2 percent of body weight. About 99 percent of the calcium in a person's body is found in bones and teeth. Milk is a good source of calcium. The body uses calcium in a compound known as hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) to make bones and teeth hard and resistant to wear.

Calcium has many other important functions in the human body. For example, it helps control the way the heart beats. An excess (too much) or deficiency (not enough) of calcium can change the rhythm of the heart and cause serious problems. Calcium also controls the function of other muscles and nerves.

Californium



Key Facts

Symbol: Cf

Atomic Number: 98

Atomic Mass: [251]

Family: Actinoid; transuranium element

Pronunciation: cal-uh-FOR-nee-um

Overview

Californium is a transuranium element, or "beyond **uranium**" on the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Uranium is element number 92 in the periodic table, so elements with atomic numbers greater than 92 are said to be transuranium elements.

Discovery and Naming

Californium was discovered in 1950 by a research team at the University of California at Berkeley. The team—made up of Glenn Seaborg (1912–1999), Albert Ghiorso (1915–), Kenneth Street Jr. (1920–2006), and Stanley G. Thompson (1912–1976)—named the new element after the state of California.

Californium was first prepared in a particle accelerator, or an "atom smasher," which accelerates subatomic particles or atoms to very high speeds. The particles collide with a target, such as **gold**, **copper**, or **tin**. The target atoms are converted into new elements by the interaction.

To make californium, researchers fired alpha particles (**helium** atoms without electrons) at a target of **curium**. Some collisions cause a helium

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive: Having a tendency to give off radiation.

Transuranium element: An element with an atomic number greater than 92.

atom (atomic number 2) to become part of a curium atom (atomic number 96), forming a new atom with atomic number 98.

Physical and Chemical Properties

Very little is known about the physical and chemical properties of californium. Its melting point has been found to be 1,652°F (900°C) and its density, 15.1 grams per cubic centimeter, about 15 times that of water. It is also very radioactive. One microgram (millionth of a gram) of the element emits about three million neutrons per second.

Albert Ghiorso was part of the team that discovered Californium. AP IMAGES.

Occurrence in Nature

Californium does not occur naturally on Earth. However, it has been observed in the spectra of supernovae.

Isotopes

All 21 isotopes of californium are radioactive. The most stable isotope is californium-251. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation.

The half life of californium-251 is 898 years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. For instance, in 898 years, only half of a 100-gram sample of californium-251 would remain. After another 898 years, only half of that amount (25 grams) would remain.

One isotope of californium is of special interest: californium-252. This isotope has the unusual property of giving off neutrons when it breaks apart. Isotopes that behave in this way are somewhat rare.

Extraction

Californium has not been observed naturally on Earth.

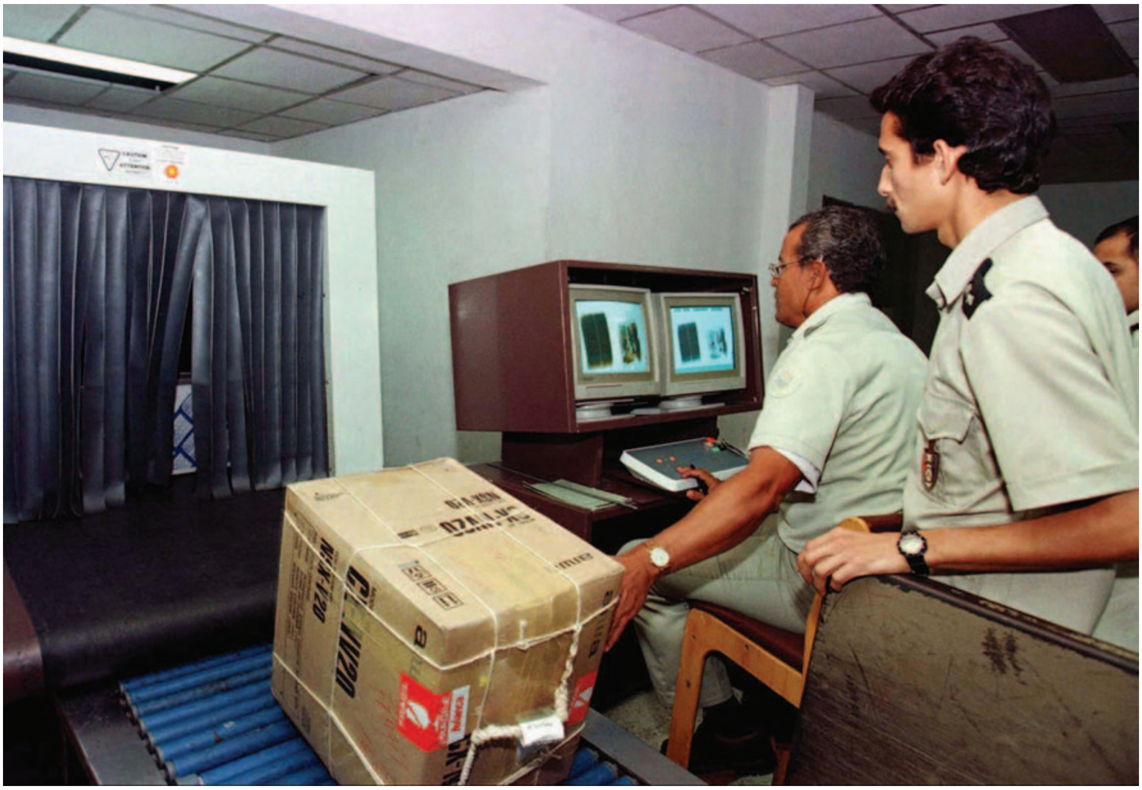
Uses

When neutrons collide with an atom, they tend to become part of the nucleus, making the atom less stable:

neutron from californium + ordinary copper → radioactive copper

The radioactive copper then gives off radiation or energy and particles that can be measured.

Based on this property, californium-252 has been used to prospect for oil and to test materials without breaking them apart or destroying them. The isotope can also be used to determine the amount of moisture in soil, information that is very important to road builders and construction companies. Neutrons from californium-252 can be used to inspect



Security personnel use equipment that features californium-252 to inspect luggage. AP IMAGES.

airline baggage. The luggage can be tested quickly and efficiently without having to open it.

Californium-252 is also used in medicine. When injected into the body, it tends to be deposited in bones. The radiation it gives off can be used to determine the health of the bone. Californium-252 is also used to treat ovarian and cervical cancer. Some experts see a number of important medical uses for californium-252 in the future, especially in radiotherapy (medical treatment using radiation).

Today, californium can be made only in small amounts. It is available from the U.S. government via the Oak Ridge National Laboratory in Tennessee.

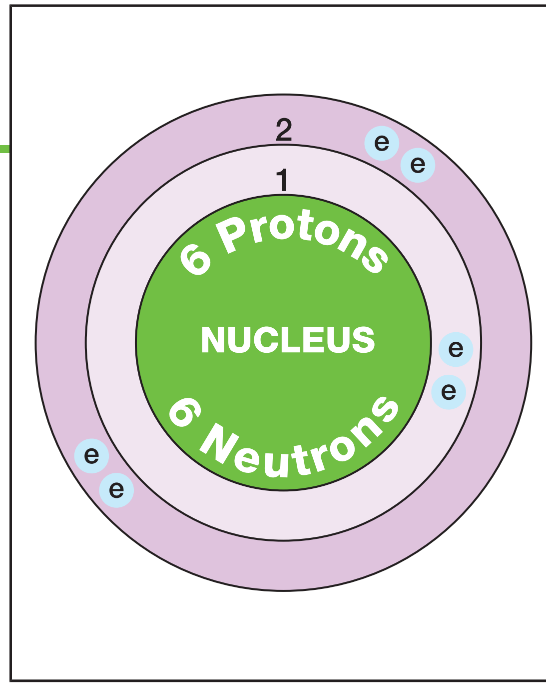
Compounds

There are no commercially important compounds of californium.

Health Effects

Radioactive materials, such as californium, are hazardous to living cells. As the element's atoms decay, they emit energy and particles that damage or kill the cell. The damaged cells rapidly divide, producing masses called tumors. Cancerous cells can crowd out healthy cells, reduce or stop organ function, and break free to spread through the body.

Carbon



Key Facts

Symbol: C

Atomic Number: 6

Atomic Mass: 12.0107

Family: Group 14 (IVA); carbon

Pronunciation: CAR-bun

Overview

Carbon is an extraordinary element. It occurs in more compounds than any other element in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. More than 10 million compounds of carbon are known. No other element, except for **hydrogen**, occurs in even a fraction of that number of compounds.

As an element, carbon occurs in a striking variety of forms. Coal, soot, and diamonds are all nearly pure forms of carbon. Carbon also occurs in a form known as fullerenes or buckyballs. Buckyball carbon holds the promise for opening a whole new field of chemistry.

Carbon occurs extensively in all living organisms as proteins, fats, carbohydrates (sugars and starches), and nucleic acids.

Carbon is such an important element that an entirely separate field of chemistry is devoted to this element and its compounds. Organic chemistry is the study of carbon compounds.

Discovery and Naming

Humans have been aware of carbon since the earliest of times. When cave people made a fire, they saw smoke form. The black color of smoke is

WORDS TO KNOW

Amorphous: Lacking crystalline structure.

Biochemistry: The field of chemistry concerned with the study of compounds found in living organisms.

Buckminsterfullerene (buckyball or fullerene): An allotrope of carbon whose 60 carbon atoms are arranged in a sphere-like form.

Carbon-14 dating: A technique that allows archaeologists to estimate the age of once-living materials by using the knowledge that carbon-14 is found in all living carbon materials and that once an organism dies, no more carbon-14 remains.

Global warming: A phenomenon in which the average temperature of Earth rises, melting icecaps, raising sea levels, and causing other environmental problems. Causes include human-activities, including heavy emissions of carbon dioxide (CO_2).

Hydrocarbons: Compounds made of carbon and hydrogen.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Mohs scale: A way of expressing the hardness of a material.

Nanotubes: Long, thin, and extremely tiny tubes.

Organic chemistry: The study of the carbon compounds.

Periodic table: A chart that shows how the chemical elements are related to each other.

Photosynthesis: The process by which plants convert carbon dioxide and water to carbohydrates (starches and sugars).

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Refractory: A material that can withstand very high temperatures and reflect heat away from itself.

Sublimation: The process by which a solid changes directly to a gas when heated, without first changing to a liquid.

Toxic: Poisonous.

caused by unburned specks of carbon. The smoke may have collected on the ceiling of their caves as soot.

Later, when lamps were invented, people used oil as a fuel. When oil burns, carbon is released in the reaction, forming a sooty covering on the inside of the lamp. That form of carbon became known as lampblack. Lampblack was also often mixed with olive oil or balsam gum to make ink. Ancient Egyptians sometimes used lampblack as eyeliner.

One of the most common forms of carbon is charcoal. Charcoal is made by heating wood in the absence of air so it does not catch fire. Instead, it gives off water vapor, leaving pure carbon. This method for producing charcoal was known as early as the Roman civilization (which thrived from about 509 BCE to about 455 CE).

French physicist René Antoine Ferchault Réaumur (1683–1757) believed carbon might be an element. He studied the differences between wrought **iron**, cast iron, and steel. The main difference among these materials, he said, was the presence of a "black combustible material" that he knew was present in charcoal.

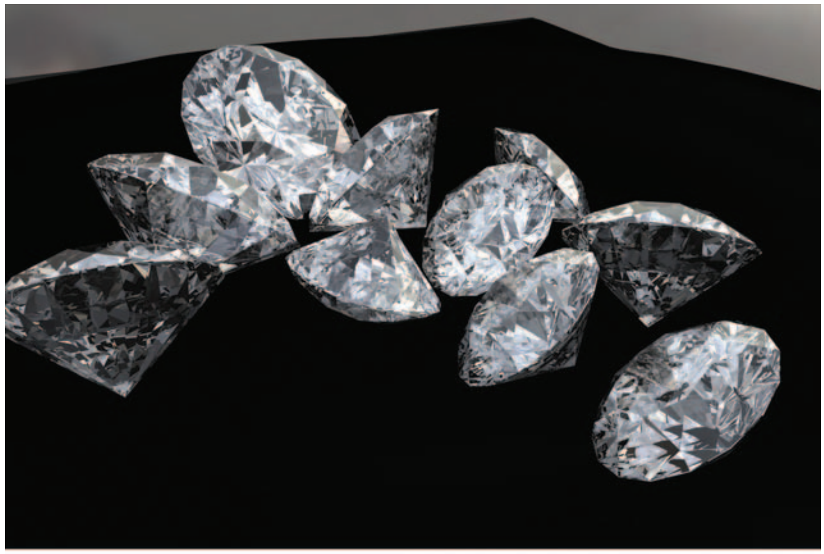
Carbon was officially classified as an element near the end of the 18th century. In 1787, four French chemists–Guyton de Morveau, Antoine Laurent Lavoisier, Claude Louis Berhollet, and Antoine François Fourcroy–wrote a book outlining a method for naming chemical substances, *A Method for Chemical Nomenclature.* The name they gave to carbon was *carbone,* which was based on the earlier Latin term for charcoal, *charbon.*

Physical Properties

Carbon exists in a number of allotropic forms. Allotropes are forms of an element with different physical and chemical properties. Two allotropes of carbon have crystalline structures: diamond and graphite. In a crystalline material, atoms are arranged in a neat orderly pattern. Graphite is found in pencil "lead" and ball-bearing lubricants. Among the non-crystalline allotropes of carbon are coal, lampblack, charcoal, carbon black, and coke. Carbon black is similar to soot. Coke is nearly pure carbon formed when coal is heated in the absence of air. Carbon allotropes that lack crystalline structure are amorphous, or without crystalline shape.

The allotropes of carbon have very different chemical and physical properties. For example, diamond is the hardest natural substance known. It has a rating of 10 on the Mohs scale. The Mohs scale is a way of expressing the hardness of a material. It runs from 0 (for talc) to 10 (for diamond). The melting point of diamond is about 6,700°F (3,700°C) and its boiling point is about 7,600°F (4,200°C). Its density is 3.50 grams per cubic centimeter.

On the other hand, graphite is a very soft material. It is often used as the "lead" in lead pencils. It has a hardness of 2.0 to 2.5 on the Mohs scale. Graphite does not melt when heated, but sublimes at about 6,600°F (3,650°C). Sublimination is the process by which a solid changes directly to a gas when heated, without first changing to a liquid. Its density is about 1.5 to 1.8 grams per cubic centimeter. The numerical value for these properties varies depending on where the graphite originates.



Carbon occurs in a striking variety of forms, from sparkling diamonds (top) to sooty coal (bottom). IMAGE COPYRIGHT 2009, SALLY WALLIS (COAL) AND NGUYEN THAI (DIAMONDS). BOTH IMAGES USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

The amorphous forms of carbon, like other non-crystalline materials, do not have clear-cut melting and boiling points. Their densities vary depending on where they originate.

Chemical Properties

Carbon does not dissolve in or react with water, acids, or most other materials. It does, however, react with **oxygen**. It burns in air to produce carbon dioxide (CO_2) and carbon monoxide (CO). The combustion (burning) of coal gave rise to the Industrial Revolution (which began about 1750).

Another highly important and very unusual property of carbon is its ability to form long chains. It is not unusual for two atoms of an element to combine with each other. Oxygen (O_2), **nitrogen** (N_2), hydrogen (H_2), **chlorine** (Cl_2), and **bromine** (Br_2) are a few of the elements that can do this. Some elements can make even longer strings of atoms. Rings of six and eight **sulfur** atoms (S_6 and S_8), for example, are not unusual.

Carbon has the ability to make virtually endless strings of atoms. If one could look at a molecule of almost any plastic, for example, a long chain of carbon atoms attached to each other (and to other atoms as well) would be evident. Carbon chains can be even more complicated. Some chains have side chains attached to them.

In other cases, carbon atoms can join together in rings, boxes, or other shapes. There is almost no limit to the size and shape of molecules that can be made with carbon atoms.

Buckyballs are another form of pure carbon. These spheres are made up of exactly 60 linked carbon atoms.

Occurrence in Nature

Carbon is the fifth most common element in the universe, by weight, and the fourth most common element in the solar system. It is the second most common element in the human body after oxygen. About 18 percent of a person's body weight is due to carbon.

Carbon is the 17th most common element in Earth's crust. Its abundance has been estimated to be between 180 and 270 parts per million. It rarely occurs as a diamond or graphite. Both allotropes are formed in the earth over millions of years, when dead plant materials are squeezed together at very high temperatures. Diamonds are usually found hundreds or thousands of feet beneath the earth's surface. Africa has many diamond mines.

Carbon also occurs in a number of minerals. Among the most common of these minerals are the carbonates of **calcium** ($CaCO_3$) and **magnesium** ($MgCO_3$). Carbon also occurs in the form of carbon dioxide (CO_2) in the atmosphere. Carbon dioxide makes up only a small part of the atmosphere (about 300 parts per million), but it is a crucial gas. Plants use carbon dioxide in the atmosphere in the process of photosynthesis. Photosynthesis is the process by which plants convert carbon dioxide and water to carbohydrates (starches and sugars). This process is the source of life on Earth.

Carbon also occurs in coal, oil, and natural gas. These materials are often known as fossil fuels. They get that name because of the way they were formed. They are the remains of plants and animals that lived millions of years ago. When they died, they fell into water or were trapped in mud. Over millions of years, they slowly decayed. The products of that decay process were coal, oil, and natural gas.

Some forms of coal are nearly pure carbon. Oil and natural gas are made primarily of hydrocarbons, which are compounds made of carbon and hydrogen.

Isotopes

Three isotopes of carbon occur in nature: carbon-12, carbon-13, and carbon-14. One of these isotopes, carbon-14, is radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Ten artificial radioactive isotopes of carbon have also been synthesized. A radioactive isotope is one that breaks apart and gives off some form of radiation. Artificial radioactive isotopes can be made by firing very small particles (such as protons) at atoms. These particles stick in the atoms and make them radioactive.

Carbon-14 has some limited applications in industry. For example, it can be used to measure the thickness of objects, such as sheets of steel.

In this process, a small sample of carbon-14 is placed above the conveyor belt carrying the steel sheet. A detection device is placed below the sheet. The detection device counts the amount of radiation passing through the sheet. If the sheet gets thicker, less radiation gets through. If the sheet gets thinner, more radiation gets through. The detector records how much radiation passes through the sheet. If the amount becomes too high or too low, the conveyor belt is turned off.

How Carbon-14 Dating Works

When an organism is alive, it takes in carbon dioxide from the air around it. Most of that carbon dioxide is made of carbon-12, but a tiny portion consists of carbon-14. So the living organism always contains a very small amount of radioactive carbon, carbon-14. A detector next to the living organism would record radiation given off by the carbon-14 in the organism.

When the organism dies, it no longer takes in carbon dioxide. No new carbon-14 is added, and the old carbon-14 slowly decays into nitrogen. The amount of carbon-14 slowly decreases as time goes on. Over time, less and less radiation from carbon-14 is produced. The amount of carbon-14 radiation detected for an organism is a measure, therefore, of how long the organism has been dead. This method of determining the age of an organism is called carbon-14 dating.

The decay of carbon-14 allows archaeologists (people who study old civilizations) to find the age of once-living materials. Measuring the amount of radiation remaining indicates the approximate age.

The machine making the sheet is adjusted to produce steel of the correct thickness.

The most important use of carbon-14 is in finding the age of old objects (see accompanying sidebar for more information).

Extraction

Diamond, graphite, and other forms of carbon are taken directly from mines in the earth. Diamond and graphite can also be made in laboratories. Synthetic diamonds, for example, are made by placing pure carbon under very high pressures (about 800,000 pounds per square inch/56,000 kilograms per square centimeter) and temperatures (about 4,900°F/2,700°C;). The carbon is heated and squeezed in the same way organic material is heated and squeezed in the earth. Today, about a third of all diamonds used are synthetically produced.

Uses

There are many uses for carbon's two key allotropes, diamond and graphite. Diamonds are one of the most beautiful and expensive gemstones in the world. But they also have many industrial uses. Because they are so hard, they are used to polish, grind, and cut glass, metals, and other materials. The bit on an oil-drilling machine may be made of diamonds. The tool used to make thin **tungsten** wires is also made of diamonds.

Synthetic diamonds are more commonly used in industry than in jewelry. Industrial diamonds do not have to be free of flaws, as do jewelry diamonds.

Graphite works well as pencil lead because it rubs off easily. It is also used as a lubricant. Graphite is added to the space between machine parts that rub against each other. The graphite allows the parts to slide over each other smoothly.

Graphite is also used as a refractory. Refractory material can withstand very high temperatures by reflecting heat away from itself. Refractory materials are used to line ovens to maintain high temperatures.

Graphite is used in nuclear power plants. A nuclear power plant converts nuclear energy to electrical power. Graphite acts as a moderator by slowing down the neutrons used in the nuclear reaction.

Graphite is used to make black paint, in explosives and matches, and in certain kinds of cathode ray tubes, like the ones used in television sets.

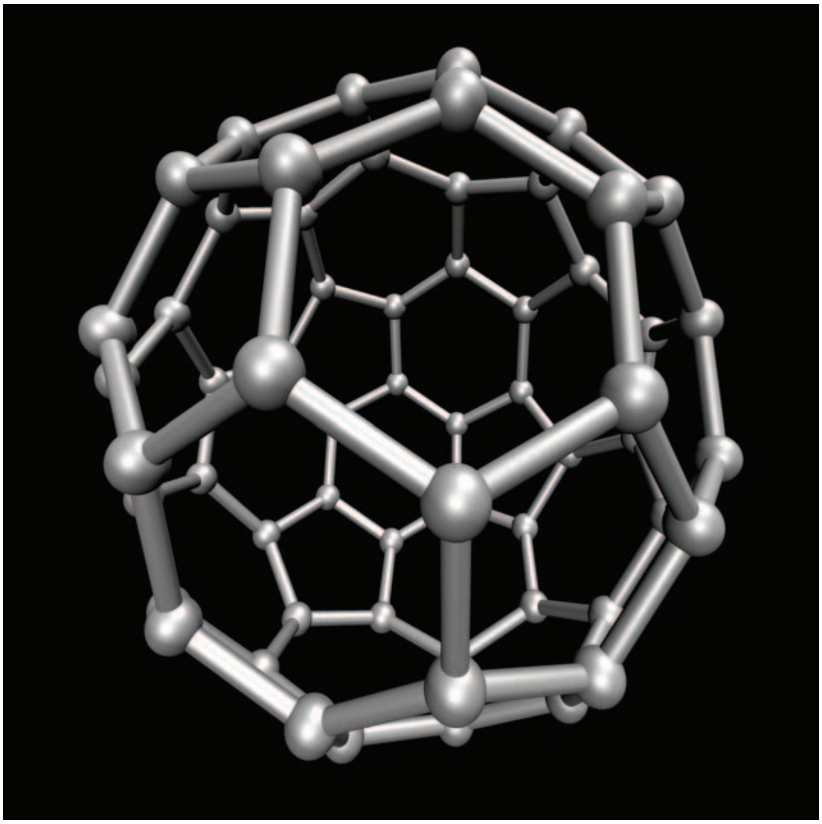
Amorphous forms of carbon have many uses. These include the black color in inks, pigments (paints), rubber tires, and dry cells.

One form of carbon is known as activated charcoal. The term "activated" means that the charcoal has been ground into a very fine powder. In this form, charcoal can remove impurities from liquids that pass through. For example, activated charcoal removes color and odor from oils and water solutions.

Buckyballs and Nanotubes In the 1980s, chemists discovered a new allotrope of carbon. The carbon atoms in this allotrope are arranged in a sphere-like form of 60 atoms. The form resembles a building invented by American architect Buckminster Fuller (1895–1983). The building is known as a geodesic dome.

The discoverers named this new form of carbon "buckminsterfullerene" in honor of Fuller. That name is too long to use in everyday conversation so it is usually shortened to fullerene or buckyball.

The discovery of the fullerene molecule was very exciting to chemists. They had never seen a molecule like it. They have been studying ways of working with this molecule. One interesting technique has been to cut open just one small part of the molecule. Then they cut open a small part



A model of a buckyball, which resembles a geodesic dome.

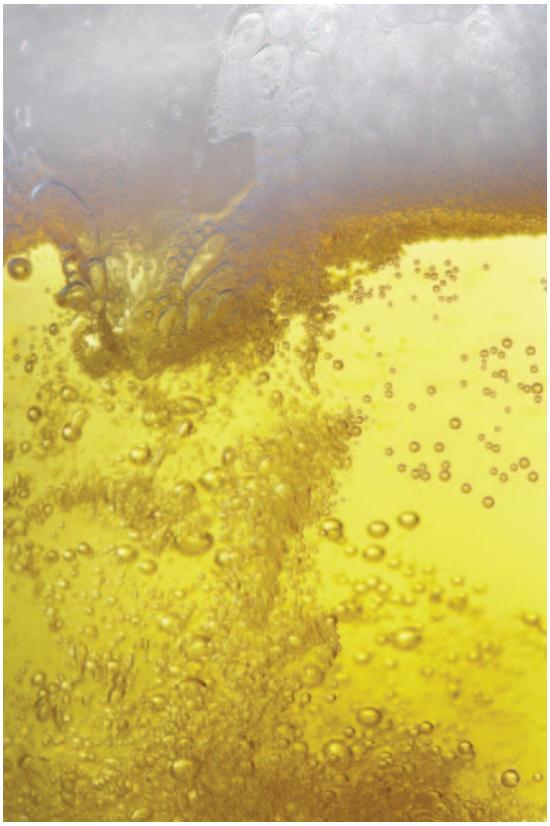
on a second molecule. Finally, they join the two buckyballs together. They get a double-buckyball.

Repeating this process over and over could result in triple-buckyballs, quadruple-buckyballs, and so on. As this process is repeated, the buckyball becomes a long narrow tube called a nanotube. Nanotubes are long, thin, and extremely tiny tubes somewhat like a drinking straw or a long piece of spaghetti.

Scientists have discovered ways of using nanotubes. One idea is to run a thin chain of metal atoms through the center of a nanotube. The nanotube then acts like a tiny electrical wire.

Compounds

Carbon dioxide (CO_2) is used in fire extinguishers and as a propellant in aerosol products. A propellant is a gas that pushes liquids out of a spray can,



The fizz in various beverages is caused by carbonation. IMAGE COPYRIGHT 2009, VOLODYMYR KRASYUK. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

such as those used for deodorant or hair spray. It is also used to make carbonated beverages (it produces the fizz in soda pop and beer). Carbon dioxide can also be frozen to a solid called dry ice, widely used as a way of keeping objects cold.

Carbon monoxide (CO) is another compound formed between carbon and oxygen. Carbon monoxide is a very toxic gas produced when something burns in a limited amount of air. Carbon monoxide is always formed when gasoline burns in the engine of an automobile and is a common part of air pollution. Old heating units can produce carbon monoxide. This colorless and odorless gas can cause headaches, illness, coma, or even death.

Carbon monoxide has a few important industrial uses. It is often used to obtain a pure metal from the ore of that metal:

$$3CO + Fe_2O_3 \rightarrow 3CO_2 + 2Fe$$

It would take a very large book to describe all the uses of organic compounds, which are divided into a number of families. An organic family is a group of organic compounds with similar structures and properties. The largest organic family is the hydrocarbons, compounds that contain only carbon and hydrogen. Methane, or natural gas (CH_4), ethane (C_2H_6), propane (C_3H_8), ethylene (C_2H_4), and benzene (C_6H_6) are all hydrocarbons.

Hydrocarbons are used as fuels. Gas stoves burn natural gas, which is mostly methane. Propane gas is a popular camping fuel, used in small stoves and lanterns. Another important use of hydrocarbons is in the production of more complicated organic compounds.

Other organic families contain carbon, hydrogen, and oxygen. Methyl alcohol (wood alcohol) and ethyl alcohol (grain alcohol) are the most common members of the alcohol family. Methyl alcohol is used to make other organic compounds and as a solvent (a substance that dissolves other substances). Ethyl alcohol is used for many of the same purposes. It is also the alcohol found in beer, wine, and hard liquor, such as whiskey and vodka.

All alcohols are poisonous but some alcohols are more poisonous than others. If not drunk in moderation, alcoholic beverages can damage the body and brain. If consumed in large quantities, they can cause death. Methyl alcohol is more toxic than ethyl alcohol. People who have consumed methyl alcohol by mistake have died.

The list of everyday products made from organic compounds is very long. It includes drugs, artificial fibers, dyes, artificial colors and flavors, food additives, cosmetics, plastics of all kinds, detergents, synthetic rubber, adhesives, antifreeze, pesticides and herbicides, synthetic fuels, and refrigerants.

Health Effects

Carbon is essential to life. Nearly every molecule in a living organism contains carbon. The study of carbon compounds that occur in living organisms is called biochemistry (*bio-* = life + *-chemistry*).

Carbon can also have harmful effects on organisms. For example, coal miners sometimes develop a disease known as black lung. The name comes from the appearance of the miner's lungs. Instead of being pink and healthy, the miner's lungs are black. The black color is caused by coal dust inhaled by the miner. The longer a miner works digging coal, the more the coal dust is inhaled. That worker's lungs become more and more black.

Color is not the problem with black lung disease however. The coal dust in the lungs blocks the tiny holes through which oxygen gets into the lungs. As more coal dust accumulates, more holes are plugged up, making it harder for the miner to breathe. Many miners eventually die from black lung disease because they lose the ability to breathe.

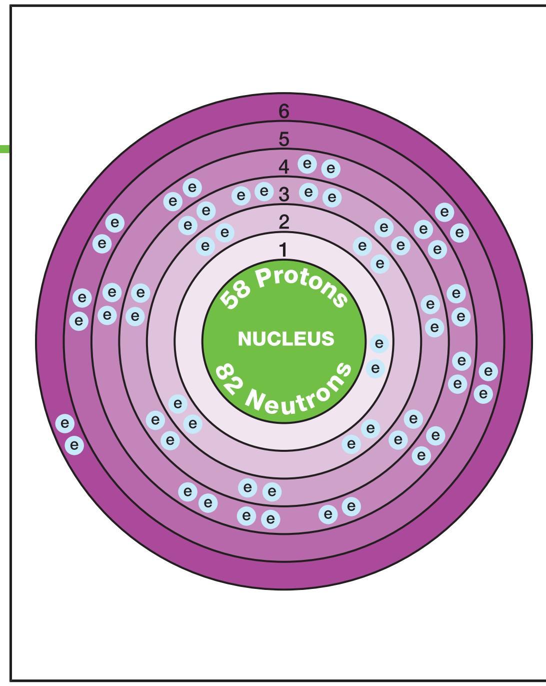
Carbon monoxide poisoning is another serious health problem. Carbon monoxide is formed whenever coal, oil, or natural gas burns. For example, the burning of gasoline in cars and trucks produces carbon monoxide. Today, almost every person in the United States inhales some carbon monoxide every day.

Small amounts of carbon monoxide are not very dangerous. But larger amounts cause a variety of health problems. At low levels, carbon monoxide causes headaches, dizziness, nausea, and loss of balance. At higher levels, a person can lose consciousness. At even higher levels, carbon monoxide can cause death.

Most cars emit exhaust containing CO_2.

Scientists are actively studying the effects of carbon dioxide (CO_2) on people and the environment. CO_2 is released into the air primarily through the burning of fossil fuels (gas and oil), the logging of forests (clear-cutting), and the use of fuel-powered vehicles. Many climate scientists believe that the release of CO_2 into the atmosphere is causing climate change, including global warming. They are studying the situation to see if the melting of glaciers and icebergs, increased storm activity, and warmer-than-normal temperatures are due to increasing amounts of CO_2 being released into the atmosphere by humans.

Cerium



Overview

Cerium is the most abundant of the rare earth metals. Rare earth metals are found in row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The rare earth elements are not really rare. In fact, cerium ranks about number 26 in abundance among elements found in Earth's crust.

Cerium is a gray metal that easily reacts with other elements. It is used in making a number of different alloys, in the production of many kinds of specialty glass, and in the chemical industry.

Key Facts

Symbol: Ce

Atomic Number: 58

Atomic Mass: 140.116

Family: Lanthanoid (rare earth metal)

Pronunciation: SEER-ee-um

Discovery and Naming

Cerium was the first rare earth element to be discovered. It was isolated in 1839 by Swedish chemist Carl Gustav Mosander (1797–1858). Mosander was studying a new rock that had been discovered outside the town of Bastnas, Sweden. Mosander named the new element cerium, in honor of the asteroid Ceres that had been discovered in 1801.

Credit for the discovery of cerium is sometimes given to scientists who studied the black rock of Bastnas earlier. These scientists included Swedish chemists Jöns Jakob Berzelius (1779–1848) and Wilhelm

WORDS TO KNOW

Abrasive: A powdery material used to grind or polish other materials.

Allotropes: Forms of an element with different physical and chemical properties.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids: The elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to each another.

Phosphor: A material that gives off light when struck by electrons.

Hisinger (1766–1852) and German chemist Martin Heinrich Klaproth (1743–1817). It would be difficult to say that one or another of these chemists was the one and only discoverer of cerium.

The substance these scientists discovered was not a pure element but cerium combined with oxygen and other elements. Pure cerium was not produced for another 70 years.

Physical Properties

Cerium is an iron-gray metal with a melting point of 1,460°F (795°C) and a boiling point of 5,895°F (3,257°C). It is ductile and malleable. Ductile means capable of being made into thin wires. Malleable means capable of being hammered into thin sheets. Cerium's density is 6.78 grams per cubic centimeter. It exists in four different allotropic forms. Allotropes are forms of an element with different physical and chemical properties.

Chemical Properties

Cerium is the second most active lanthanoid after **europium**. Lanthanoids are the elements with atomic numbers 57 through 71. Cerium reacts so readily with **oxygen** that it can be set on fire simply by scratching the surface with a knife. It also reacts with cold water (slowly), hot water (rapidly), acids, bases, **hydrogen** gas, and other metals. Because it is so active, it must be handled with caution.

Occurrence in Nature

The most important ores of cerium are cerite, monazite, and bastnasite. It is thought to occur in Earth's crust with a concentration of 40 to 66 parts per million. This makes cerium about as abundant as **copper** or **zinc**.

Isotopes

Four naturally occurring isotopes of cerium have been discovered: cerium-136, cerium-138, cerium-140, and cerium-142. The last of these isotopes is radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation.

Thirty-three radioactive isotopes of cerium have also been made. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. None of the radioactive isotopes of cerium has any commercial use.

Extraction

Cerium is prepared by methods similar to those used for other lanthanoids. It is obtained by passing an electric current through cerium chloride:

$$2CeCl_3 \rightarrow 2Ce + 3Cl_2$$

or by heating calcium metal together with cerium fluoride:

$$3Ca + 2CeF_3 \rightarrow 2Ce + 3CaF_2$$

Uses and Compounds

Cerium metal and its compounds have a great variety of uses, many in the field of glass and ceramics. Cerium and its compounds are added to these materials to add color (yellow), remove unwanted color, make glass sensitive to certain forms of radiation, add special optical (light) qualities to glass, and strengthen certain kinds of dental materials.

Important applications are being found for cerium lasers. A laser is a device that produces bright light of a single frequency or color. Cerium lasers contain a crystal made of **lithium**, **strontium**, **aluminum**, and **fluorine**, to which a small amount of cerium is added. A cerium laser produces light in the ultraviolet region. Ultraviolet radiation is not visible, but it is very similar to the blue and violet light our eyes can see. Cerium lasers are used to search for ozone and **sulfur** dioxide, two air pollutants, in the atmosphere.

Cerium compounds are also used in making phosphors. A phosphor is a material that shines when struck by electrons. The color of the phosphor depends on the elements of which it is made. Phosphors that contain cerium compounds produce a red or orange light when struck by electrons.

Cerium is also used in catalytic systems. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction. Compounds of cerium are used in the refining of petroleum. They help break down compounds found in petroleum into simpler forms that work better as fuels.

Misch metal, a cerium alloy, gives off a spark when struck. It is used in the flints of cigarette lighters. IMAGE COPYRIGHT 2009, JAMES A. KOST. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Another application of cerium (in the form of cerium oxide) is in internal combustion engines, like the one found in cars. Adding cerium oxide (CeO_2) to the engine's fuel helps the fuel burn more cleanly, producing fewer pollutants.

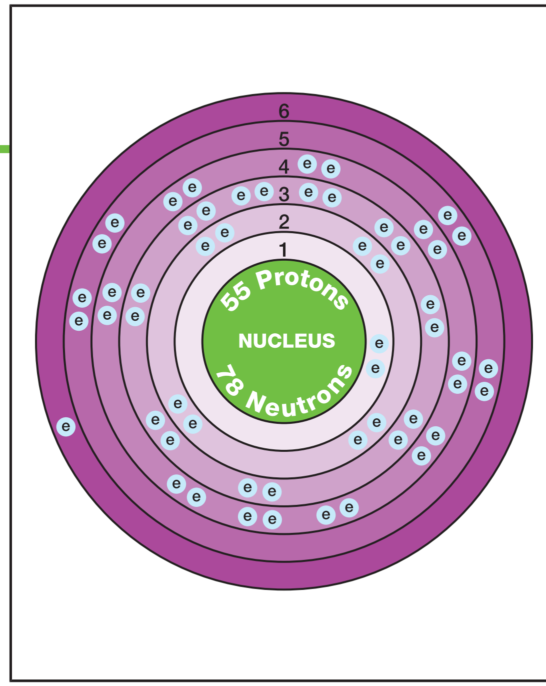
A number of alloys contain cerium. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Perhaps the best known alloy of cerium is misch metal. Misch metal contains a number of different rare earth elements and has the unusual property of giving off a spark when struck. It is used, for example, in the flint of a cigarette lighter.

Cerium oxide is also used as an abrasive. An abrasive is a powdery material used to grind or polish other materials. Cerium oxide has replaced an older abrasive known as rouge for polishing specialized glass, such as telescope mirrors.

Health Effects

There is no evidence that cerium compounds pose a health hazard to humans.

Cesium



Overview

Cesium is a member of the alkali family, which consists of elements in Group 1 (IA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The alkalis also include **lithium**, **sodium**, **potassium**, **rubidium**, and **francium**. Cesium is considered the most active metal. Francium is the most active of the alkali elements. It is a very rare element, however, and has few commercial uses.

Cesium was discovered in 1861 by German chemists Robert Bunsen (1811–1899) and Gustav Kirchhoff (1824–1887). They found the element using a method of analysis they had just invented: spectroscopy. Spectroscopy is the process of analyzing light produced when an element is heated. The light produced is different for every element. The spectrum (plural: spectra) of an element consists of a series of colored lines.

Cesium is not a common element, and it has few commercial uses. One of its radioactive isotopes, cesium-137, is widely used in a variety of medical and industrial applications.

Key Facts

Symbol: Cs

Atomic Number: 55

Atomic Mass: 132.9054519

Family: Group 1 (IA); alkali metal

Pronunciation: SEE-zee-um

WORDS TO KNOW

Alkali metal: An element in Group 1 (IA) of the periodic table.

Ductile: Capable of being drawn into thin wires.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear fission: The process in which large atoms break apart.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Spectroscopy: The process of analyzing light produced when an element is heated.

Discovery and Naming

The invention of spectroscopy gave chemists a powerful new tool. In many cases, the amount of an element present in a sample is too small to detect by most methods of analysis. But the element can be found by spectroscopy. When a substance is heated, elements give off characteristic spectral lines. Using spectroscopy, a chemist can identify the elements by these distinctive lines.

Such was the case with the discovery of cesium. In 1859, Bunsen and Kirchhoff were studying a sample of mineral water taken from a spring. They saw spectral lines for sodium, potassium, lithium, **calcium**, and **strontium**. These elements were already well known.

After Bunsen and Kirchhoff removed all these elements from their sample, they were surprised to find two beautiful blue lines in the spectrum of the "empty" spring water. The water contained an unknown element. Bunsen suggested calling the element cesium, from the Latin word *caesius* for "sky blue." For many years, the name was also spelled caesium.

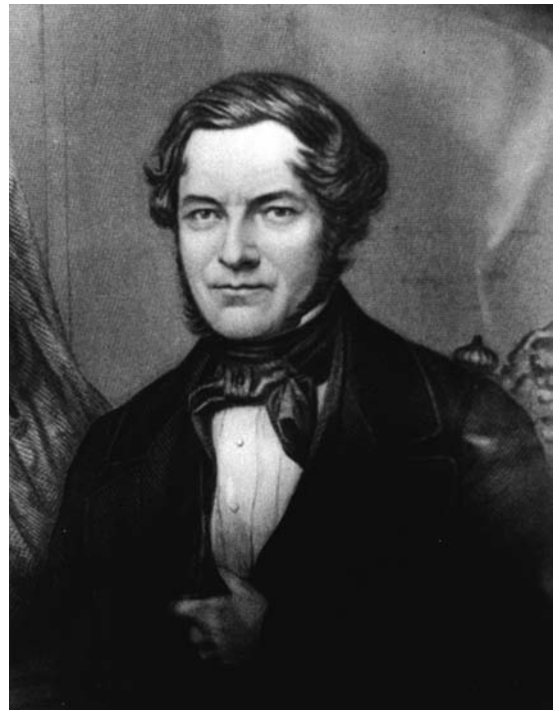
Physical Properties

Cesium is a silvery-white, shiny metal that is very soft and ductile. Ductile means capable of being drawn into thin wires. Its melting point is 83.3°F (28.5°C). It melts easily in the heat of one's hand, but should never be handled that way. Cesium's boiling point is 1,300°F (705°C), and its density is 1.90 grams per cubic centimeter.

Chemical Properties

Cesium is a very reactive metal. It combines readily with **oxygen** in the air and reacts violently with water. In the reaction with water, **hydrogen** gas is released. Hydrogen gas ignites immediately as a result of the heat given off by the reaction. Cesium must be stored under kerosene or a mineral oil to protect it from reacting with oxygen and water vapor in the air.

Cesium also reacts vigorously with acids, the halogens, **sulfur**, and **phosphorus**.



German chemist Robert ***Bunsen.*** LIBRARY OF CONGRESS.

Occurrence in Nature

The abundance of cesium in Earth's crust has been estimated at about 1 to 3 parts per million. It ranks in the middle of the chemical elements in terms of their abundance in the earth.

Cesium occurs in small quantities in a number of minerals. It is often found in an ore of lithium called lepidolite. The mineral containing the largest fraction of cesium is pollucite ($Cs_4Al_4Si_9O_{26}$). This ore is mined in large quantities in the Canadian province of Manitoba. Pollucite is also known to exist in Maine and South Dakota, among other places. Cesium is also found in small amounts in a mineral called rhodizite that also contains potassium, **beryllium**, aluminum, and **boron**.

Isotopes

Only one naturally occurring isotope of cesium is known: cesium-133. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fifty-two radioactive isotopes of cesium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation.

During the 1986 disaster at the Chernobyl Nuclear Power Plant in the Ukraine, cesium-137 escaped into the air. IMAGE COPYRIGHT 2009, SERGEY KAMSHYLIN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Cesium-137 One radioactive isotope of cesium is of special importance, cesium-137. It is produced in nuclear fission reactions. Nuclear fission is the process in which large atoms break apart. Large amounts of energy and smaller atoms are produced during fission. The smaller atoms are called fission products. Cesium-137 is a very common fission product.

Nuclear fission is used in nuclear power plants. The heat produced by nuclear fission can be converted into electricity. While this process is going on, cesium-137 is being produced as a by-product. That cesium-137 can be collected and used for a number of applications.

For example, cesium-137 can be used to monitor the flow of oil in a pipeline. In many cases, more than one oil company may use the same pipeline. How does a receiving station know whose oil is coming through the pipeline? One way to solve that problem is to add a little cesium-137 when a new batch of oil is being sent. The cesium-137 gives off radiation. That radiation can be detected easily by holding a detector at the end of the pipeline. When the detector shows the presence of radiation, a new batch of oil has arrived.

This isotope of cesium can also be used to treat some kinds of cancer. One procedure is to fill a hollow steel needle with cesium-137. The needle can then be implanted into a person's body. The cesium-137 gives off radiation inside the body. That radiation kills cancer cells and may help cure the disease.

Cesium-137 is often used in scientific research. For example, cesium tends to stick to particles of sand and gravel. This fact can be used to measure the speed of erosion in an area. Cesium-137 is injected into the ground at some point. Some time later, a detector is used to see how far the isotope has moved. The distance moved tells a scientist how fast soil is being carried away. In other words, it tells how fast erosion is taking place.

Cesium-137 has also been approved for the irradiation of certain foods. The radiation given off by the isotope kills bacteria and other organisms that cause disease. Foods irradiated by this method last longer before beginning to spoil. Wheat, flour, and potatoes are some of the foods that can be preserved by cesium-137 irradiation.

Extraction

Cesium can be obtained in pure form by two methods. In one, calcium metal is combined with fused (melted) cesium chloride:

$$\mathbf{Ca + 2CsCl \rightarrow 2Cs + CaCl_2}$$

In the other, an electric current passes through a molten (melted) cesium compound:

$$\mathbf{2CsCl \quad \text{electrical current} \rightarrow 2Cs + Cl_2}$$

Uses

Cesium has a limited number of uses. One is as a getter in bulbs and evacuated tubes. The bulb must be as free from gases as possible to work properly. Small amounts of cesium react with any air left in the bulb. It converts the gas into a solid cesium compound. Cesium is called a getter because it gets gases out of the bulb.

Cesium is also used in photoelectric cells, devices for changing sunlight into electrical energy. When sunlight shines on cesium, it excites or energizes the electrons in cesium atoms. The excited electrons easily flow away, producing an electric current.

Atomic clocks were invented in the late 1940s. Cesium is used in some atomic clocks, the most precise instrument of timekeeping. ROYAL GREENWICH OBSERVATORY, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

An important use of cesium is in an atomic clock. An atomic clock is the most precise method now available for measuring time. Here is how an atomic clock works:

A beam of energy is shined on a very pure sample of cesium-133. The atoms in the cesium are excited by the energy and give off radiation. That radiation vibrates back and forth, the way a violin string vibrates when plucked. Scientists measure the speed of that vibration. The second is officially defined as that speed of vibration multiplied by 9,192,631,770.

Atomic clocks keep very good time. The best of them lose no more than one second in 60 million years.

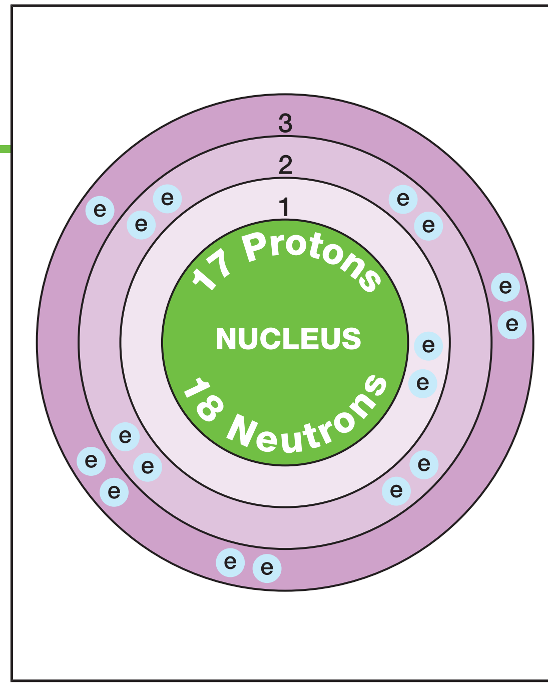
Compounds

Cesium compounds have relatively few commercial uses. Cesium bromide is used to make radiation detectors and other measuring devices. Cesium carbonate and cesium fluoride are used to make specialty glasses. Cesium carbonate and cesium chloride are used in the brewing of beers. Cesium compounds are also used in chemical research.

Health Effects

Cesium is not regarded as essential to the health of plants or animals, nor does it present a hazard to them.

Chlorine



Key Facts

Symbol: Cl

Atomic Number: 17

Atomic Mass: 35.453

Family: Group 17 (VIIA); halogen

Pronunciation: CLOR-een

Overview

Chlorine ranks among the top 10 chemicals produced in the United States. In 2008 approximately 11.5 million short tons (10.4 million metric tons) of chlorine were produced in the United States. Chlorine, in one form or another, is added to many swimming pools, spas, and public water supplies because it kills bacteria that cause disease. Many people also use chlorine to bleach their clothes. Large paper and pulp mills use chlorine to bleach their products.

Chlorine is a greenish-yellow poisonous gas. It was discovered in 1774 by Swedish chemist Carl Wilhelm Scheele (1742–1786). Scheele knew that chlorine was a new element, but thought it contained **oxygen** as well.

Chlorine is a member of the halogen family. Halogens are the elements that make up Group 17 (VIIA) of the periodic table, a chart that shows how elements are related to one another. They also include **fluorine**, **bromine**, **iodine**, and **astatine**. Chlorine is highly reactive, ranking only below fluorine in its chemical activity.

Discovery and Naming

Chlorine compounds have been important to humans for thousands of years. Ordinary table salt, for example, is sodium chloride (NaCl). Still, chlorine

WORDS TO KNOW

Chlorofluorocarbons (CFCs): A family of chemical compounds once used as propellants in commercial sprays but now regulated because of their harmful environmental effects.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Micronutrient: A substance needed in very small amounts to maintain good health.

Noble gas: An element in Group 18 (VIIIA) of the periodic table.

Oxidizing agent: A chemical substance that takes on electrons from another substance.

Ozone: A form of oxygen that filters out harmful radiation from the sun.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Salt dome: A large mass of salt found underground.

Toxic: Poisonous.

Tracer: An isotope whose presence in a material can be traced (followed) easily.

was not recognized as an element until 1774, when Scheele was studying the mineral pyrolusite. Pyrolusite consists primarily of **manganese** dioxide (MnO_2). Scheele mixed pyrolusite with hydrochloric acid (HCl), then called *spiritus salis.* He found that a greenish-yellow gas with a suffocating odor "most oppressive to the lungs" was released. The gas was chlorine.

Scheele found that the new gas reacted with metals, dissolved slightly in water, and bleached flowers and leaves. He gave the gas the rather complex name of dephlogisticated marine acid.

The true nature of Scheele's discovery was not completely understood for many years. Some chemists argued that his dephlogisticated marine acid was really a compound of a new element and oxygen. This confusion was finally cleared up in 1807. English chemist Sir Humphry Davy (1778–1829) proved that Scheele's substance was a pure element. He suggested the name chlorine for the element, from the Greek word *chloros,* meaning "greenish-yellow."

Physical Properties

Chlorine is a dense gas with a density of 3.21 grams per liter. By comparison, the density of air is 1.29 grams per liter. Chlorine changes from a gas into a liquid at a temperature of –29.29°F (–34.05°C) and from a liquid to a solid at –149.80°F (–101°C). The gas is soluble (dissolvable) in water. It also reacts chemically with water as it dissolves to form hydrochloric acid (HCl) and hypochlorous acid (HOCl).

Swedish pharmacist Carl Wilhelm Scheele. LIBRARY OF CONGRESS.

Chemical Properties

Chlorine is a very active element. It combines with all elements except the noble gases. The noble gases are the elements that make up Group 18 (VIIIA) of the periodic table. The reaction between chlorine and other elements can often be vigorous. For example, chlorine reacts explosively with **hydrogen** to form hydrogen chloride:

$$H_2 + Cl_2 \rightarrow 2HCl$$

Chlorine does not burn but, like oxygen, it helps other substances burn. Chlorine is a strong oxidizing agent (a chemical substance that takes on electrons from another substance).

Occurrence in Nature

Chlorine occurs commonly both in Earth's crust and in seawater. Its abundance in the earth is about 100 to 300 parts per million. It ranks 20th among the elements in abundance in the earth. Its abundance in seawater is about 2 percent. The most common compound of chlorine in seawater is sodium chloride. Smaller amounts of potassium chloride also occur in seawater.

The most common minerals of chlorine are halite, or rock salt (NaCl), sylvite (KCl), and carnallite ($KCl \bullet MgCl_2$). Large amounts of these minerals are mined from underground salt beds that were formed when ancient oceans dried up. Over millions of years, the salts that remained behind were buried underground. They were also compacted (packed together) to form huge salt "domes." A salt dome is a large mass of salt found underground.

Isotopes

Two naturally occurring isotopes of chlorine exist: chlorine-35 and chlorine-36. Isotopes are two or more forms of an element. Isotopes differ

Halite (NaCl) is a common mineral of chloride. IMAGE COPYRIGHT 2009, K MIKE. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Sixteen radioactive isotopes of chlorine are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of chlorine is used in research. That isotope is chlorine-36. This isotope is used because compounds of chlorine occur so commonly in everyday life. The behavior of these compounds can be studied if chlorine-36 is used as a tracer. A tracer is an isotope whose presence in a material can be traced (followed) easily.

For example, engineers are interested in knowing how seawater damages metals. This information is important in determining the best techniques to use in building ships. An experiment can be done by adding pieces of metal to seawater that contains radioactive chlorine-36. The sodium chloride in the seawater is changed slightly so that it contains radioactive chlorine instead of normal chlorine. As the sodium

Chlorine is added to the water of many swimming pools to kill bacteria. IMAGE COPYRIGHT 2009, BRIAN CHASE. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

chloride attacks the metal, its actions can be followed easily. The radioactive chlorine, chlorine-36, gives off radiation. That radiation can be detected by holding an instrument near the experiment. A scientist can find out exactly what happens when the sodium chloride attacks the metal.

Extraction

Chlorine is produced by passing an electric current through a water solution of sodium chloride or through molten (melted) sodium chloride. This process is one of the most important commercial processes in industry. The products formed in the first process include two of the most widely used materials: sodium hydroxide (NaOH) and chlorine (Cl_2). With a water solution, the reaction that occurs is:

$$\mathbf{2NaCl + 2H_2O \quad electrical\ current \rightarrow 2NaOH + Cl_2 + H_2}$$

Hydrogen gas (H_2) is also formed in the reaction.

Uses and Compounds

Chlorine is widely used throughout the world to purify water. In the United States, about 4 percent of the chlorine manufactured is used in water purification. Very small amounts of chlorine (about 1 percent of all the chlorine produced) is used in the paper and pulp industry as a bleach.

The use of chlorine by the paper and pulp industry has decreased dramatically in the past few decades because of concerns about the effects of the element on the environment.

The most important use of chlorine is to make other chemicals. For example, chlorine can be combined with ethene, or ethylene, gas (C_2H_2), to make ethylene dichloride ($C_2H_2Cl_2$):

$$\mathbf{Cl_2 + C_2H_2 \rightarrow C_2H_2Cl_2}$$

Much of the ethylene dichloride produced is used to make polyvinyl chloride (PVC or vinyl). In fact, in the United States, about 40 percent of the chlorine produced goes to the manufacture of PVC. In addition to piping, tubing, flooring, siding, film, coatings, and many other products, PVC is also used in the production of prosthetic (artificial) limbs.

Another compound made using chlorine is propylene oxide (CH_3CHOCH_2). There is no chlorine in propylene oxide, but chlorine is used in the process by which the compound is made. Propylene oxide is used to make a group of plastics known as polyethers, the primary component of polyurethane foams. Polyethers are found in a wide range of materials, including car and boat bodies, bowling balls, fabrics for clothing, and rugs.

At one time, a large amount of chlorine was used to make a group of compounds known as chlorofluorocarbons (CFCs). CFCs are a family of chemical compounds containing **carbon**, fluorine, and chlorine. CFCs were once used in a wide variety of applications, such as air conditioning and refrigeration, aerosol spray products, and cleaning materials. They are now known to have serious environmental effects and have been banned from use in the United States and many other countries.

The reason for this ban is the damage caused by CFCs to Earth's ozone layer. Ozone (O_3) is a form of oxygen that filters out harmful radiation from the sun. When CFCs escape into the atmosphere, they attack and destroy ozone molecules. They reduce the protection against radiation provided by ozone.

Pesticides: DDT Chlorine has been used in making pesticides. A pesticide is a chemical used to kill pests. Pesticides have special names depending on the kind of pests they are designed to kill. Insecticides kill insects, rodenticides kill rodents (rats and mice), fungicides kill fungi, and nematicides kill worms.

Initially, people were unaware of the dangers posed by DDT. The pesticide was used on crops, in neighborhoods, and in other areas. Here, people are exposed to the pesticide while at the beach. LIBRARY OF CONGRESS.

Certain chlorine compounds have become very popular as pesticides. These compounds are called chlorinated hydrocarbons. They contain carbon, hydrogen, and chlorine.

Probably the most famous chlorinated hydrocarbon is dichlorodiphenyltrichloroethane, or DDT. First prepared in 1873, DDT was not used as a pesticide until World War II (1939–1945). Public health officials were at first delighted to learn that DDT kills disease-carrying insects very efficiently. There was great hope that DDT could be used to wipe out certain diseases in some parts of the world.

Farmers were also excited about DDT. They found it could kill many of the pests that attacked crops. By the end of the 1950s, many farmers were spraying huge amounts of DDT on their land to get rid of pests.

But problems began to appear. Many fish and birds in sprayed areas began to die or become deformed. Soon, these problems were traced to the use of DDT. The fish and birds ate insects that had been sprayed with DDT or drank water that contained DDT. It had a toxic effect on the fish and birds, just as it did on insects. Bird populations declined drastically as DDT caused eggs to be so thin-shelled that young birds did not survive.

Eventually, many governments began to ban the use of DDT, including the United States. It is still used in some nations, however, because the benefits of using DDT outweigh the harm it may cause. They believe that DDT can save many lives by killing insects that cause deadly diseases in humans, such as malaria. They know they can increase their food supplies by using DDT on crops as well. To lessen the risk of harming people, various governments follow strict procedures when using the pesticide.

DDT is not the only chlorinated hydrocarbon used as a pesticide. Other compounds in this class include dieldrin, aldrin, heptachlor, and chlordan. The use of these compounds has also been banned or restricted in the United States. The U.S. government has decided the harm they cause to the environment is more important than the benefits they provide to farmers and other users.

Health Effects

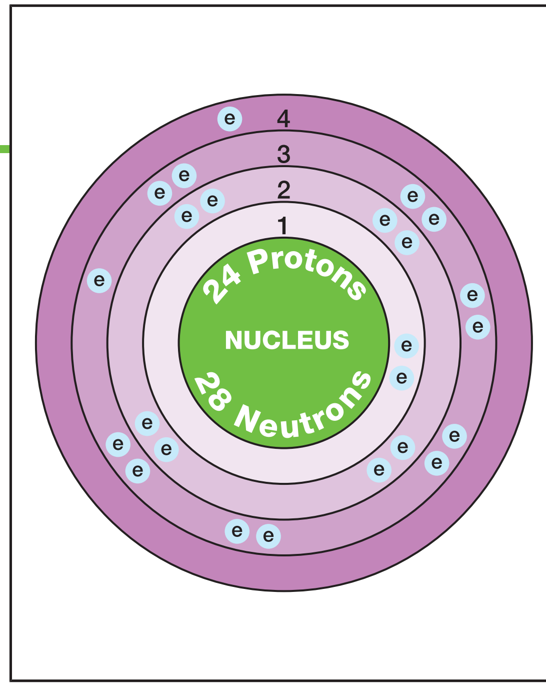
Chlorine gas is extremely toxic. In small doses, it irritates the nose and throat. A person exposed to chlorine may experience sneezing, running nose, and red eyes.

In larger doses, chlorine can be fatal. In fact, chlorine gas was used during World War I (1914–1918) by German soldiers as a biological weapon. Thousands of soldiers were killed or seriously wounded by breathing it. Those who survived gas attacks were often crippled for life. They were unable to breathe normally as a result of the damage to their throats and lungs.

On the other hand, chlorine compounds are essential to plants. They become sick or die without it. In plants, chlorine is regarded as a micronutrient, which is a substance needed in very small amounts to maintain good health. Leaves turn yellow and die when plants get too little chlorine from the soil.

Compounds of chlorine are important in maintaining good health in humans and other animals. The average human body contains about

95 grams (about 3.5 ounces) of chlorine. Hydrochloric acid (HCl) in the stomach, for example, helps in the digestion of foods. Sodium chloride (NaCl) and potassium chloride (KCl) play an important role in the way nerve messages are sent throughout the body. Because humans eat so much salt (NaCl), a lack of chlorine compounds is seldom a health problem.



Chromium

Key Facts

Symbol: Cr

Atomic Number: 24

Atomic Mass: 51.9961

Family: Group 6 (VIB); transition metal

Pronunciation: CRO-mee-um

Overview

Chromium is found in the center of the periodic table, a chart that shows how chemical elements are related to each other. Elements in Groups 3 through 12 are known as the transition metals. These elements all have similar physical and chemical properties. They have a bright, shiny surface and high melting points.

Chromium was discovered in 1797 by French chemist Louis-Nicolas Vauquelin (1763–1829). The element's name comes from the Greek word *chroma,* meaning "color," because chromium compounds are many different colors.

Much of the chromium produced today is used in alloys, including stainless steel. An alloy is made by melting and mixing two or more metals. The mixture has different properties than the individual metals. Chromium is also used to cover the surface of other metals. This technique protects the base metal and gives the surface a bright, shiny appearance at a low cost.

Discovery and Naming

Chromium was discovered in a mineral known as Siberian red lead. The mineral was first described in 1766 by German mineralogist Johann

WORDS TO KNOW

Abrasive: A powdery material used to grind or polish other materials.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Electroplating: The process by which an electric current is passed through a water solution of a metallic compound.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Refractory: A material that can withstand very high temperatures and reflect heat away from itself.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Gottlob Lehmann (1719–1767). Scientists were puzzled about what elements this new mineral contained. It had a form and a color not seen in other minerals. In some cases, it was found, as some said, "attached like little rubies to quartz."

Studies of Siberian red lead were difficult, however. It was mined at only one location in Germany and miners found it difficult to remove. Scientists had only small amounts of the mineral to study. They guessed that it contained **lead** as well as **arsenic**, **molybdenum**, or some other metal.

In 1797, Vauquelin began his own studies of Siberian red lead. He was convinced that the mineral contained a new element. None of the elements then known could account for his results. He reported finding "a new metal, possessing properties entirely unlike those of any other metal."

A year later, Vauquelin was able to isolate a small sample of the metal itself. He heated charcoal (nearly pure **carbon**) with a compound of chromium, chromium trioxide (Cr_2O_3). When the reaction was complete, he found tiny metallic needles of chromium metal:

$$2Cr_2O_3 + 3C \quad \text{heat}\rightarrow \ 3CO_2 + 4Cr$$

The name chromium was suggested by two French chemists, Antoine François de Fourcroy (1755–1809) and René-Just Haüy (1743–1822), because chromium forms so many different colored compounds. The colors range from purple and black to green, orange, and yellow.

Physical Properties

Chromium is a hard, steel-gray, shiny metal that breaks easily. It has a melting point of 3,450°F (1,900°C) and a boiling point of 4,788°F (2,642°C). The density is 7.1 grams per cubic centimeter. One important property is that chromium can be polished to a high shine.

Chemical Properties

Chromium is a fairly active metal. It does not react with water, but reacts with most acids. It combines with **oxygen** at room temperature to form chromium oxide (Cr_2O_3). Chromium oxide forms a thin layer on the surface of the metal, protecting it from further corrosion (rusting).

Occurrence in Nature

The abundance of chromium in Earth's crust is about 100 to 300 parts per million. It ranks about number 20 among the chemical elements in terms of their abundance in the earth.

Chromium does not occur as a free element. Today, nearly all chromium is produced from chromite, or chrome iron ore ($FeCr_2O_4$).

As of 2008, the leading producer of chromite ore is South Africa. Other important producers are Kazakhstan and India. According to the U.S. Geological Survey (USGS), most of the world's supply (95 percent) of chromium resources are in Kazakhstan and southern Africa. In the United States in 2008, one company was mining for chromite ore in Oregon.

Isotopes

There are four naturally occurring isotopes of chromium: chromium-50, chromium-52, chromium-53, and chromium-54. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Of the four naturally occurring isotopes, one (chromium-50) is radioactive. Seventeen radioactive isotopes of chromium have also been made in the laboratory. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of chromium is used in medical research, chromium-51. This isotope is used as a tracer in studies on blood. A tracer is a radioactive isotope whose presence in a system can be easily detected. The isotope is injected into the system at some point. Inside the system, the isotope gives off radiation. That radiation can be followed by means of detectors placed around the system.

A common use of chromium-51 is in studies of red blood cells. The isotope can be used to find out how many blood cells are present in a person's body. It can be used to measure how long the blood cells survive in the body. The isotope can also be used to study the flow of blood into and out of a fetus (an unborn child).

Extraction

The methods for producing chromium are similar to those used for other metals. One method is to heat chromium oxide (Cr_2O_3) with charcoal or **aluminum**. The charcoal (nearly pure carbon) or aluminum takes oxygen from the chromium oxide, leaving pure chromium metal. This method is similar to the one used by Vauquelin:

$$2Cr_2O_3 + 3C \xrightarrow{\text{heat}} 3CO_2 + 4Cr$$

Chromium can also be obtained by passing an electric current through its some of its compounds:

$$2CrCl_3 \xrightarrow{\text{electric current}} 2Cr + 3Cl_2$$

Sometimes chromite is converted directly to an alloy known as ferrochromium (or ferrochrome):

$$FeCr_2O_4 + C \xrightarrow{\text{heated}} CO_2 + \text{ferrochromium}$$

Ferrochromium is an important chromium alloy. It is used to add chromium to steel. When steel is first made, it is a very hot, liquid material. To make chromium steel, ferrochromium is added to the hot liquid steel. There, the chromium dissolves into the hot steel. When the molten steel hardens, the chromium is trapped inside. It is now chromium steel.

Chromium comes from the Greek word for color. In these bottles, the different shades represent various colors of chromium compounds. © YOAV LEVY/PHOTOTAKE NYC.

Uses

Much of the chromium used in the United States goes into alloys. The addition of chromium makes the final product harder and more resistant to corrosion. Another significant use of chromium is in the production of stainless steel. The applications of stainless steel are almost endless. They include automobile and truck bodies, plating for boats and ships, construction parts for buildings and bridges, parts for chemical and petroleum equipment, electric cables, machine parts, eating and cooking utensils, and reinforcing materials in tires and other materials.

Two other major uses of chromium are electroplating and the manufacture of refractory bricks. Electroplating is the process by which an electric current is passed through a water solution of a metallic compound. The current causes the material to break down into two parts, as the following reaction shows:

$$2CrCl_3 \xrightarrow{\text{electric current}} 2Cr + 3Cl_2$$

The free chromium produced in this reaction is laid down in a thin layer on the surface of another metal, such as steel. The chromium protects the steel from corrosion and gives it a bright, shiny surface. Many kitchen appliances are "chrome-plated" this way.

Some chromium is also used to make refractory bricks. A refractory material can withstand very high temperatures by reflecting heat. Refractory materials are used to line high-temperature ovens.

Compounds

Chromium compounds have many different uses. Some include:

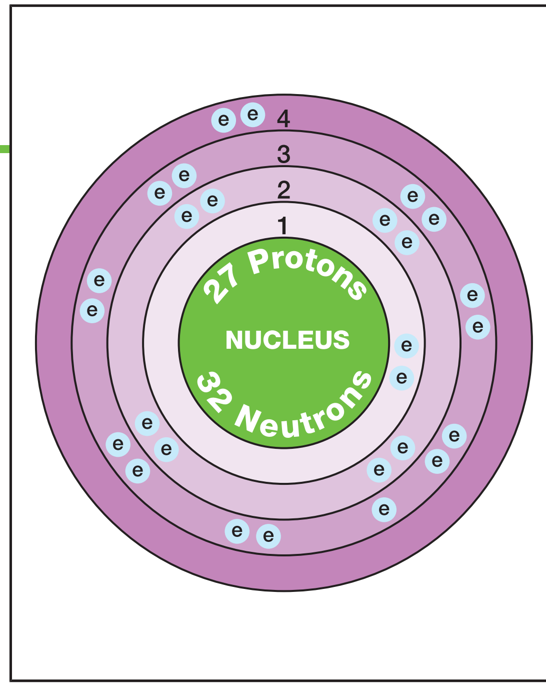
- chromic fluoride (CrF_3): printing, dyeing, and mothproofing woolen cloth
- chromic oxide (Cr_2O_3): a green pigment (coloring agent) in paint, asphalt roofing, and ceramic materials; refractory bricks; abrasive
- chromic sulfate ($Cr_2(SO_4)_3$): a green pigment in paint, ceramics, glazes, varnishes, and inks; chrome plating
- chromium boride (CrB): refractory; high-temperature electrical conductor
- chromium dioxide (CrO_2): covering for magnetic tapes ("chromium" tapes)
- chromium hexacarbonyl ($Cr(CO)_6$): catalyst; gasoline additive

Health Effects

Chromium is an element with two faces, as far as health effects are concerned. Small amounts of chromium are essential for the health of plants and animals. In humans, a chromium deficiency leads to diabetes-like symptoms. Diabetes is a disease that develops when the body does not use sugar properly. Chromium seems to play a role in helping the body use sugar.

In larger amounts, chromium is harmful. Some compounds are especially dangerous, causing a rash or sores if spilled on the skin. They can also cause sores in the mouth and throat if inhaled. If swallowed, some chromium compounds can seriously damage the throat, stomach, intestines, kidneys, and circulatory (blood) system. Scientists believe exposure to some chromium compounds on a long-term basis causes cancer. As a result, the U.S. Environmental Protection Agency (EPA) has established rules about the amount of chromium to which workers can be exposed.

Cobalt



Key Facts

Symbol: Co

Atomic Number: 27

Atomic Mass: 58.933195

Family: Group 9 (VIIIB); transition metal

Pronunciation: CO-balt

Overview

Humans have been using compounds of cobalt since at least 1400 BCE. The compounds were used to color glass and glazes blue. In 1735, Swedish chemist Georg Brandt (1694–1768) analyzed a dark blue pigment found in copper ore. Brandt demonstrated that the pigment contained a new element, later named cobalt.

Cobalt is a transition metal, one of the elements found in Rows 4 through 7 between Groups 2 and 13 in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Cobalt is located between **iron** and **nickel** and shares many chemical and physical properties with these two elements.

The United States has to import all the cobalt it uses. One of the most important applications of cobalt is in the production of superalloys. These superalloys consist primarily of iron, cobalt, or nickel, with small amounts of other metals, such as **chromium**, **tungsten**, **aluminum**, and **titanium**. Superalloys are resistant to corrosion (rusting) and retain their properties at high temperatures. Superalloys are used in jet engine parts and gas turbines.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Magnetic field: The space around an electric current or a magnet in which a magnetic force can be observed.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Superalloys: Consist primarily of iron, cobalt, or nickel, with small amounts of other metals that are resistant to corrosion (rusting) and retain their properties at high temperatures.

Trace mineral: An element needed by plants and animals in minute amounts.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

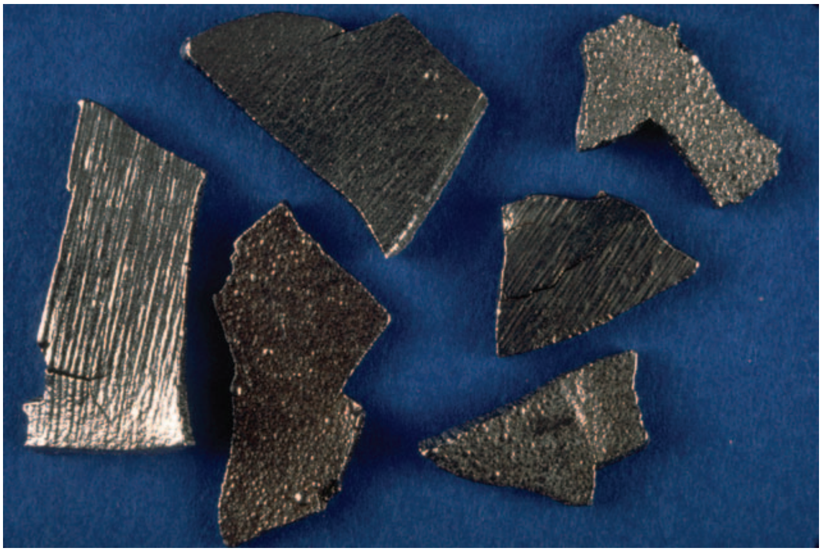
Cobalt dyes have been used for centuries. Craftsmen used materials from the earth to color glass, pottery, glazes, and other materials. Cobalt minerals were especially prized for their rich blue color.

The word cobalt may date back to the end of the 15th century. In German, the word *Kobold* means "goblin" or "evil spirit." The term was used by miners to describe a mineral that was very difficult to mine and was damaging to their health. When the mineral was heated, it gave off an offensive gas that caused illness. The gas that affected the miners was **arsenic** trioxide (As_4O_6), which often occurs with cobalt in nature.

At first, chemists were skeptical about Brandt's claims of a new element, but he continued his research on the mineral. He showed that its compounds were a much deeper blue than copper compounds. (Copper and cobalt compounds had long been confused with each other.) Eventually, Brandt was given credit for the discovery of the element. The name chosen was a version of the original German term, Kobold.

Physical Properties

Cobalt is a hard, gray metal that looks much like iron and nickel. It is ductile, but only moderately malleable. Ductile means capable of being



Cobalt Samples. © RUSS LAPPA/ SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

drawn into thin wires. Malleable means capable of being hammered into thin sheets.

Cobalt is one of only three naturally occurring magnetic metals. The other two are iron and nickel. The magnetic properties of cobalt are even more obvious in alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals.

The melting point of cobalt metal is 2,719°F (1,493°C), and the boiling point is about 5,600°F (3,100°C). The density is 8.9 grams per cubic centimeter.

Chemical Properties

Cobalt is a moderately reactive element. It combines slowly with **oxygen** in the air, but does not catch fire and burn unless it is in a powder form. It reacts with most acids to produce **hydrogen** gas. It does not react with water at room temperatures.

Occurrence in Nature

Cobalt is a relatively abundant element at about 10 to 30 parts per million. This places it in the upper third of elements according to their abundance in Earth's crust.

The most common ores of cobalt are cobaltite, smaltite, chloranthite, and linnaeite. As of 2008, the major suppliers of cobalt in the world are Congo (Kinshasa), Canada, Zambia, Australia, Russia, Cuba, and China. No cobalt was mined or refined in the United States, although significant resources exist in the country. According to the U.S. Geological Survey (USGS), states with cobalt resources include: Alaska, California, Idaho, Minnesota, Missouri, Montana, and Oregon.

Isotopes

There is only one naturally occurring isotope of cobalt: cobalt-59. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-six radioactive isotopes of cobalt are known also, for which half lives are available. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Cobalt-60 One of the most widely used of all radioactive isotopes is cobalt-60. In medicine, it is used to find and treat diseases. For example, it is used in a test known as the Schilling test. This test is a method for determining whether a person's body is making and using vitamin B_{12} properly. Two other isotopes of cobalt, cobalt-57 and cobalt-58, are used for the same purpose.

Cobalt-60 is also used to treat cancer. The radiation given off by the isotope kills cancer cells. The isotope has been used for more than 50 years to treat various forms of cancer.

A growing use of cobalt-60 is in food irradiation. Food irradiation is a method for preserving food. The food is exposed to radiation from cobalt-60. That radiation kills bacteria and other organisms that cause disease and spoilage. The food can be stored longer without going bad after being irradiated.

There is some controversy about the use of irradiation as a way of preserving food. Some people worry that harmful compounds will be produced during irradiation. So far, no proof has been found that irradiation is a dangerous method of food preservation.

Cobalt-60 is also used in industrial applications. The radiation it gives off acts like X rays from an X-ray machine. It can penetrate metals. The X-ray pattern produced by radiating a material tells about its strength, composition, and other properties.

Extraction

Cobalt is obtained by heating its ores to produce cobalt oxide (Co_2O_3). That compound is then heated with aluminum to free the pure metal:

$$2Al + Co_2O_3 \rightarrow Al_2O_3 + 2Co$$

In a second method, cobalt oxide is first converted to cobalt chloride ($CoCl_3$). An electric current is then passed through molten (melted) cobalt chloride to obtain the free element:

$$2CoCl_3 \quad \text{electric current} \rightarrow 2Co + 3Cl_2$$

Uses

About 46 percent of cobalt used in the United States is used to make alloys, mostly superalloys. These superalloys are used in situations where metals are placed under extreme stress, often at high temperatures. A gas turbine, a device for making electricity, is a good example. It looks a bit like a large airplane propeller, with many blades. A hot, high speed gas pushes against the turbine blades, making them spin very fast. The motion generates electricity. Cobalt superalloys hold up to the high temperature stress produced in the machine.

Cobalt is also used in making magnetic alloys. These alloys are used to make devices that must hold a magnetic field, such as electric motors and generators. A magnetic field is the space around an electric current or a magnet in which a magnetic force can be observed. Another application of cobalt alloys is in the production of cemented carbides. In metallurgy, cementation is the process by which one metal is covered with a fine coating of a second metal. Cementation is used to make very hard, strong alloys, such as those used in drilling tools and dies.

The primary use of cobalt worldwide is in the production of rechargeable battery electrodes.

Cobalt compounds are widely used to color materials, including glass. IMAGE COPYRIGHT 2009, BLUECRAYOLA. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Compounds

Cobalt compounds are widely used to make coloring materials. The following compounds are used to color glass, glazes, cosmetics, paints, rubber, inks, and pottery: cobalt oxide, or cobalt black (Co_2O_3); cobalt potassium nitrite, or cobalt yellow ($CoK_3(NO_2)_6$); cobalt aluminate, or cobalt blue ($Co(AlO_2)_2$); and cobalt ammonium phosphate, or cobalt violet ($CoNH_4PO_4$).

Another important use of cobalt compounds is as catalysts. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction. Cobalt molybdate ($CoMoO_4$) is used in the petroleum industry to convert crude oil to gasoline and other petroleum products. It is also used to remove **sulfur** from crude oil.

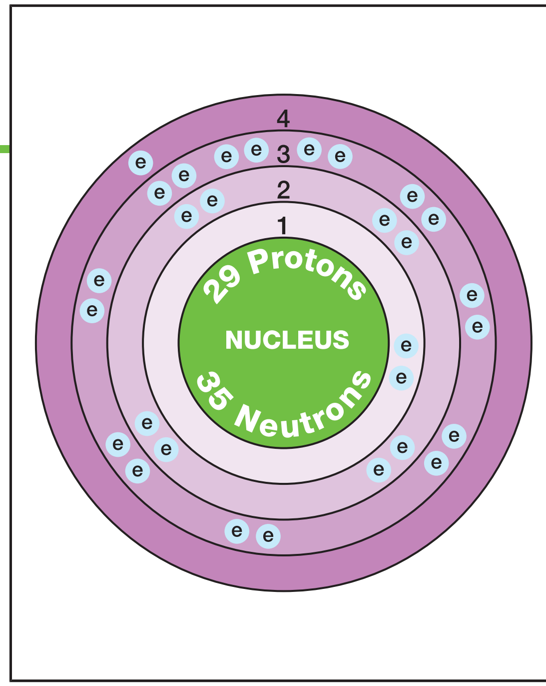
Health Effects

Cobalt is a trace mineral in the human body. A trace mineral is an element needed by plants and animals in minute amounts. The absence of a trace mineral in the diet often leads to health problems. In animals, cobalt is used to make certain essential enzymes. An enzyme is a catalyst in a living organism. It speeds up the rate at which certain changes take place in the body. Enzymes are essential in order for living cells to function properly. Cobalt is needed for the production of vitamin B_{12}. Vitamin B_{12} is necessary to ensure that an adequate number of red blood cells is produced in the body.

A lack of cobalt in the soil can cause health problems, too. For example, sheep in Australia are subject to a disease known as Coast disease, due to a deficiency of cobalt in the soil.

An excess of cobalt can also cause health problems. For example, people who work with the metal may inhale its dust or get the dust on their skin. Cobalt dust can cause vomiting, diarrhea, or breathing problems. On the skin, it can cause rashes and irritation.

Copper



Overview

Copper was one of the earliest elements known to humans. At one time, it could be found lying on the ground in its native, or uncombined, state. Copper's distinctive red color made it easy to identify. Early humans used copper for many purposes, including jewelry, tools, and weapons.

Copper is a transition metal, one of the elements found in Rows 4 through 7 between Groups 2 and 13 in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other.

Copper and its compounds have many important uses in modern society. For example, copper wiring is used in electrical equipment. Copper is also used to make many alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The most familiar alloys of copper are probably brass and bronze. Many compounds of copper are commercially important, too. They are used as coloring agents in paints, ceramics, inks, varnishes, and enamels.

Key Facts

Symbol: Cu

Atomic Number: 29

Atomic Mass: 63.546

Family: Group 11 (IB); transition metal

Pronunciation: COP-per

Discovery and Naming

The oldest known objects made of copper are beads found in northern Iraq, which date to about 9000 BCE. Tools for working with copper,

WORDS TO KNOW

Alkali: A chemical with properties opposite those of an acid.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Ductile: Capable of being drawn into thin wires.

Electrolysis: The process by which an electrical current is used to cause a chemical change, usually the breakdown of some substance.

Enzyme: A substance that stimulates certain chemical reactions in the body.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Slurry: A soup-like mixture of crushed ore and water.

Transition metal: An element in Groups 3 through 12 of the periodic table.

made in about 5000 BCE, have also been found. In the New World, Native Americans used copper objects as early as 2000 BCE.

The symbol for copper, Cu, comes from the Latin word *cuprum.* Cuprum is the ancient name of the island of Cyprus, which is located in the Mediterranean Sea near Turkey. The Romans obtained much of their copper from Cyprus.

Bronze was one of the first alloys produced. It consists primarily of copper and **tin**. The two metals can be melted together rather easily. Humans discovered methods for making the alloy as early as 4000 BCE. Bronze was used for a great variety of tools, weapons, jewelry, and other objects. It was such an important metal that the period from 3500 to 1000 BCE is now known as the Bronze Age. The Iron Age followed the Bronze Age when **iron** began to replace bronze in tools and weapons.

Physical Properties

An important physical property of copper is its color. In fact, people often refer to anything with a reddish-brown tint as being copper colored.

Copper metal is fairly soft and ductile. Ductile means capable of being drawn into wires. Both heat and electricity pass through copper very easily. The high electrical conductivity makes it ideal for many electrical purposes.

Copper has a melting point of 1,982°F (1,083°C) and a boiling point of 4,703°F (2,595°C). Its density is 8.96 grams per cubic centimeter.

Chemical Properties

Copper is a moderately active metal. It dissolves in most acids and in alkalis. An alkali is a chemical with properties opposite those of an acid. Sodium hydroxide, commonly found in bleach and drain cleaners, is an example of an alkali. An important chemical property of copper is the way it reacts with **oxygen**. In moist air, it combines with water and carbon dioxide. The product of this reaction is called hydrated copper carbonate ($Cu_2(OH)_2CO_3$), which changes copper's reddish-brown color to a beautiful greenish color, called a patina. Copper roofs eventually develop this color.

Statue of Liberty Perhaps the most famous and dramatic example of this phenomenon is the Statue of Liberty on Ellis Island near New York City. The Statue, or Lady Liberty as it is often called, was a gift to the United States from France. It was dedicated on October 28, 1886. It symbolizes political freedom and democracy.

The Statue of Liberty is covered with copper plates. When it was new, Lady Liberty was copper in color. Over time, the plates slowly turned green. The statue was given a thorough cleaning for its 100th birthday party on July 4, 1986. But the color remained green. It would take a lot of elbow grease to return the Lady to her original copper color.

The Statue of Liberty. IMAGE COPYRIGHT 2009, DONALD R. SWARTZ. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Occurrence in Nature

The abundance of copper in Earth's crust is estimated to be about 70 parts per million. It ranks in the upper quarter among elements present in Earth's crust. Small amounts (about 1 part per billion) also occur in seawater.

At one time, it was not unusual to find copper metal lying on the ground. However, native copper can still be found only rarely today, always in areas where humans seldom travel.

Today, essentially all copper is obtained from minerals such as azurite, or basic copper carbonate ($Cu_2(OH)_2CO_3$); chalcocite, or copper glance or copper sulfide (Cu_2S); chalcopyrite, or copper pyrites or copper iron sulfide ($CuFeS_2$); cuprite, or copper oxide (Cu_2O); and malachite, or basic copper carbonate ($Cu_2(OH)_2CO_3$).

Copper is mined in more than 50 nations, from Albania and Argentina to Zambia and Zimbabwe. As of 2008, the leading producers are Chile, the United States, Peru, and China. The next largest producers are Australia, Russia, Indonesia, and Canada. According to the U.S. Geological Survey (USGS), about 99 percent of copper mined in the United States comes from Arizona, Utah, New Mexico, Nevada, and Montana.

Isotopes

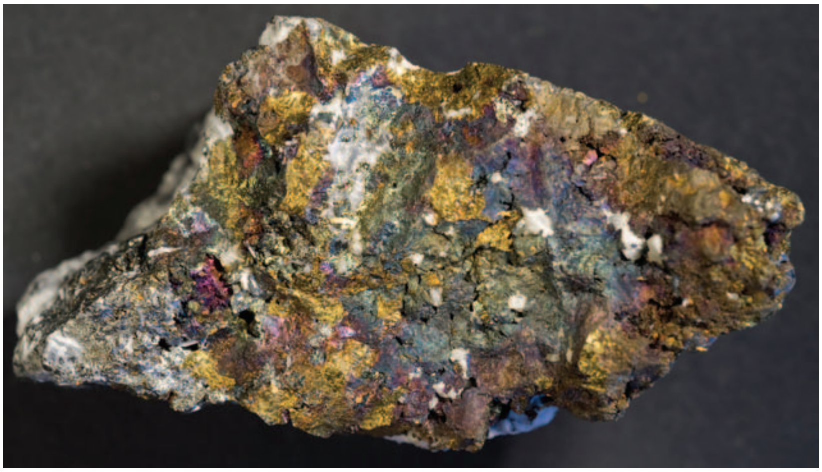
There are two naturally occurring isotopes of copper: copper-63 and copper-65. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-four radioactive isotopes of copper are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Two radioactive isotopes of copper are used in medicine. One is copper-64. This isotope is used to study brain function and to detect Wilson's disease. This disease is the inability to eliminate copper from one's body. The second isotope is copper-67. This isotope can be used to treat cancer. The isotope is injected into the body. It then goes to cells that have become cancerous. In these cells, the isotope gives off radiation that can kill the cancerous cells.

Extraction

Converting copper ore to copper metal often involves many steps. First, the ore is crushed into small pieces. Then the crushed pieces are mixed with water to form a slurry, a soup-like mixture of crushed ore and water.



Sample of chalcopyrite, a copper ore. IMAGE COPYRIGHT 2009, JENS MAYER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

The slurry is spun around in large vats with steel balls to crush the ore to an even finer powder.

Next, blasts of air are passed through the slurry. Impure copper rises to the top of the mixture and unwanted earthy materials sink to the bottom. The copper mixture is skimmed off the top of the slurry and dissolved in sulfuric acid (H_2SO_4).

Bars of **iron** are added to the copper/sulfuric acid mixture. Iron is a more active metal than copper. It replaces the copper from the sulfuric acid solution. Copper deposits on the surface of the iron bar where it is easily scraped off.

The copper is still not pure enough for most purposes. The most common method for copper purification relies on electrolysis. Electrolysis is the process by which an electrical current is used to cause a chemical change, usually the breakdown of some substance. The copper is dissolved in sulfuric acid again and an electric current is passed through the solution. Pure copper metal is deposited on one of the metal electrodes. By repeating this process, copper of 99.9 percent purity can be made.

Other methods are also used to remove copper from its ores. The method chosen depends on the kind of ore used.

Uses

One of the most important applications of copper metal is electrical wiring. Many electrical devices rely on copper wiring because copper metal is highly conductive and relatively inexpensive. These devices include electric clocks, stoves, portable CD and DVD players, and transmission wires that carry electricity. A large skyscraper contains miles of copper wiring for all its electrical needs. Older telephone lines are thick bundles of copper wires. And computers contain circuit boards imprinted with minute copper pathways.

Alloys of copper, such as bronze and brass, are also used in construction. These alloys are used in roofs, heating and plumbing systems, and the skeleton of the building itself.

A number of copper alloys have been developed for special purposes. For example, gun metal is an alloy used to make guns. It contains about 90 percent copper and 10 percent tin. Monel metal is an alloy of nickel and copper that is resistant to corrosion (rusting). Coinage metal is a copper alloy from which U.S. coins are made.

The Value of a Penny When the penny was first introduced in the United States in 1787, it consisted of pure copper. The first Lincoln penny, released in 1909, was 95 percent copper. Depending on the year, the other 5 percent was either all zinc or a combination of zinc and tin (bronze). In 1943—during World War II (1939–1945)—the penny consisted of zinc-plated steel. This penny was a failure. The steel was magnetic (so it got stuck in vending machines), the zinc corroded easily, and the public often confused it with a dime.

By the 1980s, copper had become more valuable than the one cent that the penny was worth. So in 1982, the U.S. mint switched the penny's core to an inexpensive zinc coated with copper. The rest of U.S. pocket change—dimes, nickels, and quarters—have a core of coinage metal with a thin coating of a silvery metal.

Compounds

A number of copper compounds are used as pesticides, chemicals that kill insects and rodents like rats and mice:

- basic copper acetate ($Cu_2O(C_2H_3O_2)_2$): insecticide (kills insects) and fungicide (kills fungi)
- copper chromate ($CuCrO_4 \cdot 2CuO$): fungicide for the treatment of seeds
- copper fluorosilicate ($CuSiF_6$): grapevine fungicide

Pennies no longer consist primarily of copper. IMAGE COPYRIGHT 2009, NBELZ. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

- copper methane arsenate ($CuCH_3AsO_3$): algicide (kills algae)
- copper-8-quinolinolate ($Cu(C_9H_6ON)_2$): protects fabric from mildew
- copper oxalate (CuC_2O_4): seed coating to repel rats
- copper oxychloride ($3CuO \bullet CuCl_2$): grapevine fungicide
- tribasic copper sulfate ($CuSO_4 \bullet 3Cu(OH)_2$): fungicide, used as a spray or dust on crops

Other copper compounds are found in battery fluid; fabric dye; fire retardants; food additives for farm animals; fireworks (bright emerald color); manufacture of ceramics and enamels; photographic film; pigments (coloring agents) in paints, metal preservatives, and marine paints; water purification; and wood preservatives.

Turquoise and malachite are semi-precious gemstones made up of copper compounds. Turquoise ranges in color from green to blue.

Blue-Blooded Creatures In humans, the blood that comes from the lungs to the cells is bright red. The red color is caused by oxyhemoglobin (the compound hemoglobin combined with oxygen). Hemoglobin carries oxygen through the blood and is red because of the iron it carries. Compounds of iron are often red or reddish-brown. Blood returning from cells to the lungs (which flows through the veins) is purplish-red because the hemoglobin has lost its oxygen.

Some animals, however, do not have hemoglobin to carry oxygen through the blood. For example, crustaceans (shellfish like lobsters, shrimps, and crabs) use a compound called hemocyanin. Hemocyanin is similar to hemoglobin but contains copper instead of iron. Many copper compounds, including hemocyanin, are blue. Therefore, the blood of a crustacean is blue, not red.

Health Effects

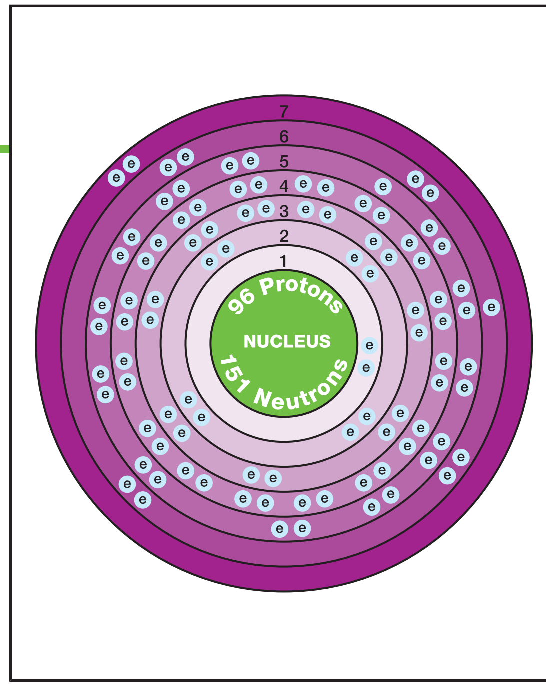
Copper is an essential micronutrient for both plants and animals. A micronutrient is an element needed in minute amounts to maintain good health in an organism. A healthy human has no more than about 2 milligrams of copper for every 2.2 pounds (1 kilogram) of body weight.

Copper is critical to the production of some enzymes. An enzyme is a substance that stimulates certain chemical reactions in the body. Without enzymes, the reactions would be too slow. Copper enzymes function in the production of blood vessels, tendons, bones, and nerves. Animals seldom become ill from a lack of copper, but copper-deficiency disorders (problems because of lack of copper) can occur with animals who live on land that lacks copper.

Crustaceans have blue blood because of a copper compound called hemocyanin. IMAGE COPYRIGHT 2009, DMITRIJS MIHEJEVS. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Large amounts of copper in the human body are usually not a problem either. One exception is the condition known as Wilson's disease. Some people are born without the ability to eliminate copper from their bodies. The amount of copper they retain increases. The copper level can become so great it begins to affect a person's brain, liver, or kidneys. Mental illness and death can result. Fortunately, this problem can be treated. The person is given a chemical that combines with the copper. The copper's damaging effects on the body are reduced or eliminated.

Curium



Overview

Curium is called a transuranium element because it follows **uranium** in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Uranium has an atomic number of 92, so any element with a higher atomic number is a transuranium element.

Curium was discovered in 1944 by Glenn Seaborg (1912–1999), Ralph A. James, and Albert Ghiorso (1915–). These researchers, from the University of California at Berkeley, were working at the Metallurgical Research Laboratory (MRL) at the University of Chicago where research on the first atomic bomb was being conducted.

Discovery and Naming

Curium was first produced in a particle accelerator at the MRL. A particle accelerator is also called an atom smasher. It is used to accelerate small particles, such as protons, to move at very high speeds. The particles approach the speed of light, 186,000 miles per second (300,000 kilometers per second), and collide with target elements, such as **gold**, **copper**, or **tin**. The targets break apart or combine with a particle to form new elements and other particles.

Key Facts

Symbol: Cm

Atomic Number: 96

Atomic Mass: [247]

Family: Actinoid; transuranium element

Pronunciation: CURE-ee-um

WORDS TO KNOW

Actinoids: Elements in Row 7 of the periodic table with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear reactor: A device in which nuclear reactions occur.

Particle accelerator ("atom smasher"): A device used to cause small particles, such as protons, to move at very high speeds.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive: Having a tendency to give off radiation.

Transuranium element: An element with an atomic number greater than 92.

The first samples of curium were so small they could be detected only by the radiation they gave off. In 1947, the first significant sample of the element was produced. It weighed about 30 milligrams, or the equivalent of about one-thousandth of an ounce. The element was named for Polish-French physicist Marie Curie (1867–1934) and her husband, French physicist Pierre Curie (1859–1906). The Curies carried out some of the earliest research on radioactive elements.

Physical Properties

Curium is a silvery-white metal with a melting point of about 2,444°F (1,340°C) and a density of 13.5 grams per cubic centimeter, about 13 times the density of water.

Chemical Properties

The chemical properties of curium are similar to those of the rare earth elements. The rare earth elements are the elements in the periodic table with atomic numbers 57 through 71. Curium is not very reactive at room temperature, but does combine with oxygen when heated to form curium oxide (Cm_2O_3). The element also reacts with the halogens to form curium fluoride (CmF_4), curium chloride ($CmCl_3$), curium bromide ($CmBr_3$), and curium iodide (CmI_3). A number of other curium compounds have also been made.

Curium was named after Polish-French physicists Marie and Pierre Curie, who conducted research on radioactive elements.
AP IMAGES.

Occurrence in Nature

Very small amounts of curium are thought to occur in Earth's surface with deposits of uranium. The curium is formed when uranium breaks down and forms new elements. The amounts that exist, if they do, are too small to have been discovered so far.

Isotopes

All 21 known isotopes of curium are radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation.

Some of the equipment on the Mars Pathfinder, *shown here in a NASA illustration, was powered by a curium battery.* NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA).

The curium isotope with the longest half life is curium-247. Its half life is 15.6 million years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. After about 15.6 million years, only 0.5 grams of the isotope would remain from a one-gram sample produced today. The other 0.5 gram would have changed into another element.

Extraction

Large quantities of curium are now easily made in nuclear reactors. A nuclear reactor is a device in which neutrons split atoms to release energy for electricity production.

Uses

Curium is sometimes used to analyze materials taken from mines and as a portable source of electrical power. It gives off a large amount of energy that can be used to generate electricity for space vehicles.

A relatively recent use of curium was in the *Mars Pathfinder* that was sent to Mars in 1997 to study that planet's surface. Some of the equipment on the spacecraft was powered by a curium battery.

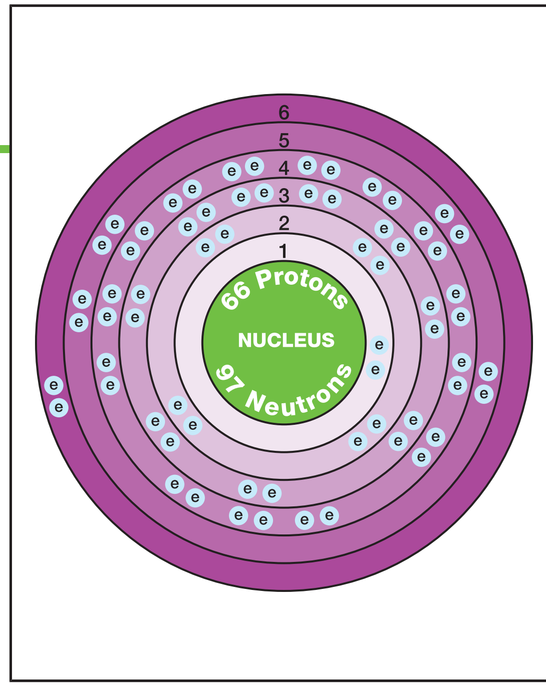
Compounds

A number of compounds of curium have been produced, including two forms of curium oxide (Cm_2O_3 and CmO_2), two forms of curium fluoride (CmF_3 and CmF_4), curium chloride ($CmCl_3$), curium bromide ($CmBr_3$), and curium hydroxide ($Cm(OH)_3$).

Health Effects

Curium is an extremely hazardous substance. If taken into the body, it tends to concentrate in the bones, where the radiation it gives off kills or damages cells and can cause cancer.

Dysprosium



Key Facts

Symbol: Dy

Atomic Number: 66

Atomic Mass: 162.500

Family: Lanthanoid (rare earth metal)

Pronunciation: dis-PRO-zee-um

Overview

Dysprosium is one of 15 rare earth elements in Row 6 of the periodic table. The name rare earth is misleading because the elements in this group are not especially uncommon. However, they often occur together in the earth and were once difficult to separate from each other. A better name for the rare earth elements is lanthanoids. This name comes from the element **lanthanum**, which is sometimes considered part of the lanthanoids group in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another.

Dysprosium was discovered in 1886, but was not commercially available until after 1950. The reason for the long delay was that methods for separating dysprosium from other lanthanoids had not been developed. Dysprosium has few applications but is used in some hybrid cars.

Discovery and Naming

In 1787, Carl Axel Arrhenius (1757–1824), a Swedish army officer and amateur mineralogist, found a rock in a mine at Ytterby, a region near Stockholm. He named the rock ytterite. A few years later, the rock was analyzed by Johan Gadolin (1760–1852), a professor of chemistry at the

WORDS TO KNOW

Earth: In mineralogy, a naturally occurring form of an element, often an oxide of the element.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Periodic table: A chart that shows how chemical elements are related to each other.

University of Åbo in Finland, who found that the rock contained a new kind of "earth," which a colleague called yttria.

The term "earth" in mineralogy refers to a naturally occurring form of an element, usually an oxide. For example, one kind of earth is magnesia, a term that refers to **magnesium** oxide. Magnesium oxide is one form in which the element magnesium occurs naturally in the earth.

The discovery by Arrhenius and Gadolin initiated a long series of experiments on yttria. These experiments produced puzzling results for two reasons. First, it turned out that yttria is actually a mixture of many similar elements. Second, the equipment that chemists had to work with was still very primitive. They had serious difficulties separating these elements from each other.

Over a period of more than a century, chemists argued about the composition of yttria. Eventually, chemists agreed that yttria is actually a combination of nine different elements that had not been seen before. One of those elements is dysprosium. Dysprosium was finally proved to be a new element in 1886 by French chemist Paul-émile Lecoq de Boisbaudran (1838–1912). The name chosen for this new element comes from the Greek word meaning "difficult to obtain."

Physical Properties

Dysprosium has a metallic appearance with a shiny silver luster. The metal is so soft it is easily cut with a knife. It has a melting point of 2,565°F (1,407°C) and a boiling point of about 4,200°F (about 2,300°C). Dysprosium's density is 8.54 grams per cubic centimeter, about eight times that of water.

Chemical Properties

Dysprosium is relatively unreactive at room temperatures. It does not oxidize very rapidly when exposed to the air. It does react with both dilute and concentrated acids, however. For example, it reacts with hydrochloric acid to form dysprosium trichloride.

$$2Dy + 6HCl \rightarrow 2DyCl_3 + 3H_2$$

Occurrence in Nature

More than 100 minerals are known to contain one or more of the rare lanthanoids. Only two of these minerals, monazite and bastnasite, are commercially important. These minerals occur in North and South Carolina, Idaho, Colorado, and Montana in the United States, and in countries such as Australia, Brazil, China, and India, among others.

Experts estimate that no more than about 8.5 parts per million of dysprosium occur in Earth's crust. That makes the element more common than better known elements such as **bromine**, **tin**, and **arsenic**. Studies of stony meteorites have found about 0.3 parts per million of dysprosium.

Isotopes

Seven naturally occurring isotopes of dysprosium are known. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. The four most abundant isotopes of dysprosium are dysprosium-161, dysprosium-162, dysprosium-163, and dysprosium-164.

Twenty-eight radioactive isotopes of dysprosium have been made. A radioactive isotope is one that is unstable, gives off radiation, and breaks down to form a new isotope. Of these isotopes, only one, dysprosium-166, has much commercial importance. It is used to treat certain types of cancer, to relieve pain due to cancer, and in the treatment of joint problems.

The radioactive isotope dysprosium-165 is also being studied for some potential applications in medicine. Radiation with dysprosium-165 has proved to be more effective in treating damaged joints than traditional surgery.

Extraction

The dysprosium in monazite and bastnasite is first converted to dysprosium trifluoride (DyF_3). The compound then reacts with calcium metal to obtain pure dysprosium:

$$2DyF_3 + 3Ca \rightarrow 3CaF_2 + 2Dy$$

Uses

Dysprosium has a tendency to soak up neutrons, which are tiny particles that occur in atoms and are produced in nuclear reactions. Metal rods (control rods) containing dysprosium are used in nuclear reactors to control the rate at which neutrons are available.

Dysprosium is also used to make alloys for various electrical and electronic devices. An alloy is made by melting and mixing two or more metals. The mixture has properties different than any of the elements. Some dysprosium alloys have very good magnetic properties that make them useful in CD players. The element is also used in some hybrid cars.

The magnetic properties of dysprosium alloys make them useful in CD players. IMAGE COPYRIGHT 2009, SILVER-JOHN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

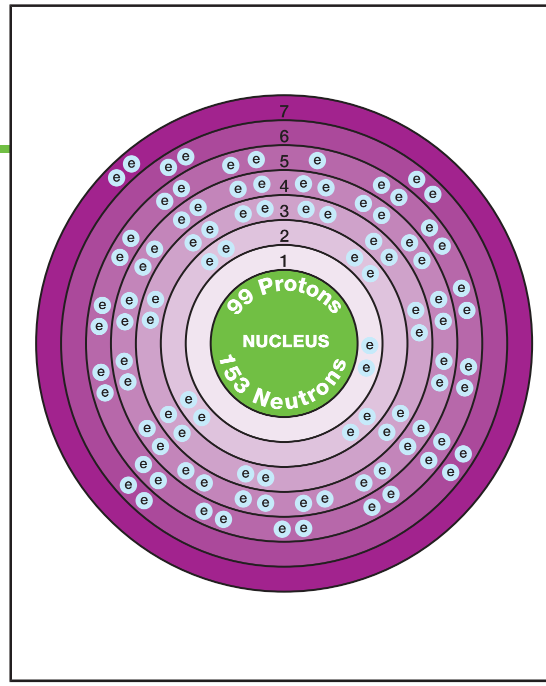
Compounds

Like the element itself, some compounds of dysprosium are used in nuclear reactors and the manufacture of electrical and electronic equipment.

Health Effects

Very little is known about the health effects of dysprosium.

Einsteinium



Key Facts

Symbol: Es

Atomic Number: 99

Atomic Mass: [252]

Family: Actinoid; transuranium element

Pronunciation: ein-STY-nee-um

Overview

Einsteinium is a member of the actinoid family. The actinoid elements are found in Row 7 of the periodic table, a chart that shows how chemical elements are related to each other. The actinoids fall between **radium** (element number 88) and **rutherfordium** (element number 104). They are usually listed in a separate row at the very bottom of the periodic table.

Einsteinium is also a transuranium element. Transuranium elements are those beyond **uranium** on the periodic table. Uranium has an atomic number of 92, so elements with larger atomic numbers are transuranium elements.

Discovery and Naming

Einsteinium was discovered by a research team from the University of California at Berkeley. The team was led by Albert Ghiorso (1915–). The element was discovered in the "ashes" after the first hydrogen bomb test in November 1952 at Eniwetok Atoll, Marshall Islands, in the Pacific Ocean. The discovery was a remarkable accomplishment because no more than a hundred millionth of a gram of the element was present. It was detected because of the characteristic radiation it produced.

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear reactor: A device in which nuclear reactions occur.

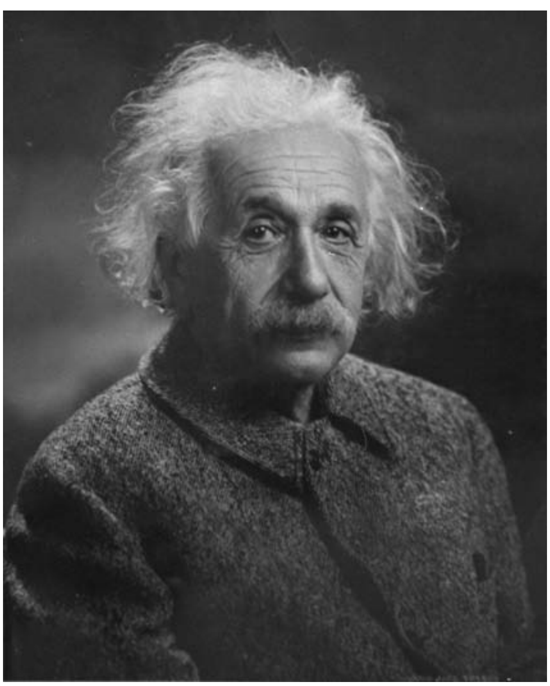
Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive: Having a tendency to give off radiation.

Transuranium element: An element with an atomic number greater than 92.

Element number 99 was named after German-American physicist Albert Einstein (1879–1955). Some people regard Einstein as the greatest scientist who ever lived.

The element einsteinium is named after Albert Einstein. LIBRARY OF CONGRESS.



Physical and Chemical Properties

Very little information about the physical and chemical properties of einsteinium is available. Its melting point has been found to be 1,580°F (860°C).

Occurrence in Nature

Einsteinium does not occur naturally in Earth's crust.

Isotopes

All 19 isotopes of einsteinium are radioactive. The most stable is einsteinium-254. Its half life is 275.7 days. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation.

The half life of a radioactive element is the time it takes for half of a sample of the element to break down. For example, suppose that scientists made 10 grams of einsteinium-254. About eight months later (275.7 days later), only 5 grams of the element would be left. After another eight months (275.7 days more), only half of that amount (2.5 grams) would remain.

Extraction

Einsteinium is not extracted from Earth's crust.

Uses

Einsteinium is sometimes used for research purposes, but it has no practical applications.

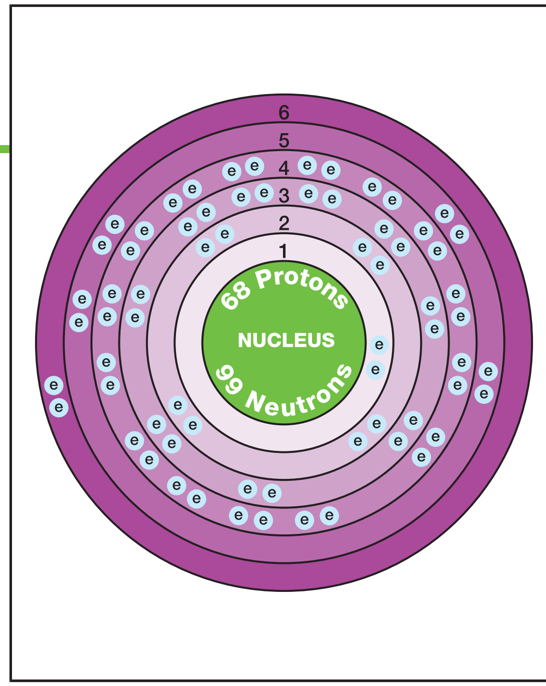
Compounds

There are no commercially important compounds of einsteinium.

Health Effects

Scientists know too little about einsteinium to be aware of its health effects. As a radioactive element, however, it does pose a threat to human health.

Erbium



Key Facts

Symbol: Er

Atomic Number: 68

Atomic Mass: 167.259

Family: Lanthanoid (rare earth metal)

Pronunciation: ER-bee-um

Overview

Erbium is one of 15 rare earth elements with atomic numbers 57 through 71 in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Rare earth is a misleading category because these elements are not especially rare in Earth's crust. Rare earth metals were rarely used because the elements were once difficult to separate from each other.

Today, the rare earth elements can be separated easily, and they can be bought at a reasonable cost. Two common uses of erbium today are in lasers and special kinds of optical fibers. Optical fibers are glass-like materials used to carry telephone messages.

The rare earth elements are called the lanthanoids, a name that comes from **lanthanum** (element 57).

Discovery and Naming

The discovery of the lanthanoids began outside the small town of Ytterby, Sweden, in 1787. A Swedish army officer named Carl Axel Arrhenius (1757–1824) found an unusual kind of black mineral in a rock quarry. That mineral was later given the name gadolinite.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Malleable: Capable of being hammered into thin sheets.

Optical fiber: A thin strand of glass through which light passes; the light carries a message, much as an electric current carries a message through a telephone wire.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Stable: Not likely to react with other materials.

Gadolinite was full of surprises. As chemists analyzed the new mineral, they found nine new elements. No mineral had ever produced such a wealth of new information.

One of the first scientists to work on gadolinite was Swedish chemist Carl Gustav Mosander (1797–1858). Mosander was able to separate gadolinite into three parts: yttria, terbia, and erbia. Later, the parts he called erbia and terbia were given different names.

In 1843, Mosander found that erbia was an entirely new substance. It consisted of a new element combined with **oxygen**. He called the new element erbium. The name came from the town near where it had been found, Ytterby. Interestingly, three other elements were also named after this small town: **terbium**, **yttrium**, and **ytterbium**.

Although Mosander is given credit for discovering erbium, he saw only erbia, the compound of erbium and oxygen. The erbia he saw was not even pure, but was mixed with other rare earth element oxides.

The first pure samples of erbium oxide (erbia) were produced in 1905 by French chemist George Urbain (1872–1938) and American chemist Charles James (1880–1928). It was not until 1934 that the first pure erbium metal was produced.

Physical Properties

Erbium metal has a bright, shiny surface, much like metallic silver. It is soft and malleable. Malleable means capable of being hammered into thin sheets. Erbium has a melting point of 2,784°F (1,529°C) and a boiling point of about 5,194°F (2,868°C). Its density is 9.16 grams per cubic centimeter.

Chemical Properties

Erbium is fairly stable in air. It does not react with oxygen as quickly as most other lanthanoids. Erbium compounds tend to be pink or red. They are sometimes used to color glass and ceramics.

Occurrence in Nature

Erbium ranks about number 42 in abundance in Earth's crust. It is more common than **bromine**, **uranium**, **tin**, **silver**, and **mercury**. It occurs in many different rare earth minerals, naturally occurring lanthanoid mixtures. Some common sources of erbium are xenotime, fergusonite, gadolinite, and euxenite.

Isotopes

Six naturally occurring stable isotopes of erbium are known. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. The naturally occurring isotopes of erbium are erbium-162, erbium-164, erbium-166, erbium-167, erbium-168, and erbium-170.

Thirty radioactive isotopes of erbium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles, such as protons or neutrons, are fired at atoms. These particles stick in the atoms and make them radioactive. None of the radioactive isotopes of erbium has any important uses.

Extraction

Erbium in a mineral is first converted into erbium fluoride (ErF_3). Pure erbium is then obtained by passing an electric current through molten (melted) erbium fluoride:

$$2ErF_3 \rightarrow 2Er + 3F_2$$

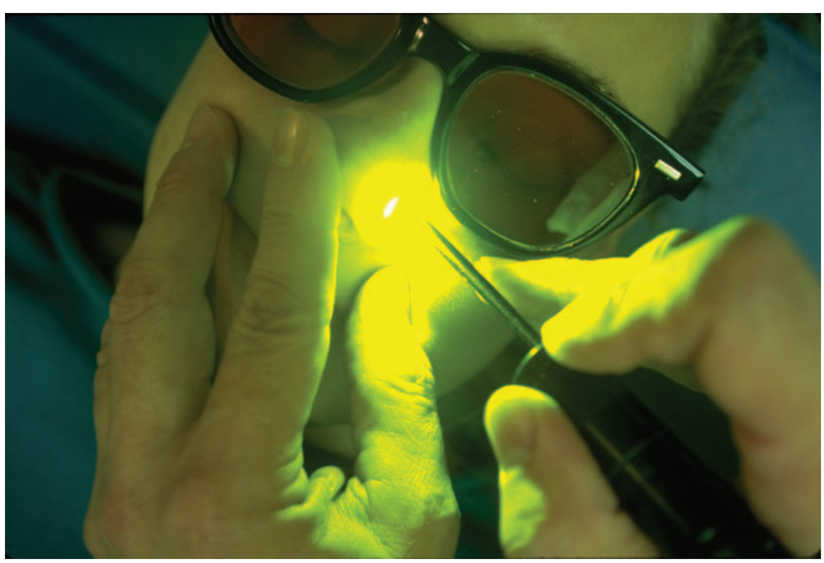
Uses

Erbium metal has few uses. It is sometimes alloyed with **vanadium** metal. An alloy is made by melting and mixing two or more metals. The mixture has properties different than those of the individual metals. A vanadium-erbium alloy is easier to work with than pure vanadium metal.

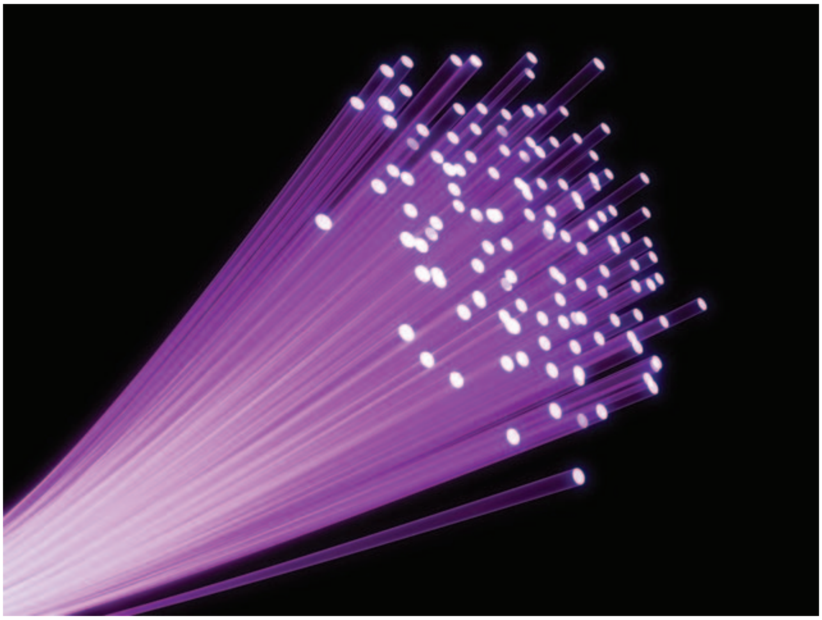
The most important uses of erbium are in lasers and optical fibers. A laser is a device for making very intense light of one specific color. The light is intensified and focused into a narrow beam that can cut through metal. Lasers have many practical applications.

Erbium lasers are used to treat skin problems. The lasers have been used to remove wrinkles and scars. They work better than other kinds of lasers because they do not penetrate the skin very deeply. They also produce little heat and cause few side effects.

An optical fiber is a thin thread-like piece of glass or plastic through which light travels easily. Light carries messages along the fiber, much as



An important use of erbium is in lasers. Here, a patient undergoes cosmetic laser surgery. © WILL & DENI MCINTYRE/PHOTO RESEARCHERS, INC.



Erbium is used in optical fibers, very thin pieces of glass or plastic used in the communications industry. IMAGE COPYRIGHT 2009, SEBASTIAN KAULITZKI. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

electricity carries messages along **copper** telephone wires. Erbium optical fibers carry messages in long distance communication systems and in military applications. Telephone providers have converted various copper phone lines to optical fibers for improved clarity. Optical fibers carry far more information than the old bundles of copper.

Optical fibers have proven to be an ideal method of transmitting high-definition television (HDTV) signals. HDTV has become one of the most popular new technology items for consumers. Since HDTVs were introduced in the late 1990s, sales of the sets have increased rapidly. By some estimates, the sales of HDTVs will reach 250 million by the year 2015.

The signals in HDTVs contain twice as much "information" as conventional TVs do. These signals result in a much clearer picture. However, the picture on an HDTV looks just like a regular TV unless optical fibers are used. With optical fibers, the HDTV signal can transmit a nearly perfect image.

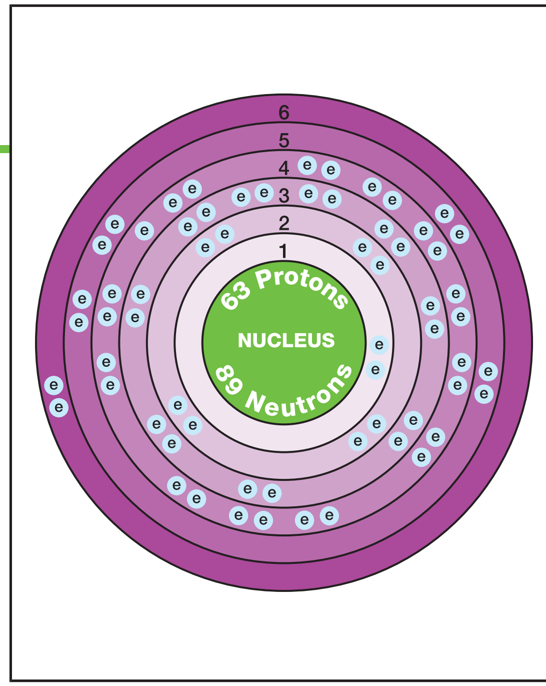
Compounds

There are no commercially important erbium compounds.

Health Effects

Almost nothing is known about the health effects of erbium on plants, humans, or other animals. In such cases, it is usually safest to assume that the element is toxic.

Europium



Overview

Europium was discovered in 1901 by French chemist Eugène-Anatole Demarçay (1852–1904). Demarçay named the element after the continent of Europe. It was one of the last of the rare earth elements discovered.

The rare earth elements include numbers 57 to 71 in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. A better name for these elements is lanthanoids. This name comes from the element **lanthanum**. Rare earth elements are not especially rare, but were originally very difficult to separate from one another.

Europium is the most active of the lanthanoids. It is more likely to react with other elements than the other rare earth elements.

Europium is quite expensive to produce, so it has few practical uses. It is used in television tubes and lasers.

Key Facts

Symbol: Eu

Atomic Number: 63

Atomic Mass: 151.964

Family: Lanthanoid (rare earth metal)

Pronunciation: yuh-RO-pea-um

Discovery and Naming

In 1901, Demarçay was studying **samarium**, a new element that had been discovered some 20 years earlier. In his studies, Demarçay made

WORDS TO KNOW

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Fission: The process in which large atoms break apart, releasing large amounts of energy, smaller atoms, and neutrons in the process.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Periodic table: A chart that shows how chemical elements are related to each other.

Phosphor: A material that gives off light when struck by electrons.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

an interesting discovery. The new element was not one, but two elements. Demarçay gave the original name of samarium to one, and the other he called europium, after the continent of Europe.

More than a century earlier, a heavy new mineral had been found near the town of Bastnas, Sweden, and given the name cerite.

Chemists found that cerite was a complex material. One hundred years of research revealed seven new elements in cerite. Europium was the last of these new elements to be identified.

Physical Properties

Europium has a bright, shiny surface. It is steel gray and has a melting point of 1,520°F (826°C) and a boiling point of about 2,784°F (1,529°C). The density is 5.24 grams per cubic centimeter, about five times the density of water.

Europium has a strong tendency to absorb neutrons, making it useful in nuclear power production. A nuclear power plant produces electricity from the energy released by nuclear fission. Slow-moving neutrons collide with **uranium** or **plutonium** atoms, breaking them apart and releasing energy as heat. The amount of energy produced in a nuclear power plant is controlled by the number of neutrons present. Europium is used to absorb neutrons in this kind of control system.

Chemical Properties

Europium is the most active of the lanthanoids. It reacts vigorously with water to give off **hydrogen**. It also reacts with **oxygen** in the air, catching fire spontaneously. Scientists must use great care in handling the metal.

Occurrence in Nature

Europium is not abundant in Earth's surface. It is thought to occur at a concentration of no more than about one part per million. That makes it one of the least abundant of the rare earth elements. The study of light from the sun and certain stars indicates that europium is present in these bodies as well.

The most common ores of europium are monazite, bastnasite, and gadolinite.

Isotopes

Two naturally occurring stable isotopes of europium exist: europium-151 and europium-153. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-six radioactive isotopes of europium have also been made artificially. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. None of the radioactive isotopes of europium has any commercial use.

Extraction

Europium is prepared by heating its oxide with lanthanum metal:

$$Eu_2O_3 + 2La \rightarrow La_2O_3 + 2Eu$$

Europium metal is quite expensive to make.

Uses

There are no commercially important uses for europium metal.

Compounds

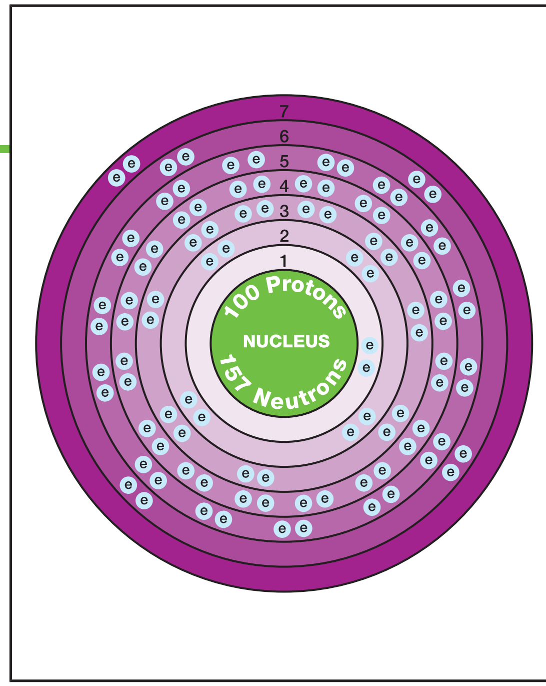
The most common use of europium compounds is in making phosphors. A phosphor is a material that shines when struck by electrons. The color of the phosphor depends on the elements from which it is made. Phosphors containing europium compounds give off red light. The red color on a television screen, for example, may be produced by phosphors containing europium oxide. It is also used in energy-efficient LED lightbulbs. Europium oxide is a compound made of europium metal and oxygen. In 2007 europium oxide sold for about $1,200 per kilogram.

Europium oxide phosphors are also used in printing postage stamps. These phosphors make it possible for machines to "read" a stamp and know what its value is. If the wrong stamp is on a letter, the machine can tell from reading the phosphor. The machine will then send the letter back to the person who mailed it.

Health Effects

Except for europium's tendency to catch fire, little information is available on its health effects. In general, it is regarded as toxic and must be handled with great caution.

Fermium



Overview

Fermium is one of the transuranium elements, which lie beyond **uranium** in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Uranium is element number 92, so all elements with larger atomic numbers are transuranium elements.

Key Facts

Symbol: Fm

Atomic Number: 100

Atomic Mass: [257]

Family: Actinoid; transuranium element

Pronunciation: FER-me-um

Discovery and Naming

Fermium was discovered in 1952, among the products formed during the first hydrogen bomb test at Eniwetok Atoll, Marshall Islands, in the Pacific Ocean. For security reasons, this discovery was not announced until 1955. Credit for the discovery of fermium goes to a group of University of California scientists under the direction of Albert Ghiorso (1915–). The element was named for Italian physicist Enrico Fermi (1901–1954). Fermi, who made many important scientific discoveries in his life, was a leader of the U.S. effort to build the world's first fission (atomic) bomb during World War II.

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear reactor: A device in which nuclear reactions occur.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive: Having a tendency to give off radiation.

Transuranium element: An element with an atomic number greater than 92.

Physical and Chemical Properties

Too little fermium has been prepared to allow scientists to determine most of its physical and chemical properties. Its melting point has been determined to be 2,780°F (1,527°C).

Occurrence in Nature

Fermium does not occur naturally in Earth's crust.

Isotopes

All 20 known isotopes of fermium are radioactive. The most stable isotope is fermium-257. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The half life of fermium-257 is 100.5 days. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. A radioactive isotope is one that breaks apart and gives off some form of radiation. For example, suppose 100 grams of fermium-257 is made. Fifty grams of the isotope would be left about 100 days later. After another 100 days, only 25 grams of the isotope would remain.

Facts about Enrico Fermi

Fermium's namesake Enrico Fermi taught physics and did research at the University of Rome from 1926 to 1938. During this period, he learned how to use neutrons to change elements from one form (isotope) to another. He received the Nobel Prize in physics in 1938 for these discoveries.

The year he received the Nobel Prize was a difficult time in Europe. Benito Mussolini (1883–1945) had just come to power in Italy. Mussolini followed many of the same unjust policies as Nazi leader Adolf Hitler (1889–1945) did in Germany. One of these policies was anti-Semitism (hostility toward Jews). Fermi, whose wife was Jewish, began to worry about what might happen if they stayed in Italy. Like many other scientists in Europe, he decided to come to the United States, where he took a job at Columbia University in New York.

Soon after Fermi arrived in the United States, he discovered that his experience with neutrons was very valuable. The U.S. government had undertaken a huge top-secret research program called the Manhattan Project. The purpose of the Manhattan Project was to find a way to build an atomic bomb. Fermi was placed in charge of one part of that project.

Fermi's responsibility was to study the reaction that occurs when uranium atoms are bombarded by neutrons. His team did most of this research at the University of Chicago. On December 2, 1942, the team made an important breakthrough. They produced the first self-sustaining chain reaction in history. A self-sustaining chain reaction is one in which neutrons split uranium atoms apart. Large amounts of energy are produced in the reaction. Additional neutrons are also formed. These neutrons can be used to make the reaction repeat over and over again. The reaction eventually formed the basis of the first atomic bombs built three years later.

After the war, Fermi returned to the University of Chicago as professor of physics. He died at the early age of 53 of stomach cancer. In his honor, the U.S. government created the Enrico Fermi Award for accomplishments in nuclear physics.

Extraction

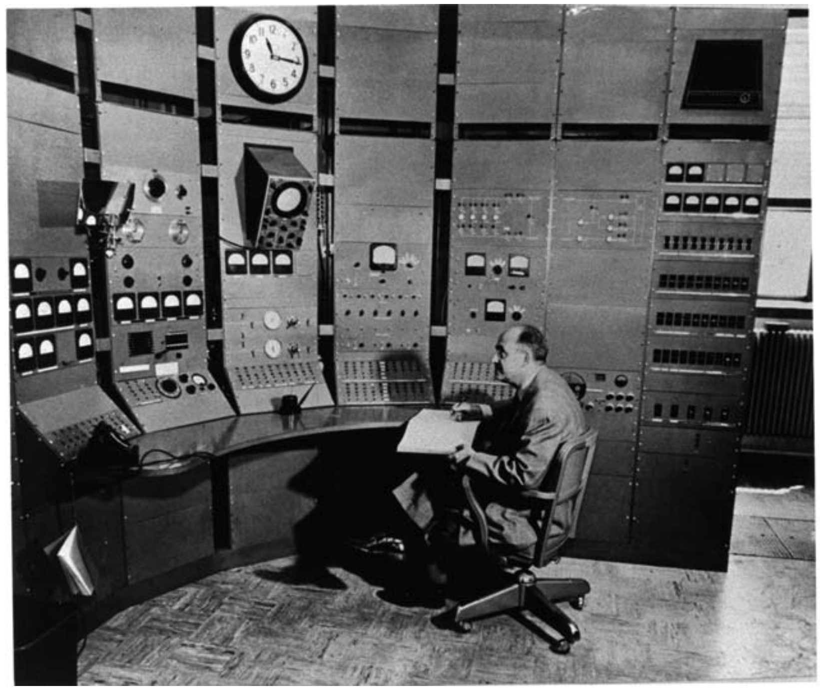
Fermium is not extracted from Earth's crust.

Uses

Fermium is sometimes used in scientific research, but it has no commercial applications.

Compounds

There are no commercially important compounds of fermium.

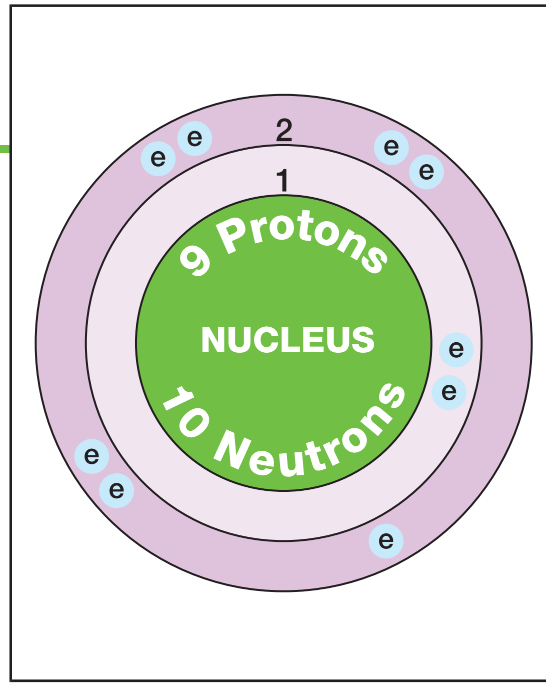


Enrico Fermi. LIBRARY OF CONGRESS.

Health Effects

Scientists know too little about fermium to be aware of its health effects. As a radioactive element, however, it does pose a threat to human health.

Fluorine



Key Facts

Symbol: F

Atomic Number: 9

Atomic Mass: 18.9984032

Family: Group 17 (VIIA); halogen

Pronunciation: FLOR-een

Overview

Fluorine is the lightest member of the halogen family, elements in Group 17 (VIIA) of the periodic table. The periodic table is a chart that shows how elements are related to one another. The halogens also include **chlorine**, **bromine**, **iodine**, and **astatine**. Fluorine is the most active chemical element, reacting with virtually every element. It even reacts with the noble gases at high temperatures and pressures. The noble gases, Group 18 (VIIIA) in the periodic table, are also known as the inert gases. They generally do not react with other elements.

Fluorine was discovered in 1886 by French chemist Henri Moissan (1852–1907). Moissan collected the gas by passing an electric current through one of its compounds, hydrogen fluoride (H_2F_2).

One of the best known uses of fluorine is in the production of fluorides, used as additives in toothpastes and municipal water supplies. Fluorides are effective in preventing tooth decay and have been widely used in the United States for this purpose since the 1950s.

Another well known group of fluorine compounds is the chlorofluorocarbons (CFCs). For many years, the CFCs were used for a wide variety of industrial purposes, including refrigeration, cleaning systems, and as

WORDS TO KNOW

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Noble gas: An element in Group 18 (VIIIA) of the periodic table.

Ozone: A form of oxygen that filters out harmful radiation from the sun.

Ozone layer: The layer of ozone that shields Earth from harmful ultraviolet radiation from the sun.

Periodic table: A chart that shows how chemical elements are related to each other.

Polymerization: The process by which many thousands of individual tetrafluoroethlylene (TFE) molecules join together to make one very large molecule.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Serendipity: Discovering something of value when not seeking it; for example, making a discovery by chance or accident.

Toxic: Poisonous.

Ultraviolet (UV) radiation: Electromagnetic radiation (energy) of a wavelength just shorter than the violet (shortest wavelength) end of the visible light spectrum and thus with higher energy than visible light.

propellants in aerosol products. They were considered to be one of the most successful family of synthetic compounds ever invented.

However, CFCs react with ozone (O_3) in the upper atmosphere. Scientists discovered that the CFCs were depleting the ozone layer. The ozone layer filters harmful ultraviolet (UV) radiation from the sun. Ultraviolet radiation is electromagnetic radiation (energy) of a wavelength just shorter than the violet (shortest wavelength) end of the visible light spectrum and thus with higher energy than visible light. To protect the ozone layer, the production of CFCs was banned in the United States and many other countries.

Discovery and Naming

Chemistry has always been a dangerous science. Early chemistry was a hazardous occupation. Men and women worked with chemicals about which they knew very little. The discovery of new compounds and elements could easily have tragic consequences.

Fluorine was particularly vicious. Chemists suffered terrible injuries and even died in their attempts to study the element. Fluorine gas is extremely damaging to the soft tissues of the respiratory tract.

In the early 1500s, German scholar Georgius Agricola (1494–1555) described a mineral he called fluorspar. The name fluorspar comes from the Latin word *fluere,* meaning "to flow." Agricola claimed that fluorspar added to molten metallic ores made them more liquid and easier to work with. Although Agricola did not realize it, fluorspar is a mineral of fluorine and contains calcium fluoride (CaF_2).

Fluorspar became the subject of intense study by early chemists. In 1670, German glass cutter Heinrich Schwanhard discovered that a mixture of fluorspar and acid formed a substance that could be used to etch glass. Etching is a process by which a pattern is drawn into glass. The chemical reaction leaves a frosted image. Etching is used to produce artistic shapes on glass as well as in the manufacture of precise scientific measuring instruments.

The new etching material was identified in 1771 by Swedish chemist Carl Wilhelm Scheele (1742–1786). Scheele described, in detail, the properties of this material, hydrofluoric acid (H_2F_2). His work set off an intense study of the acid and its composition.

One goal was to find ways to break hydrofluoric acid into elements. Chemists suspected that one element had never been seen before. Little did they know, however, what a dangerous new element it would be. During studies of hydrofluoric acid, many chemists were disabled when they inhaled hydrogen fluoride gas. One chemist, Belgian Paulin Louyet (1818–1850), died from his exposure to the chemical.

Finally, in 1888, the problem was solved. Moissan made a solution of hydrofluoric acid in potassium hydrogen fluoride (KHF_2). He then cooled the solution to –9.4°F (–23°C) and passed an electric current through it. A gas appeared at one end of the apparatus. He gave the name fluorine to the new element. The name comes from the mineral fluorspar.

Physical Properties

Fluorine is a pale yellow gas with a density of 1.695 grams per liter. That makes fluorine about 1.3 times as dense as air. Fluorine changes from a gas to a liquid at a temperature of –306.5°F (–188.13°C) and from a liquid to a solid at –363.30°F (–219.61°C).

Fluorine has a strong and characteristic odor that can be detected in very small amounts, as low as 20 parts per billion. This property is very helpful to those who work with fluorine. It means that the gas can be detected and avoided in case it leaks into a room.

Chemical Properties

Fluorine is the most reactive nonmetallic element. It combines easily with almost every other element. Compounds of fluorine and the noble gases have even been made. The noble gases are the elements in Group 18 (VIIIA) of the periodic table. They are normally very unreactive. Fluorine also reacts with most compounds, often violently. For example, when mixed with water, it reacts explosively. For these reasons, it must be handled with extreme care in the laboratory.

Occurrence in Nature

Fluorine never occurs as a free element in nature. The most common fluorine minerals are fluorspar, fluorapatite, and cryolite. Apatite is a complex mineral containing primarily **calcium**, **phosphorus**, and **oxygen**, usually with fluorine. Cryolite is also known as Greenland spar. (The country of Greenland is the only commercial source of this mineral.) It consists primarily of sodium **aluminum** fluoride (Na_3ALF_6). The major sources of fluorspar are China, Mexico, Mongolia, and South Africa. In 2008 in the United States, fluorspar was produced as a by-product of limestone quarrying in Illinois. The United States imports most of the fluorspar it needs from China and Mexico.

Fluorine is an abundant element in Earth's crust, estimated at about 0.06 percent in the earth. That makes it about the 13th most common element in the crust. It is about as abundant as **manganese** or **barium**.

Isotopes

Only one naturally occurring isotope of fluorine (fluroine-19) is known to exist. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

In addition, 10 artificial radioactive isotopes of fluorine are known. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope, fluorine-18, is sometimes used for medical studies. It is combined chemically with glucose (blood sugar) molecules and injected into the body. It then travels to cancer cells, which reproduce rapidly and use glucose very quickly. The presence of fluorine-18 can be detected in these cells because of the radiation it gives off. Using this method, medical workers can determine the location, size, and other properties of cancerous cells in the body.

Extraction

Fluorine is made commercially by Moissan's method. An electric current is passed through a mixture of hydrogen fluoride and potassium hydrogen fluoride:

$$H_2F_2 \quad \text{electric current} \rightarrow H_2 + F_2$$

Uses and Compounds

Fluorine has relatively few uses as an element. It is much too active for such applications. One use of elemental fluorine is in rocket fuels. It helps other materials burn, like oxygen does. The greatest majority of fluorine is used to make compounds of fluorine.

Fluorides are compounds of fluorine with (usually) one other element. **Sodium** fluoride (NaF), calcium fluoride (CaF_2), and stannous fluoride (SnF_2) are examples of fluorides.

A familiar use of some fluoride compounds is in toothpastes. Studies show that small amounts of fluorides can help reduce tooth decay. Fluorides are deposited as new tooth material is formed, making it strong and resistant to decay.

Some cities add fluorides to their water supply. By doing so, they hope to improve the dental health of everyone living in the city. Young people, whose teeth are still developing, benefit the most. The process of adding fluorides to public water supplies is called fluoridation. Too much fluorine in the water leads to a light brown and permanent staining of teeth.

Some people worry about the long-term health effect of fluorides added to public water supplies. They point out that fluorine is a deadly poison and that fluorides can be toxic as well. It is true that fluorine gas is very toxic, but the properties of compounds are different from the elements involved. Little evidence exists to support these concerns.

Many toothpastes contain fluoride, which helps to prevent tooth decay. However, some people worry about the long-term effects of fluoride in toothpastes as well as in the water supply. IMAGE COPYRIGHT 2009, MAU HORNG. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Fluorides tend to be dangerous only in large doses. The amount of fluoride added to public water supplies is usually very small, only a few parts per million. Most dental and health experts believe that fluoridation is a helpful public health practice, not a threat to the health of individuals.

Chlorofluorocarbons (CFCs) At one time, another major use of fluorine was in the production of CFCs. CFCs were discovered in the late 1920s by American chemical engineer Thomas Midgley Jr. (1889–1944). These compounds have a number of interesting properties. They are very stable and do not break down when used in a variety of industrial operations. They were widely used in cooling and refrigeration systems, as cleaning agents, in aerosol sprays, and in specialized polymers. The production of CFCs grew from about 1 million kilograms in 1935 to more than 300 million kilograms in 1965 to more than 700 million kilograms in 1985.

By the mid-1980s, however, evidence showed that the compounds were damaging Earth's ozone layer. This layer lies at an altitude of 12 to 30 miles (20 to 50 kilometers) above Earth's surface. It is important to life because it shields Earth from the sun's harmful ultraviolet radiation. As a result, CFCs were phased out. The compounds are no longer produced

Accidents Happen!

Serendipity plays a big part in scientific research. The term serendipity means a discovery made by accident. One of the most profitable discoveries made this way is the material Teflon. The name Teflon is the trade name of a type of plastic made by the DuPont Chemical Company. It has become an important commercial product for one main reason: very few things stick to Teflon. Most kitchen cupboards probably contain skillets and other pans with cooking surfaces covered with Teflon. Most food will not stick to Teflon-covered pans as it cooks. And foods cooked in Teflon pans need no oil or butter.

Teflon was discovered by accident in 1938 by a DuPont chemist named Roy Plunkett (1911–1994). Plunkett was working on the development of chlorofluorocarbons (CFCs) for DuPont. He wanted to see what happened when one compound, tetrafluoroethylene, or TFE (C_2F_4), was mixed with hydrochloric acid (HCl). To carry out the experiment, he set up the equipment so that the gaseous TFE would flow into a container of HCl.

When he opened the valve on the TFE container, however, nothing came out. Plunkett could have discarded the tank, but he did not. Instead, he sawed open the container. Inside he found that the TFE had polymerized into a single mass. Polymerization is the process by which many thousands of individual TFE molecules join together to make one very large molecule. The large molecule is called polytetrafluorethylene, or PTFE.

Plunkett scraped the white PTFE powder out and sent it to DuPont scientists working on artificial fibers. The scientists studied the properties of PTFE. They discovered its non-stick qualities and were soon working on a number of applications for the new material.

DuPont registered the Teflon trademark in 1945 and released its first Teflon products a year later. Since then the non-stick coating has become a household staple on kitchen cookware, in baking sprays, and as a stain repellant for fabrics and textiles.

or used in the United States and most other parts of the world. Safer substitutes are now being used in the products that once used CFCs.

People are often confused about CFCs. They were popular industrial chemicals because they do not break down very easily. They were long used in most car air conditioners as a heat transfer fluid. CFCs took heat out of the car and moved it into the outside air. This process was carried out over and over again. CFCs in a car's system lasted a very long time.

But eventually scientists realized the threat that CFCs posed to the ozone layer *because* they break down. How can that be?

CFCs were once used in aerosol cans. But researchers discovered that CFCs were damaging Earth's ozone layer. As a result, CFCs have been replaced by more environmentally friendly substitutes. IMAGE COPYRIGHT 2009, MIKAEL DAMKIER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

There is always a little leakage from auto air conditioning units and from every device in which CFCs are used. CFCs are gases or liquids that easily vaporize and float upward into the atmosphere, eventually reaching the ozone layer. At this height above Earth's surface, CFCs encounter intense radiation from the sun and break apart. A molecule that was stable near Earth's surface has now become *un*stable.

When a CFC molecule breaks apart, it forms a single chlorine atom:

$$\textbf{CFC} \xrightarrow{\textbf{sunlight}} \textbf{CFC* + Cl}$$

(The CFC* indicates a CFC molecule without one chlorine atom.) The chlorine formed in this reaction can react with an ozone (O_3) molecule:

$$Cl + O_3 \rightarrow ClO + O_2$$

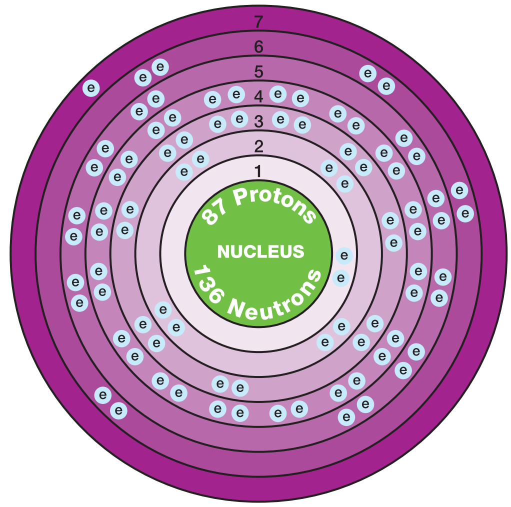
Here's the problem: The ozone (O_3) will filter out harmful radiation from the sun. It removes most of the radiation that causes severe sunburns and skin cancer. But oxygen (O_2) cannot do the same thing. Therefore, (1) the more CFCs in the atmosphere, the more chlorine atoms; (2) the more chlorine atoms, the fewer ozone molecules; (3) the fewer ozone molecules, the more harmful radiation reaching Earth's surface; and (4) the more harmful radiation, the more cases of skin cancer and other health problems.

It is this series of events that convinced most nations to ban the further production and use of CFCs.

Health Effects

As noted under "Discovery and Naming," fluorine can be quite dangerous. If inhaled in small amounts, it causes severe irritation to the respiratory system (nose, throat, and lungs). In larger amounts, it can cause death. The highest recommended exposure to fluorine is one part per million of air over an eight-hour period.

Francium



Overview

Francium is an alkali metal, a member of Group 1 (IA) in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other.

Francium may be the rarest element found on Earth's surface. Some experts believe that no more than 15 grams (less than an ounce) of the element exist in Earth's crust. The element was discovered in 1939 by French chemist Marguerite Perey (1909–1975). All isotopes of francium are radioactive.

Key Facts

Symbol: Fr

Atomic Number: 87

Atomic Mass: [223]

Family: Group 1 (IA); alkali metal

Pronunciation: FRAN-see-um

Discovery and Naming

Francium was one of the last naturally occurring elements to be discovered. Chemists had been searching for it since the development of the periodic table.

In the early 1900s, nearly all boxes on the periodic table had been filled. One element had been found to fit into each box. By the 1930s, only three remained empty—elements with atomic numbers of 43, 85, and 87.

WORDS TO KNOW

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Particle accelerator ("atom smasher"): A machine used to get small particles, like protons, moving very rapidly.

Periodic table: A chart that shows how chemical elements are related to each other.

Radiation: Energy transmitted in the form of electromagnetic waves or subatomic particles.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

The search for the three remaining elements produced a number of incorrect results. For example, American chemist Fred Allison (1882–1974) announced the discovery of elements 85 and 87 in 1931. He suggested the names of alabamine and virginium, in honor of the states in which he was born (Virginia) and worked (Alabama). But other scientists were not able to confirm Allison's discoveries.

Element 87 was isolated by Marguerite Perey, who was studying the radioactive decay of the element **actinium**. Radioactive elements like actinium break apart spontaneously, giving off energy and particles. This process results in the formation of new elements.

Perey found that 99 percent of all actinium atoms decay into **thorium**. The remaining 1 percent breaks down into a new element, number 87.

Perey's Legacy Marguerite Perey made important discoveries during an era when few women held prominent roles in the sciences. She was interested in science even as a small child. However, her father died early on, and there was no money for Perey to attend a university. Instead, she found a job at the Radium Institute in Paris. The Radium Institute had been founded by Marie Curie (1867–1934) and her husband, Pierre Curie (1859–1906), to study radioactive materials.

Perey was originally hired for a three-month period. But Madame Curie was very impressed with Perey's skills in the laboratory. Perey eventually ended up working at the Radium Institute until 1935.

One of the projects Perey worked on was the radioactive decay of actinium. When actinium decays, it gives off radiation and changes into another element, thorium. Thorium, in turn, also gives off radiation and changes into another element, **radium**. This process is repeated a number of times. In each step, a radioactive element decays to form another element.

As Perey studied this series of reactions, she made an interesting discovery. The mixture of elements that are formed in these reactions contained a substance she did not recognize. She decided to find out what that substance was. She was eventually able to show that it was a new element, with atomic number 87. The element was one of the last naturally occurring elements to be discovered. Perey named the element in honor of her native land, France.

Perey was the first woman ever elected to the French Academy of Science. Even Marie Curie had not earned that honor. Perey died in 1975 after a 15-year battle with cancer.

French physicist Marguerite Perey. AIP/PHOTO RESEARCHERS, INC.

Physical and Chemical Properties

Until very recently, there was not enough francium to permit a study of its properties. In 1991, scientists at the State University of New York at Stony Brook developed a method for making small amounts of francium and holding them in a "laser trap" for up to 30 seconds. A laser trap is made by focusing a number of laser beams at a bunch of atoms, holding them motionless so that they can be studied. This research confirmed the fact that francium is similar to the other alkali metals above it on the periodic table. The alkali metals are the elements in Group 1. Francium's melting point has been determined to be 81°F (27°C), and its boiling point is estimated to be about 1,250°F (677°C).

Occurrence in Nature

Francium is now produced in particle accelerators, which are also called atom smashers. These machines accelerate small particles, like protons, to nearly the speed of light, 186,000 miles per second (300,000 kilometers per second). The particles collide with target atoms, such as **copper**, **gold**, or **tin**. Target atoms fragment, forming new elements and particles.

Isotopes

Forty-one isotopes of francium have been produced artificially. The most stable is francium-223. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Francium-223 has a half life of 21.8 minutes. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. That means that 100 grams of francium-223 will break down so that only 50 grams are left after 21.8 minutes. Another 21.8 minutes later, 25 grams of francium-223 will remain, and so on.

Extraction

Francium is not extracted from Earth's crust.

Uses

Francium has no uses because of its rarity. Scientists hope to learn about the composition of matter by studying the element, however.

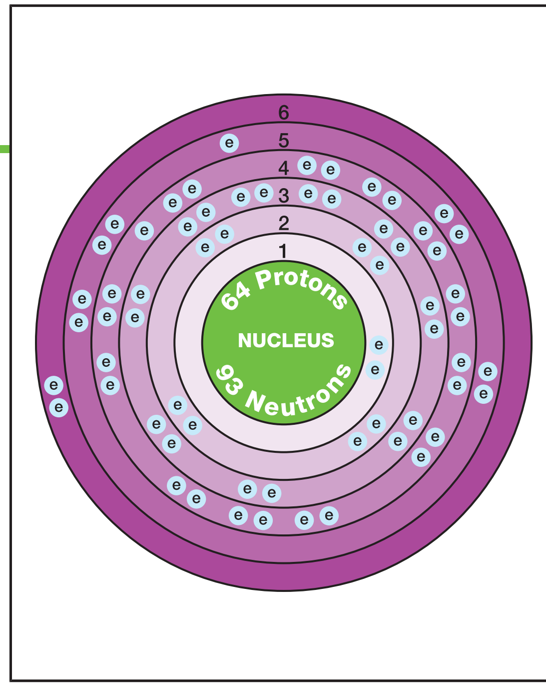
Compounds

There are no commercially important compounds of francium.

Health Effects

Scientists know too little about francium to be aware of its health effects. As a radioactive element, however, it does pose a threat to human health.

Gadolinium



Key Facts

Symbol: Gd

Atomic Number: 64

Atomic Mass: 157.25

Family: Lanthanoid (rare earth metal)

Pronunciation: gad-uh-LIN-ee-um

Overview

Gadolinium was named for Finnish chemist Johan Gadolin (1760–1852). Gadolin served for many years as professor of chemistry at the University of Åbo in Finland. He was the first person to study an unusual black stone discovered near the town of Ytterby, Sweden, in 1787. The stone was an unusually important discovery. Chemists isolated nine new elements from the stone, one of which was gadolinium.

Gadolinium is in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. It is one of the rare earth elements. They really aren't rare, but they *were* difficult to separate. For this reason, scientists know less about the rare earth elements than they do about most other elements. The rare earth metals are also called lanthanoids. That name comes from element 57, **lanthanum**.

Discovery and Naming

Two unusual rocks were discovered in Sweden near the end of the 18th century. The rocks were unusual because they both contained a complex mixture of substances. Chemists worked for nearly a century to separate

WORDS TO KNOW

Ductile: Capable of being drawn into a thin wire.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Malleable: Capable of being hammered into thin sheets.

Neutron radiography: A technique that uses neutrons to study the internal composition of material.

Nuclear fission: The process in which large atoms break apart, releasing large amounts of energy, smaller atoms, and neutrons in the process.

Periodic table: A chart that shows how the chemical elements are related to each other.

Phosphor: A material that gives off light when struck by electrons.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

the mixtures and find out what they were. The 15 rare earth elements were first discovered in the two Swedish rocks.

One rock contained a mineral that had never been seen before, cerite. Cerite was first discovered in 1803. The last new element found in cerite was not identified until almost a century later, in 1901. In 1880, French chemist Jean-Charles-Galissard de Marignac (1817–1894) was studying a new material found in cerite called samaria. Earlier chemists had identified samaria as a new element.

Marignac found that samaria was not a pure element. Instead, it consisted of two parts, which he called samaria and gadolinia. He believed each was a new element. He was right about gadolinia, but wrong about samaria.

Physical Properties

Gadolinium has a shiny metallic luster with a slight yellowish tint. It is both ductile and malleable. Ductile means capable of being made into wires. Malleable means capable of being hammered or rolled into thin sheets. It has a melting point of 2,394°F (1,312°C) and a boiling point of about 5,400°F (3,000°C). Its density is 7.87 grams per cubic centimeter.

Few elements are as strongly magnetic as gadolinium. It also has the highest neutron-absorbing ability of any element. A piece of gadolinium stops neutrons better than any other element.

What's in a Name?

Books on the chemical elements sometimes talk about gadolin*ium* and gadolin*ia*; about erb*ium* and sometimes erb*ia*; sometimes about samar*ium* and sometimes samar*ia.* Is the *-ium* ending any different from the *-ia* ending?

The answer is yes. Almost all metal names end in *-ium* or just *-um*, like sod*ium*, potass*ium*, magnes*ium*, alumin*um*, and gadolin*ium*. The ending *-ia* or just *-a*, on the other hand, stands for the form in which an element occurs in the earth. When miners take gadolinium out of the earth, it is called *gadolinia.*

The natural form of the element is often called an "earth." Gadolinium is the element that comes from the earth, gadolinia.

Earths are compounds of the element and one or more other element. Two common combining elements are oxygen and sulfur. For example, gadolinia contains gadolinium oxide (Gd_2O_3).

These terms can be confusing when reading the history of chemical elements. Many elements were first discovered not in their pure form, but as compounds—as earths.

Chemical Properties

Gadolinium metal is not especially reactive. It dissolves in acids and reacts slowly with cold water. It also reacts with oxygen at high temperatures.

Occurrence in Nature

The abundance of gadolinium in Earth's surface is estimated at about 4.5 to 6.4 parts per million. That would make it one of the most abundant of the rare earth elements. It ranks above **bromine** and **uranium**, but just below **lead** and **boron** in order of abundance. Some minerals in which it occurs are monazite, bastnasite, samarskite, gadolinite, and xenotime.

Isotopes

Seven naturally occurring isotopes of gadolinium are known. They are gadolinium-152, gadolinium-154, gadolinium-155, gadolinium-156, gadolinium-157, gadolinium-158, and gadolinium-160. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. One of gadolinium's naturally occurring isotopes is radioactive, gadolinium-152. A radioactive isotope is one that breaks apart and gives off some form of radiation.

Radioactive isotopes can also be produced artificially when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. Twenty-four artificial radioactive isotopes have been produced. Some of these are used in medicine. For example, gadolinium-153 is used to study the composition of bones. The radiation it gives off acts like X rays, penetrating the bones to reveal the minerals present.

Gadolinium is also used in another X-ray-like technique called neutron radiography. In this technique, neutrons are fired through a sample of material. The neutrons act somewhat like X rays. They show the structure of the material. Adding gadolinium to the back side of the material makes the neutron image easier to read. Neutron radiography is especially useful because one can look for damage inside a piece of metal without having to take the material apart.

Extraction

The method for obtaining gadolinium from its ores is similar to that for other rare earth elements. The ore is converted into gadolinium chloride ($GdCl_3$) or gadolinium fluoride (GdF_3). Passing an electric current through the first compound releases pure gadolinium:

$$2GdCl_3 \xrightarrow{\text{electric current}} 2Gd + 3Cl_2$$

Adding calcium to the second compound also releases pure gadolinium:

$$3Ca + 2GdF_3 \rightarrow 3CaF_2 + 2Gd$$

Uses and Compounds

Gadolinium is used in control rods in nuclear power plants. Energy produced during nuclear fission is used to generate electricity. Nuclear fission is the process in which large atoms (usually uranium or **plutonium**) break apart, releasing energy. The smaller atoms produced are called fission products and are radioactive.

Neutrons are also produced in the reaction. In order for a nuclear power plant to work properly, the number of neutrons must be carefully

Special gadolinium minerals called yttrium garnets are used in microwave ovens. IMAGE COPYRIGHT 2009, TEREKHOV IGOR. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

controlled. Rods containing gadolinium are raised out of or lowered into the reactor. This allows more or fewer neutrons to remain in the reaction.

Gadolinium also has medical uses. It is used to locate the presence of tumors in the inner ear. Gadolinium is injected into the bloodstream. It then goes to any tumor that happens to be present in the ear. The tumor appears darker when seen with X rays.

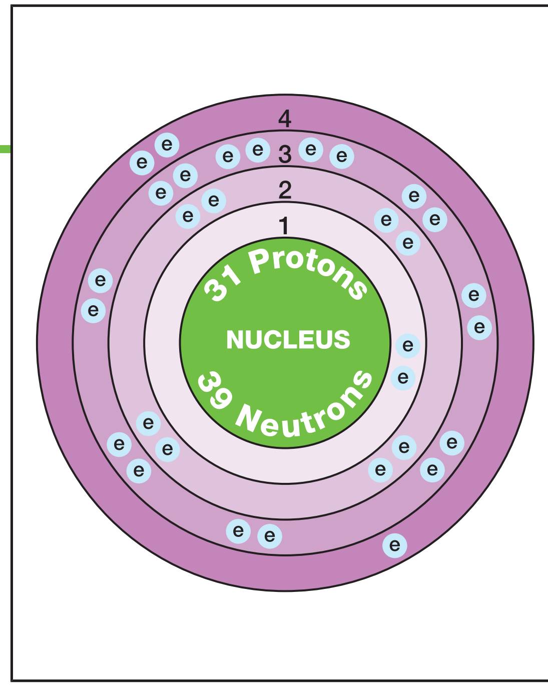
Gadolinium compounds are used as phosphors in television tubes. A phosphor is a material that shines when struck by electrons. The color of the phosphor depends on the elements of which it is made.

Gadolinium is also found in alloys and special minerals known as **yttrium** garnets. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Gadolinium alloys are easier to work with than alloys without gadolinium. Gadolinium yttrium garnets are used in microwave ovens to produce the microwaves.

Health Effects

Not many details of the health effects of gadolinium are known. It is usually handled as if it were very toxic.

Gallium



Key Facts

Symbol: Ga

Atomic Number: 31

Atomic Mass: 69.723

Family: Group 13 (IIIA); aluminum

Pronunciation: GA-le-um

Overview

In the late 1860s Russian chemist Dmitri Mendeleev (1834–1907) made one of the greatest discoveries in modern chemistry: the periodic law. The periodic law describes how chemical elements are related to each other. The periodic law is often depicted in the form of the periodic table. The periodic table is a chart that lists all of the chemical elements and sorts them into groups based on similarities. Elements in vertical columns are similar to each other in many ways.

When Mendeleev first proposed the periodic law, he made a troubling discovery. There were a few empty spots in his table. For example, the box set aside for element number 31 was empty. No element had been found that belonged in that box.

Part of Mendeleev's genius was what he did next. He said that an "element number 31" did exist. Scientists simply had not found it yet. Mendeleev then described what the element would be like. He based his prediction on elements on all sides of the box for element number 31. He said it would be similar to **aluminum** (in box 13, above 31) and **indium** (in box 49, below 31). He named this missing element eka-aluminum.

WORDS TO KNOW

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Semiconductor: A material that conducts an electrical current.

Spectra: The lines produced when chemical elements are heated.

Transistor: A device used to control the flow of electricity in a circuit.

Using Mendeleev's periodic law, the element was soon found. It was discovered by French chemist Paul-émile Lecoq de Boisbaudran in 1875.

Until recently, gallium had few applications. Then, some of its compounds were discovered to have unusual properties when exposed to light. These properties make gallium an important and essential element in many electronic devices.

Discovery and Naming

Lecoq de Boisbaudran did not discover gallium by accident. For 15 years, he had studied the spectra of the chemical elements. Spectra (singular: spectrum) are the lines produced when chemical elements are heated. Each element produces its own distinctive set of lines, or spectra. An element can be identified in a sample by the spectrum it produces.

Lecoq de Boisbaudran knew that the element between aluminum and indium was missing. He also knew about Mendeleev's prediction. Lecoq de Boisbaudran wanted to learn more about the spectra of elements. He thought that element number 31 might be found in **zinc** ores. Zinc has an atomic number of 30, so it is next to gallium on the periodic table.

Lecoq de Boisbaudran had to work through a large amount of zinc ore. But his hunch turned out to be correct. The missing element was present in the ore, but only in very small amounts. Finally, in August 1875, Lecoq de Boisbaudran reported that "the new substance gave under the action of the electric spark a spectrum composed chiefly of a violet ray, narrow, readily visible, and [located at] about 417 on the scale of wave lengths."

Later in the same year, Lecoq de Boisbaudran isolated gallium metal. He was given several tons of zinc ore by miners for his research. Out of this ore, he was able to produce a few grams of nearly pure gallium.

Lecoq de Boisbaudran proposed the name gallium for the new element. The name was given in honor of the ancient name for France, Gallia.

Physical Properties

Gallium is a soft, silvery metal with a shiny surface. In some ways, however, it is very un-metal-like. It is so soft that it can be cut with a knife. It has a very low melting point of only 85.5°F (29.7°C). A sample of gallium will melt if held in the human hand (body temperature, about 98.6°F/37°C).

Another unusual property is that gallium can be supercooled rather easily. Supercooling is the cooling of a substance below its freezing point without it becoming a solid. Gallium is a liquid at 86°F (30°C), so one would expect it to become a solid at 85.5°F (29.7°C). Instead it is fairly easy to cool gallium to below 85.5°F (29.7°C) without having it solidify.

Gallium melts when held in one's hand. © RUSS LAPPA/SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Gallium's boiling point is about 4,400°F (2,400°C) and its density is 5.9037 grams per cubic centimeter, almost six times the density of water.

Chemical Properties

Gallium is a fairly reactive element. It combines with most metals at high temperatures, and it reacts with both acids and alkalis. An alkali is a chemical with properties opposite those of an acid. Sodium hydroxide (common lye) is an example of an alkali.

Occurrence in Nature

Gallium is a moderately abundant element in Earth's crust. Its abundance is estimated to be about 5 parts per million. It is found primarily in combination with zinc and aluminum ores. It is also found in germanite, an ore of **copper** sulfide (CuS).

As of 2008, the largest producers of gallium were China, Germany, Kazakhstan, and Ukraine. According to the U.S. Geological Survey (USGS), leaders in refined gallium production included China, Japan, and the United States.

Isotopes

Two naturally occurring isotopes of gallium are known: gallium-69 and gallium-71. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-four radioactive isotopes of gallium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of gallium, gallium-67, has long been used in medicine. This isotope has a tendency to seek out cancer cells in the body. Its presence in a cell can be detected by the radiation it gives off. By giving a patient a dose of gallium-67, a doctor can determine whether the patient has cancer. Gallium-67 has been used to look for cancer in the liver, spleen, bowels, breasts, thymus, kidneys, and bones.

Extraction

Pure gallium metal can be prepared by passing an electric current through a gallium compound, such as gallium oxide (Ga_2O_3):

$$2Ga_2O_3 \xrightarrow{\text{electric current}} 4Ga + 3O_2$$

Uses and Compounds

About 95 percent of all gallium produced is used to make a single compound, gallium arsenide (GaAs). Gallium arsenide has the ability to convert an electrical current directly into light. The lighted numbers on hand-held calculators, for example, are produced by a device known as a light-emitting diode (LED). Gallium arsenide is used to make LEDs.

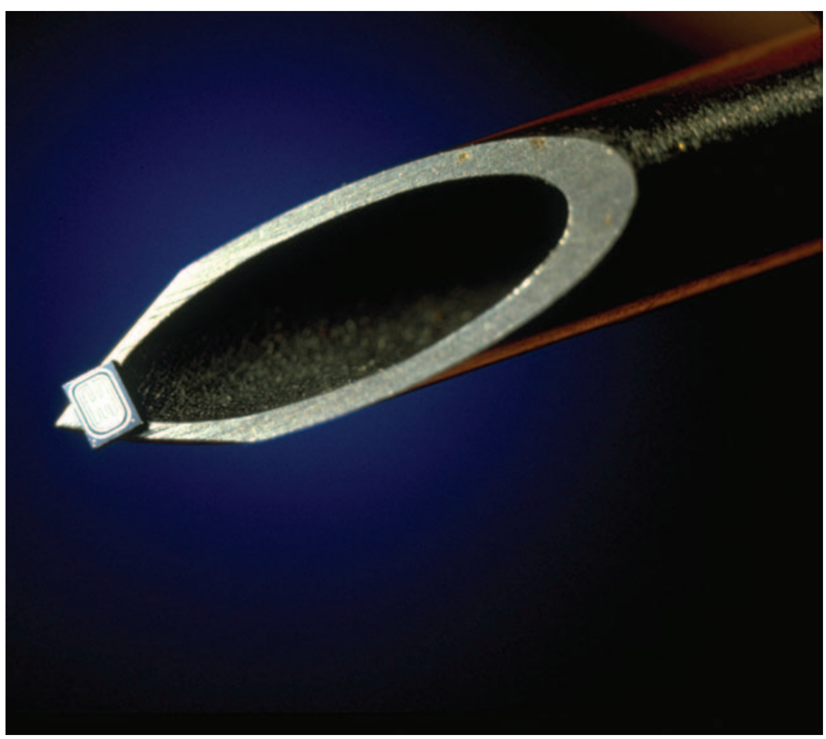
Close-up view of LED numerical display on a digital scale. Gallium arsenide is used to make LEDs. IMAGE COPYRIGHT 2009, BALONCICI. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

An LED allows an electric current to flow in one side, but not the other. When it flows into a piece of gallium arsenide, a flash of light is produced. When a button is pushed on a calculator, a circuit is closed. The electric current flows into an LED and produces a light.

Similar devices are used in making lasers. An electric current passes into a piece of gallium arsenide. The current produces an intense beam of laser light. A laser is a device for producing very bright light of a single color. Gallium arsenide lasers are used in a number of applications. The laser that operates a compact disc (CD) player, for example, may contain a piece of gallium arsenide.

Gallium arsenide is also used to make transistors. A transistor is a device used to control the flow of electricity in a circuit. Gallium arsenide has many of the properties of a semiconductor. A semiconductor is a material that conducts an electrical current, but not as well as a metal, such as **silver** or copper.

Gallium arsenide has one big advantage over **silicon**, another element used in transistors. Gallium arsenide produces less heat. Therefore,



Gallium arsenide is used in the production of transistors.
© MICHAEL ABBEY. SCIENCE SOURCE, THE NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

more transistors can work together at the same time to produce a higher computing capacity.

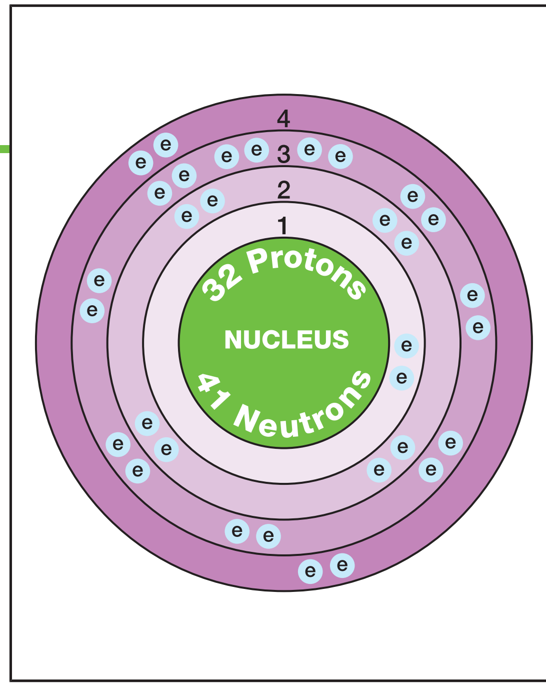
Gallium arsenide is also used in photovoltaic cells. These devices turn sunlight into electricity. Many people believe that photovoltaic cells will someday replace coal-fired generating and nuclear power plants as the major source of electricity.

Large amounts of gallium have also been used to study radiation given off by the sun. In experiments conducted at the National Laboratory at Gran Sasso, Italy, containers holding more than 33 short tons (30 metric tons) of gallium were used to detect and measure various types of radiation originating from the sun. These experiments were conducted from 1991 to 1997 and from 1998 to 2002.

Health Effects

Gallium and its compounds are somewhat hazardous to the health of humans and animals. They produce a metallic taste in the mouth, skin rash, and a decrease in the production of blood cells. Gallium and its compounds should be handled with caution.

Germanium



Overview

Germanium is a metalloid. A metalloid is an element that has characteristics of both metals and non-metals. Germanium is located in the middle of the **carbon** family, which is Group 14 (IVA) in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Carbon and **silicon** are above germanium and **tin** and **lead** are below it.

The existence of germanium was predicted by Russian chemist Dmitri Mendeleev (1834–1907), who developed the periodic table. Mendeleev predicted a new element would be found to fill an empty spot on the table. He was proved correct in 1886.

Until the 1950s, there were no important uses for germanium. Then, the transistor was invented. A transistor is a device used to control the flow of electricity in a circuit. Today, germanium is used in making a number of electronic devices, including the transistor.

Key Facts

Symbol: Ge

Atomic Number: 32

Atomic Mass: 72.64

Family: Group 14 (IVA); carbon

Pronunciation: jur-MAY-nee-um

Discovery and Naming

In the 1860s, Mendeleev wondered if the chemical elements could be arranged in any systematic way. Are all chemical elements very different from each other, he asked. Do they have certain common properties?

WORDS TO KNOW

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Doping: Containing a small amount of a material as an impurity.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Metalloid: An element that has characteristics of both metals and non-metals.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Semiconductor: A material that conducts an electric current, but not nearly as well as metals.

Transistor: A device used to control the flow of electricity in a circuit.

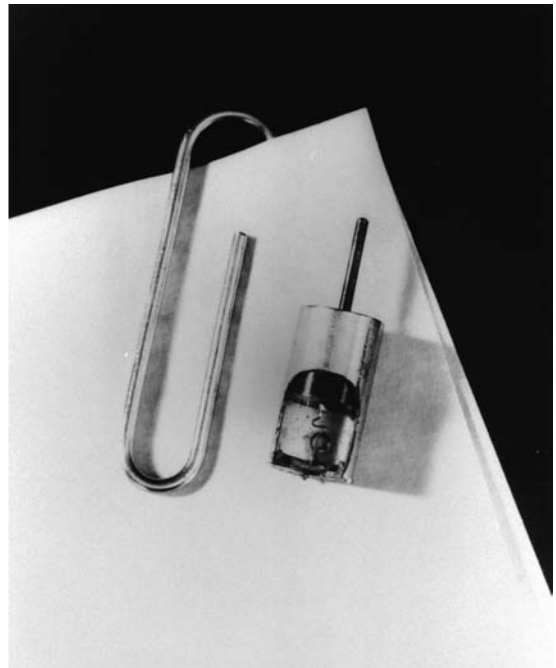
He explored a number of ways of arranging the elements. Finally, he decided to arrange them according to their atomic weights. He found that doing so resulted in a pattern. After awhile, each element could be placed in a position beneath one or more elements before it. Mendeleev described his result in the periodic law. The periodic table is the most common way of illustrating the periodic law. Elements that are similar to each other fall into the same group. For example, the elements in Group 1 (IA) are like each other in many ways.

Mendeleev found that his periodic table made sense, however, only if he left some blank spaces in it. His table had a blank space for element number 32. No element was known to exist at that time that had properties like silicon (number 14) and could be put beneath it in the periodic table.

This finding did not disturb Mendeleev. Element number 32 simply had not been discovered yet, he said.

A number of chemists took up Mendeleev's challenge. In 1885, a new ore was discovered in a mine near Freiberg, Germany. **Silver** and **sulfur** were found in the ore, but about 7 percent of the ore could not be identified. The ore was sent to German chemist Clemens Alexander Winkler (1838–1904). At the time, Winkler was professor of chemical technology and analytical chemistry at the Freiberg School of Mines. He was convinced that the new ore contained a new element. He isolated the new element from the ore and named it germanium, in honor of Winkler's native country, Germany.

Winkler discovered that the properties of germanium were very similar to those that Mendeleev had predicted 15 years earlier. For example, he thought element 32 would have a density of 5.5 grams per cubic centimeter. The actual density for germanium is 5.47 grams per cubic centimeter. Mendeleev had based his predictions on the new element's place in the periodic table. His success in making these predictions gave chemists a great deal of confidence in the periodic table. They came to see how useful it could be in their research.



Germanium is used in the production of transistors. This transistor was made in the 1950s. LIBRARY OF CONGRESS.

Physical Properties

Germanium looks like a metal. It has a bright, shiny, silvery color. But it is brittle and breaks apart rather easily, which metals normally do not do. It has a melting point of 1,719°F (937.4°C) and a boiling point of 5,130°F (2,830°C). It conducts an electric current poorly. Substances of this kind are called semiconductors, which conduct an electric current, but not nearly as well as metals like silver, **copper**, and **aluminum**.

The ability of semiconductors to conduct electricity depends greatly on the presence of small amounts of impurities. The addition of an impurity to a semiconductor is called doping. Doping a semiconductor has significant effects on its ability to conduct an electric current.

Chemical Properties

Germanium is a relatively inactive element. It does not react with **oxygen** at room temperature. It does dissolve in hot acids and with oxygen at high temperatures, however. It becomes more active when finely divided. It will combine with **chlorine** and **bromine** to form germanium chloride ($GeCl_4$) and germanium bromide ($GeBr_4$). For example:

$$\textbf{Ge (finely divided)} + 2Cl_2 \xrightarrow{\text{high temperature}} GeCl_4$$

Occurrence in Nature

The abundance of germanium in Earth's crust is estimated to be about 7 parts per million. That places it in the bottom third of the elements arranged according to their abundance.

The two most common minerals of germanium are argyrodite and germanite. Argyrodite is the mineral in which Winkler first discovered germanium. Germanite contains about 8 percent germanium.

Most germanium today is obtained from **zinc** ores. When those ores are treated to obtain zinc metal, some germanium is produced at the same time.

In 2008, germanium from zinc ores was obtained from several mines in the United States: one mine in Alaska, one in Washington state, and another in Tennessee. According to the U.S. Geological Survey (USGS), germanium refineries were in operation in New York and Oklahoma. The United States also imports germanium from Belgium, Canada, China, Germany, and a few other nations.

Isotopes

There are five naturally occurring isotopes of germanium: germanium-70, germanium-72, germanium-73, germanium-74, and germanium-76. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-five radioactive isotopes of germanium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of germanium has any important commercial use.

Extraction

Germanium in zinc ores is heated in the presence of chlorine gas. Germanium chloride ($GeCl_4$) is formed:

$$\textbf{Ge (in ores)} + 2Cl_2 \quad \text{heat}\rightarrow GeCl_4$$

Pure germanium metal is then produced by passing an electric current through molten (melted) germanium chloride:

$$GeCl_4 \xrightarrow{\text{electric current}} Ge + 2Cl_2$$

This method produces very pure germanium. It is possible to buy germanium that is 99.9999 percent pure. This level of purity is needed in order to use the metal in the production of semiconductors.

Uses

Germanium first became important for its use in semiconductors. This application still accounts for about 15 percent of the germanium produced. But other uses of the element are now more important. About 50 percent of the germanium produced in the United States is now used in the manufacture of infrared optics and another 30 percent in fiber optic systems.

An optical fiber is a very thin thread made out of pure glass. The fiber acts somewhat like a copper wire. It can carry messages in the same way a copper wire carries messages. The difference is that optical fibers carry messages on light waves. Copper wires carry messages on electric currents.

The ability of a glass thread to carry light depends on the presence of impurities. Optical fibers are doped with germanium and other elements to improve their ability to carry light messages. Optical fibers are used to carry telephone messages instead of electric wires.

Germanium is also used as a catalyst. A catalyst is used to speed up a chemical reaction. The catalyst does not undergo any chemical change during the reaction. Germanium catalysts are used primarily in the production of plastics.

Germanium is also used to make specialized glass for military applications. For example, it is used to make weapons-sighting systems that can be used in the dark as well as other night

Germanium is used in night vision equipment. Here, a man wearing a gas mask becomes visible at night to others who are using night vision technology.

vision technology. Satellite systems and fire alarm systems may also contain glass that contains germanium.

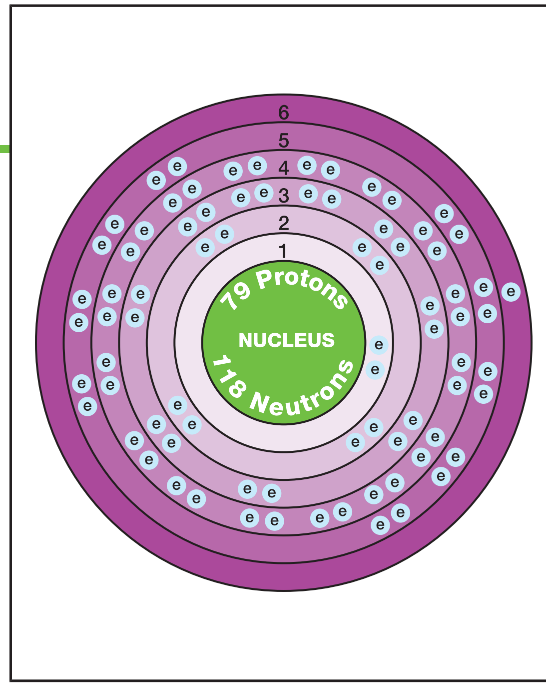
Compounds

Few germanium compounds have any important commercial uses.

Health Effects

Germanium is not thought to be essential to the health of plants or animals. Some of its compounds present a hazard to human health, however. For example, germanium chloride and germanium fluoride (GeF_4) are a liquid and gas, respectively, that can be very irritating to the eyes, skin, lungs, and throat.

Gold



Key Facts

Symbol: Au

Atomic Number: 79

Atomic Mass: 196.966569

Family: Group 11 (IB); transition metal

Pronunciation: GOLD

Overview

Gold has been called the most beautiful of all chemical elements. Its beauty has made it desirable for use in jewelry, coins, and artwork for thousands of years. It was one of the first pure metals to be used by humans.

Gold is one of the few elements that can affect politics and economics. Wars have been fought over access to gold. Cities and towns have sprung up and died out as gold was discovered and then mined out. Many nations still count their wealth according to the amount of gold they keep in storage.

Gold lies in the middle of the periodic table. The periodic table is a chart that shows how elements are related to one another. Gold is a heavy metal in a group known as the transition metals. Gold is also known as a precious metal (as are **platinum** and **silver**).

Large amounts of gold are still used in the manufacture of coins, medals, jewelry, and art. Gold also has a number of uses in industry, medicine, and other applications. For example, one radioactive isotope of gold is commonly used to treat cancer.

The chemical symbol for gold is Au. The symbol comes from the Latin word for gold, *aurum.* Aurum means "shining dawn."

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Amalgam: A mixture of two or more metals, one of which is mercury.

Carat: A unit of weight for gold and other precious metals, equal to one fifth of a gram, or 200 milligrams.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

Gold objects dating to 2600 BCE have been found. They were discovered in the royal tombs of the ancient civilization of Ur, located in the modern country of Iraq. These objects showed that humans had already learned how to work with gold this early in history. Some of the gold, for example, had been formed into wires.

One of the special skills developed by the Egyptians was adding gold to glass objects. They found a way to use gold to make glass a beautiful ruby-red color. The glass became known as gold ruby glass.

Gold is also mentioned in a number of places in the Bible. A passage in Exodus, for example, refers to the clothing worn by Aaron: “And they did beat the gold into thin plates, and cut it into wires, to work it in the blue, and in the purple, and in the scarlet, and in the fine linen, with cunning work.”

Writings from every stage of human history tell of the discovery and use of gold. Roman historian Pliny the Elder (23–79 CE), for example, describes gold-mining locations. The Romans found gold lying in stream beds in the Tagus River in Spain, the Po River in Italy, the Hebrus River in Thracia (now Greece), the Pactolus River in Asia Minor (now Turkey), and the Ganges River in India.

Gold has long been known in the New World, too. During a visit to Haiti, Christopher Columbus (1451–1506) found gold nuggets lying on the bottom of rivers and harbors. A Portuguese explorer in 1586,

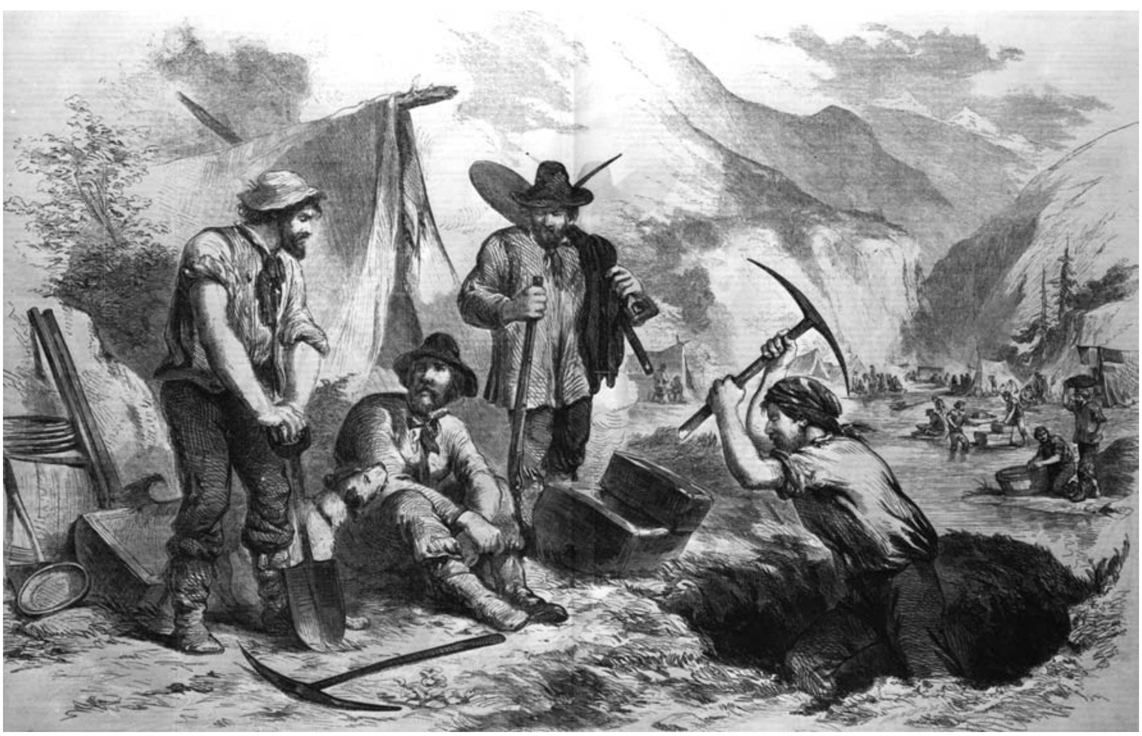
The coffin of Egyptian Pharaoh Tutankhamun (1358–1340 BCE) is inlaid with gold and other materials. AP IMAGES/ MUSEUM OF ANTIQUITIES BASEL, VOEGELIN.

Lopez Vaz, wrote that the region called Veragua (now Panama) was the "richest Land of Gold [in] all the rest of the Indies."

The Gold Rush As early as the 16th century, records contained stories about a great El Dorado ("the gilded one," in Spanish; gilded means "covered in gold") on the western coast of the United States. Tales of this magical city were repeated for centuries.

In the late 1840s, explorers began to travel from the Eastern seaboard to California in search of El Dorado. The flow of visitors was slow at first. Then, gold was first discovered in 1848 at a place called Sutter's Mill in California. Sutter's Mill is located near the present town of Coloma.

Word of the discovery spread quickly. Within a year, thousands of men and women made the long, expensive, and tiring trip. Many of them traveled across the United States in covered wagons or on horseback. Most had to cross mountains, plains, and deserts. Because of the difficult conditions, many people and animals got sick or died. Other people



Gold was discovered in California in January of 1848, prompting thousands to head West in a quest for fortune. By year's end, some $6 million in gold dust and nuggets had been retrieved. LIBRARY OF CONGRESS.

braved the seas and sailed to California, heading around Cape Horn at the bottom of South America or across the Isthmus of Panama. No matter which route was used, the journey usually took months.

As people arrived in California, hundreds of mining camps sprang up. Some of them had colorful names. Poker Flat, Hangtown, Red Dog, Hell's Delight, and Whiskey Bar were just a few! Mining for gold was hard work. Gold miners usually wound up being wildly successful or terrible failures. The Gold Rush completely changed the state of California. It also helped expand the United States.

Physical Properties

Gold is both ductile and malleable. Ductile means it can be drawn into thin wires. Malleable means capable of being hammered into thin sheets. A piece of gold weighing only 20 grams (slightly less than an ounce) can be hammered into a sheet that will cover more than 68 square feet (6 square meters). The sheet will be only one ten-thousandth of an inch (0.00025 centimeters) thick. Gold foil of this thickness is often used to make the lettering on window signs.

Gold is quite soft. It can usually be scratched by a penny. Its melting point is 1,948.57°F (1,064.76°C) and its boiling point is about 4,900°F (2,700°C). Its density is 19.3 grams per cubic centimeter, almost 20 times that of water.

Two other important properties of gold are its reflectivity and lack of electrical resistance. Both heat and light reflect off gold very well. But an electric current passes through gold very easily.

Chemical Properties

Generally speaking, gold is not very reactive. It does not combine with **oxygen** or dissolve in most acids. It does not react with halogens, such as **chlorine** or **bromine**, very easily.

These chemical properties also account for some important uses of gold. Gold coins, for example, do not corrode (rust) or tarnish very easily. Neither does jewelry or artwork made of gold.

Occurrence in Nature

Gold occurs in nature in both its native state and in compounds. The native state of an element is its free state. It is not combined with any

Pound for Pound: Measuring Gold

Which weighs more: A pound of feathers or a pound of gold? Teachers sometimes try to fool students with this old question. The answer would seem to be easy: a pound is a pound. A pound of feathers and a pound of gold should weigh the same amount.

In terms of weight, gold is weighed differently than most substances, which are measured using the avoirdupois (pronounced a-ver-de-POIZ) system. In the avoirdupois system, there are 16 ounces to the pound. But gold is weighed using the troy system. In the troy system, one pound contains only 12 ounces. So, a pound of feathers (avoirdupois system) weighs four ounces more than a pound of gold (troy system). The weight of other precious metals, like silver and platinum, are also measured using the troy system.

Gold is also weighed in carats. A carat is defined as one fifth of a gram, or 200 milligrams.

Gold is seldom used in a pure form. The metal is too soft. It would bend or break if used pure. Instead, it is used in combination with other metals called alloys. An alloy is a mixture of two or more metals. The mixture has properties different from those of the individual metals.

The amount of gold in an alloy is expressed in carats. Pure gold metal (mixed with no other metal) is said to be 24-carat gold. An alloy that contains 20 parts of gold and 4 parts of silver is 20-carat gold. The "20-carat" designation means the alloy contains 20 parts of gold and 4 parts of something else (silver, in this case).

Gold stored in a national bank can be 24-carat gold. It is never used for any practical purpose. But gold used for any real application is almost always less than 24 carats. It must include other metals that make it stronger and tougher.

other element. The most common compounds of gold are the tellurides. A telluride is a compound of the element **tellurium** and one or more other elements. For example, the mineral calavarite is mostly gold telluride ($AuTe_2$).

At one time, gold was found in chunks or nuggets large enough to see. People mined gold by picking it out of streams and rivers. In fact, gold was once very common in some parts of the world. People valued it not because it was rare, but because it was so beautiful.

The abundance of gold in Earth's crust is estimated to be about 0.005 parts per million. That makes it one of the 10 rarest elements in Earth's crust. Gold is thought to be much more common in the oceans. Some people believe as much as 70 million tons of gold are dissolved in seawater. They also think there may be another 10 billion tons on the bottom of the oceans. So far, however, no one has found a way to mine this gold.

As of 2008, the leading producers of the metal included China, South Africa, the United States, Australia, Peru, and Russia. According to the U.S. Geological Survey (USGS), the price of gold rose 29 percent between 2007 and 2008. In the United States, gold is mined primarily in western states, including Nevada, California, and Alaska.

Isotopes

There is only one naturally occurring isotope of gold: gold-197. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty-nine radioactive isotopes of gold are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of gold is widely used in medicine, gold-198. This isotope has two major uses. First, it can be used to study the liver. It is made into a form known as colloidal gold, which consists of very fine particles of gold mixed in a liquid solution. The colloidal gold is injected into the patient's body, where it travels to the liver. There, it can be detected because of the radiation it gives off. The radiation can be used to tell if the liver is functioning normally or not.

Colloidal gold is also used to treat medical problems. In some forms of cancer, the body develops large amounts of liquid in the space around the stomach and intestines (the peritoneum). Some doctors treat this collection of liquid by injecting colloidal gold into the peritoneum. It is not able to leave the peritoneum and go into the stomach and intestines. While in the peritoneum, the colloidal gold gives off radiation. The radiation kills cancer cells that cause the accumulation of fluid.

Extraction

There are at least two main ways to remove gold from its ores. One is to mix an ore with **mercury** metal. Mercury combines with gold in the ore to form an amalgam. An amalgam is a mixture of two or more metals, one of which is mercury. The gold amalgam is then removed from the ore. It is heated to drive off the mercury. Pure gold remains.

Gold ores can also be treated with potassium cyanide (KCN) or some other kind of cyanide. The gold combines with the cyanide to form a new compound, gold cyanate. The gold cyanate is then treated with an active metal, such as zinc. The active metal replaces gold in the compound, leaving pure gold.

Uses

The World Gold Council has estimated that about 140,000 short tons (about 125,000 metric tons) of gold has been mined throughout history. Of that amount, about 10 percent has been used for industrial, research, health, and other "dissipative" uses. Dissipative means that the gold was gone once it was used. It was made into devices that were eventually thrown away. The gold could not or was not recovered from the devices.

About a third of the gold has been made into gold bars held by national banks. The gold bars are used as security for national money systems. In the United States, for example, the nation's supply of gold is stored at Fort Knox in Kentucky.

Finally, the remaining gold is owned by private individuals. This gold exists in the form of jewelry, art, coins, or bullion. Gold bullion are bars or other large pieces of pure gold.

One of the most famous items using gold is the Olympic gold medal. Athletes from around the world dream of coming in first place at the Olympics. That means they can step up to the winner's podium and wear their gold medal proudly. But the gold medal isn't solid gold. It's actually made out of silver. A thin layer of gold covers the silver. The last time a solid gold medal was used in the Olympics was 1912. For the 2010 Olympic Games in Vancouver, British Columbia, Canada, 2.05 kilograms of gold, 1,950 kilograms of silver, and 903 kilograms of copper will be used in the medals.

Jewelry and art objects account for the largest single use of gold. In 2008, 80 percent of the gold used in the United States was for this purpose. The second largest use of gold (about 8 percent) was for electrical and electronic products, such as electrical contacts and switches, printed circuits, and instruments on space vehicles. Medical and dental applications accounted for most of the remaining gold used.

Olympic champion Michael Phelps holds up one of the eight gold medals he won at the Beijing Olympics in 2008.
AP IMAGES.

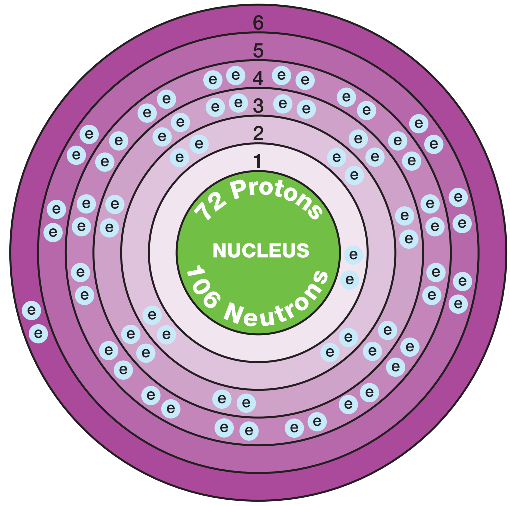
Compounds

Few gold compounds have any important commercial uses.

Health Effects

Gold is not required to maintain good health in plants or animals. It can be injected into a plant or animal without causing harmful effects. Some medical and commercial uses are based on this property.

Hafnium



Key Facts

Symbol: Hf

Atomic Number: 72

Atomic Mass: 178.49

Family: Group 4 (IVB); transition metal

Pronunciation: HAF-nee-um

Overview

Hafnium is an element that chemists knew existed, but could not find. They knew it must exist because of an empty space in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other.

By the 20th century, nearly all the spaces in the periodic table had been filled. One of the empty spaces was element 72. A number of chemists searched for the element. Some even claimed they had found it. But these claims could not be confirmed. In fact, it was not until 1923 that element number 72 was finally discovered.

Hafnium is a shiny, silvery-white metal. It is always found with another chemical element, **zirconium**. The two elements are very much alike. In fact, their similarity is the reason that it took so long to find hafnium.

Hafnium has only a few applications. Probably its most important use is in nuclear power plants. A nuclear power plant is a facility where energy released from nuclear fission reactions is used to generate electricity.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Ductile: Capable of being drawn into thin wires.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Discovery and Naming

In the early 1900s, scientists had found a new way to identify elements. This method is called X-ray diffraction analysis. Here is how this method works:

A stream of electrons is fired at a metal plate. The electrons cause the metal plate to give off X rays. The process is similar to what happens when a person has a chest X ray or an X ray of a broken bone.

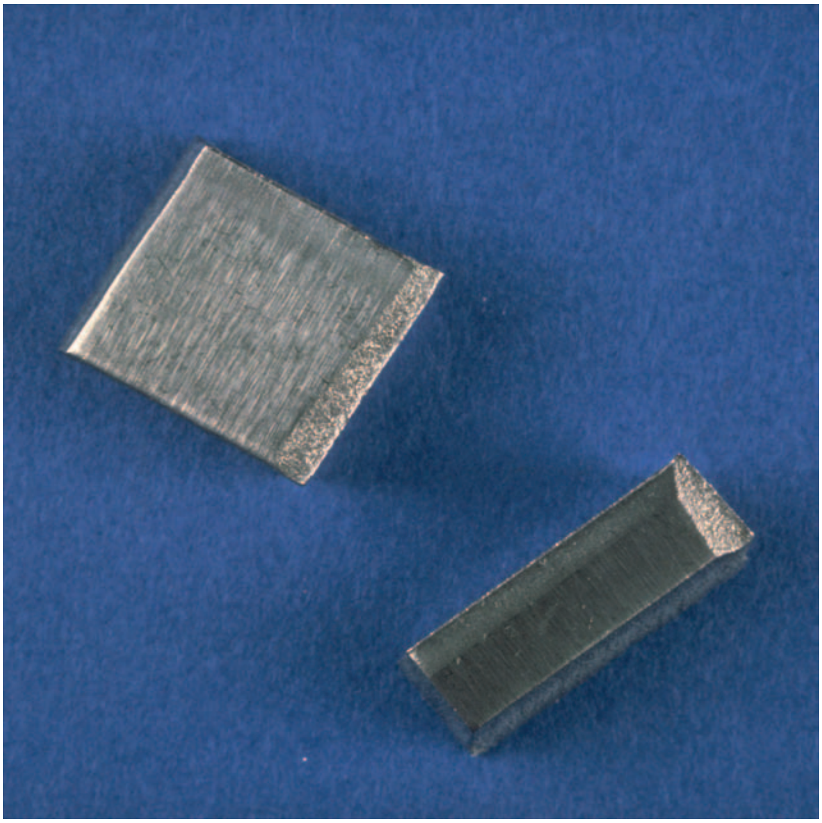
The kind of X ray produced depends on the metal used. Each metal produces its own special X-ray pattern. In fact, the pattern produced can be used to identify a metal.

In 1923 Dutch physicist Dirk Coster (1889–1950) and Hungarian chemist George Charles de Hevesy (1889–1966) found element 72 by X-ray analysis. The element was present in a piece of Norwegian zircon. Zircon also contains the mineral zirconium.

Chemists later developed a better understanding about the relationship of zirconium and hafnium. These two elements are as alike as any two elements in the periodic table. They have nearly identical chemical and physical properties. This similarity explains why it took so long to find hafnium. Chemists had probably discovered hafnium before 1923, but thought it was zirconium. The differences in the X-ray patterns of the two elements finally proved that hafnium was different from zirconium.

Physical Properties

Hafnium is a bright, silvery-gray metal that is very ductile. Ductile means capable of being drawn into thin wires. Its melting point is about 3,900°F



Hafnium samples. © RUSS LAPPA/SCIENCE SOURCE/ NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

(2,150°C) and its boiling point about 9,700°F (5,400°C). Its density is 13.1 grams per cubic centimeter, about 13 times that of water.

The physical property of greatest interest for hafnium is how it responds to neutrons. A neutron is a very small particle found in the nucleus (center) of an atom. Neutrons are used to make nuclear fission reactions occur. Nuclear fission reactions take place when a neutron strikes a large atom, such as an atom of **uranium**. The neutron makes the atom break apart. In the process, a large amount of energy is released. That energy can be converted to electricity.

In order to make electricity from nuclear fission, the fission reaction must be carefully controlled. To do that, the number of neutrons must also be kept under close control. Hafnium has the ability to absorb ("soak up") neutrons very easily. It is used in rods that control how fast a fission reaction takes place. This property is one of the few ways in which hafnium differs from zirconium. Although hafnium is very good at

Hafnium is used in nuclear power plants. IMAGE COPYRIGHT 2007, KRISTIN SMITH. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

absorbing neutrons, zirconium hardly absorbs neutrons at all. Neutrons pass right through it.

Chemical Properties

Like zirconium, hafnium is not very reactive. It does not combine easily with **oxygen** in the air or react with water or cold acids. It may be more active with hot acids, however.

Occurrence in Nature

Hafnium is a moderately common element in Earth's crust. Its abundance is estimated to be about 5 parts per million. That makes it about as abundant as **bromine**, uranium, or **tin**.

Hafnium is always found with ores of zirconium in the earth. The most common of those ores are zircon and baddeleyite.

Isotopes

Hafnium has six naturally occurring isotopes: hafnium-174, hafnium-176, hafnium-177, hafnium-178, hafnium-179, and hafnium-180. The first of these isotopes is radioactive. It has a half life of an astounding two quadrillion years. (That's 2 followed by 15 zeroes!) Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Artificial radioactive isotopes can also be produced by firing very small particles at atoms. These particles stick in the atoms and make them radioactive. Thirty-six artificial radioactive isotopes of hafnium are known. There are no important commercial applications for any of these isotopes.

Extraction

The greatest problem in working with hafnium is finding a way to separate it from zirconium. Today, chemists know that compounds of hafnium dissolve more easily in some liquids than do compounds of zirconium. This method can be used to separate compounds of the two elements from each other.

Uses and Compounds

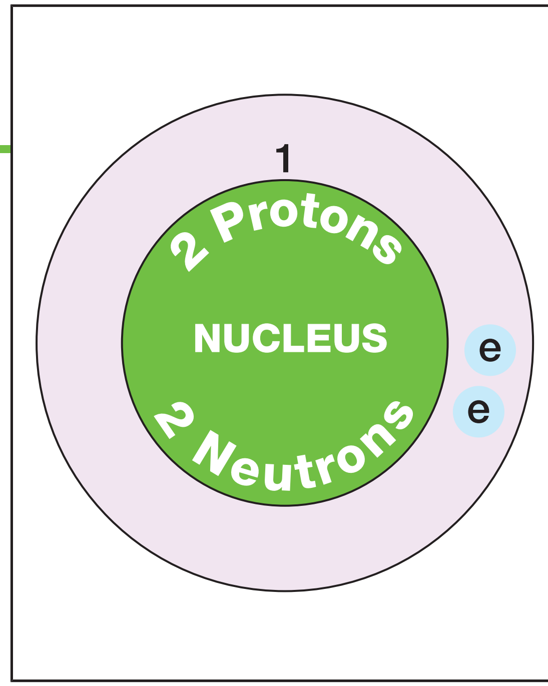
Nuclear power plant applications account for the largest use of hafnium metal. A growing use of hafnium metal is in the production of nickel-based superalloys. A superalloy is a mixture of two or more metals with properties superior to those of traditional alloys. They are stronger, more resistant to corrosion (rusting), and able to retain their properties at high temperature without oxidizing (reacting with oxygen in the air). One of their most common uses is in turbine blades used in electrical generating plants and in jet engines.

Hafnium is also used to make binary compounds with interesting properties. A binary compound consists of two elements. These compounds are among the best refractory materials known. A refractory material is one that can withstand very high temperatures. It reflects heat away from itself. Refractory materials are used to line the inside of high-temperature ovens. For example, some alloys are made at temperatures of thousands of degrees in refractory ovens. Some hafnium compounds used to line these furnaces are hafnium boride (HfB_2), hafnium nitride (HfN), and hafnium oxide (HfO_2).

Health Effects

Both hafnium and its compounds are toxic. They are most dangerous when inhaled. Powdered hafnium metal is also dangerous. It can ignite and explode very easily.

Helium



Key Facts

Symbol: He

Atomic Number: 2

Atomic Mass: 4.002602

Family: Group 18 (VIIIA); noble gas

Pronunciation: HEE-lee-um

Overview

Helium is a member of the noble gas family. The noble gases are the elements in Group 18 (VIIIA) of the periodic table. The periodic table is a chart that shows how the elements are related to one another. The noble gases are also called the inert gases. Inert means that an element is not very active. It will not combine with other elements or compounds. In fact, no compounds of helium have ever been made.

Helium is the second most abundant element in the universe. Only **hydrogen** occurs more often than helium. Helium is also the second simplest of the chemical elements. Its atoms consist of two protons, two neutrons, and two electrons. Only the hydrogen atom is simpler than a helium atom. The hydrogen atom has one proton, one electron, and no neutrons.

Helium was first discovered not on Earth, but in the sun. In 1868 French astronomer Pierre Janssen (1824–1907) studied light from the sun during a solar eclipse. He found proof that a new element existed in the sun. He called the element helium.

Helium has some interesting and unusual physical properties. For example, at very low temperatures it can become a superfluid—a material

WORDS TO KNOW

Alpha particles: Helium atoms without their electrons.

Inert: Not very active.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Liquid air: Air that has been cooled to a very low temperature.

Noble gas: An element in Group 18 (VIIIA) of the periodic table.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Spectroscope: A device for studying the light produced by a heated object.

Superconductor: A material that has no resistance to the flow of electricity; once an electrical current begins flowing in the material, it continues to flow forever.

that behaves very strangely. It can flow upward out of a container, against the force of gravity. It can also squeeze through very small holes that should be able to keep it out. The Nobel Prize in physics for 1996 was awarded to three Americans who discovered superfluidity. They were David M. Lee (1931–), Douglas D. Osheroff (1945–), and Robert C. Richardson (1937–).

For an inactive gas, helium has a surprising number of applications. It is used in low-temperature research, for filling balloons and dirigibles (blimps), to pressurize rocket fuels, in welding operations, in lead detection systems, in **neon** signs, and to protect objects from reacting with **oxygen**.

Discovery and Naming

One of the most powerful instruments for studying chemical elements is the spectroscope. The spectroscope is a device for studying the light produced by a heated object. For example, a lump of **sodium** metal will burn with a yellow flame. The flame looks quite different, however, when viewed through a spectroscope.

A spectroscope contains a triangular piece of glass (called a prism) that breaks light into its basic parts. These basic parts consist of a series of colored lines. In the case of sodium, the yellow light is broken into a series of yellow lines. These lines are called the element's *spectrum.* Every element has its own distinctive spectrum.

The spectroscope gives scientists a new way of studying elements. They can identify an element by recognizing its distinctive spectral lines even when they can't actually see the element itself.

An Element on the Sun This principle led to the discovery of helium. In 1868, Pierre Janssen visited India in order to observe a full eclipse of the sun. A solar eclipse occurs when the Moon comes between the sun and Earth. The Moon blocks nearly all of the sun's light. All that remains is a thin outer circle (corona) of sunlight around the dark Moon. Solar eclipses provide scientists with an unusual chance to study the sun.

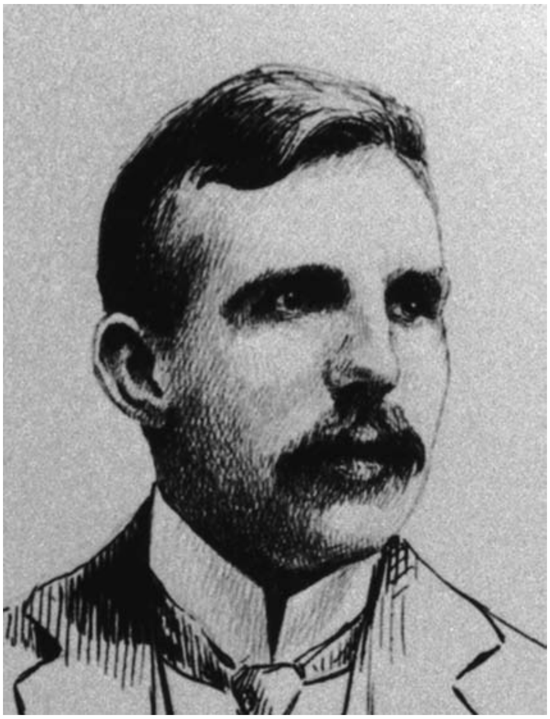
Janssen examined light from the sun with a spectroscope. As he looked at the spectral lines, he was surprised to see some lines that could not be traced to any known element. He concluded that there must be an element on the sun that had never been seen on Earth. The name helium was later suggested for this element. The name comes from the Greek word *helios* for "sun."

Chemists did not know what to make of Janssen's discovery. Was there an element on the sun that did not exist on Earth? Had he made a mistake? Some scientists even made fun of Janssen.

Helium on Earth For the next 30 years, chemists looked for helium on Earth. Then, in 1895, the English physicist Sir William Ramsay (1852–1916) found helium in a mineral of the element **uranium**. Credit for the earthly discovery of helium is sometimes given to two other scientists also. Swedish chemists Per Teodor Cleve (1840–1905) and Nils Abraham Langlet also discovered helium at about the same time in a mineral called cleveite.

Ramsay did not know why helium occurred in an ore of uranium. Some years later, the reason for that connection became obvious. Uranium is a radioactive element—an element that breaks apart spontaneously. It releases radiation and changes into a new element.

Ernest Rutherford's Work One form of radiation produced by uranium consists of alpha particles. Alpha particles are tiny particles moving at very high rates of speed. In 1907, English physicist Ernest Rutherford (1871–1937) showed that an alpha particle is nothing more than a helium atom without its electrons. As uranium atoms broke apart, then, they



Ernest Rutherford. LIBRARY OF CONGRESS.

gave off alpha particles (helium atoms). That is the reason helium was first found on Earth in connection with uranium ores.

Rutherford was one of the great scientific figures of the 20th century. He made a number of important discoveries about the structure of atoms and about radioactivity. For example, he found that an atom consists of two distinct parts, the nucleus and the electrons. He also discovered one form of radiation given off by radioactive materials: alpha particles. Alpha particles, he found, are simply helium atoms without their electrons.

Rutherford was also the first scientist to change one element into another. He accomplished this by bombarding **nitrogen** gas with alpha particles. Rutherford found that oxygen was formed in this experiment. He had discovered a way to convert one element (nitrogen) into a different element (oxygen). The method Rutherford used later became a standard procedure used by many other scientists.

Physical Properties

Helium is a colorless, odorless, tasteless gas. It has a number of unusual properties. For example, it has the lowest boiling point of any element, –452.0°F (–268.9°C). The boiling point for a gas is the temperature at which the gas changes to a liquid. The freezing point of helium is –458.0°F (–272.2°C). Helium is the only gas that cannot be made into a solid simply by lowering the temperature. It is also necessary to increase the pressure on the gas in order to make it a solid.

At a temperature of about –456°F (–271°C), helium undergoes an unusual change. It remains a liquid, but a liquid with strange properties. Superfluidity is one of these properties. The forms of helium are so different that they are given different names. Above –456°F (–271°C), liquid helium is called helium I; below that temperature, it is called helium II.

Chemical Properties

Helium is completely inert. It does not form compounds or react with any other element.

Occurrence in Nature

Helium is the second most abundant element after hydrogen in the universe and in the solar system. About 11.3 percent of all atoms in the universe are helium atoms. By comparison, about 88.6 percent of all atoms in the universe are hydrogen. Thus, at least 99.9 percent of all atoms are either hydrogen or helium atoms.

By contrast, helium is much less abundant on Earth. It is the sixth most abundant gas in the atmosphere after nitrogen, oxygen, **argon**, carbon dioxide, and neon. It makes up about 0.000524 percent of the air.

It is probably impossible to estimate the amount of helium in Earth's crust. The gas is produced when uranium and other radioactive elements break down. But it tends to escape into the atmosphere almost immediately.

Isotopes

Two isotopes of helium occur naturally: helium-3 and helium-4. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Six radioactive isotopes of helium have been made also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of helium has any commercial application.

Extraction

In theory, helium could be collected from liquid air. Liquid air is air that has been cooled to a very low temperature. All of the gases in air have

Party balloons are often filled with helium. IMAGE COPYRIGHT 2009, HFNG. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

liquefied in liquid air. If the liquid air were allowed to evaporate, the last gas remaining after all other gases had evaporated would be helium. There is too little helium in air to make this process worthwhile, however.

There is a much better source of helium. The gas often occurs along with natural gas in reservoirs deep beneath Earth's surface. When wells are dug to collect the natural gas, helium comes to the surface with the natural gas. Then, helium can be separated from natural gas very easily. The temperature of the mixture is lowered, and the natural gas liquefies and is taken away. Gaseous helium is left behind.

An estimated 78 percent of the world's helium was produced in the United States in 2008. Other producers included Algeria, Qatar, Russia, and Poland. Nineteen U.S. plants extracted helium from natural gas. Those plants were located in Colorado, Kansas, New Mexico, Oklahoma, Texas, Utah, and Wyoming. According to the U.S. Geological Survey (USGS), between 2009 and 2015, about nine new helium plant projects are slated to begin work worldwide. Such plants will be located in the United States (2), Algeria, Australia, China, India, Indonesia, Qatar, and Russia.

For many years, the U.S. government operated the Federal Helium Program. This program was responsible for collecting and storing helium for government use. The main customers for this helium were the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE). The helium was stored underground in huge natural caves.

In 1996, the government decided to end this program. Helium was no longer regarded as essential to national security. The Bureau of Mines began to sell off the federal reserves.

Uses

One of the most important single uses for helium in the United States is in pressure and purge systems. In many industrial operations, it is necessary to pressurize a system. The easiest way to do that is to pump a gas into the system. But the gas should not be one that will react with other substances in the system. Being inert, helium is a perfect choice. Helium is also used for purging, a process that sweeps away all gas in a container. Again, helium is used because it does not react with anything in the container.

Another major use of helium is in low-temperature cooling systems. This application is based on the fact that liquid helium—at –454°F (–270°C)—is cold enough to cool *anything* else. For example, it is used in superconducting devices.

A superconducting material is one that has no resistance to the flow of electricity. Once an electric current begins to flow in the material, it will continue to flow forever. No energy is wasted in moving electricity from one place to another. Superconducting materials may revolutionize electrical systems worldwide someday. The problem is that superconductivity occurs only at very low temperatures. One way to achieve those temperatures is with liquid helium.

Because of its inactivity, helium is also used in welding systems. Welding is the process by which two metals are heated to high temperatures in order to join them to each other. Welding rarely works well in "normal" air. At high temperatures, the metals may react with oxygen to form metal oxides. If they do, they are less likely to join to each other. If the welding is done in a container of helium, this is not a problem. The metals will not react with helium. They will simply join to each other.

Helium is also used in leak-detection systems. If a leak is suspected in a long pipe, helium can be used to look for that leak. It is pumped into one end of the pipe. A detector is held outside the pipe. The detector is designed to measure whether helium is escaping from the system. The detector is moved along the length of the pipe. It is possible to find out whether there is a leak, where it is, and the extent of the leak. Helium is a good gas to use for this purpose because it does not react with anything in the pipe.

Helium is also used to inflate balloons and other lighter-than-air craft, such as dirigibles (blimps). Helium does not have the lifting power of hydrogen. However, hydrogen is flammable and helium is not.

At one time, people thought that dirigibles would be a popular form of transportation. But that never happened. Blimps are still used for limited purposes, such as advertising at major sports and recreational events.

Helium is used to inflate dirigibles, such as blimps.

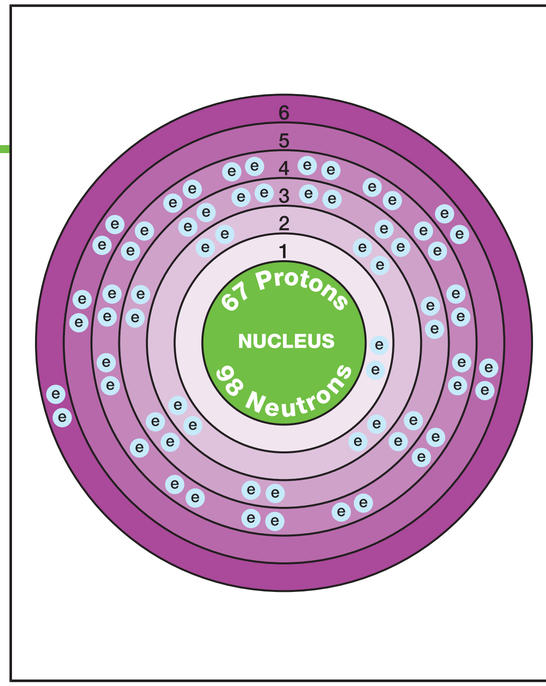
Compounds

No compounds of helium have ever been made.

Health Effects

There are no known health hazards resulting from exposure to helium.

Holmium



Overview

Holmium occurs in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Elements with atomic numbers 57 through 71 are known as the lanthanoids. The name comes from the first element in the series, **lanthanum**. The lanthanoids are also known as rare earth elements. Although lanthanoids are not especially rare, they were once very difficult to separate from each other.

Holmium was discovered by Swedish chemist Per Teodor Cleve (1840–1905) in 1879. He named the element after his birthplace, Stockholm, Sweden. Holmium occurs with other rare earth elements in minerals such as monazite and gadolinite. It can now be separated from other rare earth elements somewhat easily. But no major uses have been found for it or its compounds.

Key Facts

Symbol: Ho

Atomic Number: 67

Atomic Mass: 164.93032

Family: Lanthanoid (rare earth metal)

Pronunciation: HOL-me-um

Discovery and Naming

In 1787, a lieutenant in the Swedish army named Carl Axel Arrhenius (1757–1824) was exploring a mine near Ytterby, Sweden. Arrhenius was a "rock hound," a person interested in the study of rocks and minerals. In his explorations, Arrhenius found a rock he had never seen before. He

WORDS TO KNOW

Ductile: Capable of being drawn into thin wires.

Earth: In mineralogy, a naturally occurring form of an element, often an oxide of the element.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers between 57 and 71.

Laser: A device for producing very bright light of a single color.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope whose presence in a system can easily be detected.

asked his friend Johan Gadolin (1760–1852), professor of chemistry at the University of Åbo in Finland, to study it. Gadolin discovered in the rock a new mineral, which was given the name ytterite.

Ytterite proved to be a fascinating puzzle for chemists. The mineral contained a number of different "earths." In chemistry, the term earth refers to a naturally occurring compound of an element. For example, magnesia is a naturally occurring compound—an earth—of the element **magnesium**.

Chemists found the earths in ytterite all had very similar properties. For that reason, they had trouble separating them from each other. In fact, it took more than a century to analyze ytterite completely.

In 1879, Per Teodor Cleve was studying an earth taken from yttria called erbia. Erbia had been regarded as a new element for some time. But Cleve separated erbia into three different parts. He called them erbia, holmia, and thulia. Holmia is the earth from which the element holmium comes. For his work, Cleve is given credit for the discovery of holmium.

In Cleve's time, chemical equipment was not very advanced. Chemists usually could not prepare very pure samples of materials. Ten years after the "discovery" of holmium, chemists realized it was actually holmium mixed with another new element, **dysprosium**.

Physical Properties

Like other rare earth elements, holmium is a silvery metal that is soft, ductile, and malleable. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. Both properties are common for metals. Holmium also has some rather unusual magnetic and electrical properties.

Holmium has a melting point of 2,680°F (1,470°C) and a boiling point of 4,930°F (2,720°C). Its density is 8.803 grams per cubic centimeter, almost nine times the density of water.

Chemical Properties

Holmium metal tends to be stable at room temperature. In moist air and at higher temperatures, it becomes more reactive. For example, it combines with **oxygen** to form holmium oxide (Ho_2O_3), a yellow solid. Like most other metals, the element also dissolves in acids.

Occurrence in Nature

The abundance of holmium in Earth's crust is estimated to be about 0.7 to 1.2 parts per million. It is less common than most other rare earth elements, but more common than **iodine**, **silver**, **mercury**, and **gold**. The most common ores of holmium are monazite and gadolinite.

Isotopes

Only one naturally occurring isotope of holmium exists: holmium-165. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fifty radioactive isotopes of holmium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of holmium has any practical uses.

Extraction

Pure holmium is obtained by reacting **calcium** metal with holmium fluoride (HoF_3):

$$3Ca + 2HoF_3 \rightarrow 3CaF_2 + 2Ho$$

Pure holmium in significant amounts has been available only very recently.

Uses

In the past there were almost no practical uses for holmium and its compounds. However, holmium is now used in specialized lasers. A laser is a device for producing very bright light of a single color. The kind of light produced in a laser depends on the elements of which it is made. Holmium lasers are used to reduce abnormal eye pressure, to treat glaucoma (an eye disorder), and to repair failed glaucoma surgeries.

Another potential use for holmium is a result of its very unusual and strong magnetic properties. It has been used in alloys with other metals to produce some of the strongest magnetic fields ever produced. Holmium also has some limited use in the manufacture of control rods for nuclear power plants. Control rods limit the number of neutrons available to cause the fission of uranium in nuclear reactors, thus controlling the amount of energy produced in the plant.

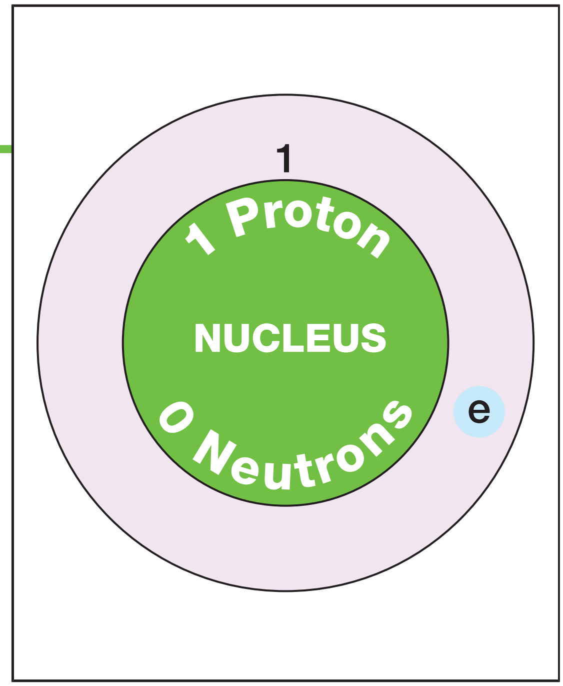
Compounds

Few holmium compounds have any important commercial uses. The one exception is holmium oxide (Ho_2O_3), used to add a yellowish color to glass, in the manufacture of refractory materials, and as a catalyst for some chemical reactions. A refractory material is a material that can withstand very high temperatures and reflect heat back away from itself. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself. In 2007, the price of holmium oxide was approximately $750 per kilogram.

Health Effects

Very little is known about the health effects of holmium. It does not appear to pose any serious health hazards to humans or other animals.

Hydrogen



Overview

Hydrogen is the most abundant element in the universe. Nearly nine out of every 10 atoms in the universe are hydrogen atoms. Hydrogen is also common on Earth. It is the third most abundant element after **oxygen** and **silicon**. About 15 percent of all the atoms found on Earth are hydrogen atoms.

Hydrogen is also the simplest of all elements. Its atoms consist (usually) of one proton and one electron.

Hydrogen was first discovered in 1766 by English chemist and physicist Henry Cavendish (1731–1810). Cavendish was also the first person to prove that water is a compound of hydrogen and oxygen.

Some experts believe that hydrogen forms more compounds than any other element. These compounds include water, sucrose (table sugar), alcohols, vinegar (acetic acid), household lye (sodium hydroxide), drugs, fibers, dyes, plastics, and fuels.

Key Facts

Symbol: H

Atomic Number: 1

Atomic Mass: 1.00794

Family: Group 1 (IA)

Pronunciation: HY-dru-jin

Discovery and Naming

Hydrogen was probably "discovered" many times. Many early chemists reported finding a "flammable gas" in some of their experiments. In

WORDS TO KNOW

Catalyst: A substance used to speed up a chemical reaction without undergoing any change.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

1671, for example, English chemist Robert Boyle (1627–1691) described experiments in which he added **iron** to hydrochloric acid (HCl) and sulfuric acid (H_2SO_4). In both cases, a gas that burned easily with a pale blue flame was produced.

The problem with these early discoveries was that chemists did not understand the nature of gases very well. They had not learned that there are many kinds of gases. They thought that all the "gases" they saw were some form of air with impurities in it.

Cavendish discovered hydrogen in experiments like those that Boyle performed. He added iron metal to different acids and found that a flammable gas was produced. But Cavendish thought the flammable gas came from the iron and not from the acid. Chemists later showed that iron is an element and does not contain hydrogen or anything else. Therefore, the hydrogen in Cavendish's experiment came from the acid:

$$\mathbf{Fe + 2HCl \rightarrow FeCl_2 + H_2}$$

Hydrogen was named by French chemist Antoine-Laurent Lavoisier (1743–1794). Lavoisier is sometimes called the father of modern chemistry because of his many contributions to the science. Lavoisier suggested the name hydrogen after the Greek word for "water former" (that which forms water).

Physical Properties

Hydrogen is a colorless, odorless, tasteless gas. Its density is the lowest of any chemical element, 0.08999 grams per liter. By comparison, a liter of air weighs 1.29 grams, 14 times as much as a liter of hydrogen.

Hydrogen changes from a gas to a liquid at a temperature of –422.99°F (–252.77°C) and from a liquid to a solid at a temperature of –434.6°F (–259.2°C). Hydrogen gas is slightly soluble in water, alcohol, and a few other common liquids.

Chemical Properties

Hydrogen burns in air or oxygen to produce water:

$$2H_2 + O_2 \rightarrow 2H_2O$$

It also combines readily with other non-metals, such as **sulfur**, **phosphorus**, and the halogens. The halogens are the elements that make up Group 17 (VIIA) of the periodic table. They include **fluorine**, **chlorine**, **bromine**, **iodine**, and **astatine**. As an example:

$$H_2 + Cl_2 \rightarrow 2HCl$$

Occurrence in Nature

Hydrogen occurs throughout the universe in two forms. First, it occurs in stars. Stars use hydrogen as a fuel with which to produce energy. The process by which stars use hydrogen is known as fusion. Fusion is the process by which two or more small atoms are pushed together to make one larger atom. In most stars, the primary fusion reaction that occurs is:

$$4H \rightarrow 1He$$

This equation shows that four hydrogen atoms are squeezed together (fused) to make one helium atom. In this process, enormous amounts of energy are released in the form of heat and light.

Hydrogen also occurs in the "empty" spaces between stars. At one time, scientists thought that this space was really empty, that it contained no atoms of any kind. But, in fact, this interstellar space (space between stars) contains a small number of atoms, most of which are hydrogen atoms. A cubic mile of interstellar space usually contains no more than a handful of hydrogen and other atoms.

Hydrogen occurs on Earth primarily in the form of water. Every molecule of water (H_2O) contains two hydrogen atoms and one oxygen atom. Hydrogen is also found in many rocks and minerals. Its abundance is estimated to be about 1,500 parts per million. That makes hydrogen the 10th most abundant element in Earth's crust.

Hydrogen also occurs to a very small extent in Earth's atmosphere. Its abundance there is estimated to be about 0.000055 percent.

Stars use hydrogen as a fuel with which to produce energy. Antares—the brightest star in the constellation Scorpius—is shown.
© RONALD ROYER/SCIENCE PHOTO LIBRARY, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Hydrogen is not abundant in the atmosphere because it has such a low density. Earth's gravity is not able to hold on to hydrogen atoms very well. Hydrogen floats away into outer space very easily. Most of the hydrogen that was once in the atmosphere has now escaped into outer space.

Isotopes

There are three isotopes of hydrogen: hydrogen-1, hydrogen-2, and hydrogen-3. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The three isotopes of hydrogen have special names.

- Hydrogen-1 is sometimes called protium. It is the simplest and most common form of hydrogen. Protium atoms all contain one proton and one electron. About 99.9844 percent of the hydrogen in nature is protium.
- Hydrogen-2 is known as deuterium. A deuterium atom contains one proton, one electron, and one neutron. About 0.0156 percent of the hydrogen in nature is deuterium.
- The third isotope of hydrogen, hydrogen-3, is tritium. An atom of tritium contains one proton, one electron, and two neutrons. There are only very small traces of tritium in nature.

Tritium is a radioactive isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation. Some radioactive isotopes (such as tritium) occur in nature. They can also be produced in the laboratory. Very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. Tritium is a widely used isotope and is now made in large amounts in the laboratory.

Tritium is widely used as a tracer in both industry and research. A tracer is a radioactive isotope whose presence in a system can be easily detected. The isotope is injected into the system at some point. Inside the system, the isotope gives off radiation. That radiation can be followed by means of detectors placed around the system.

Tritium is popular as a tracer because hydrogen occurs in so many different compounds. For example, suppose a scientist wants to trace the movement of water through soil. The scientist can make up a sample of water made with tritium instead of protium. As that water moves through the soil, its path can be followed by means of the radioactivity the tritium gives off.

Tritium is also used in the manufacture of fusion bombs. A fusion bomb is also known as a hydrogen bomb. In a fusion bomb, small atoms are squeezed together (fused) to make a larger atom. In the process, enormous amounts of energy are given off. For example, the first fusion bomb tested by the United States in 1952 had the explosive power of 15 million tons of TNT. A type of fusion bomb fuses tritium with deuterium to make helium atoms:

$$^{3}\mathbf{H} + {}^{2}\mathbf{H} \rightarrow \mathbf{He}$$

Extraction

The obvious source for hydrogen is water. Earth has enough water to supply people's need for hydrogen. The problem is that it takes a lot of energy to split a water molecule:

$$2H_2O \xrightarrow{\text{electrical current}} 2H_2 + O_2$$

In fact, it simply costs too much to make hydrogen by this method. The cost of electricity is too high. So it is not economical to make hydrogen by splitting water.

A number of other methods can be used to produce hydrogen, however. For example, steam can be passed over hot charcoal (nearly pure **carbon**):

$$H_2O + C \xrightarrow{\text{heat}} CO + H_2$$

The same reaction can be used with steam and other carbon compounds. For example, using methane, or natural gas (CH_4), the reaction is:

$$H_2O + CH_4 \xrightarrow{\text{heat}} CO + 3H_2$$

Hydrogen can also be made by the reaction between carbon monoxide (CO) and steam:

$$CO + H_2O \xrightarrow{\text{heat}} CO_2 + H_2$$

Because hydrogen is such an important element, many other methods for producing it have been invented. However, the preceding methods are the least expensive.

Uses

The most important single use of hydrogen is in the manufacture of ammonia (NH_3). Ammonia is made by combining hydrogen and nitrogen at high pressure and temperature in the presence of a catalyst. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change during the reaction:

$$N_2 + 3H_2 \xrightarrow{\text{pressure, heat, catalyst}} 2NH_3$$

Ammonia is a very important compound. It is used in making many products, the most important of which is fertilizer.

Hydrogen is also used for a number of similar reactions. For example, it can be combined with carbon monoxide to make methanol—methyl alcohol, or wood alcohol (CH_3OH):

$$CO + H_2 \xrightarrow{\text{with catalyst}} CH_3OH$$

Like ammonia, methanol has a great many practical uses in a variety of industries. The most important use of methanol is in the manufacture of other chemicals, such as those from which plastics are made. Small amounts are used as additives to gasoline to reduce the amount of pollution released to the environment. Methanol is also used widely as a solvent (to dissolve other materials) in industry.

Another important use of hydrogen is in the production of pure metals. Hydrogen gas is passed over a hot metal oxide to produce the pure metal. For example, **molybdenum** can be prepared by passing hydrogen over hot molybdenum oxide:

$$MoO_2 + 2H_2 \xrightarrow{\text{heat}} 2H_2O + Mo$$

Hydrogenation is an important procedure to the food industry. In hydrogenation, hydrogen is chemically added to another substance. The reaction between carbon monoxide and hydrogen is an example of hydrogenation. Liquid oils are often hydrogenated. Hydrogenation changes the liquid oil to a solid fat. Most kitchens contain foods with hydrogenated or partially hydrogenated oils. Vegetable shortening is a good example. Hydrogenation makes it easier to pack and transport oils.

Hydrogen is also used in oxyhydrogen ("oxygen + hydrogen") and atomic hydrogen torches. These torches produce temperatures of a few thousand degrees. At these temperatures, it is possible to cut through steel and most other metals. These torches can also be used to weld (join together with heat) two metals.

Another use for hydrogen is in lighter-than-air balloons. Hydrogen is the least dense of all gases. So a balloon filled with hydrogen can lift very large loads. Such balloons are not used to carry people anymore. The danger of fire or explosion is too great.

The best example of this is the hydrogen fire that destroyed the German airship *Hindenburg,* as it was landing in New Jersey on May 6, 1937 (see sidebar and photo on pages 258 and 259). Today, hydrogen balloons are used for lifting weather instruments into the upper atmosphere.

One of the best known uses of hydrogen is as a rocket fuel. Many rockets obtain the power they need for lift-off by burning hydrogen with pure oxygen in a closed tank. The energy produced by this reaction provides thrust to the rocket.

The Loss of the *Hindenburg*

The *Hindenburg* was Germany's largest passenger airship. It was built in 1936 as a luxury liner, and it made the trip to the United States faster than an ocean liner.

The *Hindenburg* was designed to be filled with helium, a safer gas than the highly flammable hydrogen. But in those pre-World War II days, the United States suspected that Germany's new leader, Adolf Hitler (1889–1945), had military plans for helium-filled ships. So the United States refused to sell helium to the Zeppelin airship company. Seven million cubic feet of hydrogen were used instead. This made the crew very nervous about the potential for fire. Passengers were even checked for matches as they boarded!

On May 3, 1937, the *Hindenburg* left Frankfurt, Germany, for Lakehurst, New Jersey. It traveled over the Netherlands, down the English Channel, through Canada, and into the United States. Bad weather forced the ship to slow down several times, lengthening the trip. But it finally approached the field in Lakehurst around 7 PM on May 6. After several minutes of maneuvers due to rain and wind, crewmen dropped ropes to the ground at 7:21. The ship was 200 feet (61 meters) above ground. Four minutes later, a small flame emerged on the skin of the ship, and crewmen heard a pop and felt a shudder. Seconds later, the *Hindenburg* exploded. Flaming hydrogen blasted out of the top. Within 32 seconds, the entire airship had burned, the framework had collapsed, and the entire ship lay smoldering on the ground. Thirty-six people died. Amazingly, 62 survived.

Although claims of sabotage have always surrounded the *Hindenburg* tragedy, American and German investigators both agreed it was an accident. Both sides concluded that the airship's hydrogen was ignited probably by some type of atmospheric electric discharge. Witnesses had noticed some of the skin of the ship flapping; they also observed the nose of the ship rise suddenly. Both indicate the likelihood that free hydrogen had escaped. The *Hindenburg* disaster ended lighter-than-air airship travel for many decades.

The Hydrogen Economy Some people believe that hydrogen can help to end the world's dependence on burning fossil fuels (coal, oil, and natural gas) for energy. They have talked about the day when the age of fossil fuels will be replaced by a hydrogen economy.

"The Hydrogen economy" refers to a world in which the burning of hydrogen will be the main source of energy and power. Hydrogen seems like a good choice for helping to meet future energy needs. When it burns, it produces only water:

$$2H_2 + O_2 \rightarrow 2H_2O$$

The dramatic explosion of the Hindenburg *in 1937 occurred when hydrogen was ignited. More than a third onboard died.* PUBLIC DOMAIN.

A lot of energy is produced in this reaction. That energy can be used to operate cars, trucks, trains, boats, and airplanes. It can be used as a source of heat for keeping people warm and running chemical reactions.

So why doesn't a hydrogen economy exist today? The answer is easy. It is still too expensive to make hydrogen gas. No one has found a way to remove hydrogen from water or some other source at a low cost. It is still cheaper to mine for coal or drill for oil than to make hydrogen.

Various automobile companies have researched and created prototypes of hydrogen-powered vehicles. Although a few companies dropped their plans to build such cars in 2009, other corporations announced their intentions to continue such efforts. At that time, most of the hydrogen-powered cars in use in the United States were in California. And more than 60 hydrogen fueling stations were in operation in the country.

Compounds

Millions of hydrogen compounds are known. One of the most important groups of hydrogen compounds is the acids. An acid is any compound

Some cars run on hydrogen. Shown here is a hydrogen fuel dispenser for vehicles at a service station. IMAGE COPYRIGHT 2009, MONA MAKELA. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

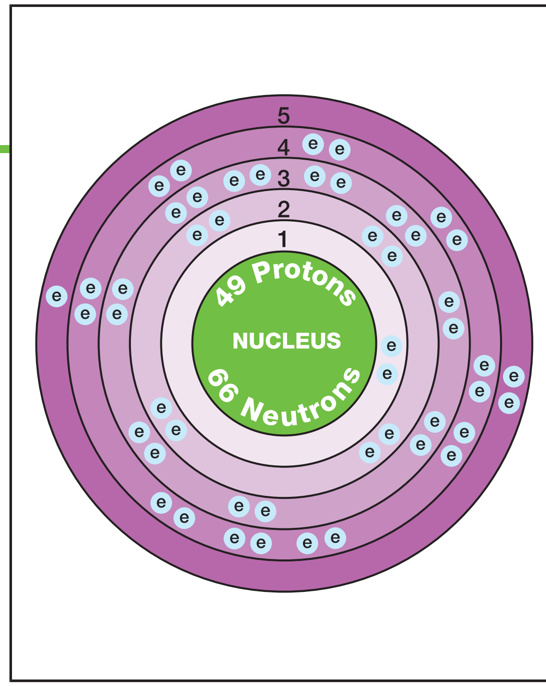
that contains hydrogen as its positive part. Common acids include: hydrochloric acid (HCl), sulfuric acid (H_2SO_4), nitric acid (HNO_3), acetic acid ($HC_2H_3O_2$), phosphoric acid (H_3PO_4), and hydrofluoric acid (HF).

Acids are present in thousands of natural substances and artificial products. The following list gives a few examples: vinegar, or acetic acid ($HC_2H_3O_2$); sour milk, or lactic acid ($C_3H_6O_3$); lemons and other citrus fruits, or citric acid ($C_6H_8O_7$); soda water, or carbonic acid (H_2CO_3); battery acid, or sulfuric acid (H_2SO_4); and boric acid (H_3BO_3).

Health Effects

Hydrogen is essential to every plant and animal. Nearly every compound in a living cell contains hydrogen. It is harmless to humans unless taken in very large amounts. In this case, it is dangerous only because it cuts off the supply of oxygen that humans need to breathe.

Indium



Overview

Indium is part of the aluminum family in Group 13 (IIIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Indium was discovered in 1863 by German chemists Ferdinand Reich (1799–1882) and Hieronymus Theodor Richter (1824–1898).

Indium has a number of interesting properties. For example, it has a low melting point for metals, 313.9°F (156.6°C). When pure, it sticks very tightly to itself or to other metals. This property makes it useful as a solder. Solder is a material used to join two metals to each other. Other uses of indium are in the manufacture of batteries, electronic devices, liquid crystal displays (LCD), and in research.

Key Facts

Symbol: In

Atomic Number: 49

Atomic Mass: 114.818

Family: Group 13 (IIIA); aluminum

Pronunciation: IN-dee-um

Discovery and Naming

Between 1860 and 1863, indium, **cesium**, **rubidium**, and **thallium** were found using spectroscopy. Spectroscopy is the process of analyzing light produced when an element is heated. The light produced is different for every element. The spectrum (plural: spectra) of an element consists of a series of colored lines. Reich and Richter also produced the first impure sample of indium in 1863.

WORDS TO KNOW

Absolute zero: The lowest temperature possible, about –459°F (–273°C).

Alloy: A mixture of two or more metals that has properties different from those of the individual metals.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Radioactivity: The process by which an isotope or element breaks down and gives off some form of radiation.

Solder: A material used to join two metals to each other.

Spectroscopy: The process of analyzing light produced when an element is heated.

Scientists use a spectroscope in this process. The spectroscope was invented in 1814 by German physicist Joseph von Fraunhofer (1787–1826). Forty years later, German chemists Robert Bunsen (1811–1899) and Gustav Robert Kirchhoff (1824–1887) improved on the instrument. They showed how it could be used to study the chemical elements.

Reich and Richter suggested the name indium for the element they discovered because its main spectral lines are a brilliant indigo blue.

Physical Properties

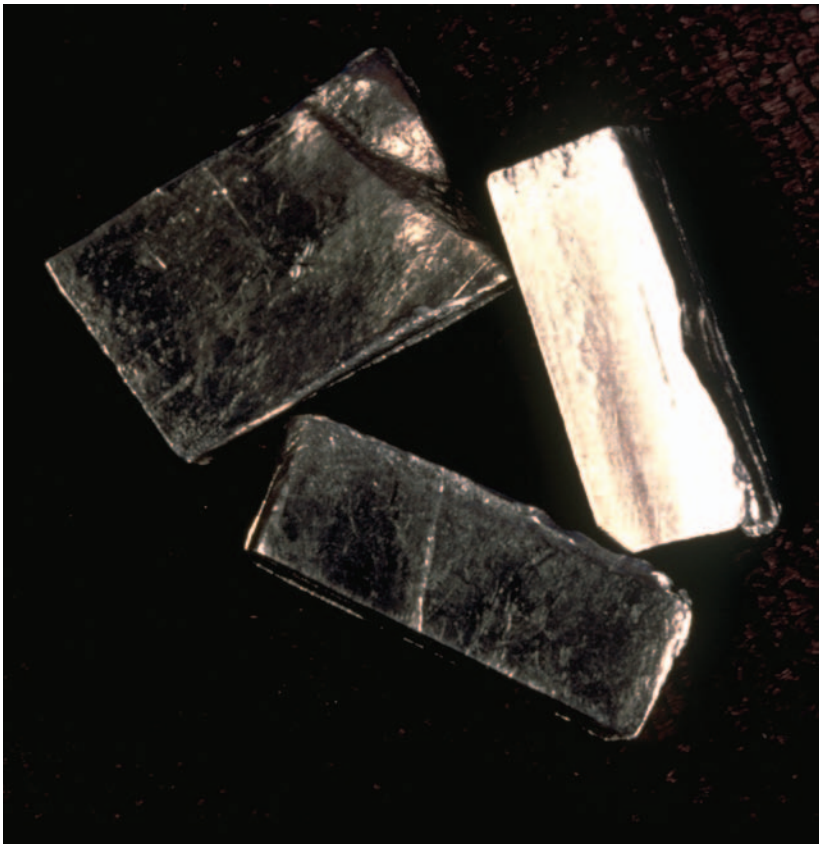
Indium is a silvery-white, shiny metal with a density of 7.31 grams per cubic centimeter. It is one of the softest metals known, even softer than **lead**. If drawn across a piece of paper, it leaves a mark like a "lead" pencil (which is actually **carbon**).

An unusual property of indium is that it produces a "**tin** cry." A tin cry is a scream-like sound made when the metal is bent.

Indium has a melting point of 313.9°F (156.6°C) and a boiling point of 3,767°F (2,075°C). It has the unusual property of remaining soft and workable at very low temperatures. This property allows it to be used in special equipment needed for temperatures near absolute zero. Absolute zero is the coldest temperature possible. It is about –459°F (–273°C).

Chemical Properties

Indium metal dissolves in acids, but does not react with **oxygen** at room temperature. At higher temperatures, it combines with oxygen to form indium oxide (In_2O_3).



Indium samples. © RUSS LAPPA/ SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Occurrence in Nature

Indium is relatively rare. Its abundance in Earth's crust is estimated to be about 0.1 part per million. That makes it slightly more abundant than **silver** or **mercury**.

Indium is generally found in ores of **zinc**. The metal is not usually produced in the United States. It is imported mainly from China, Japan, Canada, and Belgium. Use of indium in liquid crystal displays (LCD) products, such as flat-panel monitors, has spiked demand in recent years for indium tin oxide.

Isotopes

Two naturally occurring isotopes of indium exist: indium-113 and indium-115. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Indium-115 is radioactive. A radioactive isotope is one that breaks apart and gives off some form of radiation. Indium-115 has a half life of about 440 trillion years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. Starting with 10 grams of indium-115 today, only 5 grams would be left 440 trillion years from now.

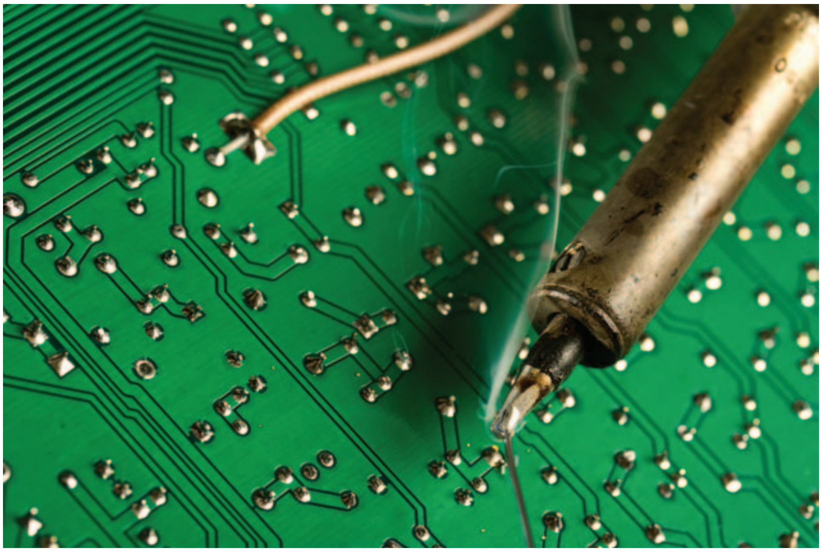
Seventy artificial radioactive isotopes of indium also exist. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. Two of these isotopes are used in medicine. Indium-113 is used to examine the liver, spleen, brain, pulmonary ("breathing") system, and heart and blood system. Indium-111 is used to search for tumors, internal bleeding, abscesses, and infections and to study the gastric (stomach) and blood systems. In both cases, the radioactive isotope is injected into the bloodstream. Inside the body, the isotope gives off radiation. That radiation can be detected by means of a camera or other device. The radiation pattern observed provides information about the organ or system being studied.

Extraction

Indium is obtained in its pure form by separating it from zinc and other elements in zinc ores.

Uses and Compounds

One of the primary uses of indium is in making alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Indium has been called a "metal vitamin" in alloys. That means that very small amounts of indium can make big changes in an alloy. For example, very small amounts of indium are sometimes added to **gold** and **platinum** alloys to make them much harder. Such alloys are used in electronic devices and dental materials.



When indium is in its pure form, it sticks very tightly to itself or to other metals, making it useful as a solder. Here, a circuit board is being soldered. IMAGE COPYRIGHT 2009, JOHN STEBBINS. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Indium is also added to solders. It reduces the melting point of some solders, strengthens other solders, and prevents still other solders from breaking down too easily.

An important use of indium is in making coatings. For example, some aircraft parts are made of alloys that contain indium. The indium prevents them from wearing out or reacting with oxygen in the air.

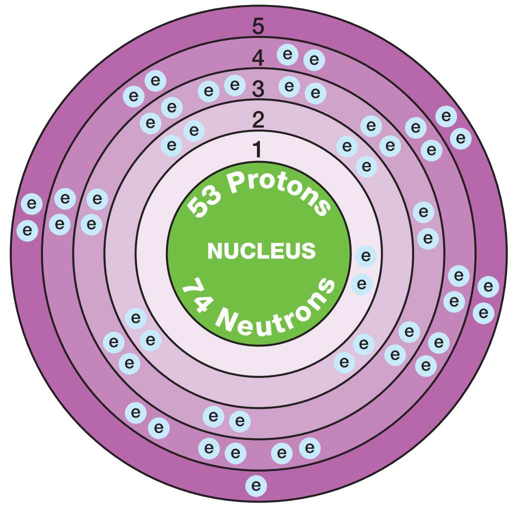
Alloys and compounds of indium are also used in making optical (light) devices. For example, indium **gallium** arsenide (InGaAs) is able to convert pulses of light into electrical signals. One application of a device like this is in solar cells. A solar cell is a device used to change sunlight into electrical current. Many scientists think that solar cells may replace coal, oil, and natural gas for many purposes in the future.

Another primary use of indium is in liquid crystal displays (LCDs). Products using LCDs include large flat panel monitors and televisions, cell phones, and digital cameras. Indium is also used in the production of light-emitting diodes (LEDs). A light-emitting diode is a device that gives off light when an electric current passes through it. The numbers on a hand-held calculator are produced with LEDs. In 2004, the U.S. National Park Service replaced all of the conventional lighting at the Thomas Jefferson Memorial in Washington, D.C., with light-emitting diodes containing indium. The conversion reduced the amount of electricity used at the monument by 80 percent and the number of electrical fixtures by 30 percent. At the same time, the total amount of light produced was increased by 20 percent.

Health Effects

Indium is an irritant to the skin, eyes, and respiratory (breathing) system. If taken into the body, it can cause coughing, wheezing, and shortness of breath. Exposure to very high levels of indium may cause damage to the liver and kidneys.

Iodine



Key Facts

Symbol: I

Atomic Number: 53

Atomic Mass: 126.90447

Family: Group 17 (VIIA); halogen

Pronunciation: EYE-uh-dine

Overview

Iodine is the heaviest of the commonly occurring halogens. The halogens are in Group 17 (VIIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Iodine's chemical properties are similar to the lighter halogens above it, **fluorine**, **chlorine**, and **bromine**. But its physical appearance is very different. It is a steel-gray solid that changes into beautiful purple vapors when heated.

Iodine was discovered in 1811 by French chemist Bernard Courtois (1777–1838). The element occurs primarily in seawater and in solids formed when seawater evaporates. Its single most important property may be the ability to kill germs. It is used in antiseptics, germicides (products that kill germs), and other medical applications. However, it has a great many other important commercial applications.

Discovery and Naming

One of Bernard Courtois' first jobs was to assist his father in making compounds of **sodium** and **potassium** from seaweed. Seaweed plants take sodium and potassium compounds out of seawater. The compounds become part of the growing seaweed.

WORDS TO KNOW

Antiseptic: A chemical that stops the growth of germs.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Sublimation: The process by which a solid turns directly to a gas without first melting.

Tincture: A solution made by dissolving a substance in alcohol.

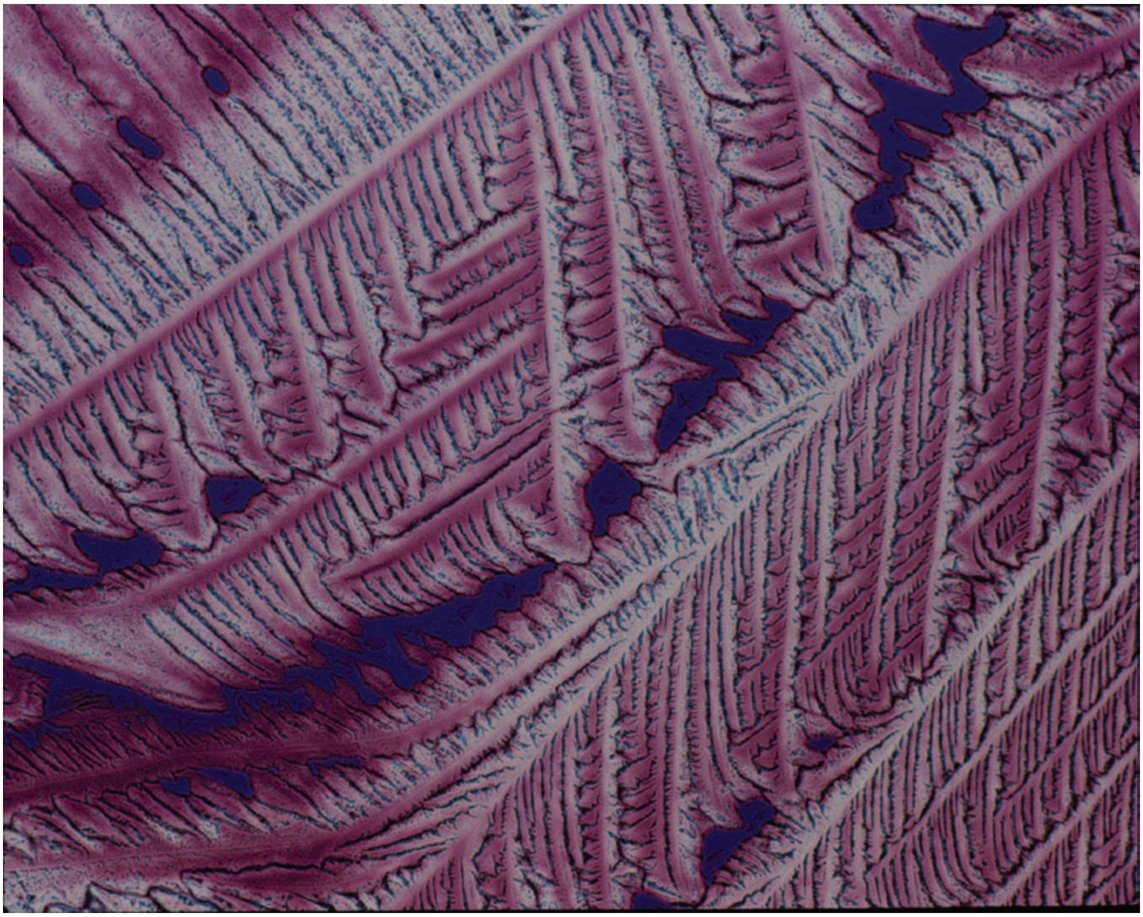
Courtois and his father collected seaweed on the coasts of Normandy and Brittany in France. Then they burned it. Next, they soaked the seaweed ashes in water to dissolve the sodium and potassium compounds. Sulfuric acid was added to react with the unwanted seaweed chemicals. Finally, they allowed the water to evaporate, leaving the compounds behind. These compounds are white crystals, much like ordinary table salt. The compounds were sold to large industrial businesses for use in such products as table salt and baking soda.

One day in 1811, Courtois made a mistake. He added too much sulfuric acid to the mixture. He was amazed to see clouds of beautiful violet vapor rising from the mixture. He decided to study the new material. Eventually, he proved it was a new element. He named the element after its color. In Greek, the word *iodes* means "violet."

Physical Properties

Iodine is one of the most striking and beautiful of all elements. As a solid, it is a heavy, grayish-black, metallic-looking material. When heated, it does not melt. Instead, it sublimes. Sublimation is the process by which a solid turns directly to a gas without first melting. The resulting iodine vapor has a violet color and a harsh odor. If a cold object, such as an **iron** bar, is placed in these vapors, iodine changes back to a solid. It forms attractive, delicate, metallic crystals.

Iodine dissolves only slightly in water. But it dissolves in many other liquids to give distinctive purple solutions. If heated under the proper



A magnified view of a crystal of iodine. © ALFRED PASIEKA/PHOTO RESEARCHERS, INC.

conditions, it can be made to melt at 236.3°F (113.5°C) and to boil at 363°F (184°C). The density of the element is 4.98 grams per cubic centimeter, nearly five times that of water.

Chemical Properties

Like the other halogens, iodine is an active element. However, it is less active than the three halogens above it in the periodic table. Its most common compounds are those of the alkali metals, sodium, and potassium. But it also forms compounds with other elements. It even forms compounds with the other halogens. Some examples are iodine monobromide (IBr), iodine monochloride (ICl), and iodine pentafluoride (IF_5).

Occurrence in Nature

Iodine is not very abundant in Earth's crust. Its abundance is estimated to be about 0.3 to 0.5 parts per million. It ranks in the bottom third of the elements in terms of abundance. It is still more common than **cadmium**, **silver**, **mercury**, and **gold**. Its abundance in seawater is estimated to be even less, about 0.0003 parts per million.

Iodine tends to be concentrated in Earth's crust in only a few places. These places were once covered by oceans. Over millions of years, the oceans evaporated. They left behind the chemical compounds that had been dissolved in them. The dry chemicals left behind were later buried by earth movements. Today, they exist underground as salt mines.

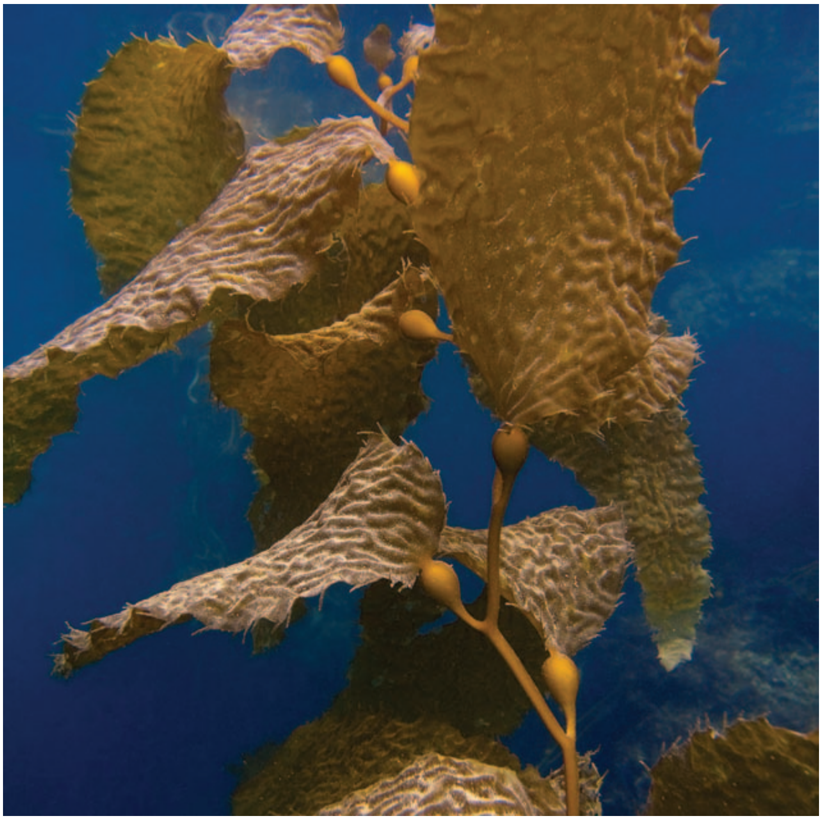
Iodine can also be collected from seawater, brackish water, brine, or sea kelp. Seawater is given different names depending on the amount of solids dissolved in it. Brackish water, for example, has a relatively low percentage of solids dissolved in water. The range that is sometimes given is 0.05 to 3 percent solids in the water. Brine has a higher percentage of dissolved solids. It may contain anywhere from 3 to 20 percent of solids dissolved in water.

Finally, sea kelp is a form of seaweed. As it grows, it takes iodine out of seawater. Over time, sea kelp has a much higher concentration of iodine than seawater. Sea kelp is harvested, dried, and burned to collect iodine. The process is not much different from the one used by Courtois in 1811.

Isotopes

Only one naturally occurring isotope of iodine is known: iodine-127. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty-three radioactive isotopes of iodine have been made artificially. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

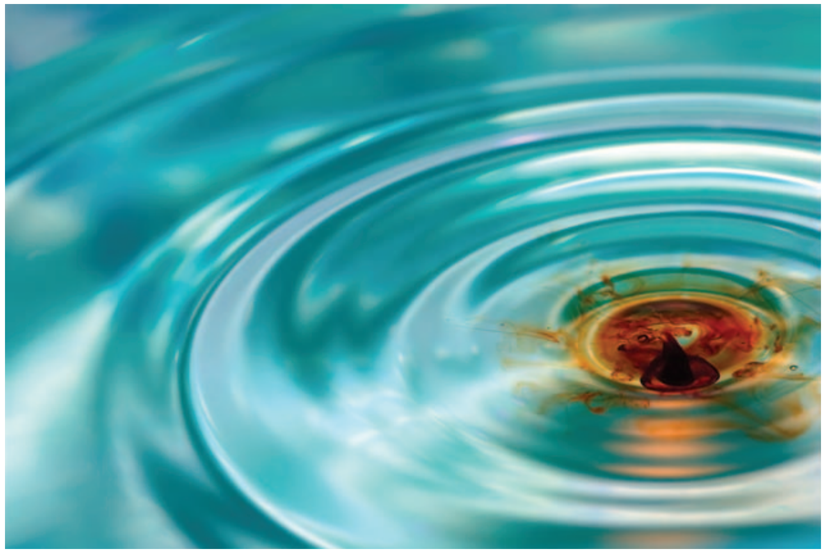


Kelp, a type of seaweed, is a popular source of iodine, since it absorbs the element from seawater. IMAGE COPYRIGHT 2009, EPIC STOCK. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

A number of iodine isotopes are used commercially. In medical applications, these isotopes are injected into the body or given to the patient through the mouth. The isotopes then travel through the body in the bloodstream. As they travel, they give off radiation. That radiation can be detected by using X-ray film. A medical specialist can tell how well the body is functioning by observing the pattern of radiation.

Iodine isotopes are used in many ways. Iodine-123 is used in studies of the brain, kidneys, and thyroid. Iodine-125 is used in studies of the pancreas, blood flow, thyroid, liver, take-up of minerals in bones, and loss of proteins in the body. And iodine-131 is used in studies of the liver, kidneys, blood flow, lungs, brain, pancreas, and thyroid.

The most common iodine isotope used is iodine-131. When iodine (of any kind) enters the body, it tends to go directly to the thyroid. The iodine is then used to make thyroid hormones. If radioactive iodine is used, a doctor can tell how well the thyroid gland is working. If a high



A drop of iodine is shown splashing into a bowl of water.

level of radiation is given off, the gland may be overactive. If a low level of radiation is given off, the gland may be underactive. In either case, the person may need some treatment to help the thyroid gland work more normally.

Extraction

A number of methods are available for producing iodine. In one method, sodium iodide (NaI) or potassium iodide (KI) from brine wells is treated with chlorine (Cl_2) gas. The more active chlorine replaces iodine from the sodium or potassium iodide, leaving behind free iodine. In another process, silver nitrate ($AgNO_3$) is added to brine. The silver iodide (AgI) that forms in this process precipitates out (settles out of solution) and is treated with metallic iron. The iron replaces silver in the silver iodide, forming iron(III) iodide (FeI_3). The iron(III) iodide is then reacted with chlorine to obtain free iodine. A third method begins with sodium iodate ($NaIO_3$), commonly found in Chilean saltpeter. The sodium iodate is first treated with sodium bisulfite ($NaHSO_3$) to obtain sodium iodide. The sodium iodide is then allowed to react with excess sodium iodate to produce pure iodine.

Uses and Compounds

One of the major uses of iodine and its compounds is in sanitation systems or in making various antiseptics and drugs. Iodine is also used to make

Low Iodine Levels: A Correctable Problem

The amount of iodine in the human body is very small. To calculate the amount of iodine in one's body, one's body weight is divided by 2,500,000. That number is the weight of iodine in the typical human body. For normal people, the amount is about equal to the size of the head of a pin.

That tiny dot of iodine can mean the difference between good and bad health. People who do not have enough iodine may develop serious health problems. At one time, the most common of those problems was a disease known as goiter. Goiter is a large lump in the neck that develops as the thyroid grows out of control. (It can grow as large as a grapefruit.) A goiter develops as the thyroid tries to make certain hormones, but it does not receive enough iodine from the person's diet. So the thyroid keeps expanding, trying to do its job, until it forms a goiter.

A lack of iodine can cause other problems too. For example, thyroid hormones are needed for normal brain development in an unborn child. They are also needed to continue that development after birth. People who do not include enough iodine in their diet do not develop normally. Today, experts say that low levels of iodine are the leading cause of mental retardation, deafness, mutism (the inability to speak), and paralysis. They also say less serious problems can be blamed on low iodine levels. These problems include lethargy (drowsiness), clumsiness, and learning disabilities.

Low iodine levels can be easily corrected. In most developed countries today, companies that make table salt add a small amount of potassium iodide (KI) to their salt. The salt is labeled "iodized salt." People who use iodized salt get all the iodine they need for normal thyroid function.

But people who live in developing countries may not be able to get iodized salt. The World Health Organization (WHO) is trying to find ways to provide iodine to such people. In 2007, the WHO estimated that 31 percent of people worldwide were not getting enough iodine in their diets. WHO scientists noted that severe iodine deficiency leads many people to develop mental disabilities. The WHO and other organizations are working to ensure that future generations in these regions get the iodine needed to develop and function normally.

dyes, photographic film, and specialized soaps. It is used in some industries as a catalyst. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction.

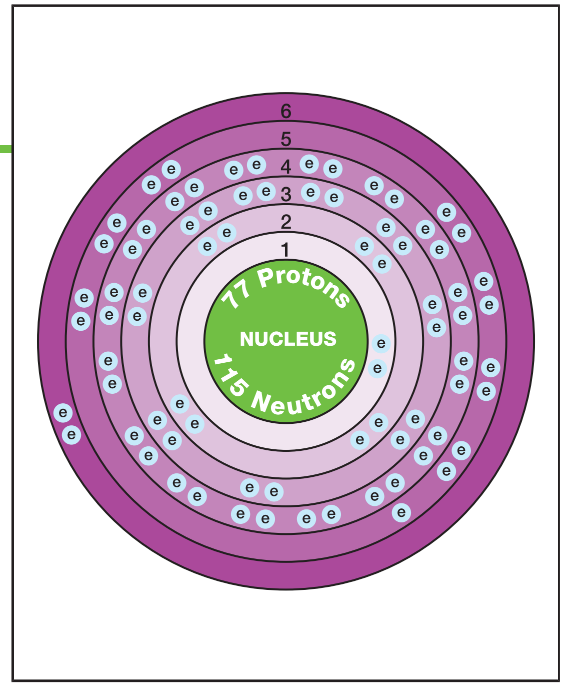
Health Effects

Iodine can have both favorable and unfavorable effects on living organisms. It tends to kill bacteria and other disease-causing organisms. In fact, this property leads to its use in sanitation systems and as an antiseptic. An antiseptic is a chemical that stops the growth of germs. Not so long ago, tincture of iodine was one of the most popular antiseptics. It was applied to cuts and wounds to prevent infection. Tincture is a solution made by dissolving some substance (such as iodine) in alcohol rather than in water. Today, tincture of iodine has been replaced by other antiseptics.

One reason that tincture of iodine is used less commonly today is that it can also cause problems. In higher doses, iodine can irritate or burn the skin. It can also be quite poisonous if taken internally.

Iodine plays an important role in the health of plants and animals. It is needed to maintain good health and normal growth. In humans, iodine is used to make a group of important compounds known as thyroid hormones. These chemicals are produced in the thyroid gland at the base of the neck. These chemicals control many important bodily functions. A lack of thyroid hormones can result in the disorder known as goiter. Goiter causes a large lump in the neck as the thyroid grows out of control. Iodine is added to table salt today, so goiter is rarely seen in the United States.

Iridium



Overview

Iridium is in Group 9 (VIIIB) of the periodic table. The periodic table is a chart that shows how elements are related to one another. Iridium is a transition metal that is also part of the **platinum** family.

The metals in the platinum family are also known as the noble metals. They have this name because they do not react well with other elements and compounds. They appear to be "too superior" to react with most other substances.

In fact, iridium is the most corrosion-resistant metal known. It is not affected by high temperatures, acids, bases, or most other strong chemicals. That property makes it useful in making objects that are exposed to such materials.

Iridium may be a key element in the puzzle of dinosaur extinction. Scientists search for iridium in the soil to track the impact that a giant meteor had on Earth 65 million years ago.

Discovery and Naming

The platinum metals posed a difficult problem for early chemists. These metals often occurred mixed together in the earth. When a scientist

Key Facts

Symbol: Ir

Atomic Number: 77

Atomic Mass: 192.217

Family: Group 9 (VIIIB); transition metal; platinum group

Pronunciation: i-RI-dee-um

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of any one metal alone.

Aqua regia: A mixture of two strong acids—nitric acid and hydrochloric acid.

Density: The mass of a substance per unit volume.

Ductile: Capable of being drawn into thin wires.

Halogens: Elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Platinum family (noble metals): A group of elements that occur close to platinum in the periodic table and in Earth's surface.

Radioactive isotope: An isotope that gives off radiation and changes into a new form.

Reactive: Combines with other substances relatively easily.

thought that he or she was analyzing a sample of platinum, the sample often contained iridium, **rhodium**, **osmium**, and other metals as well.

The work of French chemist Pierre-François Chabaneau is an example. In the late 1780s, the Spanish government gave its entire supply of platinum to Chabaneau to study. But Chabaneau's experiments puzzled him. Sometimes the platinum he worked with could be hammered into flat plates easily. At other times, it was brittle and shattered when hammered. Chabaneau did not realize that the "platinum" he was studying included various amounts of other noble metals.

In the early 1800s, a number of chemists worked to separate the platinum metals. One of those chemists was an English scientist named Smithson Tennant (1761–1815). Like so many others, Tennant became interested in chemistry at an early age. He is said to have made gunpowder to use in fireworks when he was only nine years old!

In 1803, Tennant attempted to dissolve platinum in aqua regia. Aqua regia is a mixture of two strong acids—nitric acid and hydrochloric acid. He found that most of the platinum metal dissolved, leaving a small amount of black powder. Other chemists had not bothered to study the powder. But Tennant did. He discovered that it had properties very different from those of platinum. He realized he had discovered a new element. He named it iridium, from the Greek goddess Iris, whose symbol is a rainbow. Tennant chose this name because the compounds of iridium have so many different colors. For example, iridium potassium

Small amounts of iridium can be found in meteorites. The Barrington Crater (also known as Meteor Crater), in northern Arizona, was created about 25,000 years ago by a meteorite the size of a large house. It hit the ground at 9 miles per second, and it created a hole 0.7 miles (1.2 kilometers) across and 590 feet (180 meters) deep. IMAGE COPYRIGHT 2009, ALEX NEAUVILLE. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

chloride (K_2IrCl_6) is dark red, iridium tribromide ($IrBr_3$) is olive-green, and iridium trichloride ($IrCl_3$) is dark green to blue-black.

Physical Properties

Iridium metal is silvery-white with a density of 22.65 grams per cubic centimeter. A cubic centimeter of iridium weighs 22.65 times as much as a cubic centimeter of water. It is one of the two densest elements known (the other being osmium). Iridium has a melting point of 4,429°F (2,443°C) and a boiling point of about 8,130°F (4,500°C). Cold iridium metal cannot be worked easily. It tends to break rather than bend. It becomes more ductile (flexible) when hot. Ductile means capable of being drawn into thin wires. Therefore, it is usually shaped at high temperatures.

What caused the dinosaurs to die off? Many scientists theorize that the fate of the dinosaurs was sealed after an asteroid struck Earth about 65 million years ago. Can iridium help solve the puzzle? IMAGE COPYRIGHT 2009, aGINGER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Chemical Properties

Iridium is unreactive at room temperatures. When exposed to air, it reacts with oxygen to form a thin layer of iridium dioxide (IrO_2).

$$Ir + O_2 \rightarrow IrO_2$$

At high temperatures, the metal becomes more reactive. Then it reacts with oxygen and halogens to form iridium dioxide and iridium trihalides. For example:

$$2Ir + 3Cl_2 \rightarrow 2IrCl_3$$

Occurrence in Nature

Iridium is one of the rarest elements in Earth's crust. Its abundance is estimated to be about two parts per billion. Interestingly, it is more abundant in other parts of the universe. Iron meteorites, for example, generally contain about 3 parts per million of iridium. Stony meteorites contain less iridium, about 0.64 parts per million.

Iridium usually occurs in combination with one or more other noble metals. Two common examples are osmiridium and iridosmine,

This image from the National Aeronautics and Space Administration (NASA) shows what it might have looked like when an asteroid struck Earth millions of years ago. Scientists theorize that an iridium-rich layer formed on Earth when the asteroid hit. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA).

combinations of iridium and osmium. The most important sources of iridium metal are Canada, South Africa, Russia, and the state of Alaska.

Iridium's Link to Dinosaur Extinction Iridium occurrences may hold the key to solving the mystery of why the dinosaurs went extinct. The question of what happened to the dinosaurs has long been one of the most interesting and puzzling issues in science. What happened to make these huge reptiles disappear in such a short period of geologic time?

One answer might be found in the Asteroid Disaster Theory. According to this theory, a huge asteroid struck Earth's surface about 65 million years ago. The exploding asteroid threw enormous amounts of dust into the air. The dust blocked out sunlight for more than a year.

As a result, plants on Earth's surface died. Dinosaurs who lived on those plants died out. So did the meat-eating dinosaurs who lived off the plant eaters.

But how is it possible to know if an asteroid really did hit Earth's surface so long ago? Scientists believe they have now found an answer.

In some parts of the earth, scientists have found a layer of crust that contains an unusually high level of iridium metal. Although iridium rarely occurs on Earth, it is found much more commonly in meteors and asteroids. Scientists believe the iridium-rich layer was formed when an asteroid struck Earth's surface.

This "iridium clue" is a key, therefore, to understanding how dinosaurs disappeared from Earth. And could explain why they, and so many other species of plants and animals, died out so suddenly.

Isotopes

Two naturally occurring isotopes of iridium exist: iridium-191 and iridium-193. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fifty-three radioactive isotopes of iridium have been made. A radioactive isotope is one that gives off radiation and changes into a new form. The only important radioactive isotope of iridium is iridium-192. This isotope has a half-life of about 74 days. A half-life is the time it takes for one half of a sample to break down. Iridium-192 is used to make X-ray photographs of metal castings and to treat cancer.

Extraction

Iridium and the other platinum metals tend to occur together. A series of chemical reactions is used to separate one metal from the other. The other metals are then removed by other techniques. Very little iridium is produced each year, probably no more than a few metric tons. According to the U.S. Geological Survey (USGS), the price of iridium in 2008 was estimated to be approximately $450 per troy ounce.

Uses

One of the primary uses of iridium is in the manufacture of alloys. An alloy is made by melting and mixing two or more metals. An alloy's properties differ from those of the elements that make it up. Iridium is often combined with platinum, for example, to provide a stronger material than the platinum itself. These alloys are very expensive and are used for only special purposes. For instance, the spark plugs used in helicopters are made of a platinum-iridium alloy. Such alloys are also used for electrical contacts, special types of electrical wires, and electrodes.

Iridium metal is also being used as catalysts. Catalysts are substances that speed up a reaction without changing themselves. Iridium catalysts have been used in amazing new products. For example, one kind of iridium catalyst is able to capture sunlight and turn it into chemical energy. That process is similar to the one used by plants in photosynthesis. Finding a synthetic (artificial) way to make photosynthesis happen is one of the great goals of modern chemistry.

Space technology often uses alloys that are too expensive for everyday use. An example is the propulsion systems used for keeping satellites in place. Some of these systems use alloys made of iridium and another platinum metal, **rhenium**. These alloys remain strong at high temperatures and are not attacked by fuels used in the systems.

An interesting use of iridium involves the official world standard for the kilogram. The standard, kept at the International Bureau of Weights and Measures in Paris, France, is a piece of platinum-iridium metal stored in an airtight jar. The standard is made of platinum and iridium to protect it from reacting with oxygen and other chemicals in the air. In this way, the standard's weight will always remain exactly the same.

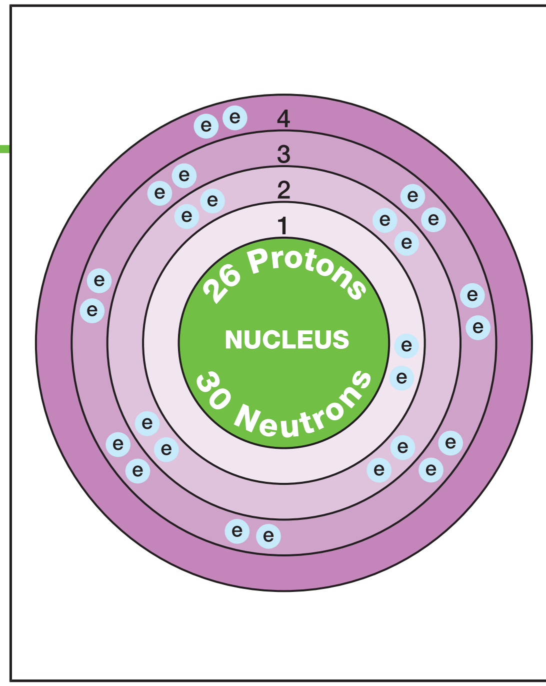
Compounds

The compounds of iridium have almost no practical applications. A few are used in coloring ceramics because of their striking colors.

Health Effects

Scientists are not aware of any health benefits or risks associated with iridium. Its compounds are thought to be irritating to the skin, eyes, and respiratory system, and toxic if ingested (swallowed).

Iron



Key Facts

Symbol: Fe

Atomic Number: 26

Atomic Mass: 55.845

Family: Group 8 (VIIIB); transition metal

Pronunciation: EYE-urn

Overview

The period in human history beginning in about 1200 BCE is called the Iron Age. It was at about this time that humans first learned how to use iron metal. But in some ways, one could refer to the current era as the New Iron Age. Iron is probably the most widely used and most important metal today. No other metal is available to replace iron in all its many applications.

Iron is a transition metal. The transition metals are the elements that make up Groups 3 through 12 in the periodic table. The periodic table is a chart that shows how elements are related to one another. The transition metals are typical metals in that they tend to be bright, shiny, silvery solids. They all tend to conduct heat and electricity well. And they usually have high melting points.

Iron normally does not occur as a free element in the earth. In fact, iron was not of much value to humans until they learned how to free iron from its compounds. Once they could do that, humans were able to make tools, weapons, household implements, and other objects out of iron. This step forward marked the beginning of the Iron Age.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Tensile: Capable of being stretched without breaking.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Workability: The ability to work with a metal to get it into a desired shape or thickness.

Iron is most valuable not as a pure metal, but in alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The best known and most widely used alloy of iron is steel. Steel contains iron and at least one other element. Today, specialized steels of all kinds are available for many different applications.

Discovery and Naming

Ancient Egyptians had learned how to use iron before the First Dynasty, which began in about 3400 BCE. The Egyptians probably found the iron in meteorites. Meteorites are chunks of rock and metal that fall from the sky. Some meteorites are very rich in iron. The Egyptians made tools and jewelry out of iron.

Iron was also known to early Asian civilizations. In Delhi, India, for example, a pillar made out of iron built in 415 CE still stands. It weighs about 7 short tons (6.5 metric tons) and remains in good condition after nearly 1,600 years.

Early Chinese civilizations also knew about iron. Workers learned to produce iron as early as 200 BCE. A number of iron objects, including cannons, remain from the Han period (202 BCE to 221 CE.)

Some meteorites are very rich in iron. Here, children play on the Williamette meteorite in Hayden Planetarium in New York City, in 1939. Named for the Williamette Valley in Oregon where it was discovered, the meteorite weighs 15.5 tons and is the largest one yet found in the United States. © CORBIS-BETTMANN.

The Bible also includes many mentions of iron. For example, a long passage in the book of Job describes the mining of iron. Other passages tell about the processing of iron ore to obtain iron metal.

By the time of the Roman civilization, iron had become an essential metal. The historian Pliny (23–79 CE) described the role of iron in Rome:

> It is by the aid of iron that we construct houses, cleave rocks, and per form so many other useful offices of life. But it is with iron also that wars, murders, and robberies are effected, and this, not only hand to hand, but from a distance even, by the aid of weapons and winged

weapons, now launched from engines, now hurled by the human arm, and now furnished with feathery wings.

Even from the earliest days, humans probably seldom used iron in a pure form. It was difficult to make iron that was free of impurities, such as **carbon** and other elements. More important, however, it became obvious that iron *with* impurities was a stronger metal than iron *without* impurities.

It was not until 1786, however, that scientists learned what it was in steel that made it a more useful metal than iron. Three researchers, Gaspard Monge (1746–1818), C. A. Vandermonde, and Claude Louis Berthollet (1748–1822), solved the puzzle. They found that a small amount of carbon mixed with iron produced a strong alloy. That alloy was steel. Today, the vast amount of iron used in so many applications is used in the form of steel, not pure iron.

The chemical symbol for iron is Fe. That symbol comes from the Latin name for iron, *ferrum.*

Physical Properties

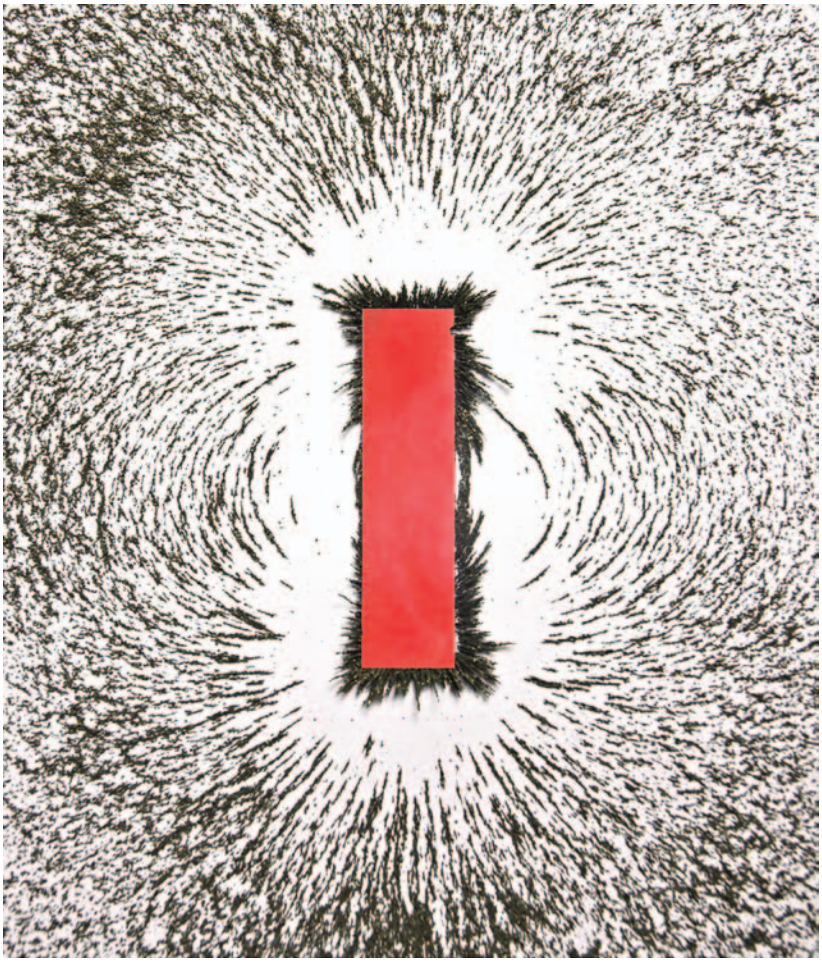
Iron is a silvery-white or grayish metal. It is ductile and malleable. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. It is one of only three naturally occurring magnetic elements. The other two are **nickel** and **cobalt**.

Iron has a very high tensile strength. Tensile strength is a measure of a substance's ability to be stretched without breaking. Iron is also very workable. Workability is the ability to bend, roll, hammer, cut, shape, form, and otherwise work with a metal to get it into a desired shape or thickness.

The melting point of pure iron is 2,797°F (1,536°C) and its boiling point is about 5,400°F (3,000°C). Its density is 7.87 grams per cubic centimeter, almost eight times that of water. The melting point, boiling point, and other physical properties of steel alloys may be quite different from those of pure iron.

Chemical Properties

Iron is a very active metal. It readily combines with **oxygen** in moist air. The product of this reaction, iron oxide (Fe_2O_3), is known as rust. Iron also reacts with very hot water and steam to produce **hydrogen** gas. It also dissolves in most acids and reacts with many other elements.



Iron is one of only three naturally occurring magnetic elements. Here, a bar magnet with iron filings shows a magnetic field pattern.

Occurrence in Nature

Iron is the fourth most abundant element in Earth's crust. Its abundance is estimated to be about 5 percent. Most scientists believe that Earth's core consists largely of iron. Iron is also found in the sun, asteroids, and stars.

The most common ores of iron are hematite, or ferric oxide (Fe_2O_3); limonite, or hydrated ferric oxide; magnetite, or iron oxide (Fe_3O_4); and siderite, or iron carbonate ($FeCO_3$). An increasingly important source of iron is taconite. Taconite is a mixture of hematite and silica (sand). It contains about 25 percent iron.

As of 2008, the largest producers of iron ore in the world were Brazil, Australia, India, Russia, and China. According to the U.S. Geological

Survey, 98 percent of the usable iron ore shipped in the United States came from mines in Michigan and Minnesota. The value of those shipments alone was estimated at more than $3 billion.

Isotopes

There are four naturally occurring isotopes of iron: iron-54, iron-56, iron-57, and iron-58. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-two radioactive isotopes of iron are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Two radioactive isotopes of iron are used in medical and scientific research. They are iron-55 and iron-59. These isotopes are used primarily as tracers in studies on blood. A tracer is a radioactive isotope whose presence in a system can easily be detected. The isotope is injected into the system. Inside the system, the isotope gives off radiation. That radiation can be followed by detectors placed around the system. Iron-55 and iron-59 are used to study the way in which red blood cells develop in the body. These studies can be used to tell if a person's blood is healthy.

Extraction

Iron goes through a number of stages between ore and final steel product. In the first stage, iron ore is heated with limestone and coke (pure carbon) in a blast furnace. A blast furnace is a very large oven in which the temperature may reach 2,700°F (1,500°C). In the blast furnace, coke removes oxygen from iron ore:

$$3C + 2Fe_2O_3 \xrightarrow{heat} 3CO_2 + 4Fe$$

The limestone removes impurities in the iron ore.

Iron produced by this method is about 91 to 92 percent pure. The main impurity left is carbon from the coke used in the furnace. This form of iron is known as pig iron. Pig iron is generally too brittle (it breaks too easily) to be used in most products.

A number of methods have been developed for purifying pig iron. A common method used is the basic oxygen process. In this process, pig iron is melted in a large oven. Then pure oxygen gas is blown through the molten pig iron. The oxygen burns off much of the carbon in the pig iron:

$$C + O_2 \xrightarrow{heat} CO_2$$

A small amount of carbon remains in the iron. The iron produced in this reaction is known as steel.

The term "steel" actually refers to a wide variety of products. The various forms of steel all contain iron and carbon. They also contain one or more other elements, such as **silicon**, **titanium**, **vanadium**, **chromium**, **manganese**, cobalt, nickel, **zirconium**, **molybdenum**, and **tungsten**. Two other steel-like products are cast iron and wrought iron. Cast

Although now outdated, cast-iron stoves were once the primary source of heat for many homes, as well as a means for cooking. IMAGE COPYRIGHT 2009, TYLER OLSON. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Long before digital cameras were invented, photographers printed pictures on metal plates. The tintype photograph (also known as a ferrotype), shown here featuring two African American soldiers during the Civil War (1861–1865), was actually made from a sheet of iron (not tin). LIBRARY OF CONGRESS.

iron is an alloy of iron, carbon, and silicon. Wrought iron contains iron and any one or more of many other elements. In general, however, wrought iron tends to contain very little carbon.

Uses

It would be impossible to list all uses of iron and steel products. In general, those products can be classified into categories: (1) automotive; (2) construction; (3) containers, packaging, and shipping; (4) machinery and industrial equipment; (5) rail transportation; (6) oil and gas industries; (7) electrical equipment; and (8) appliances and utensils.

Compounds

Some iron is made into compounds. The amount is very small compared to the amount used in steel and other iron alloys. Probably the fastest growing use of iron outside of alloys is in water treatment systems. The terms ferric and ferrous refer to two different forms in which iron occurs in compounds. Some of the important iron compounds are:

- ferric acetate ($Fe(C_2H_3O_2)_3$): used in the dyeing of cloth
- ferric ammonium oxalate ($Fe(NH_4)_3(C_2O_4)_4$): blueprints
- ferric arsenate ($FeAsO_4$): insecticide
- ferric chloride ($FeCl_3$): water purification and sewage treatment systems; dyeing of cloth; coloring agent in paints; additive for animal feed; etching material for engraving, photography, and printed circuits
- ferric chromate ($Fe_2(CrO_4)_3$): yellow pigment (coloring) for paints and ceramics
- ferric hydroxide ($Fe(OH)_3$): brown pigment for coloring rubber; water purification systems
- ferric phosphate ($FePO_4$): fertilizer; additive for animal and human foods
- ferrous acetate ($Fe(C_2H_3O_2)_2$): dyeing of fabrics and leather; wood preservative

- ferrous gluconate ($Fe(C_6H_{11}O_7)_2$): dietary supplement in "iron pills"
- ferrous oxalate (FeC_2O_4): yellow pigment for paints, plastics, glass, and ceramics; photographic developer
- ferrous sulfate ($FeSO_4$): water purification and sewage treatment systems; catalyst in production of ammonia; fertilizer; herbicide; additive for animal feed; wood preservative; additive to flour to increase iron levels

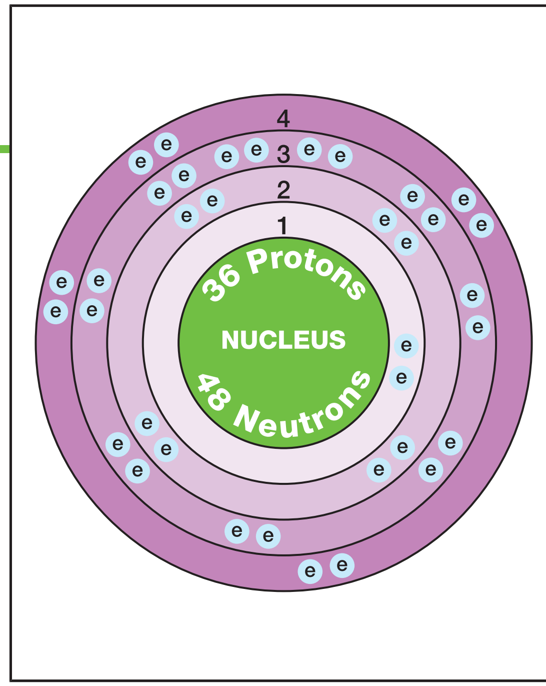
Health Effects

Iron is of critical importance to plants, humans, and other animals. It occurs in hemoglobin, a molecule that carries oxygen in the blood. It picks up oxygen in the lungs and carries it to the cells. In the cells, oxygen is used to produce energy that the body needs to survive, grow, and stay healthy.

The U.S. Department of Agriculture (USDA) provides recommendations regarding the amount of vitamins and minerals that people should consume daily in order to stay healthy. Using a calculator on the USDA Web site, a person can determine how much iron he or she needs, based on the person's age, gender, height, weight, and physical activity level. Iron is found in a number of foods, including meat, eggs, and raisins.

An iron deficiency (lack of iron) can cause serious health problems in humans. For instance, hemoglobin molecules may not form in sufficient numbers. Or they may lose the ability to carry oxygen. If this occurs, a person develops a condition known as anemia. Anemia results in fatigue. Severe anemia can result in a lowered resistance to disease and an increase in heart and respiratory (breathing) problems. Some forms of anemia can even cause death.

Krypton



Key Facts

Symbol: Kr

Atomic Number: 36

Atomic Mass: 83.798

Family: Group 18 (VIIIA); noble gas

Pronunciation: KRIP-ton

Overview

Krypton was one of three noble gases discovered in 1898 by Scottish chemist and physicist Sir William Ramsay (1852–1916) and English chemist Morris William Travers (1872–1961). Ramsay and Travers discovered the gases by allowing liquid air to evaporate. As it did so, each of the gases that make up normal air boiled off, one at a time. Three of those gases—krypton, **xenon**, and **neon**, were discovered for the first time this way.

The term noble gas refers to elements in Group 18 (VIIIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. These gases have been given the name "noble" because they act as if they are "too arrogant" to react with other elements. Until the 1960s, no compound of these gases was known. Since they are so inactive, they are also called the inert gases. Inert means inactive.

Krypton has relatively few commercial uses. All of them involve lighting systems in one way or another.

Discovery and Naming

By 1898, two members of the noble gas family had been discovered. They were **helium** (atomic number 2) and **argon** (atomic number 18).

WORDS TO KNOW

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Noble gas: An element in Group 18 (VIIIA) of the periodic table.

Periodic table: A chart that shows how the chemical elements are related to each other.

Phosphor: Material that gives off light when struck by electrons.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Spectrum (plural: spectra): The pattern of light given off by a glowing object, such as a star.

But no other elements in the family had been found. The periodic table contained empty boxes between helium and argon and below argon. The missing noble gases had atomic numbers 10, 36, 54, and 86. Chemists think of empty boxes in the periodic table as "elements waiting to be discovered."

Since the two known noble elements, helium and argon, are both gases, Ramsay and Travers hoped the missing elements were also gases. And if they were, they might be found in air. The problem was that air had already been carefully analyzed and found to be about 99.95 percent **oxygen**, **nitrogen**, and argon. Was it possible that the missing gases were in the last 0.05 percent of air?

To answer the question, the chemists worked not with air itself, but with liquid air. Air becomes liquid simply by cooling it far enough. The colder air becomes, the more gases within it turn into liquids. At –297.33°F (–182.96°C), oxygen changes from a gas into a liquid. At –320.42°F (–195.79°C), nitrogen changes from a gas into a liquid. And so on. Eventually, all the gases in air can be made to liquefy (change into a liquid).

But the reverse process also takes place. Suppose a container of liquid air holds 100 liters. The liquid air will warm up slowly. When its temperature reaches –320.42°F (–195.79°C), liquid nitrogen changes back to a gas. Since about 78 percent of air is nitrogen, only 22 percent of the original liquid air (22 liters) will be left.

When the temperature reaches –297.33°F (–182.96°C), oxygen changes from a liquid back to a gas. Since oxygen makes up 21 percent of air, another 21 percent (21 liters) of the liquid air will evaporate.

The work of Ramsay and Travers was very difficult, however, because the gases they were looking for are not abundant in air. Krypton, for example, makes up only about 0.000114 percent of air. For every 100 liters of liquid air, there would be only 0.00011, or about one-tenth of a milliliter of krypton. A 10th of a milliliter is about a drop. So Ramsay and Travers—although they didn't know it—were looking for one drop of krypton in 100 liters of liquid air!

Amazingly, they found it. The discovery of these three gases was a great credit to their skills as researchers. They suggested the name krypton for the new element. The name was taken from the Greek word *kryptos* for "hidden."

Physical Properties

Krypton is a colorless, odorless gas. It has a boiling point of –243.2°F (–152.9°C) and a density of 3.64 grams per liter. That makes krypton about 2.8 times as dense as air.

Chemical Properties

For many years, krypton was thought to be completely inert. Then, in the early 1960s, it was found to be possible to make certain compounds of the element. English chemist Neil Bartlett (1932–2008) found ways to combine noble gases with the most active element of all, **fluorine**. In 1963, the first krypton compounds were made—krypton difluoride (KrF_2) and krypton tetrafluoride (KrF_4). Other compounds of krypton have also been made since that time. However, these have no commercial uses. They are only laboratory curiosities.

Occurrence in Nature

The abundance of krypton in the atmosphere is thought to be about 0.000108 to 0.000114 percent. The element is also formed in Earth's crust when **uranium** and other radioactive elements break down. The amount in Earth's crust is too small to estimate, however.

Isotopes

Six naturally occurring isotopes of krypton exist. They are krypton-78, krypton-80, krypton-82, krypton-83, krypton-84, and krypton-86. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the

Krypton vs. Kryptonite

The famous cartoon character Superman has many super powers. Everybody knows that. He's the Man of Steel. He has X-ray vision. His hearing is so good, he can tune in on one voice in a crowded city. And, of course: "He's faster than a speeding bullet! More powerful than a locomotive! Able to leap tall buildings in a single bound!"

But there's one substance that weakens Superman: kryptonite! If exposed to kryptonite, Superman experiences pain and loses his super powers. If exposed for too long, he can even die.

Kryptonite, of course, is purely fictional. Despite the similarity in names, kryptonite has nothing to do with element 36, krypton. According to cartoon legend, Superman came from the planet Krypton. Kal-El, as he was originally known, was placed in a spaceship by his parents, moments before the planet exploded.

Unfortunately, as the young Superman blasted away from Krypton, a piece of kryptonite got stuck on the spaceship. The same terrible forces that caused the planet to explode, also had created the deadly kryptonite. And, as Superman would later find out, arch-villains always seem to get their hands on this green glowing rock!

Aside from the fictitious nature of kryptonite, there is another difference between it and krypton. Kryptonite is a rock—one that can cause great harm to Superman. Krypton is an inert gas that has no effect on anything.

element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-three radioactive isotopes of krypton are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of krypton is used commercially, krypton-85. It can be combined with phosphors to produce materials that shine in the dark. A phosphor is a material that shines when struck by electrons. Radiation given off by krypton-85 strikes the phosphor. The phosphor then gives off light. The same isotope is also used for detecting leaks in a container. The radioactive gas is placed inside the container to be tested. Since the gas is inert, krypton will not react with anything else in the container. But if the container has a leak, some radioactive krypton-85 will escape. The isotope can be detected with special devices for detecting radiation.

Cartoonists attempted to bring a little science into the Superman comics by having the superhero lose his powers when exposed to kryptonite. However, kryptonite is not related to krypton. In fact, it doesn't really exist. AP IMAGES.

Krypton-85 is also used to study the flow of blood in the human body. It is inhaled as a gas, and then absorbed by the blood. It travels through the bloodstream and the heart along with the blood. Its pathway can be followed by a technician who holds a detection device over the patient's body. The device shows where the radioactive material is going and how fast it is moving. A doctor can determine whether this behavior is normal or not.

Extraction

Krypton is still obtained by allowing liquid air to evaporate.

Uses

The only commercial uses of krypton are in various kinds of lamps. When an electric current is passed through krypton gas, it gives off a very

Krypton's Role in Metrics

The meter is the standard unit of length in the metric system. It was first defined in 1791. As part of the great changes brought by the French Revolution, an entirely new system of measurement was created: the metric system.

At first, the meter was defined in a very simple way. It was the distance between two lines scratched into a metal bar kept outside Paris. For many years, that definition was satisfactory for most purposes. Of course, it created a problem. Suppose someone in the United States was in the business of making meter sticks. That person would have to travel to Paris to make a copy of the official meter. Then the copy would have to be used to make other copies. The chances for error in this process are significant.

In 1960, scientists had another idea. They suggested using light produced by hot krypton as the standard of length. Here is how that standard was developed:

When an element is heated, it absorbs energy from the heat. The atoms present in the element are in an "excited," or energetic, state. Atoms normally do not remain in an excited state very long. They give off the energy they just absorbed and return to their normal, "unexcited" state. The energy they give off can take different forms. One of those forms is light.

The kind of light given off is different for each element and for each isotope. The light usually consists of a series of very bright lines called a spectrum. The number and color of the lines produced is specific to each element and isotope.

When one isotope of krypton, krypton-86, is heated, it gives off a very clear, distinct, bright line with a reddish-orange color. Scientists decided to define the meter in terms of that line. They said that a meter is 1,650,763.73 times the width of that line.

This standard had many advantages. For one thing, people worldwide could find the official length of a meter. All one needed was the equipment to heat a sample of krypton-86. Then one had to look for the reddish-orange line produced. The length of the meter, then, was 1,650,763.73 times the width of that line.

This definition for the meter lasted only until 1983. Scientists then decided to define a meter by how fast light travels in a vacuum. This system is even more exact than the one based on krypton-86.

bright light. Perhaps the most common application of this principle is in airport runway lights. These lights are so bright that they can be seen even in foggy conditions for distances up to 1,000 feet (300 meters). The lights do not burn continuously. Instead, they send out very brief pulses of light. The pulses last no more than about 10 millionths of a second (10 microseconds). They flash on and off about 40 times per minute. Krypton is also used in slide and movie projectors.

Krypton gas is also used in making "neon" lights. Neon lights are colored lights often used in advertising. They are similar to fluorescent lightbulbs. But they give off a colored light because of the gas they contain. Some neon lights *do* contain the gas neon, but others contain other noble gases. A neon light filled with krypton, for example, glows yellow.

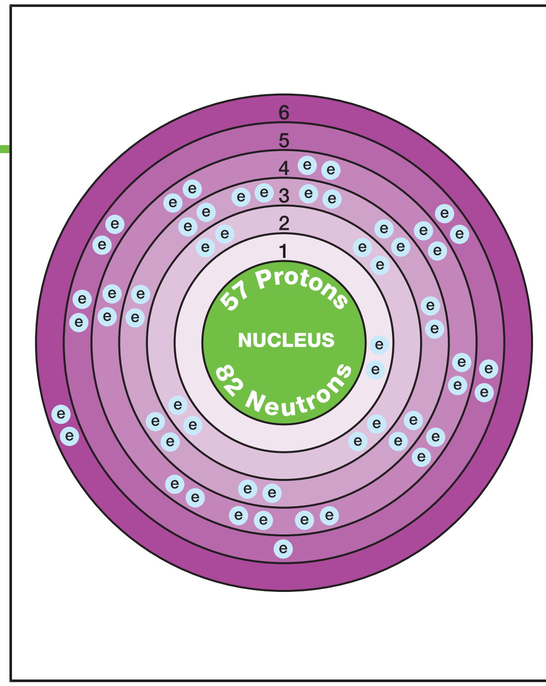
Compounds

Compounds of krypton have been prepared in the laboratory but do not exist in nature. The synthetic (artificial) compounds are used for research purposes only.

Health Effects

There is no evidence that krypton is harmful to humans, other animals, or plants.

Lanthanum



Key Facts

Symbol: La

Atomic Number: 57

Atomic Mass: 138.90547

Family: Group 3 (IIIB); transition metal

Pronunciation: LAN-tha-num

Overview

Lanthanum is the third element in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Lanthanum is a transition metal in Group 3 (IIIB) of the periodic table. The transition metals are found in the center of the periodic table, in Groups 3 through 12.

Lanthanum can also be classified as a rare earth element. The rare earth elements include the 15 elements that make up Row 6 of the periodic table between barium and hafnium. That group of elements is also called the lanthanoids. Either way of classifying lanthanum is acceptable to most chemists.

Lanthanum was first discovered by Swedish chemist Carl Gustav Mosander (1797–1858) in 1839. This discovery was the first chapter in a long and interesting story. At the end of that story, six more elements had been discovered. All of these elements occur together in nature and were once hard to separate from each other.

Lanthanum metal has relatively few uses. Some of its compounds however, are used in lamps, color television sets, cigarette lighters, optical fibers, and hybrid cars.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Carbon arc lamp: A lamp for producing very bright white light.

Ductile: Capable of being drawn into thin wires.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements that make up Row 6 of the periodic table between barium and hafnium.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Phosphor: A material that gives off light when struck by electrons.

Radioactivity: Having a tendency to break down and give off radiation.

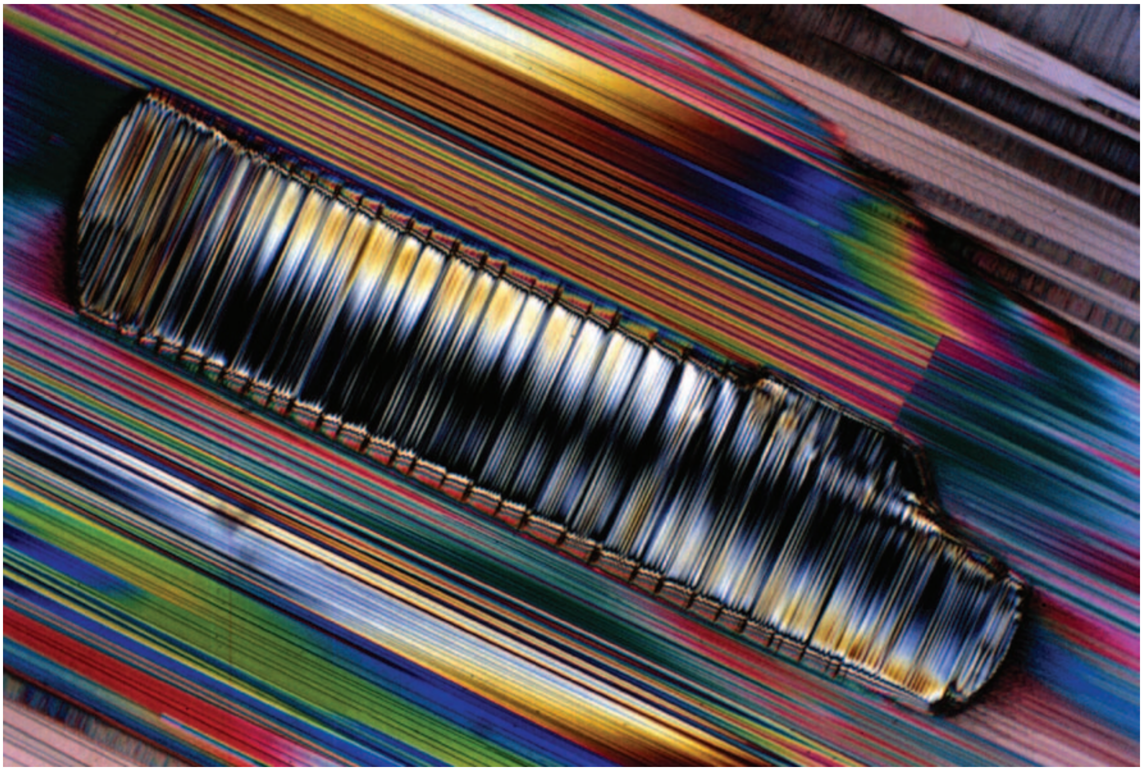
Discovery and Naming

Toward the end of the 1830s, Mosander became interested in an unusual black stone found near the town of Bastnas, Sweden. He learned that the stone contained two new materials. He thought those materials were both new elements. Mosander called them **cerium** and lanthanum. He was right about cerium, but wrong about lanthanum. The material Mosander called lanthanum later turned out to be a mixture of six new elements.

It took scientists more than 60 years to sort out these elements and separate them from each other. It was not until 1923 that a pure sample of lanthanum metal was even prepared. Still, Mosander is given credit for the discovery of lanthanum.

Physical Properties

Lanthanum is a white, ductile, malleable metal. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. Lanthanum is relatively soft and can be cut with a sharp knife. Its melting point is 1,690°F (920°C) and its boiling point is 6,249°F (3,454°C). Its density is about 6.18 grams per cubic centimeter.



Magnified view of lanthanum aluminate crystal. © MICHAEL W. DAVIDSON, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Chemical Properties

Lanthanum is a very active metal. It reacts with most acids and with cold water, although slowly. With hot water, it reacts more quickly:

$$2La + 6H_2O \rightarrow 2La(OH)_3 + 3H_2$$

Lanthanum also reacts with **oxygen** in the air, especially if the air is moist.

Occurrence in Nature

Lanthanum is relatively common in Earth's crust. Its abundance is thought to be as high as 18 parts per million. That would make it nearly as common as **copper** or **zinc**. Unlike those metals, however, it usually does not occur in one place, as in copper mines. Instead, it is spread widely throughout Earth's crust. Its most common minerals are monazite, bastnasite, and cerite. These minerals generally contain all the other rare earth elements as well.

Isotopes

Two naturally occurring isotopes of lanthanum are known. They are lanthanum-138 and lanthanum-139. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Lanthanum-138 is very rare and is radioactive. Its half life is about 100 billion years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. Only 5 grams of a 10-gram sample of lanthanum-138 will remain after 100 billion years. The other 5 grams would have broken down to form a new isotope.

Thirty-six artificial radioactive isotopes have also been made. These isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. None of the radioactive isotopes of lanthanum have any commercial use.

Extraction

The rare earth elements are very similar to each other. Separating them is a difficult task. The ores are first treated with sulfuric acid (H_2SO_4). The materials produced are then passed through a series of steps and the individual elements separated from each other.

Uses and Compounds

One of the most important uses of lanthanum compounds is in carbon arc lamps. In a carbon arc lamp, an electrical current is passed through the lamp electrode. The electrode is made of carbon and traces of other materials that have been added. The current causes the carbon to heat up and give off a brilliant white light. The exact color of the light depends on the other materials that have been added to the carbon. Lanthanum fluoride (LaF_3) and lanthanum oxide (La_2O_3) are usually used for this purpose.

These two compounds are also used in making phosphors. A phosphor is a material that gives off light when struck by electrons. The color of the phosphor depends on the elements present in the phosphor. The colors produced in a color television set are caused by phosphors painted on the back of the screen.

Compounds of lanthanum are also used to make special kinds of glass. High quality lenses, for example, are often made of glass containing a small amount of lanthanum.

One of the oldest uses of lanthanum metals is in the production of misch metal. Misch metal is an alloy that produces sparks when struck. One application of misch metal is in the manufacture of cigarette lighters.

A newer application of lanthanum glass is in making optical fibers. An optical fiber is a wire-like material made of glass. It carries light in the same way a copper wire carries electricity. Optical fibers have become popular methods for carrying audio, video, and digital messages. In many cases, optical fibers have replaced copper wires for this purpose.

In 1974, a team of French researchers invented a product called ZBLAN. It is made of **zirconium**, **barium**, lanthanum, **aluminum**, and **sodium**. ("ZBLAN" comes from the first letters of each element's symbol.) Scientists have found that ZBLAN is 100 times better at carrying messages than traditional optical fibers.

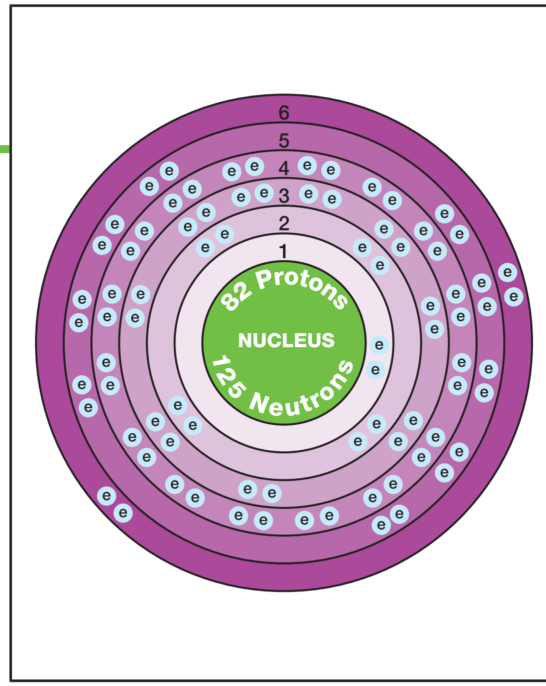
Lanthanum is also used in nickel-metal hydride (NiMH) batteries found in some hybrid cars.

As of 2010, China produced most of the rare earth elements used in high-tech and green (environmentally friendly) industries. Although such elements are found in other countries, including the United States, most nations rely on China to produce them. However, China's own growing demand for such elements raised concern about the potential for a rare earth supply shortage.

Health Effects

Lanthanum and its compounds are poisonous in high concentrations. They should be handled with care.

Lead



Key Facts

Symbol: Pb

Atomic Number: 82

Atomic Mass: 207.2

Family: Group 14 (IVA); carbon

Pronunciation: LED

Overview

Lead is the heaviest member of the **carbon** family. The carbon family consists of the five elements in Group 14 (IVA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Although a member of the carbon family, lead looks and behaves very differently from carbon.

Lead is one of only a few elements known to ancient peoples. One of the oldest examples of lead is a small statue found in Egypt. It was made during the First Dynasty, in about 3400 BCE. Mention of lead and lead objects can also be found in very old writings from India. And the Bible mentions lead in a number of passages.

Throughout history, lead has been used to make water and sewer pipes; roofing; cable coverings; type metal and other alloys; paints; wrappings for food, tobacco, and other products; and as an additive in gasoline. Since the 1960s, however, there has been a growing concern about the health effects of lead. For instance, scientists have found that lead can cause mental and physical problems in growing children. As a result, many common lead products have been or are being phased out.

WORDS TO KNOW

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

Discovery and Naming

Lead has been around for thousands of years. It is impossible to say when humans first discovered the element. It does not occur as an element in the earth very often. But one of its ores, lead sulfide (PbS), is fairly common. It is not difficult to obtain pure lead metal from lead sulfide. Humans probably discovered methods for doing so thousands of years ago.

By Roman times, lead metal was widely used. The far-reaching system that brought water to Rome contained many lead pipes. Sheets of lead were used as writing tablets and some Roman coins were also made of lead. Of particular interest was the use of lead in making pots and pans. Modern scientists believe many Romans may have become ill and died because of this practice. Cooking liquids in lead utensils tends to make the lead dissolve. It got into the food being cooked. People who ate those foods got more and more lead into their bodies. Eventually, the effects of lead poisoning must have begun to appear.

Of course, the Romans had little understanding of the connection between lead and disease. They probably never realized that they were poisoning themselves by using lead pots and pans.

No one is quite sure how lead got its name. The word has been traced to manuscripts that date to before the 12th century. Romans called the metal *plumbum.* It is from this name that the element's chemical symbol comes: Pb. Compounds of lead are sometimes called by this old name, such as plumbous chloride.

Physical Properties

Lead is a heavy, soft, gray solid. It is both ductile and malleable. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. It has a shiny surface when first cut, but it slowly tarnishes (rusts) and becomes dull. Lead is easily worked. "Working" a metal means bending, cutting, shaping, pulling, and otherwise changing the shape of the metal.

The melting point of lead is 621.3°F (327.4°C), and its boiling point is 3,180 to 3,190°F (1,750 to 1,755°C). Its density is 11.34 grams per cubic centimeter. Lead does not conduct an electric current, sound, or vibrations very well.

Chemical Properties

Lead is a moderately active metal. It dissolves slowly in water and in most cold acids. It reacts more rapidly with hot acids. It does not react with **oxygen** in the air readily and does not burn.

Occurrence in Nature

The abundance of lead in Earth's crust is estimated to be between 13 and 20 parts per million. It ranks in the upper third among the elements in terms of its abundance.

Lead rarely occurs as a pure element in the earth. Its most common ore is galena, or lead sulfide (PbS). Other ores of lead are anglesite, or lead sulfate ($PbSO_4$); cerussite, or lead carbonate ($PbCO_3$); and mimetite ($PbCl_2 \cdot Pb_3(AsO_4)_2$).

As of 2008, the largest producers of lead resources in the world included China, Australia, the United States, Peru, Mexico, Canada, and India. In the United States, most of the lead produced came from Missouri, Alaska, Idaho, Montana, and Washington. According to the U.S. Geological Survey (USGS), 88 percent of the lead used in the United States was used by the lead-acid storage battery industry.

Isotopes

Four naturally occurring isotopes of lead occur. They are lead-204, lead-206, lead-207, and lead-208. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

One naturally occurring isotope of lead is radioactive, lead-204. In addition, 44 radioactive isotopes of lead have been made artificially in the laboratory. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of lead, lead-210, is sometimes used in medicine. This isotope gives off radiation that can kill cancer cells. It is also used to treat non-cancerous eye disorders.

Extraction

Lead is obtained from its ores by a method used with many metals. First, the ore is roasted (heated in air). Roasting, also called smelting, converts the ore to a compound of lead and oxygen, lead oxide (PbO_2). Lead oxide is then heated with charcoal (pure carbon). The carbon takes oxygen away from the lead oxide. It leaves pure lead behind:

$$PbO_2 + C \quad \text{heated} \rightarrow CO_2 + Pb$$

Lead obtained in this way is not very pure. It can be purified electrolytically. Electrolytic refining involves passing an electric current through a compound. Very pure lead is collected at one side of the container in which the reaction is carried out.

Lead is also recovered in recycling programs. Recycling is the process by which a material is retrieved from a product that is no longer used. For example, old car batteries were once just thrown away. Now they are sent to recycling plants where lead can be extracted and used over and over again. It is not necessary to get all the lead that industry needs from new sources, such as ores.

Uses

The lead industry is undergoing dramatic change. Many products once made with lead no longer use the element. The purpose of this change is to reduce the amount of lead that gets into the environment. Examples of such products include ammunition, such as shot and bullets; sheet lead used in building construction; solder; water and sewer pipes; ball bearings; radiation shielding; and gasoline. These changes are possible because manufacturers are finding safer elements to use in place of lead.

Other uses of lead have not declined. The best example is lead storage batteries. A lead storage battery is a device for converting chemical energy into electrical energy. The majority of cars and trucks has at least one lead storage battery. But no satisfactory substitute for it has been found. About 88 percent of all lead consumed in the United States goes to the manufacture of lead storage batteries. In addition to cars and trucks, these batteries are used for communication networks and emergency power supplies in hospitals, and in forklifts, airline ground equipment, and mining vehicles.

Compounds

A small percentage of lead is used to make lead compounds. Although the amount of lead is small, the variety of uses for these compounds is large. Some examples of important lead compounds are:

- lead acetate ($Pb(C_2H_3O_2)_2$): insecticides; waterproofing; varnishes; dyeing of cloth; production of gold; hair dye
- lead antimonate ($Pb_3(SbO_4)_2$): staining of glass, porcelain and other ceramics
- lead azide ($Pb(N_3)_2$): used as a "primer" for high explosives
- lead chromate ("chrome yellow"; $PbCrO_4$): industrial paints (use restricted by law)
- lead fluoride (PbF_2): used to make lasers; specialized optical glasses
- lead iodide (PbI_2): photography; cloud seeding to produce rain
- lead naphthenate ($Pb(C_7H_{12}O_2)$): wood preservative; insecticide; additive for lubricating oil; paint and varnish drier
- lead phosphite ($2PbO \bullet PbHPO_3$): used to screen out ultraviolet radiation in plastics and paints
- lead stearate ($Pb(C_{18}H_{35}O_2)_2$): used to make soaps, greases, waxes, and paints; lubricant; drier for paints and varnishes
- lead telluride (PbTe): used to make semiconductors, photoconductors, and other electronic equipment

Health Effects

The health effects of lead have become much better understood since the middle of the 20th century. At one time, the metal was regarded as quite

The High Cost of Lead Gasoline

For many years, lead was regarded as a miracle chemical by the automotive industry. The power to run gas-fueled cars comes from the burning of gasoline in the engine. However, burning gasoline is not a simple process. Many things happen inside an engine when gasoline burns in the carburetor.

For example, an engine can "knock" if the gasoline does not burn properly. "Knocking" is a "bang-bang" sound from the engine. It occurs when low-grade gasoline is used.

One way to prevent knocking is to use high-grade gasoline. Another way is to add chemicals to the gasoline. The best gasoline additive discovered was a compound called tetraethyl lead ($Pb(C_2H_5)_4$. Tetraethyl lead was usually called "lead" by the automotive industry, the consumer, and advertisers. When someone bought "leaded" gasoline, it contained not lead metal, but tetraethyl lead.

Leaded gasoline was a great discovery. It could be made fairly cheaply and it prevented car engines from knocking. No wonder people thought it was a miracle chemical.

What people didn't realize was that tetraethyl lead breaks down in a car engine because of the high temperature at which engines operate. When tetraethyl lead breaks down, elemental lead (Pb) is formed:

$$\mathbf{Pb(C_2H_5)_4 \xrightarrow{heat} Pb + other\ products}$$

The result—with millions of cars being driven every day—was more and more lead getting into the air. And more and more people inhaled that lead. Eventually, doctors began to see more people with lead-related diseases.

The U.S. government finally decided that tetraethyl lead was too dangerous to use in gasoline. By 1990, the use of this compound had been banned by all governments in North America.

safe to use for most applications. Now lead is known to cause both immediate and long-term health problems, especially with children. It is toxic when swallowed, eaten, or inhaled.

Young children are most at risk from lead poisoning. Some children have a condition known as pica. They have an abnormal desire to eat materials like dirt, paper, and chalk. Children with pica sometimes eat paint chips off walls. At one time, many interior house paints were made with lead compounds. Thus, crawling babies or children with pica ran the risk of eating large amounts of lead and being poisoned.

Some symptoms of lead poisoning include nausea, vomiting, extreme tiredness, high blood pressure, and convulsions (spasms). Over a long period of time, these children often suffer brain damage. They lose the ability to carry out normal mental functions.

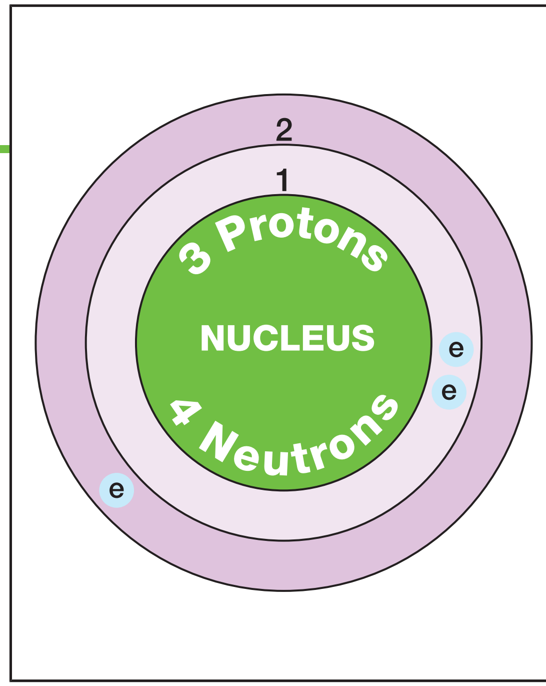
According to the U.S. Environmental Protection Agency (EPA), the most common source of lead in homes built prior to 1978 is lead-based paint. When paint peels, some of it becomes airborne and could be ingested. Also, some young children chew on chips of paint, not realizing the dangers of lead poisoning.

Other forms of lead poisoning can also occur. For example, people who work in factories where lead is used can inhale lead fumes. The amount of fumes inhaled at any one time may be small. But over months or years, the lead in a person's body can build up. This type of lead poisoning can lead to nerve damage and problems with the gastrointestinal system (stomach and intestines).

Today, there is an effort to reduce the use of lead in consumer products. For instance, older homes are often tested for lead paint before they are resold. Lead paint has also been removed from older school buildings.

However, in recent years, various toys and other products imported from other countries have been found to contain lead paint. This situation has prompted a number of recalls. The U.S. Centers for Disease Control and Prevention (CDC; www.cdc.gov) maintains of list of products being recalled due to lead concerns.

Lithium



Overview

Lithium is the first member of the alkali metal family. The alkali metals are the elements that make up Group 1 (IA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. The alkali metals include **sodium**, **potassium**, **rubidium**, **cesium**, and **francium**. Lithium is also the least dense of all metals. It has a density about half that of water.

Credit for the discovery of lithium usually goes to Swedish chemist Johan August Arfwedson (or Arfvedson; 1792–1841). Arfwedson found the new element in a mineral that had first been identified about 20 years earlier by Brazilian scientist Jozé Bonifácio de Andrada e Silva (1763–1838). That mineral, petalite, is still a major source of lithium today.

Lithium has a number of important and interesting uses. In recent years, it has been used to make lightweight, efficient batteries. Compounds of lithium have also been used to treat a mental disorder known as bipolar disorder.

Key Facts

Symbol: Li

Atomic Number: 3

Atomic Mass: [6.941]

Family: Group 1 (IA); alkali metal

Pronunciation: LI-thee-um

Discovery and Naming

The first clues to the existence of lithium surfaced in 1800. De Andrada was a Brazilian scientist and statesman visiting in Scandinavia. During

WORDS TO KNOW

Alkali metals: Elements that make up Group 1 (IA) of the periodic table.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Bipolar disorder: A condition in which a person experiences wild mood swings.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

one of his trips to the countryside, he came across a mineral that he did not recognize. He called the mineral petalite.

Some scientists were not convinced that petalite was a new mineral. But in 1817, the same mineral was rediscovered on the island of Utö. Interest in the mineral grew.

Arfwedson was troubled by the results of his analysis of petalite. In his studies, he could not identify 10 percent of the mineral. He finally concluded that the missing 10 percent must be a new element. He called the new element lithium, from the Greek word *lithos* for "stone."

Arfwedson was not able to produce pure lithium. About a year later, however, Swedish chemist William Thomas Brande (1788–1866) and English chemist Sir Humphry Davy (1778–1829) were both able to extract the pure metal from its compounds.

Physical Properties

Lithium is a very soft, silvery metal. It has a melting point of 356.97°F (180.54°C) and a boiling point of about 2,435°F (1,335°C). Its density is 0.534 grams per cubic centimeter. By comparison, the density of water is 1.000 grams per cubic centimeter. Lithium's hardness on the Mohs scale is 0.6. The Mohs scale is a way of expressing the hardness of a material. It runs from 0 (for talc) to 10 (for diamond). A hardness of 0.6 means that the material can be scratched with a fingernail.

Chemical Properties

Lithium is an active element, but not as active as the other alkali metals. It reacts slowly with water at room temperature and more rapidly at higher temperatures. It also reacts with most acids, giving off **hydrogen** gas. Lithium does not react with **oxygen** at room temperature, but above 212°F (100°C) does so to form lithium oxide (Li_2O). Under the proper conditions, the element also combines with **sulfur**, hydrogen, **nitrogen**, and the halogens.

Occurrence in Nature

The abundance of lithium in Earth's crust is estimated to be about 0.005 percent. That places it among the top 15 elements found in the earth. The most common ores of lithium are spodumene, petalite, and lepidolite. Lithium is also obtained from saltwater. As saltwater evaporates, dissolved solids are left behind. These solids include sodium chloride (NaCl), potassium chloride (KCl), and lithium chloride (LiCl).

In 2008, the world's largest consumer of lithium minerals and compounds was the United States. The major producer of lithium chemicals worldwide was Chile. Other countries involved in lithium production included Argentina, Australia, Brazil, Canada, China, Portugal, the United States, and Zimbabwe. Specific information on U.S. production was not released in order to preserve trade secrets.

Isotopes

Two naturally occurring isotopes of lithium exist: lithium-6 and lithium-7. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

In addition, five radioactive isotopes of lithium have been produced. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. None of these isotopes has any important commercial application.

Extraction

Lithium compounds are first converted to lithium chloride (LiCl). Then, an electric current is passed through molten (melted) lithium chloride. The current separates the compound into lithium and **chlorine** gas:

$$2LiCl \xrightarrow{\text{electric current}} 2Li + Cl_2$$

Uses and Compounds

One of the primary uses of lithium metal is in the production of alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The most common alloys of lithium are those with **magnesium** and **aluminum**. These alloys combine the properties of strength and lightness. One lithium alloy, called Bahnmetall, is used to make very strong ball bearings for machinery, such as the wheel bearings in railroad cars. An alloy of lithium and magnesium is used in space vehicles because it is strong, but very lightweight.

Lithium metal is also a component of certain kinds of batteries. A battery is a device for converting chemical energy into electrical energy. Lithium batteries are much lighter than the familiar **lead** and sulfuric acid batteries used in many cars and trucks. They also reduce the use of toxic lead and **cadmium**. Lithium batteries are used in products such as

Lithium-ion battery and charger. IMAGE COPYRIGHT 2009, MR. BRIGHTSIDE. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Lithium and Mood Swings

A new use for lithium carbonate was discovered in 1949 when John Cade (1912–1980), an Australian physician, found that patients with bipolar disorder benefited from taking the substance. Bipolar disorder is a condition once known as manic-depressive disorder. The condition is characterized by dramatic mood swings. A person can be very happy and carefree one moment, but terribly depressed the next moment. Some patients become so depressed that they commit suicide. Until 1949, there was no effective treatment for bipolar disorder.

Cade found that most patients who took lithium carbonate were relieved of at least some of their symptoms. Their "high" points were not as high, and their "low" points were not as low. The compound helped someone with bipolar disorder to live a quieter, more normal life. Today, more than 60 percent of those with bipolar disorder benefit from lithium treatments. It is estimated that some 5.7 million American adults have bipolar disorder; however, children as young as six have been diagnosed with the disorder.

As with most medications, lithium compounds can have side effects. They can cause nausea, dizziness, diarrhea, dry mouth, and weight gain. But these side effects can usually be controlled. And they are often a small price to pay for relief from the severe effects of bipolar disorder.

watches, microcomputers, cameras, small appliances, electronic games, toys, and many types of military and space vehicles. Although the batteries tend to be more expensive than other kinds of batteries, they have the advantages of producing a constant supply of electrical energy and having a long shelf-life.

Compounds of lithium have a number of important uses. Two of the most significant applications are in the glass and ceramics field and in the production of aluminum. The addition of a small amount of lithium carbonate (Li_2CO_3) to a glass or ceramic makes the material stronger. Examples of the use of lithium carbonate are shock-resistant cookware and black-and-white television tubes.

Producers of aluminum also use lithium carbonate in preparing aluminum metal from aluminum oxide. Lithium carbonate reduces the heat needed to make the reaction occur. As a result, producers save money by using less energy.

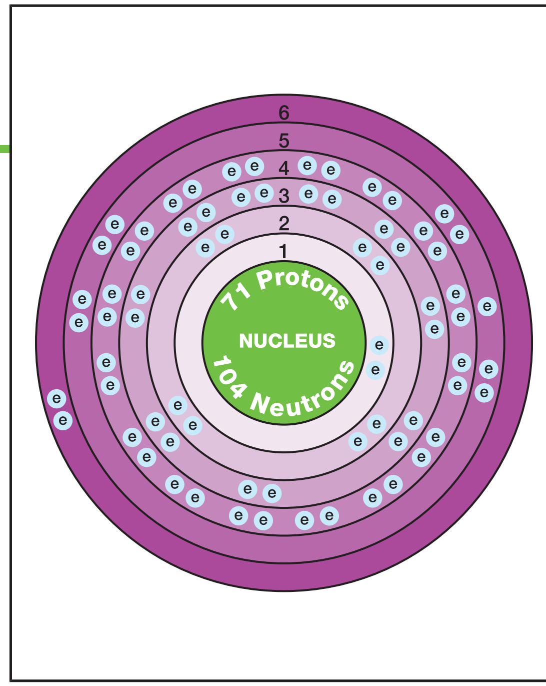
Another important compound of lithium is lithium stearate. Lithium stearate is added to petroleum to make a thick lubricating grease. The grease is used in many industrial applications because it does not break down at high temperatures, it does not become hard when cooled, and it does not react with water or oxygen in the air. Lithium greases are used in military, industrial, automotive, aircraft, and marine applications. Lithium stearate is also used as an additive in cosmetics and plastics.

Lithium compounds are also used as catalysts in many different industrial processes. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction. For example, one lithium catalyst is used to make tough, strong, synthetic (artificial) rubber. It does not have to be vulcanized (heat-treated) like natural rubber.

Health Effects

Lithium and its compounds have a range of effects on the human body. For instance, compounds of lithium tend to harm the kidneys. And lithium carbonate (Li_2CO_3) can affect a person's mental health, as shown in a discovery made in 1949 (see sidebar on page 319).

Lutetium



Overview

Lutetium is the heaviest, rarest, and most expensive lanthanoid element. The lanthanoids elements make up Row 6 of the periodic table between barium and hafnium. The periodic table is a chart that shows how chemical elements are related to one another. The lanthanoids are usually shown as a separate row at the bottom of the table. They are also called the rare earth elements. That name does not fit very well for most lanthanoids. They are not really so rare, but were once difficult to separate from each other. However, lutetium is both rare and difficult to separate from the other lanthanoids.

Lutetium was first discovered in the early 1900s by two chemists working independently. It was found in a complex black mineral that had been found near the town of Ytterby, Sweden, in 1787.

Today, there are very few uses for lutetium metal.

Key Facts

Symbol: Lu

Atomic Number: 71

Atomic Mass: 174.9668

Family: Lanthanoid (rare earth metal)

Pronunciation: loo-TEE-she-um

Discovery and Naming

In 1787, a Swedish army officer, Carl Axel Arrhenius (1757–1824), found an odd black rock outside the town of Ytterby, Sweden. He gave the rock to a chemist friend, Johan Gadolin (1760–1852), for study.

WORDS TO KNOW

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into a thin wire.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids: The elements in the periodic table with atomic numbers 57 through 71.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

That rock turned out to contain one of the most complex and interesting minerals ever discovered: yttria. Chemists kept busy for the next century trying to figure out exactly what materials were in yttria.

Eventually, they found nine new elements that had never been seen before. Separating these elements from each other was very difficult, however. The nine elements are chemically similar and all behave in nearly the same way. It is very difficult to know whether a sample of yttria contains one, two, three … or all nine of the elements.

In 1879 French chemist Jean-Charles-Galissard de Marignac (1817–1894) announced the discovery of a new element in yttria. He called the element **ytterbium**. Other chemists suspected that ytterbium was really a mixture of elements. They searched for ways to separate ytterbium into simpler parts.

It took nearly 30 years to solve this puzzle. And the answer came from three laboratories at nearly the same time. The first to report his results was French chemist Georges Urbain (1872–1938). In 1907, Urbain reported that ytterbium was not an element, but a mixture of two new elements. He called those elements neoytterbium and lutecium. The first name meant "new ytterbium." The second name comes from Lutecia, the ancient name for the city of Paris in France.

At nearly the same time, German chemist Karl Auer (Baron von Welsbach; 1858–1929) made the same discovery. He suggested different names for the two new elements in ytterbium. He called them cassiopeium and aldebaranium, in honor of the constellation Cassiopeia and the bright star Aldebaran. Today, some German chemists still refer to lutetium as cassiopeium.

A third chemist working on ytterbium was American chemist Charles James (1880–1926). James announced his discoveries after Urbain and Auer. Some authorities give credit for the discovery of lutetium to all three scientists.

None of these early scientists actually saw pure lutetium. The substance they thought was an element was actually a compound, usually lutetium oxide. The pure metal was isolated only quite recently.

In 1949, the spelling of the element changed from "lutecium" to "lutetium."

Physical Properties

Lutetium is a silvery white metal that is quite soft and ductile. The term ductile means capable of being drawn into thin wires. It has a melting point of 3,006°F (1,652°C) and a boiling point of 6,021°F (3,327°C). Its density is 8.49 grams per cubic centimeter.

Chemical Properties

Lutetium reacts slowly with water and dissolves in acids. Other chemical properties tend to be of interest only to researchers.

Occurrence in Nature

Lutetium is thought to be very rare in Earth's crust. It occurs to the extent of about 0.8 to 1.7 parts per million. That still makes it somewhat more common than better known elements such as **iodine**, **silver**, and **mercury**. The most common ore of lutetium is monazite, in which its concentration is about 0.003 percent.

Isotopes

There are two naturally occurring isotopes of lutetium: lutetium-175 and lutetium-176. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The second of these isotopes, lutetium-176, is radioactive. A radioactive isotope is one that breaks apart and gives off some form of radiation. Some radioactive isotopes occur in nature. Others can be produced by firing very small particles at atoms. These particles stick in the atoms and make them radioactive.

In addition, 55 radioactive isotopes have also been produced artificially. None of these isotopes has any commercial use.

Extraction

Lutetium is the most difficult lanthanoid to obtain in pure form. The usual method used begins with either lutetium fluoride (LuF_3) or lutetium chloride ($LuCl_3$). An active metal, such as **sodium** (Na) or **potassium** (K) is then added to LuF_3 or $LuCl_3$ to obtain pure lutetium. For example:

$$\mathbf{LuF_3 + 3Na \xrightarrow{heated} 3NaF + Lu}$$

Uses

Lutetium is one of the most expensive lanthanoids. In 2007, lutetium oxide sold for about $3,500 per kilogram. It is sometimes used as a catalyst in the petroleum industry. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction. There are virtually no other uses for lutetium.

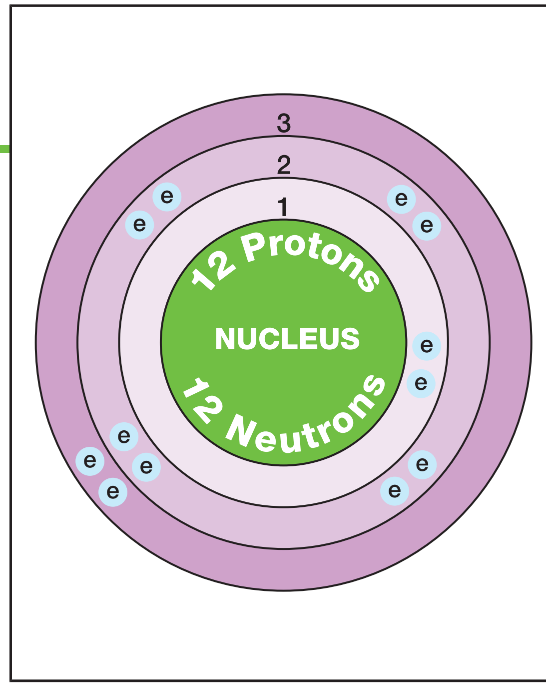
Compounds

There are no commercially important lutetium compounds.

Health Effects

The health effects of lutetium are not well known. Exposure to compounds of lutetium is thought to cause irritation of the skin, eyes, and respiratory (breathing) system.

Magnesium



Key Facts

Symbol: Mg

Atomic Number: 12

Atomic Mass: 24.3050

Family: Group 2 (IIA); alkaline earth metal

Pronunciation: mag-NEE-zee-um

Overview

Magnesium is the second element in Group 2 (IIA) of the periodic table, a chart that shows how chemical elements are related to each other. The elements in Group 2 are known as the alkaline earth elements. Other elements in that group include **beryllium**, **calcium**, **strontium**, **barium**, and **radium**.

Compounds of magnesium have been used by humans for centuries. Yet, the element itself was not isolated until 1808. The long delay occurred because magnesium forms very stable compounds. That means that such compounds do not break down very easily.

Magnesium is the seventh most abundant element in Earth's crust. It also occurs in large amounts dissolved in ocean waters.

Large amounts of magnesium are used to make alloys. An alloy is made by melting or mixing two or more metals. The mixture has properties different from those of the individual metals. Magnesium alloys are quite light, yet very strong. This property makes them useful in the construction of airplanes and spacecraft.

About 60 percent of the magnesium compounds produced in the United States are used in the manufacture of refractory materials.

WORDS TO KNOW

Alkaline earth metal: An element found in Group 2 (IIA) of the periodic table.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Enzyme: Catalyst in a living organism that speeds up the rate at which certain changes take place in the body.

Fabrication: Shaping, molding, bending, cutting, and working with a metal.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Refractory: A material that can withstand very high temperatures and reflects heat from itself.

A refractory material is one that can withstand very high temperatures by reflecting heat. Refractory materials are used to line the ovens that maintain high temperatures. Agriculture, construction, industrial, and chemical operations use portions of the remaining 40 percent.

Discovery and Naming

Compounds of magnesium are very abundant in the earth. Dolomite, or calcium magnesium carbonate ($CaMg(CO_3)_2$), is an example. Dolomite has been used as a building material for centuries.

Another well-known magnesium compound is Epsom salts, or magnesium sulfate ($MgSO_4$). Epsom salts are known for their soothing qualities, most notably when added to a bath.

Careful studies of magnesium and its compounds began in the middle 1700s. Scottish physician and chemist Joseph Black (1728–1799) carried out some of the earliest experiments on magnesium compounds. He reported on his research in an article that became famous. Black is sometimes given credit for "discovering" magnesium because of his work with the element.

By 1800, chemists knew that magnesium was an element. But no one had been able to prepare pure magnesium metal. Magnesium holds very tightly to other elements in its compounds. No one had found a way to break the bonds between magnesium and these other elements.

In 1808, English chemist Humphry Davy (1778–1829) solved the problem by passing an electric current through molten (melted) magnesium oxide (MgO). The current caused the compound to break apart, forming magnesium metal and **oxygen** gas:

$$2MgO \xrightarrow{\text{electric current}} 2Mg + O_2$$

Davy used this method to discover a number of other elements. Like magnesium, these elements form compounds that are very difficult to break apart. An electric current provides the energy to break these compounds down into their elements.

The name magnesium goes back many centuries. It was selected in honor of a region in Greece known as Magnesia. The region contains large supplies of magnesium compounds.

Physical Properties

Magnesium is a moderately hard, silvery-white metal. It is the lightest of all structural metals. These metals are strong enough to be used in constructing buildings, bridges, automobiles, and airplanes.

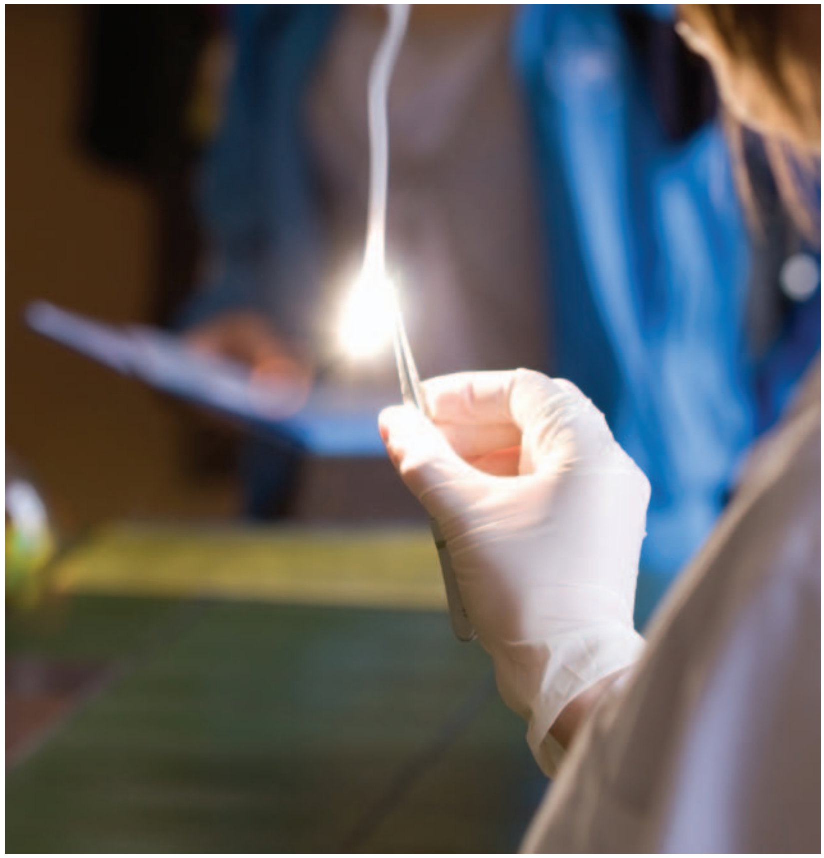
Magnesium is easily fabricated. Fabrication means shaping, molding, bending, cutting, and working with a metal. Metals must be fabricated before they can be turned into useful products. Metals that are strong, tough, or hard are not easily fabricated. They must be converted to an alloy. A metal that *is* more easily fabricated (such as magnesium) is combined with them.

The melting point of magnesium is 1,200°F (651°C) and its boiling point is 2,000°F (1,100°C). Its density is 1.738 grams per cubic centimeter.

Chemical Properties

Magnesium is a fairly active metal. It reacts slowly with cold water and more rapidly with hot water. It combines with oxygen at room temperature to form a thin skin of magnesium oxide. It burns with a blinding white light at higher temperatures. Magnesium reacts with most acids and with some alkalis. An alkali is a chemical with properties opposite those of an acid. Sodium hydroxide (common lye) and limewater are examples of alkalis.

Magnesium also combines easily with many non-metals, including **nitrogen**, **sulfur**, **phosphorus**, **chlorine**, **fluorine**, **bromine**, and **iodine**.



At high temperatures, magnesium burns with a blinding white light. IMAGE COPYRIGHT 2009, FIREMANYU. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

It also reacts readily with a number of compounds, such as carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitric oxide (NO).

Occurrence in Nature

The abundance of magnesium in Earth's crust is estimated to be about 2.1 percent. That makes it the sixth most common element in the earth. It also occurs in seawater. A cubic mile of seawater is estimated to contain up to six million tons of magnesium.

There are many naturally occurring minerals of magnesium. Some of the most important are dolomite; magnesite, or magnesium carbonate ($MgCO_3$); carnallite, or potassium magnesium chloride ($KMgCl_3$); and epsomite, or magnesium sulfate ($MgSO_4$).

In 2008, the largest producer of magnesium metal was reported to be China. Other large producers included Brazil, Israel, Kazakhstan, and Russia. The largest producers of magnesite were China, Turkey, North Korea, Russia, and Austria. The amounts of magnesium metal and magnesite produced in the United States were not reported in order to protect trade secrets.

Magnesium metal produced in the United States comes from three sources: seawater, brine, and mines. According to the U.S. Geological Survey (USGS), magnesium was recovered from brines in Utah's Great Salt Lake.

One of the sources of magnesium is seawater. It is processed in various locations in the United States and the world. Pictured here is the Dead Sea, which is bordered by Israel and Jordan in the Middle East. Much saltier than the ocean, the Dead Sea is rich in magnesium. IMAGE COPYRIGHT 2009, MYTHO. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Isotopes

There are three naturally occurring isotopes of magnesium: magnesium-24, magnesium-25, and magnesium-26. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twelve radioactive isotopes of magnesium also exist. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Extraction

Magnesium is prepared by one of two methods. The first method is similar to the method used by Davy in 1808. An electric current is passed through molten (melted) magnesium chloride:

$$2MgCl \quad \text{electric current} \rightarrow 2Mg + Cl_2$$

Magnesium alloys are used in the production of skis. IMAGE COPYRIGHT 2009, MONKEY BUSINESS IMAGES. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

The second method involves reacting magnesium oxide with ferrosilicon. Ferrosilicon is an alloy of **iron** and **silicon**. When magnesium oxide and ferrosilicon react, free magnesium metal is formed.

Uses

Although most cameras now use electronic flashes, magnesium metal is often contained in cameras that use flash bulbs. A thin strip of magnesium metal is inside the bulb. When the flash is ignited, the magnesium strip catches fire. It burns with a very bright white light. The light from the bulb illuminates a scene for the photograph.

A common use of magnesium metal is in fireworks. Most firework displays include some brilliant flashes of very white light. Those flashes are produced by the burning of magnesium metal.

Magnesium is commonly alloyed with other metals. Magnesium and **aluminum**, for instance, are two metals that combine to form alloys that are very strong and resistant to corrosion (rust). But they weigh much less than steel alloys with similar properties.

Strength and low density are important properties in the manufacture of airplanes, automobiles, metal luggage, ladders, shovels and other gardening equipment, racing bikes, skis, race cars, cameras, and power tools. A typical magnesium alloy contains about 90 percent magnesium, 2 to 9 percent aluminum, and small amounts of **zinc** and **manganese**.

Compounds

The largest single use of magnesium compounds is in refractories.

Other magnesium compounds are used in the following categories:

- Medicine: pain killer and fever reducer (magnesium acetylsalicylate); antacid to neutralize stomach acid (magnesium hydroxide; magnesium phosphate; magnesium silicate); laxative to loosen the bowels

The Popularity of Epsom Salts

Perhaps the best known magnesium compound is magnesium sulfate ($MgSO_4$). It is popularly known as Epsom salts.

One of the earliest stories about Epsom salts dates back to 1618. The town of Epsom, in Surrey, England, was suffering from a severe drought. A farmer named Henry Wicker brought his cattle to drink from a watering hole on the town commons (central park). But the cattle would not drink the water. Wicker was surprised because he knew they were very thirsty. He tasted the water himself and found that it was very bitter.

The bitterness was due to magnesium sulfate in the water. This compound became known as Epsom salts.

People soon learned that soaking in the natural waters that contained Epsom salts made them feel better. The salts seemed to have properties that soothed the body. Before long, soaking in these waters became very popular.

Today, Epsom salts can be used in bath water. They relax sore muscles and remove rough skin. Many people believe the salts have the same relaxing effect as hot springs.

Some gardeners even believe that sprinkling Epsom salts in the garden helps flowers and vegetables grow!

(magnesium carbonate; magnesium chloride; magnesium citrate; magnesium hydroxide; magnesium lactate; magnesium phosphate); antiseptic to kill germs (magnesium borate; magnesium salicylate; magnesium sulfate); sedative to help one sleep (magnesium bromide)

- Production of glass and ceramics: magnesium fluoride; magnesium oxide
- Mothproofing of textiles: magnesium hexafluorosilicate
- Fireproofing wood for construction: magnesium phosphate
- Manufacture of paper: magnesium sulfite

Health Effects

Magnesium is essential for good health in both plants and animals. It forms part of the chlorophyll molecule found in all green plants. Chlorophyll is the molecule in green plants that controls the conversion of carbon dioxide and water to carbohydrates, such as starch and sugars. Plants that do not get enough magnesium cannot make enough chlorophyll. Their leaves develop yellowish blotches as a result.

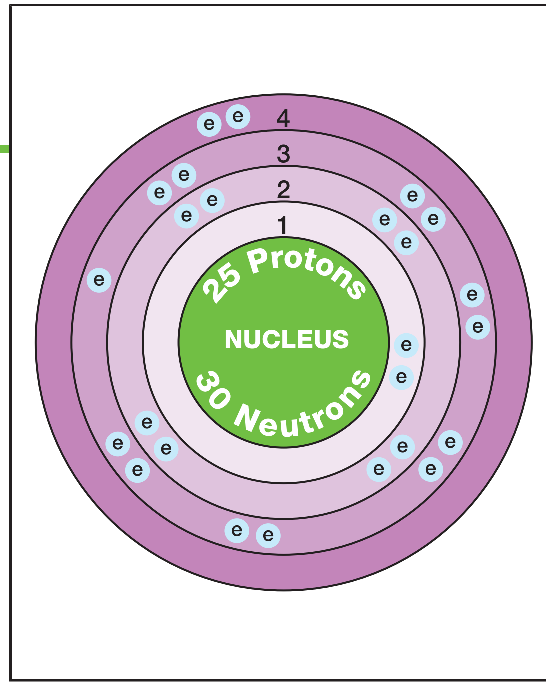
Magnesium is found in many enzymes in both plants and animals. An enzyme is a catalyst in a living organism. It speeds up the rate at which certain changes take place in the body. Enzymes are essential in order for living cells to function properly. It is difficult *not* to get enough magnesium in one's daily diet. It is found in nuts, cereals, seafoods, and green vegetables. Most people have no problem getting the 300 to 400 milligrams of magnesium recommended in the daily diet.

A lack of magnesium can occur, however. For example, alcoholics and children in poor countries sometimes develop a magnesium deficiency. In such cases, magnesium deficiency may cause a person to become easily upset or overly aggressive.

However, it is also possible to be exposed to too much magnesium. For example, inhaling magnesium powder can produce irritation of the throat and eyes, resulting in a fever. In large doses, magnesium can cause damage to muscles and nerves. It can eventually result in loss of feeling and paralysis (inability to move parts of the body).

Such conditions are rare. They are likely to occur only among people who have to work with magnesium metal on a regular basis.

Manganese



Overview

Manganese is a transition metal. The transition metals are the large block of elements in the middle of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The transition metals make up Rows 4 through 7 in Groups 3 through 12 of the periodic table. Many of the best known and most widely used metals are in this group of elements.

It took chemists some time to discover the difference between manganese and **iron**. The two metals have very similar properties and often occur together in Earth's crust. The first person to clearly identify the differences between the two elements was Swedish mineralogist Johann Gottlieb Gahn (1745–1818) in 1774.

Manganese plays an interesting role in the U.S. economy. It is absolutely essential in the production of iron and steel. No element has been found that can replace manganese is such applications. The United States has essentially no manganese supplies of its own, so it depends on imports from other nations.

Key Facts

Symbol: Mn

Atomic Number: 25

Atomic Mass: 54.938045

Family: Group 7 (VIIB); transition metal

Pronunciation: MANG-guh-neez

WORDS TO KNOW

Allotropes: Forms of an element with different physical and chemical properties.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Machining: The bending, cutting, and shaping of a metal by mechanical means.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

One of the main ores of manganese is pyrolusite, which is made up primarily of the compound manganese dioxide (MnO_2). Early artists were familiar with pyrolusite. They used the mineral to give glass a beautiful purple color. They also used the mineral to remove color from a glass. When glass is made, it often contains impurities that give the glass an unwanted color. The presence of iron, for example, can give glass a yellowish tint. Adding pyrolusite to yellowish glass removes the color. The purple tint of pyrolusite balances out the yellow color of the glass. The glass ends up being clear and colorless.

By the mid-1700s, chemists began to suspect that pyrolusite might contain a new element. Some authorities credit German chemist Ignatius Gottfried Kaim with isolating the element in 1770. However, Kaim's report was not read by many chemists and was quickly lost.

During this period, some of the most famous chemists in Europe were trying to analyze pyrolusite, but none of them was successful. The problem was solved in 1774 when Gahn developed a method for removing the new element from pyrolusite. He heated pyrolusite with charcoal (pure **carbon**). The carbon took **oxygen** away from manganese dioxide, leaving behind pure manganese:

$$MnO_2 + C \rightarrow CO_2 + Mn$$

The origin of manganese's name is a bit confusing. Early chemists associated the new element with a mineral called magnesia. That mineral got its name from a region in Greece. Magnesia does not contain manganese, but the name stuck.

Physical Properties

Manganese is a steel-gray, hard, shiny, brittle metal. It is so brittle, in fact, that it cannot be machined in its pure form. Machining refers to the bending, cutting, and shaping of a metal by mechanical means. The melting point of manganese is 2,273°F (1,245°C) and its boiling point is about 3,800°F (2,100°C). Its density is 7.47 grams per cubic centimeter.

Manganese exists in four allotropic forms. Allotropes are forms of an element with different physical and chemical properties. The element changes from one form to another as the temperature rises. The form that exists from room temperature up to about 1,300°F (700°C) is the most common form.

Chemical Properties

Manganese is a moderately active metal. It combines slowly with oxygen in the air to form manganese dioxide (MnO_2). At higher temperatures, it reacts more rapidly. It may even burn, giving off a bright white light. Manganese reacts slowly with cold water, but more rapidly with hot water or steam. It dissolves in most acids with the release of **hydrogen** gas. It also combines with **fluorine** and **chlorine** to make manganese difluoride (MnF_2) and manganese dichloride ($MnCl_2$).

Occurrence in Nature

Manganese never occurs as a pure element in nature. It always combines with oxygen or other elements. The most common ores of manganese are pyrolusite, manganite, psilomelane, and rhodochrosite. Manganese is also found mixed with iron ores. In 2008, the largest producers of manganese ore in the world were South Africa, China, Australia, Gabon, and Brazil.

Manganese also occurs abundantly on the ocean floor in the form of nodules. These nodules are fairly large lumps of metallic ores. They usually contain **cobalt**, **nickel**, **copper**, and iron, as well as manganese. Scientists estimate that up to 1.5 trillion metric tons of manganese nodules may lie on the floors of the world's oceans and large lakes. Currently, there is no profitable method for retrieving these ores.

Rhodochrosite, which derives its name from the Greek words meaning rose-colored, is one of the most common ores of manganese. It is noted for its striking color. IMAGE COPYRIGHT 2009, MIAMIA. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Manganese is the 12th most abundant element in Earth's crust. Its abundance is estimated to be 0.085 to 0.10 percent. That makes it about as abundant as fluorine or **phosphorus**.

Isotopes

Only one naturally occurring isotope of manganese exists: manganese-22. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-four radioactive isotopes of manganese are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of manganese has any important commercial uses.

Men and machine lay railroad tracks. A common alloy of manganese, ferromanganese, is contained in the steel used to produce railroad tracks. GALE GROUP.

Extraction

The usual method for producing pure manganese is to heat manganese dioxide (MnO_2) with carbon or **aluminum**. These elements remove the oxygen and leave pure manganese metal:

$$MnO_2 + C \rightarrow Mn + CO_2$$

Uses

Up to 90 percent of all manganese produced is made into steel alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The addition of manganese to steel makes the final product hard, as well as resistant to corrosion (rusting) and mechanical shock.

The most common alloy of manganese is ferromanganese. This alloy contains about 48 percent manganese combined with iron and carbon. Ferromanganese is the starting material for making a very large variety

The heavy steel found in bank vaults contains ferromanganese, a manganese alloy. IMAGE COPYRIGHT 2009, ZENTILIA. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

of steel products, including tools, heavy-duty machinery, railroad tracks, bank vaults, construction components, and automotive parts.

Another common alloy of manganese is silicomanganese. It contains manganese, **silicon**, and carbon in addition to iron. It is used for structural components and in springs.

Manganese is also used to make alloys with metals other than iron or steel. For example, the alloy known as manganin is 84 percent copper, 12 percent manganese, and 4 percent nickel. Manganin is used in electrical instruments.

Compounds

Less than 10 percent of all the manganese used in the United States goes to the production of manganese compounds. Perhaps the most important commercial use of these compounds is manganese dioxide (MnO_2). Manganese dioxide is used to make dry-cell batteries. These batteries are used in electronic equipment, flashlights, and pagers. Dry cell batteries hold a black pasty substance containing manganese dioxide. The use of manganese dioxide in a dry cell prevents hydrogen gas from collecting in the battery as electricity is produced.

Another manganese compound, manganous chloride ($MnCl_2$), is an additive in animal food for cows, horses, goats, and other domestic animals. Fertilizers also contain manganous chloride so that plants get all the manganese they need.

Finally, small amounts of manganese compounds are used as coloring agents in bricks, textiles, paints, inks, glass, and ceramics. Manganese compounds can be found in shades of pink, rose, red, yellow, green, purple, and brown.

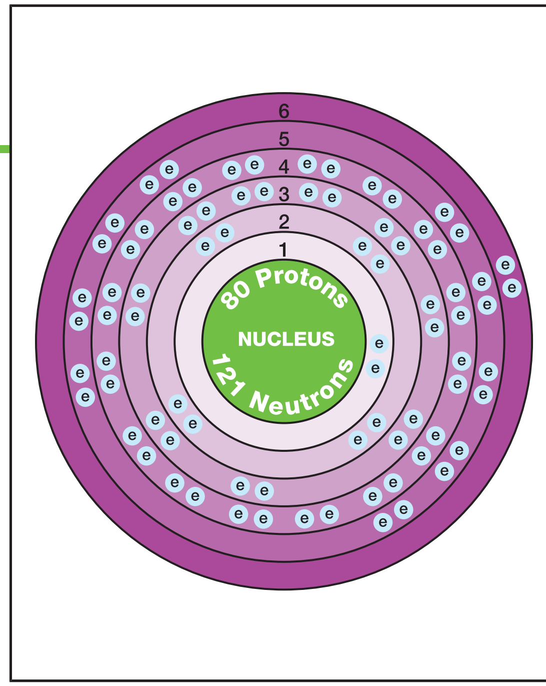
Health Effects

Manganese is one of the chemical elements that has both positive and negative effects on living organisms. A very small amount of the element is needed to maintain good health in plants and animals. The manganese is used by enzymes in an organism. An enzyme is a substance that makes chemical reactions occur more quickly in cells. Enzymes are necessary to keep any cell operating properly. If manganese is missing from the diet, enzymes do not operate efficiently. Cells begin to die, and the organism becomes ill.

Fortunately, the amount of manganese needed by organisms is very small. It is not necessary to take extra manganese to meet the needs of cells.

In fact, an excess of manganese can create health problems. These problems include weakness, sleepiness, tiredness, emotional disturbances, and even paralysis. The only way to receive such a large dose is in a factory or mine. Workers may inhale manganese dust in the air.

Mercury



Key Facts

Symbol: Hg

Atomic Number: 80

Atomic Mass: 200.59

Family: Group 12 (IIB); transition metal

Pronunciation: MER-kyuh-ree

Overview

Mercury is a transition metal. A transition metal is one of the elements found between Groups 2 (IIA) and 13 (IIIA) in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Mercury has long been known as quicksilver, because it is a silver liquid. The chemical symbol also reflects this property. The symbol, Hg, comes from the Latin term *hydrargyrum,* meaning "watery silver."

Mercury has been known for thousands of years. In many cultures, people learned to make mercury metal from its most important ore, cinnabar. When heated, cinnabar releases mercury as a vapor (gas). The vapor is cooled and captured as liquid mercury.

Some mercury compounds are known to be poisonous. For example, mercuric chloride (corrosive sublimate) was often used to kill pests and, sometimes, people. However, some mercury compounds have been used as medicines. For instance, mercurous chloride (calomel) was long used as a cure for skin rashes. Since the 1960s, the dangers of mercury have become better known. As a result, mercury use is now being phased out.

WORDS TO KNOW

Amalgam: A combination of mercury with at least one other metal.

Distillation: A process by which two or more liquids can be separated from each other by heating them to their boiling points.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Phosphor: A material that gives off light when struck by electrons.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Surface tension: A property of liquids that makes them act like they are covered with a skin.

Toxic: Poisonous.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

The oldest sample of mercury dates to about the 15th or 16th century BCE. It was found in an Egyptian tomb at Kurna, stored in a small glass container.

Mercury and cinnabar are both mentioned in ancient manuscripts. The Chinese, Hindus, Egyptians, Greeks, and Romans all recorded information about the element and its ore. Greek philosopher Theophrastus (372–287 BCE), for example, described a method for preparing mercury. Cinnabar was rubbed together with vinegar in a clay dish. Theophrastus wrote that the cinnabar had been found in **silver** mines. When the metal was first made, he said, people thought it might contain gold. They were misled by the metal's shiny appearance. They soon realized, however, that it was quite different from **gold**.

Many reports on mercury told of its poisonous effects. Slaves who worked in Roman mercury mines, for example, often died of exposure to mercury. Strangely enough, trees and plants around these mines were not affected. Mercury was sometimes very dangerous and sometimes quite safe. People even drank from streams that ran through mercury mines. Scientists now know that mercury's effects depend on the form in which it occurs.

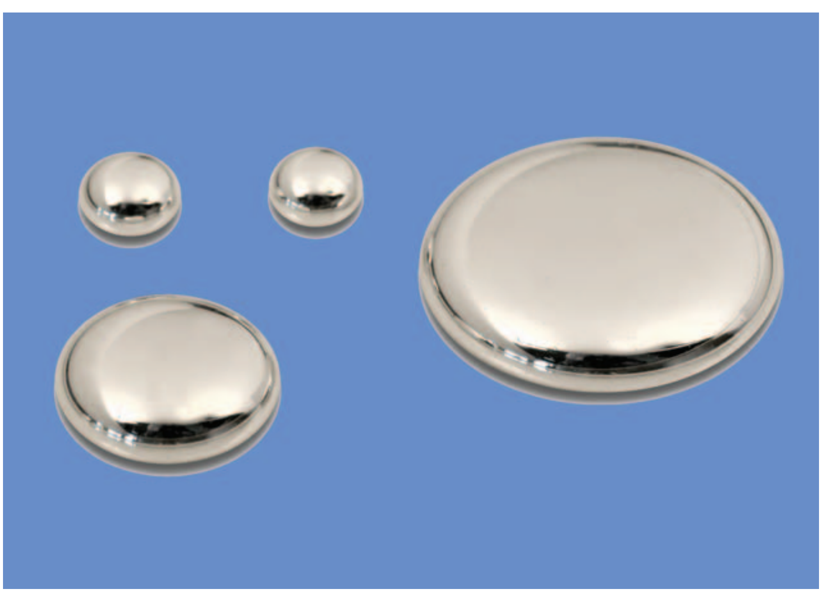
Mercury amalgams have also been around for a long time. An amalgam is a combination of mercury with at least one other metal. Amalgams are formed when a metal, such as silver, dissolves in mercury. The process is similar to dissolving salt in water. Amalgamation is used in mining to remove silver from ore. The silver dissolves in the mercury and a silver amalgam is formed. Heating the amalgam releases the silver. This method was used by miners as early as the 16th century.

Physical Properties

Mercury is the only liquid metal. In fact, there is only one other liquid element, **bromine**. Bromine is a non-metal. Mercury can be frozen (changed into a solid) at a temperature of –37.93°F (–38.85°C). It can be changed into a gas ("boiled") at 690.1°F (365.6°C). Its density is 13.59 grams per cubic centimeter, nearly 14 times the density of water.

Mercury has two physical properties of special interest. First, it has very high surface tension. Surface tension is a property of liquids that make them act like they are covered with a skin. For example, some water bugs are able to walk on the surface of water. With care, one can float a needle on the surface of water. These incidents are possible because of water's surface tension.

Mercury is also a very good conductor of electricity. This property is used in a number of practical devices. One such device is a mercury switch, such as the kind that turns lights on and off. A small amount of mercury can be placed into a tiny glass capsule. The capsule can be made



Droplets of mercury, the only liquid metal. IMAGE COPYRIGHT 2009, ANDRAZ CERAR. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

to tip back and forth. As it tips, the mercury flows from one end to the other. At one end of the capsule, the mercury may allow an electric current to flow through a circuit. At the other end, no mercury is present, so no current can flow. Mercury switches are easy to make and very efficient.

Chemical Properties

Mercury is moderately active. It does not react with **oxygen** in the air very readily. It reacts with some acids when they are hot, but not with most cold acids.

Occurrence in Nature

The abundance of mercury in Earth's crust is estimated to be about 0.5 parts per million. That makes it one of the 20 least common elements. It very rarely occurs as an element. Instead, it is usually found as a compound. Its most common ore is cinnabar, or mercuric sulfide (HgS). Cinnabar usually occurs as a dark red powder. It is often called by the common name of vermillion or Chinese vermillion.

According to the U.S. Geological Survey (USGS), as of 2008, the world's primary mercury resources can be found in China, Krygyzstan, Russia, Slovenia, Spain, and Ukraine. In the United States, mercury is found in states such as Alaska, Arkansas, California, Nevada, and Texas.

Isotopes

Seven naturally occurring isotopes of mercury are known. They are mercury-196, mercury-198, mercury-199, mercury-200, mercury-201, mercury-202, and mercury-204. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-six radioactive isotopes of mercury are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Two radioactive isotopes of mercury are used in medicine: mercury-197 and mercury-203. Both isotopes are used to study the brain and the kidneys. The isotopes are injected into the body where they travel to the brain and the kidneys. Inside these two organs, the isotopes give off radiation that is detected by instruments held above the body. The pattern of radiation provides information about how well the brain and kidneys are functioning.

Extraction

Mercury is still prepared as it was hundreds of years ago. Cinnabar is heated in air. The compound breaks down to give mercury metal:

$$HgS \xrightarrow{\text{heated}} Hg + S$$

The mercury metal is then purified by distillation. Distillation is the process of heating two or more liquids to their boiling points. Different liquids boil at different temperatures. The liquid that is wanted (such as mercury) can be collected at *its* boiling point. Mercury that is more than 99 percent pure can be collected by distillation.

Uses

Among the most important uses of mercury is in the preparation of chlorine. Chlorine is produced by passing an electric current through sodium chloride:

$$2NaCl \xrightarrow{\text{electric current}} 2Na + Cl_2$$

There is a problem with using this method, however. Sodium (Na) is a very reactive metal. If any water is present, the sodium will react violently with the water. This reaction makes the production of chlorine much more difficult.

In 1892, two English chemists developed a method for solving this problem. They made a container with a layer of mercury on the bottom. As sodium is produced by the electric current, it dissolves in the mercury, forming an amalgam. The sodium is unable to react with water. For many years, the "mercury cell" invented in 1892 was a very popular method for producing chlorine.

But today, companies are looking for other ways to make chlorine. They are worried about the harmful effects of mercury. They are also concerned that mercury can get into the environment and harm humans, other animals, and plants.

Another of the most important uses of mercury in the United States is in switches and other electrical applications. Again, there are increasing concerns about the health effects of mercury. Many companies are switching to electronic switches.

One application in which concerns about mercury have had little effect is fluorescent lamps. A fluorescent lamp contains mercury vapor (gas). When the lamp is turned on, an electric current passes through the mercury vapor, causing it to give off invisible radiation. The radiation strikes the inside of the glass tube, whose walls are coated with a phosphor. A phosphor is a material that gives off visible light when struck by electrons. The tube glows as the radiation strikes the phosphor.

Lamp manufacturers have reduced the amount of mercury in fluorescent lamps by about 60 percent. They developed ways to make the lamps work just as well with less mercury. However, mercury lamps are much more popular. Each lamp now contains much less mercury. But there are many more lamps than ever before.

With fluorescent lights, when an electric current passes through mercury vapors, the resulting invisible radiation strikes phosphors. The phosphors then give off visible light. IMAGE COPYRIGHT 2009, STOCKSNAPP. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

For a time, mercury batteries were quite popular. In the early 1980s, more than 1,000 tons of mercury a year were used to make mercury batteries. These batteries create a special environmental problem, however. People tend to just throw them away when they no longer work. The cases split open easily, releasing mercury into the environment. As a result, much less mercury is now being used to make such batteries. In fact, the use of mercury for making batteries has been discontinued in the United States.

Mercury is also used in dental applications, measuring instruments (such as mercury thermometers and barometers), and coatings for mirrors.

Compounds

The use of mercury compounds is also decreasing because of health concerns. A few of the compounds still in use follow. Notice that two different endings are used for mercury compounds. Those that end in *-ous* have less mercury than those that end in *-ic*.

- mercuric arsenate ($HgHAsO_4$): waterproofing paints
- mercuric benzoate ($Hg(C_7G_5O_2)_2$): medicine; used to treat syphilis
- mercuric chloride, or mercury bichloride, or corrosive sublimate ($HgCl_2$): disinfectant, tanning of leather, spray for potato seedlings (to protect from disease), insecticide, preservation of wood, embalming fluid, textile printing, and engraving
- mercuric cyanide ($Hg(CN)_2$): germicidal soaps (soaps that kill germs), photography
- mercuric oxide (HgO): red or yellow pigment in paints, disinfectant, fungicide (to kill fungi), perfumes and cosmetics
- mercuric sulfide (HgS): red or black pigment in paints
- mercurous chloride, or calomel (Hg_2Cl_2): fungicide, maggot control in agriculture, fireworks
- mercurous chromate (Hg_2CrO_4): green pigment in paints
- mercurous iodide (Hg_2I_2): kills bacteria on the skin

"Mad as a Hatter"

Back in the 1800s, most of the negative effects of mercury and its compounds were not yet known. Hatmakers of that time commonly used a mercury compound in their craft. It was used to treat the felt and beaver fur that lined the hats. Eventually, exposure to the mercury began to cause changes in the hatmakers' bodies. Their personalities and behavior became erratic.

Recognizing the bizarre personalities of many hatmakers, people often used the expression "mad as a hatter." In fact, author Lewis Carroll (1832–1898) created a character for *Alice's Adventures in Wonderland* that owes its origins

Health Effects

Mercury metal and most compounds of mercury are highly toxic. Interestingly enough, scientists became aware of this fact only quite recently. However, the toxicity of *some* mercury compounds has been known for many centuries. One form of mercury chloride known as calomel, for example, was sometimes used as a poison to kill people. It was also once used extensively to kill fungi and control maggots in agricultural crops.

But even as recently as the mid-20th century, there was relatively little concern about mercury metal and many mercury compounds. High school chemistry students often played with tiny droplets of mercury in the laboratory. They used mercury to coat pennies and other pieces of metal. Mercury was also widely used in dentistry. It was used to make amalgams, alloys of mercury with other metals, used to fill teeth. Most people even today are likely to have dental fillings that contain a small amount of mercury metal. The question of whether mercury is still safe to use in dental fillings is the source of considerable controversy. Some people say that so little mercury is lost from fillings that the metal presents no danger to people. Other people think that dentists should take no chances with this dangerous metal. They should stop using mercury fillings entirely.

Since the mid-20th century, chemists have learned a great deal more about the toxic effects of both mercury metal and most of its compounds. They now know that mercury itself enters the body very easily. Its vapors pass through the skin into the bloodstream. Its vapors can also be inhaled. And, of course, it can also be swallowed. In any of these cases, mercury gets into blood and then into cells. There it interferes with essential chemical reactions and can cause illness and death.

Sometimes, these effects occur over very long periods of time. People who work with mercury, for example, may take in small amounts of mercury over months or years. Health problems develop very slowly. These problems can include inflammation of the mouth and gums; loosening of the teeth; damage to the kidneys and muscles; shaking of the arms and legs; and depression, nervousness, and personality changes.

People can also be exposed to large doses of mercury over short periods of time. In such cases, even more serious health problems can arise. These include nausea, vomiting, diarrhea, stomach pain, damage to the kidneys, and death in only a week or so.

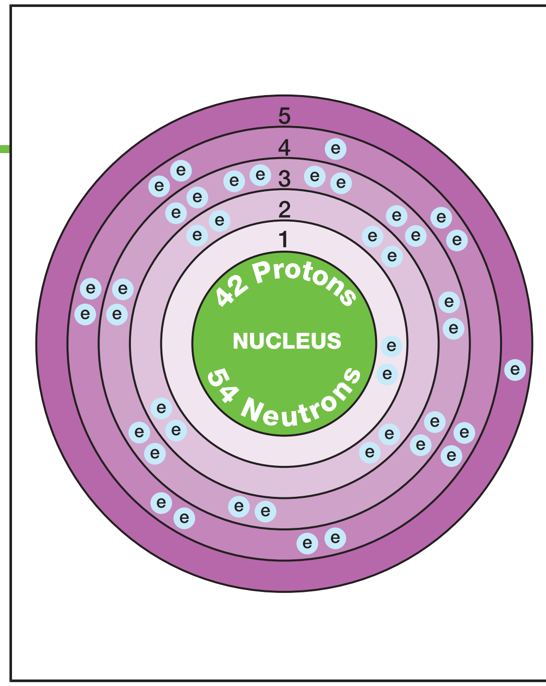
Tragic Effects of Mercury Poisoning In a tragic irony, a scientist who was helping to improve the environment died as a result of her efforts. In 1997, Dartmouth College chemistry professor Karen Wetterhahn died of mercury poisoning. Less than a year earlier, she had been experimenting with dimethyl mercury when she spilled a tiny amount on her hands. Dimethyl mercury is one of the most toxic of mercury compounds.

Wetterhahn was studying the effects that heavy metals (mercury, chromium, lead, and arsenic) have on living things. She was concerned about how these elements pollute the environment and cause disease in people.

In August 1996, as Wetterhahn was transferring some dimethyl mercury to a tube, the accident occurred. She was wearing latex gloves, but they were not adequate protection against the dangerous chemical. The mercury seeped into her skin. Wetterhahn did not begin to feel the effects of the exposure until six months later. She then started losing her balance, slurring her speech, and suffering vision and hearing loss. Tests showed her system had 80 times the lethal dose of mercury. Wetterhahn died of mercury poisoning on June 8, 1997.

Wetterhahn's death prompted some safety changes. Bright stickers on latex glove boxes warn against using the gloves with hazardous chemicals. Workshops were held to teach proper glove selection. The dangers of dimethyl mercury were stressed. And scientists were urged to use a less dangerous chemical than dimethyl mercury. Overall, Wetterhahn's death heightened awareness in the scientific community of potential laboratory dangers.

Molybdenum



Key Facts

Symbol: Mo

Atomic Number: 42

Atomic Mass: 95.96

Family: Group 6 (VIB); transition metal

Pronunciation: muh-LIB-duh-num

Overview

Molybdenum was one of the first metals to be discovered by a modern chemist. It was found in 1781 by Swedish chemist Peter Jacob Hjelm (1746–1813). Hjelm's work on the element was not published, however, until more than a century later.

Molybdenum is a transition metal, placing it in the center of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another.

Molybdenum is a hard, silvery metal with a very high melting point. It is used primarily to make alloys with other metals. An alloy is a mixture of two or more metals. The mixture has properties different from those of the individual metals. The most common alloys of molybdenum are those with steel. Molybdenum improves the strength, toughness, resistance to wear and corrosion, and ability to harden steel.

Discovery and Naming

The most common ore of molybdenum is called molybdenite. Molybdenite contains a compound of molybdenum and **sulfur**, molybdenum disulfide (MoS_2). Molybdenum disulfide is a soft black powder that looks

WORDS TO KNOW

Alloy: A mixture of two or more metals that has properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Chemical reagent: A substance, such as an acid or an alkali, used to study other substances.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Radioactive tracer: An isotope whose movement in the body can be followed because of the radiation it gives off.

Trace element: An element that is needed in very small amounts for the proper growth of a plant or animal.

Transition metal: An element in Groups 3 through 12 of the periodic table.

like graphite. Graphite is pure **carbon**; it makes up the "lead" in ordinary pencils. In fact, earlier chemists thought that graphite and molybdenum disulfide were the same material.

The soft "squishy" character of molybdenum disulfide frustrated early researchers of the compound. Chemists often grind up a material before trying to dissolve it in acids or other liquids. But molybdenum disulfide cannot be ground up. The material just slides out of the way.

It was not until 1781 that Hjelm found a way to work with the compound. He discovered that it was very different from graphite. In fact, he found that it contained an entirely new element. The name chosen for the new element illustrates a further confusion. In Greek, the word for **lead** is *molybdos.* The name chosen for the new element, molybdenum, is actually the Greek word for lead!

Hjelm's work was known to his fellow chemists because of letters they had written to each other. But the report of his discovery was not actually printed for all chemists to read until 1890. Between 1791 and 1891, Hjelm's research was repeated by other chemists. They confirmed what he discovered, and he is recognized today as the discoverer of molybdenum.

Physical Properties

As a solid, molybdenum has a silvery-white metallic appearance. It more commonly occurs as a dark gray or black powder with a metallic luster.

Its melting point is about 4,700°F (about 2,610°C) and the boiling point is 8,600 to 10,000°F (4,800 to 5,560°C). Its density is 10.28 grams per cubic centimeter, more than 10 times the density of water.

Chemical Properties

Molybdenum does not dissolve in most common chemical reagents. A chemical reagent is a substance that takes part in a chemical reaction, such as an acid or an alkali. For example, molybdenum does not dissolve in hydrochloric acid, hydrofluoric acid, ammonia, sodium hydroxide, or dilute sulfuric acid. These chemicals are reagents often used to test how reactive a substance is. Molybdenum does dissolve in hot strong sulfuric or nitric acids, however. The metal does not react with **oxygen** at room temperatures, but does react with oxygen at high temperatures.

Occurrence in Nature

Molybdenum never occurs free in nature. Instead, it is always part of a compound. In addition to molybdenite, it occurs commonly as the mineral wulfenite ($PbMoO_4$). Its abundance in Earth's crust is estimated to be about 1 to 1.5 parts per million. That makes it about as common as **tungsten** and many of the rare earth (lanthanoid) elements. In 2008, the largest producers of molybdenum in the world included the United States, China, Chile, Peru, and Canada. In the United States, molybdenum ores were found primarily in Colorado, Idaho, Nevada, and New Mexico. According to the U.S. Geological Survey (USGS), the value of the molybdenum from U.S. mines was $4.5 billion that year.

Isotopes

Seven naturally occurring isotopes of molybdenum exist: molybdenum-92, molybdenum-94, molybdenum-95, molybdenum-96, molybdenum-97, molybdenum-98, and molybdenum-100. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

None of the seven naturally occurring molybdenum isotopes is radioactive. However, 22 artificial radioactive isotopes have been produced.

A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of molybdenum is commonly used in medicine, molybdenum-99m. (The "m" in this instance stands for "metastable," which means the isotope does not last very long.) This isotope is not used directly, however. Instead, it is used in hospitals to make another radioactive isotope, technetium-99m. This isotope of **technetium** (atomic number 43) is widely used as a tracer for diagnostic studies of the brain, liver, spleen, heart, and other organs and body systems.

A radioactive tracer is an isotope whose movement in the body can be followed because of the radiation it gives off. The radiation can be "traced" with special equipment held above the body. The pattern produced by the radiation allows a doctor to diagnose any unusual functioning (behavior) of the organ or body part.

Technetium-99m cannot be used for this purpose all by itself. It changes very quickly into a new isotope. Hospitals prepare molybdenum-99m first. This isotope can be stored for short periods of time. It slowly gives off radiation and changes into technetium-99m. The technetium-99m is captured as it is formed from molybdenum-99m and injected into the body for tracer studies. Because it is used to produce technetium-99m, the isotope molybdenum-99m is sometimes referred to as a "molybdenum cow."

Extraction

Pure molybdenum metal can be obtained from molybdenum trioxide (MoO_3) in a variety of ways. For example, hot hydrogen can be passed over the oxide to obtain the metal:

$$\mathbf{MoO_3 + 3H_2 \rightarrow 3H_2O + Mo}$$

Uses

About 83 percent of the molybdenum used in the United States in 2008 was made into alloys of steel and iron. Some of these alloys, in turn, were used to make stainless and heat-resistant steel. A typical use is in airplane, spacecraft, and missile parts. Another important use of molybdenum alloys is in the production of specialized tools. Spark plugs, propeller shafts, rifle barrels, electrical equipment used at high temperatures, and boiler plates are all made of molybdenum steel.

Another important use of molybdenum is in catalysts. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction. Molybdenum catalysts are used in a wide range of chemical operations, in the petroleum industry, and in the production of polymers and plastics.

Compounds

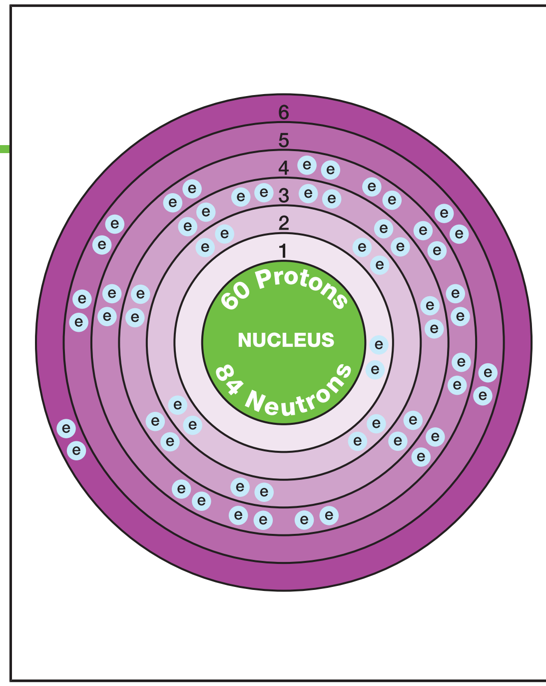
A number of molybdenum compounds are used in industry and research. Interestingly, molybdenum disulfide is still used as a lubricant, as it was more than 200 years ago. The slippery black powder looks and behaves much like graphite. Molybdenum sulfide is used in industrial operations to reduce the friction between sliding or rolling parts. It does not break down when heated or used for very long periods of time.

Other compounds of molybdenum are used as protective coatings in materials used at high temperatures; solders; as catalysts; as additives to animal feeds; and as pigments and dyes in glasses, ceramics, and enamels.

Health Effects

Molybdenum is relatively safe for humans and animals. No studies have shown it to be toxic. In fact, it is regarded as a necessary trace element for the growth of plants. A trace element is one that is needed in very small amounts for the proper growth of a plant or animal.

Neodymium



Key Facts

Symbol: Nd

Atomic Number: 60

Atomic Mass: 144.242

Family: Lanthanoid (rare earth metal)

Pronunciation: nee-oh-DIM-ee-um

Overview

Neodymium was discovered in 1885 by Austrian chemist Carl Auer (Baron von Welsbach; 1858–1929). Auer found the new element in a mineral called didymia. Didymia, in turn, had been found in another complicated mineral known as ceria, originally found in Sweden in 1803. It took chemists nearly a century to completely analyze ceria. When they had done so, they found that it contained seven new elements. Neodymium was one of these elements.

Neodymium is in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. It is one of the rare earth elements. The term "rare earth" is inaccurate, however. These elements are not especially rare but were once difficult to separate from each other. These rare earth elements are also called the lanthanoids. That name comes from the third element in Row 6, **lanthanum**.

Neodymium has long been used in coloring glass and is now used in making lasers, very powerful magnets, and special alloys.

Discovery and Naming

During the late 1700s, two important mineral discoveries were made in Sweden. One was made just outside the town of Ytterby. The mineral

WORDS TO KNOW

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for producing very bright light of a single color.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Reactive: Having a tendency to combine with other substances.

Tarnishing: Oxidizing; reacting with oxygen in the air.

found there, yttria, was eventually found to contain nine new elements. The second discovery was made near the town of Bastnas. That mineral, called cerite, was later found to contain seven new elements.

Cerite was thoroughly studied by Swedish chemist Carl Gustav Mosander (1797–1858). In 1839, Mosander was able to separate cerite into two parts, which he called **cerium** and lanthanum. Mosander believed he had found two new elements. Two years later, however, he learned that his lanthanum was not an element but a mixture of two parts. Mosander called these two new parts lanthanum and didymium. Mosander chose the name didymium because it means "twin." He said that didymium was like an identical twin to lanthanum. Chemists later confirmed that two of Mosander's discoveries were really new elements: cerium and lanthanum.

Mosander's didymium was not an element, however. In 1885, Auer found that didymium consisted of two simpler materials. The new elements were named neodymium and **praseodymium**. Auer chose the name neodymium because it means "new twin." Praseodymium, by comparison, means "green twin." Compounds of praseodymium are green.

Mosander, Auer, and other chemists of the time had only crude equipment with which to work. They never isolated any new element in a pure form. They found compounds of the element, usually a compound of the element and **oxygen**. The first pure samples of neodymium were not produced until 1925.

Physical Properties

Neodymium is a soft, malleable metal. Malleable means capable of being hammered into thin sheets. It can be cut and shaped fairly easily. It has a melting point of 1,875°F (1,024°C) and a boiling point of about 5,490°F (3,030°C). Neodymium has a density of 7.0 grams per cubic centimeter, seven times the density of water.

Chemical Properties

Neodymium is somewhat reactive. For example, it combines with oxygen in the air to form a yellowish coating. To protect it from tarnishing, the metal is usually stored in mineral oil and wrapped in plastic.

Neodymium shows typical properties of an active metal. For example, it reacts with water and acids to release **hydrogen** gas.

Occurrence in Nature

Neodymium is one of the most abundant of the rare earth elements. Its abundance in Earth's crust is thought to be about 12 to 24 parts per million. That places it about 27th among the chemical elements. It is slightly less abundant than **copper** and **zinc**.

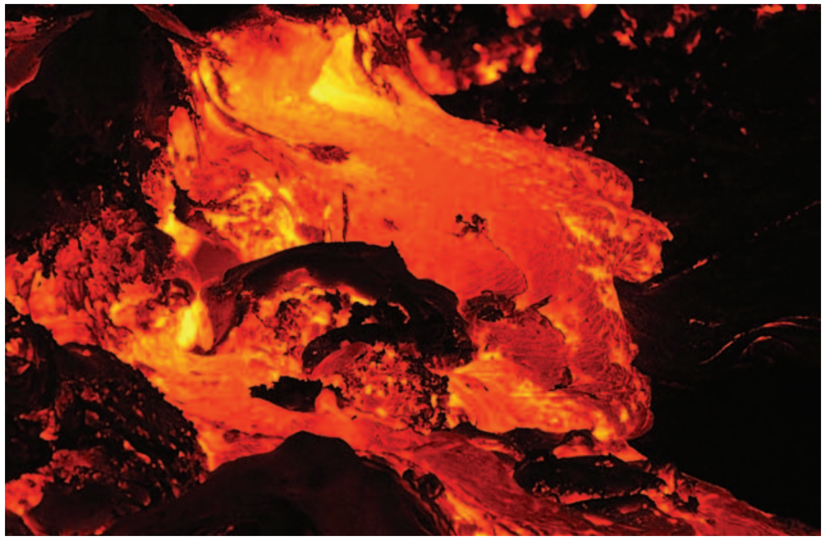
The most common ores of neodymium are monazite and bastnasite. These ores are the most common source for all the rare earth elements.

Isotopes

Seven naturally occurring isotopes of neodymium are known. They are neodymium-142, neodymium-143, neodymium-144, neodymium-145, neodymium-146, neodymium-148, and neodymium-150. Five of the isotopes are stable and two, neodymium-144 and neodymium-150, are radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-nine radioactive isotopes of neodymium have also been produced artificially. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very

Neodymium isotopes can aid scientists in the study of volcanic eruptions. IMAGE COPYRIGHT 2009, KEITH LEVIT. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.



small particles are fired at atoms. These particles stick in the atoms and make them radioactive. None of neodymium's radioactive isotopes has any important use.

Predicting Volcanic Eruptions Rare earth elements have very special applications in scientific research. For example, consider a discovery made by scientists at the Lawrence Berkeley Laboratory (LBL) Center for Isotope Geochemistry in Berkeley, California. These scientists were trying to predict the size of a volcanic eruption. If they knew an eruption was going to occur, could they estimate how much lava it would produce?

Surprisingly, they found the answer in isotopes of neodymium. They discovered that large volcanic eruptions produced lava with one kind of isotope composition. Smaller eruptions produced lava with a different isotope composition.

So when a volcano starts producing lava, it can be studied for neodymium isotopes. From the composition of isotopes, scientists may be able to predict how big the coming eruption will be. The LBL scientists plan to use this information to warn residents of the intensity of the eruption.

Extraction

Neodymium occurs with other rare earth elements in monazite, bastnasite, and allanite. It must first be separated from these other elements.

It is then obtained in a pure form by reacting neodymium fluoride (NdF_3) with calcium:

$$3NdF_3 + 2Ca \rightarrow 2CaF_2 + 3Nd$$

Uses and Compounds

Neodymium and its compounds have a number of important uses. One is in a kind of laser known as a neodymium **yttrium aluminum** garnet (Nd:YAG) laser. A laser is a device for producing very bright and focused light of a single color. The Nd:YAG laser is used for treating bronchial cancer and certain eye disorders. The bronchi are air tubes that lead into the lungs.

Another important use of neodymium is in the manufacture of very strong magnets. The neodymium-**iron**-**boron** (NIB) magnet is one of the strongest magnets known. It is so strong it has to be handled with special care. Two NIB magnets can attract each other so strongly that they can smash into each other and shatter. An NIB magnet is inexpensive. Such magnets are used in stereo audio speakers.

Neodymium-iron-boron magnets are used in audio speakers. IMAGE COPYRIGHT 2009, ANDI HAZELWOOD. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Neodymium is also used in various optical (light) devices. For example, the General Electric Company makes a lightbulb called an "Enrich" bulb. The glass of the bulb contains a small amount of neodymium that filters out yellowish and greenish colors from the filament. The filament is the metal wire that is heated and gives off light. The light produced by the Enrich bulb is a very bright white light.

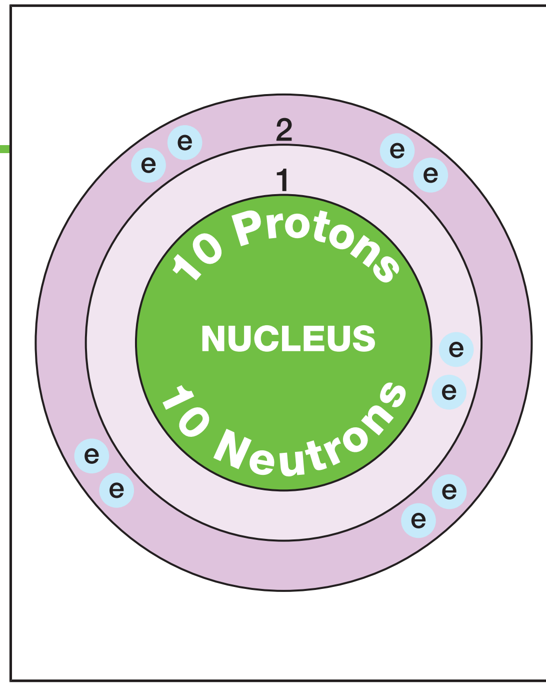
One of the oldest uses of neodymium is in coloring glass. The addition of a small amount of the element to glass gives it a greenish color. Some Tiffany lamp shades contain neodymium.

Neodymium is also used in various green (environmentally friendly) technologies, including hybrid cars and wind turbines.

Health Effects

Neodymium is regarded as moderately hazardous. Its compounds are known to irritate the eyes and skin. It should be handled with caution.

Neon



Key Facts

Symbol: Ne

Atomic Number: 10

Atomic Mass: 20.1797

Family: Group 18 (VIIIA); noble gas

Pronunciation: NEE-on

Overview

Neon is a member of the noble gas family. Other elements in this family include **helium**, **argon**, **krypton**, **xenon**, and **radon**. These gases are in Group 18 (VIIIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other.

The noble gases are sometimes called the inert gases. This name comes from the fact that these elements do not react very readily. In fact, compounds exist for only four noble gases—argon, krypton, radon, and xenon. Chemists have yet to prepare compounds of helium or neon.

Neon was discovered in 1898 by British chemists William Ramsay (1852–1916) and Morris Travers (1872–1961). It occurs naturally in the atmosphere, but only in very small amounts.

Neon has relatively few uses. The most familiar use is in neon lighting. Today, neon signs of every color, shape, and size exist. Neon signs are often filled with neon gas, but they may also contain other gases as well. The gas contained in the sign tube determines the color of light given off. The color given off by neon itself is reddish-orange.

WORDS TO KNOW

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Noble gas: An element in Group 18 (VIIIA) of the periodic table.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Spectra: The lines produced when chemical elements are heated.

Spectroscopy: The process of analyzing light produced when an element is heated.

Discovery and Naming

It took humans centuries to understand air. At one time, philosophers thought air was an element. Many ancient Greek philosophers, for example, thought that the four basic elements were air, fire, water, and earth.

The first research to disprove that idea was done in the 1770s. In that decade, two new elements were discovered in air: **nitrogen** and **oxygen**. For some time, chemists were convinced that these two gases were the only ones present in air. That idea is easy to understand. Between them, nitrogen and oxygen make up more than 99 percent of air.

But over time, chemists became more skilled at making measurements. They recognized that something else was in air besides nitrogen and oxygen. That "something else" accounted for the remaining 1 percent that is not nitrogen or oxygen. In 1894, a third element was discovered in air: argon. Argon makes up about 0.934 percent of air. So, nitrogen, oxygen, and argon together make up about 99.966 percent of air.

But what was responsible for the remaining 0.034 percent of air? Chemists knew that other gases must be present in very small amounts. But what were those gases?

That question was answered between 1895 and 1900. Five more inert gases were discovered in air. One of those gases was neon.

Detecting gases in very small amounts was very difficult in the 1890s. Equipment was often not good enough to capture a tiny fraction of a milliliter of gas. But a new method, called spectroscopy, was developed that "sees" even small amounts of an element. Spectroscopy is the process of analyzing the light produced when an element is heated. The light pattern, or spectrum, produced is different for every element. The spectrum (plural: spectra) consists of a series of very specific colored lines.

In 1898, Ramsay and Travers were studying the minute amount of gas that remained after oxygen, nitrogen, and argon had been removed from air. They heated the sample of gas and studied the spectrum produced by it. Ramsay and Travers found spectral lines they had never seen before. They described their discovery:

> The blaze of crimson light from the tube told its own story, and it was a sight to dwell upon and never to forget. It was worth the struggle of the previous two years; and all the difficulties yet to be overcome before the research was finished. The *undiscovered gas* had come to light in a manner which was no less than dramatic. For the moment, the actual spectrum of the gas did not matter in the least, for nothing in the world gave a glow such as we had seen.

Ramsay's son was one of the first people to hear about the discovery. He wanted to name the new element *novum,* meaning "new." His father liked the idea, but suggested using the Greek word for "new," *neos.* Thus, the element was named neon.

Physical Properties

Neon is a colorless, odorless, tasteless gas. It changes from a gas to a liquid at –410.66°F (–245.92°C) and from a liquid to a solid at –415.5°F (–248.6°C). Its density is 0.89994 grams per liter. By comparison, the density of air is about 1.29 grams per liter.

Chemical Properties

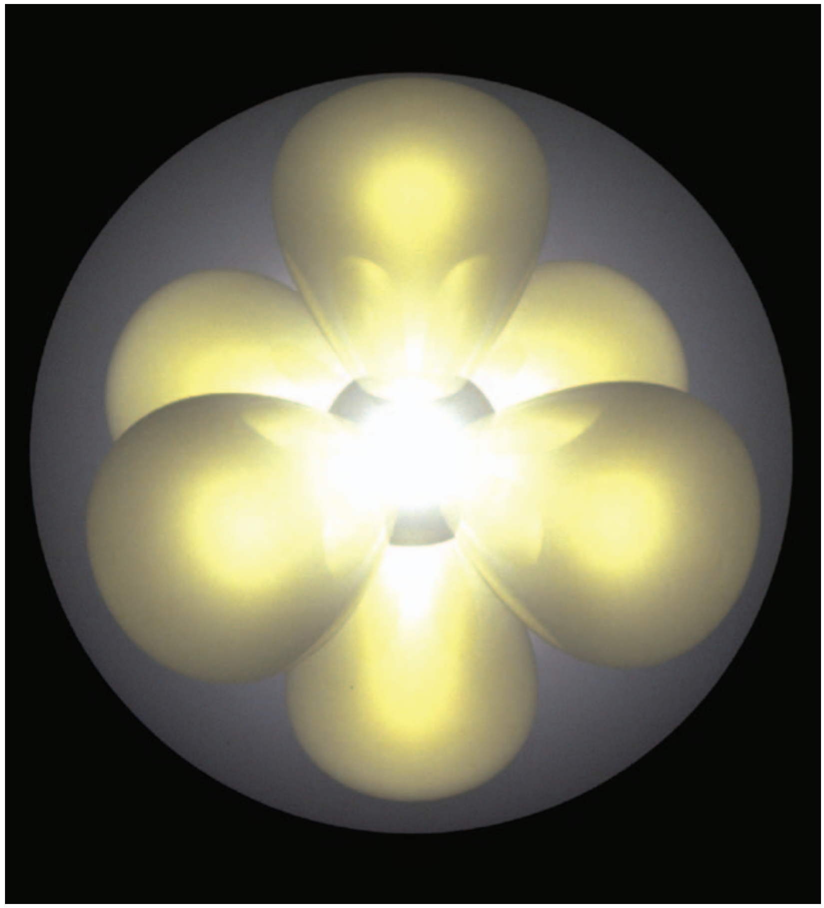
Neon is chemically inactive. So far, it has been impossible to make neon react with any other element or compound.

Occurrence in Nature

The abundance of neon in normal air is 18.2 parts per million (0.0182 percent).

Isotopes

Three isotopes of neon exist in nature: neon-20, neon-21, and neon-22. Isotopes are two or more forms of an element. Isotopes differ from each

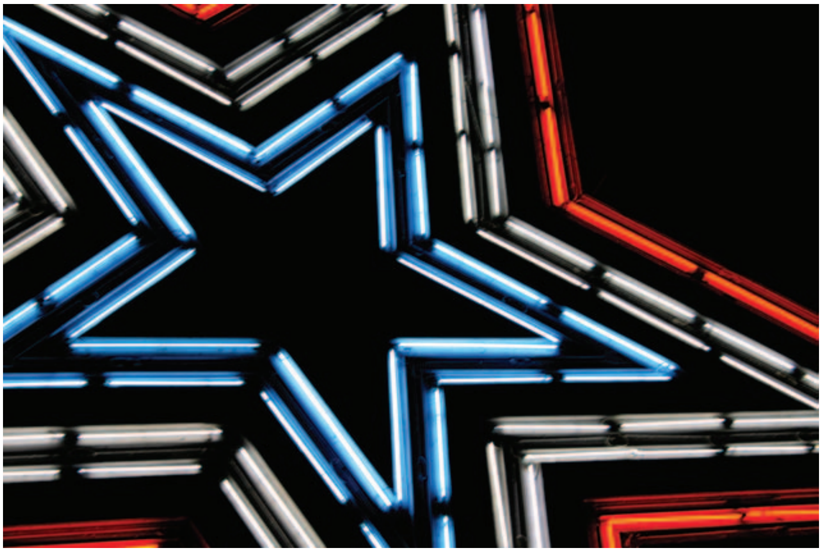


A computer-generated model of a neon atom. © KENNETH EWARD/BIOGRAFX. NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Eleven radioactive isotopes of neon are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of neon has any commercial application.



Neon tubes form the shape of a star. IMAGE COPYRIGHT 2009, DARREN K. FISHER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Extraction

Neon can be obtained from air by fractional distillation. The first step in fractional distillation of air is to change a container of air to a liquid. The liquid air is then allowed to warm up. As the air warms, each element in air changes from a liquid back to a gas at a different temperature. The portion of air that changes back to a gas at –410.66°F (–245.92°C) is neon.

Uses

The best known use of neon gas is in neon lights. A neon light consists of a glass tube filled with neon or some other inert gas. An electric current is passed through the tube. The electric current causes neon atoms to break apart. After a fraction of a second, the parts recombine. When they recombine, they give off light. The color of light produced is determined by the gas used to fill the tube.

Neon lighting was invented by French chemist Georges Claude (1870–1960). Claude displayed his first neon sign at the Paris Exposition of 1910. He sold the first neon advertising sign to a Paris barber two years later.

By the 1920s, neon lighting had become popular in many parts of the world. Neon lights were fairly inexpensive, lasted a long time, and were very attractive. Probably the most spectacular collection of neon lighting is in Las Vegas, Nevada. Hotels, night clubs, and restaurants

The glow of neon lights in Las Vegas, Nevada. IMAGE COPYRIGHT 2009, ANDY Z. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

seem to try to outdo everyone else in having the biggest and brightest neon sign.

Neon lighting is now used for many other purposes. For example, neon tubes are part of instruments used to detect electric currents. Neon is also used in the manufacture of lasers. A laser is a device for producing very bright light of a single color. Lasers now have many uses in industry and medicine. They are very efficient at cutting metal and plastic. They can also be used to do very precise kinds of surgery.

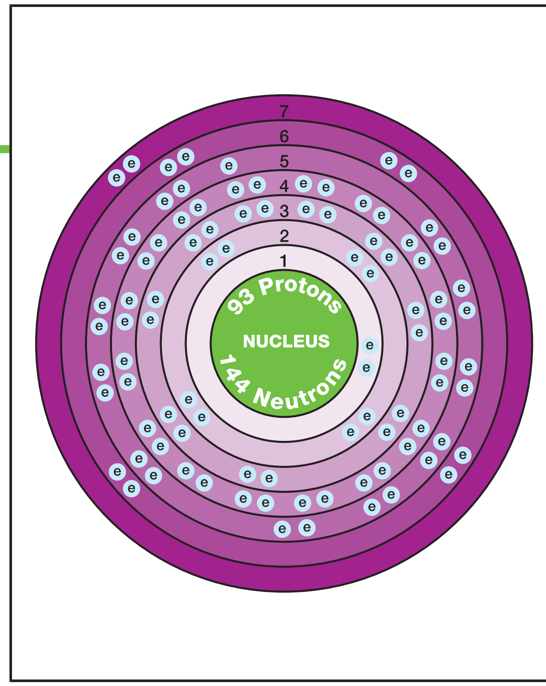
Compounds

There are no compounds of neon.

Health Effects

There are no known health effects of neon.

Neptunium



Key Facts

Symbol: Np

Atomic Number: 93

Atomic Mass: [237]

Family: Actinoid; transuranium element

Pronunciation: nep-TOO-nee-um

Overview

Neptunium lies in Row 7 of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Neptunium is the first transuranium element. The term transuranium means "beyond **uranium**." Any element with an atomic number greater than 92 (uranium's atomic number) is called a transuranium element. Actinoid elements are found in Row 7. This name comes from element 89, **actinium**.

Scientists have now found more than 20 isotopes of neptunium. Neptunium was once a very rare element, but it can now be produced somewhat easily in a nuclear reactor. A nuclear reactor is a device in which nuclear fission reactions occur. Nuclear fission is the process of splitting atoms when neutrons collide with atoms of uranium or plutonium. These collisions produce new elements. Neptunium is used commercially only in specialized detection devices.

Discovery and Naming

The discovery of neptunium in 1940 represented an important breakthrough in the study of chemical elements. Scientists had known for

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear fission: The process that occurs when neutrons collide with atoms of uranium or plutonium, causing them to break apart.

Nuclear reactor: A device in which nuclear fission reactions occur.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Transuranium (actinoid) element: An element with an atomic number greater than 92.

nearly a decade about an unusual kind of reaction. When an element is bombarded with neutrons, it sometimes changes into a new element. That new element has an atomic number one greater than the original element. For example, bombarding **copper** (atomic number 29) with neutrons may result in the production of **zinc** (atomic number 30). Bombarding **sodium** (atomic number 11) with neutrons may result in **magnesium** (atomic number 12).

One reason this discovery fascinated scientists was the possibility of bombarding uranium (atomic number 92) with neutrons. In the 1930s, uranium was the heaviest element known. It was the last element in the periodic table. But a "neutron change" like those described earlier would produce an element with atomic number 93. No one had ever heard of an element with atomic number 93!

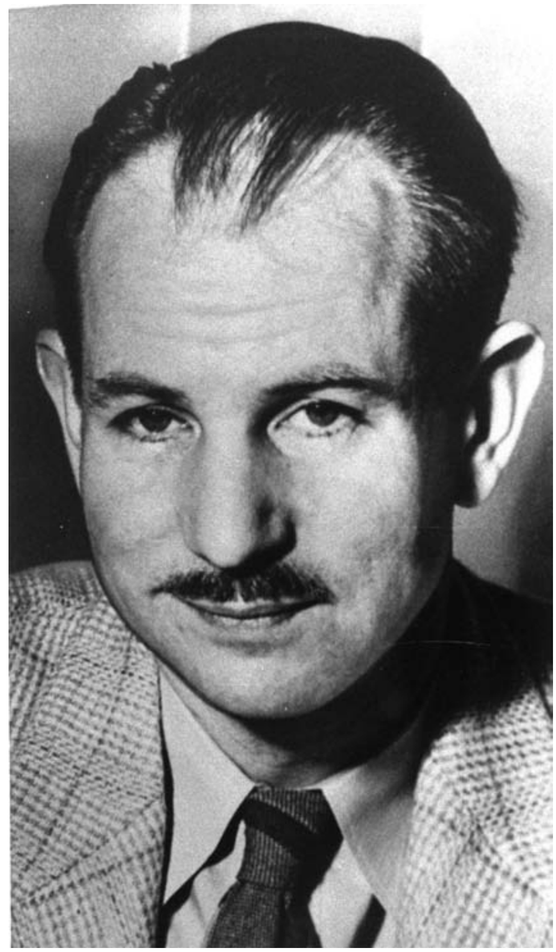
In 1940, a pair of physicists at the University of California, Berkeley, were studying this problem. Edwin M. McMillan (1907–1991) and Philip H. Abelson (1913–2004) reported finding evidence of element number 93. They suggested naming it neptunium, in honor of the planet Neptune. (Uranium, the element before neptunium, had been named for the planet Uranus.)

Physical Properties

Neptunium is a silvery white metal with a melting point of 1,180°F (640°C) and a density of 20.45 grams per cubic centimeter, more than 20 times the density of water.

Chemical Properties

Neptunium is fairly reactive and forms some interesting compounds. Examples include neptunium dialuminide ($NpAl_2$) and neptunium beryllide ($NpBe_3$). These compounds are unusual because they consist of two metals joined to each other. Normally, two metals do not react with each other very easily. Neptunium also forms a number of more traditional compounds, such as neptunium dioxide (NpO_2), neptunium trifluoride (NpF_3), and neptunium nitrite ($NpNO_2$).



One of the discoverers of neptunium, Edwin M. McMillan. LIBRARY OF CONGRESS.

Occurrence in Nature

When neptunium was first discovered, scientists thought that it was an entirely artificial, or human-made, element. In 1942, very small amounts of the element were found in Earth's crust. The element can sometimes be found in ores containing uranium and other radioactive elements.

Isotopes

All isotopes of neptunium are radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

The longest lived isotope is neptunium-237. Its half life is 2,144,000 years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. Of a sample of neptunium-237,

Where Did They Go?: Disappearing Elements

Scientists think that Earth was formed about five billion years ago. What elements would a chemist have found on Earth in those days?

Part of the answer to that question is easy. Most of the elements found today were probably present five billion years ago. Those are the stable, or constant, elements. An untouched lump of gold in Earth's crust five billion years ago would still be a lump of gold today.

But that statement is not true for radioactive elements. Radioactive elements "fall apart" spontaneously. They break down and form new, simpler elements.

The rate at which radioactive elements break down differs from element to element, however. Some break down slowly, others break down quickly. Scientists measure the rate of breakdown in half lives. An element with a long half life breaks down very slowly. An element with a short half life breaks down quickly.

Uranium, for example, has three naturally occurring isotopes. Their half lives are 4.6 billion years, 700 million years, and 25 million years. If 100 metric tons of uranium were present when Earth was formed five billion years ago, about half of the first isotope would have broken down by now. About 50 metric tons of the element would remain. Scientists would have no trouble finding the element in Earth's crust.

But neptunium is a different story. Its longest lived isotope is neptunium-237, with a half life of about two million years. If 100 million tonnes of neptunium were present at Earth's beginning, only 50 million tons would be left after two million years. After another two million years (four million years altogether), only 25 million tons would be left. After another two million years (six million years altogether), only 12.5 million tons would be left.

Continue the mathematics. How much neptunium is left after 8 million years, 10 millions years, 12 million years, …5 *billion* years? No need to do the calculations: Not very much neptunium at all would be left! Perhaps, too little to even find in Earth's crust.

So what does this example suggest about other transuranium elements, such as plutonium (number 94) and americium (number 95)? All of these elements have fairly short half lives. Of course, "fairly short" sometimes means "only" a few million years!

only half would remain after 2,144,000 years. The other half would have broken down to form new elements.

Neptunium-239 is the only isotope of neptunium to have practical uses. It is used in special instruments for detecting the presence of neutrons.

Extraction

Pure neptunium metal can be made by heating neptunium trifluoride (NpF_3) with hot barium or lithium metal:

Neptunium is used in nuclear reactors. Pictured here is Three Mile Island in Middletown, Pennsylvania, site of a partial meltdown in 1979. IMAGE COPYRIGHT 2009, DOBRESUM. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

$$3Ba + 2NpF_3 \rightarrow 3BaF_2 + 2Np$$

The metal can be purchased for legal uses.

Uses and Compounds

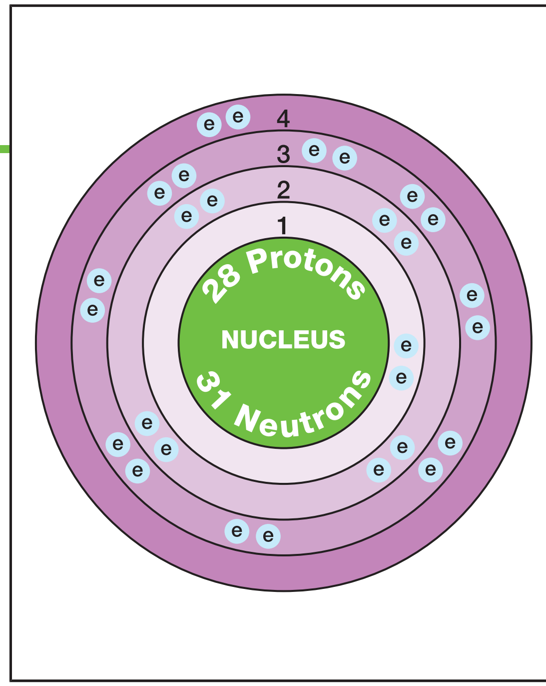
Neptunium and its compounds of neptunium have been made for research purposes. They are used in specialized detection devices and in nuclear reactors. Neither the element nor its compounds have any commercial uses.

Health Effects

Neptunium is a very hazardous material. The radiation it gives off can cause serious health problems for humans and other animals. It must be handled with great caution.

Radiation transfers large amounts of energy to cells and is quite penetrating. Cells that are damaged, but not killed, often reproduce out of control. This growth by functionally damaged cells forms tumors and causes related problems for organs and tissues.

Nickel



Key Facts

Symbol: Ni

Atomic Number: 28

Atomic Mass: 58.6934

Family: Group 10 (VIIIB); transition metal

Pronunciation: NI-kul

Overview

Nickel is the only element named after the devil. The name comes from the German word *Kupfernickel,* meaning "Old Nick's copper," a term used by German miners. They tried to remove copper from an ore that looked like copper ore, but they were unsuccessful. Instead of copper, they got slag, a useless mass of earthy material. The miners believed the devil ("Old Nick") was playing a trick on them. So they called the fake copper ore Old Nick's copper.

Since then, nickel has become a very valuable metal. The most common use is in the production of stainless steel, a strong material that does not rust easily. It is used in hundreds of industrial and consumer applications. Nickel is also used in the manufacture of many other alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals.

Nickel is classified as a transition metal. Transition metals are elements between Groups 2 (metals) and 13 (non-metals) in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Nickel is closely related to **iron**, **cobalt**, **copper**, and **zinc**. These metals are close to nickel in the periodic table.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Ductile: Capable of being drawn into thin wires.

Electroplating: The process by which a thin layer of one metal is laid down on top of a second metal.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Metallurgy: The art and science of working with metals.

Nickel allergy: A health condition caused by exposure to nickel metal.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

The study of metals was difficult for early chemists. Many metals looked very similar. They also acted very much like each other chemically. Nickel was one of the metals about which there was much confusion.

Copper miners were confused about nickel and copper because they both occurred in ores with a green tint. But copper ores reacted differently to heat than did nickel ores. This confusion led to the choice for nickel's name.

But cobalt miners were confused too. Some ores of nickel also look like cobalt ores. But these ores did not react chemically in the same way either. Cobalt mine owners called the "misbehaving" ores of nickel "cobalt which had lost its soul."

Swedish mineralogist Axel Fredrik Cronstedt (1722–1765) was the first person to realize that nickel was a new element. In 1751, he was given a new mineral from a cobalt mine near the town of Hälsingland, Sweden. While Cronstedt thought the ore might contain cobalt or copper, his tests produced a surprising result. He found something in the mineral that did not act like cobalt, copper, or any other known element. Cronstedt announced that he had found a new element. He used a shortened version of Kupfernickel for the name of the new element. He called it nickel.

Physical Properties

Nickel is a silvery-white metal. It has the shiny surface common to most metals and is both ductile and malleable. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. Its melting point is 2,831°F (1,555°C) and its boiling point is about 5,135°F (2,835°C). The density of nickel is 8.90 grams per cubic centimeter, nearly nine times the density of water.

Nickel is only one of three naturally occurring elements that is strongly magnetic. The other two are iron and cobalt. But nickel is less magnetic than either iron or cobalt.

Chemical Properties

Nickel is a relatively unreactive element. At room temperature, it does not combine with **oxygen** or water or dissolve in most acids. At higher temperatures, it becomes more active. For example, nickel reacts with oxygen to form nickel oxide (NiO):

$$2Ni + O_2 \quad heat\rightarrow \; 2NiO$$

It also reacts with steam to get nickel oxide and hydrogen gas:

$$Ni + H_2O \quad heat\rightarrow \; 2NiO + H_2$$

Occurrence in Nature

Nickel makes up about 0.01 to 0.02 percent of Earth's crust. It ranks about 22nd among the chemical elements in terms of abundance in Earth's crust. Nickel is thought to be much more abundant in Earth's core. In fact, many experts believe that the core consists almost entirely of iron and nickel.

One argument for this belief is the presence of nickel in meteorites. Meteorites are pieces of rock or metal from space that fall to Earth's surface. Meteorites often contain a high percentage of nickel.

The most common ores of nickel include pentlandite, pyrrhotite, and garnierite. The element also occurs as an impurity in ores of iron, copper, cobalt, and other metals.

Most of the nickel used in the United States is imported or obtained from recycling. As of 2008, the largest producers of nickel metal included Russia, Canada, Indonesia, Australia, and New Caledonia. One of the world's largest single deposits of nickel is located at Sudbury Basin,

Nickel is present in meteorites, such as the Hoba Meteorite in Namibia, Africa. Weighing more than 60 tons, the meteorite is 84 percent iron, 16 percent nickel, with a trace of various other elements. Scientists believe the massive meteorite fell to Earth some 80,000 years ago. IMAGE COPYRIGHT 2009, PICHUGIN DMITRY. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Ontario, Canada. The deposit was discovered in 1883. It covers an area 17 miles (27 kilometers) wide and 37 miles (59 kilometers) long. Some experts believe the deposit was created when a meteorite struck the earth at Sudbury Basin.

Isotopes

There are five naturally occurring isotopes of nickel: nickel-58, nickel-60, nickel-61, nickel-62, and nickel-64. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Eighteen radioactive isotopes of nickel are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of nickel, nickel-63, has limited use in industry. This isotope has two uses: for the detection of explosives, and in certain kinds of electronic devices, such as surge protectors. A surge protector is a device that protects sensitive electronic equipment like computers from sudden changes in the electric current flowing into them.

Extraction

The method used for making pure nickel metal is a common one in metallurgy. Metallurgy is the art and science of working with metals. Most nickel ores contain nickel sulfide (NiS). These ores are "roasted" (heated in air). Roasting converts the nickel sulfide to nickel oxide:

$$2NiS + 3O_2 \rightarrow 2NiO + 2SO_2$$

The nickel oxide is then treated with a chemical that will remove the oxygen from the nickel. For example:

$$2NiO + C \rightarrow CO_2 + 2Ni$$

A large amount of nickel is now recycled from scrap metal. Scrap metal comes from old cars, demolition of buildings, appliances like washing machines and stoves, and landfills. The task in recycling scrap metal is to find a way to separate the nickel from other metals in the scrap. This can be done by taking advantage of special properties of nickel. For example, a magnet will remove nickel from scrap, leaving copper behind.

Uses

One of the most important uses of nickel is in making alloys. About 86 percent of the primary nickel used in the United States in 2008 was used to make alloys. About half of that amount went into stainless steel. Stainless steel is common to household appliances (like coffee makers, toasters, and pots and pans), kitchen sink tops and stoves, and medical equipment (X-ray machines, for example). It is also used to make heavy machinery and large containers in which large-scale chemical reactions are carried out. Artists sometimes use stainless steel in sculpture because it does not rust easily. Stainless steel is important to the food and beverage, petroleum, chemical, pharmaceutical (drug), pulp and paper, and textile industries.

Nickel is also used to make the superalloys used in jet engine parts and gas turbines. Superalloys are made primarily of iron, cobalt, or nickel. They also include small amounts of other metals, such as **chromium**, **tungsten**, **aluminum**, and **titanium**. Superalloys are resistant to corrosion (rusting) and retain their properties at high temperatures.

The Gateway Arch in St. Louis, Missouri, has a stainless steel exterior. Weighing more than 17,000 tons, including 900 tons of stainless steel, the arch stands 630 feet (192 meters) tall and was built in the early 1960s. IMAGE COPYRIGHT 2009, MITCH AUNGER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Nickel is also very popular in the manufacture of batteries. Nickel-cadmium (nicad) and nickel-metal hydride (NiMH) batteries are the most popular of these batteries. They are used in a great variety of appliances and electronics, including hand-held power tools, compact disc (CD)

NiMH and nicad batteries are used in electronic devices, including laptops and cell phones.

players, portable DVD players, camcorders, cordless and cell telephones, scanner radios, and laptop computers.

Compounds

Some nickel compounds have important uses also. Many of these compounds are used in electroplating. Some are used to make alloys of nickel. Other nickel compounds are used as coloring agents. For example, the compound nickel dimethylglyoxime ($C_8H_{14}N_4NiO_4$) is used as a coloring agent in paints, cosmetics, and certain kinds of plastics.

Also, other nickel compounds have somewhat more unusual uses. For example, the compound nickel dibutyldithiocarbamate ($Ni[CS_2N(C_4H_9)_2]_2$) is used as an antioxidant in tires. The rubber in tires reacts with oxygen in the air. When it does so, the rubber gets hard and stiff. The tires begin to break down. An additive like nickel dibutyldithiocarbamate can reduce the rate at which this process occurs. The life of tires is extended.

Health Effects

Nickel can pose a health hazard to certain individuals. The most common health problem is called nickel allergy. Some people are more likely to develop nickel allergy than are others. People who are sensitive to nickel may develop a skin rash somewhat like poison ivy. The rash becomes

Explaining Electroplating

Nickel is also used in electroplating, a process by which a thin layer of one metal is laid down on top of a second metal. Here is how electroplating is done.

First, the nickel compound to be laid down is dissolved in water. The solution may be nickel chloride ($NiCl_2$), nickel nitrate ($Ni(NO_3)_2$), or some other nickel compound.

Second, a sheet of the metal to be electroplated is placed into the solution. Suppose the metal is steel. The steel sheet is suspended in the nickel chloride, nickel nitrate, or other nickel solution.

Third, an electric current is passed through the solution. The current causes nickel to come out of the solution. The nickel is then deposited on the surface of the steel. The longer the current runs, the more nickel is laid down. The thickness of the nickel layer can be controlled by the time the electric current runs through the solution.

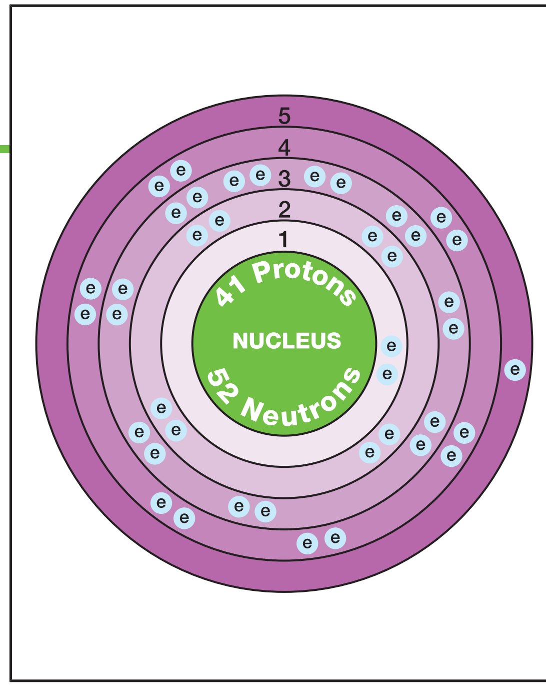
Electroplating is used to make metal products with very specific qualities. Steel is strong but tends to corrode easily. Nickel does not corrode as fast as steel. A thin layer of nickel on top of steel protects the steel from corrosion.

itchy and may form watery blisters. Once a person gets nickel allergy, it remains with him or her forever.

Nickel is present in dozens of products. So it is easy for sensitive people to develop nickel allergy. Perhaps the most common cause of nickel allergy is body piercing. Some people have their ears pierced for earrings, while others have their lips, nose, or other body parts pierced. Inexpensive jewelry placed into these piercings is frequently made of stainless steel. Stainless steel contains nickel. The presence of nickel in a piercing can cause nickel allergy to develop.

Nickel can cause more serious health problems too. For example, people who are exposed to nickel fumes (dust and gas) breathe in nickel on a regular basis. Long term nickel exposure may cause serious health problems, including cancer.

Niobium



Key Facts

Symbol: Nb

Atomic Number: 41

Atomic Mass: 92.90638

Family: Group 5 (VB); transition metal

Pronunciation: nye-OH-bee-um

Overview

Niobium is a transition metal in Group 5 (VB) of the periodic table. The periodic table is a chart that shows how chemical elements relate to one another.

Niobium has a very interesting history. It was discovered by English chemist Charles Hatchett (1765–1847) in 1801. Hatchett found the element in a stone sent from North America. He named the element columbium. For years, scientists argued about the correct name for the element. Some still call the element columbium, although the official name is now niobium.

Niobium is used in many alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Niobium alloys are used in items that come into contact with the human body, such as rings for pierced ears, nose, and other body parts. Niobium is used in this kind of jewelry because it does not cause allergies or other problems.

Discovery and Naming

Historians today give credit for the discovery of niobium to Hatchett. The English chemist found the element in a "very heavy black stone, with

WORDS TO KNOW

Alloy: A mixture of two or more metals that has properties different from those of the individual metals.

Columbium: An alternative name for niobium.

Hypoallergenic: Not causing an allergic reaction.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Superconductivity: The tendency of an electric current to flow through a material without resistance.

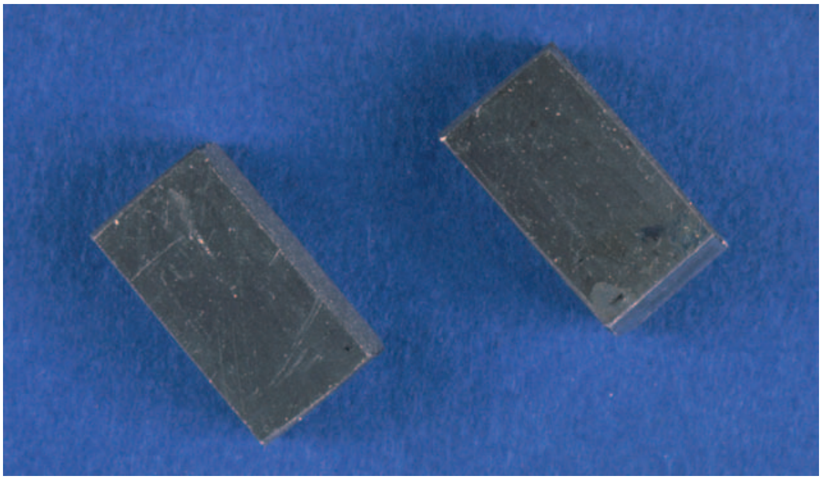
golden streaks" that he found in the British Museum. The stone had been sent to England from the United States by John Winthrop (1681–1747). Winthrop was a member of the British Royal Society, one of the most important scientific societies in the world. (He was also the grandson of the first governor of Connecticut and the great-grandson of the first governor of Massachusetts.) The rock had been in the British Museum for nearly 70 years before anyone decided to analyze it. When Hatchett did so in 1801, he discovered a new element. He named it columbium, after the mineral columbite in which it is often found.

Not everyone agreed with Hatchett's discovery at first. Some chemists were convinced that columbium was identical to the element **tantalum**, which had been discovered earlier. The confusion is easy to understand. The two elements have very similar properties and are difficult to separate. Finally, in 1844, German chemist Heinrich Rose (1795–1864) showed that tantalum and columbium really *were* different from each other. Rose then suggested the name niobium for the new element. The name comes from Greek mythology. Niobe is the daughter of the god Tantalus, from whom the name tantalum comes.

Scientists debated for nearly a century over which name to use. In 1949, niobium was officially adopted. However, many metallurgists (scientists who work with metals) still use the name columbium for the element.

Physical Properties

Niobium is a shiny gray metal with a melting point of 4,474°F (2,468°C) and a boiling point of 8,901°F (4,927°C). Its density is 8.57 grams per cubic centimeter, more than eight times the density of water.



Niobium Samples. © RUSS LAPPA/SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Chemical Properties

Niobium metal is resistant to attack by most common chemicals. It does not combine with **oxygen** or most other active elements except at high temperatures. It does not react with most strong acids unless they are hot and concentrated.

Occurrence in Nature

Niobium occurs primarily in two minerals, columbite and pyrochlore. The original name columbium was taken from the first of these minerals. Niobium always occurs with tantalum in these minerals. Separating the two elements is always the most difficult step in their preparation.

Columbite and pyrochlore are not mined in the United States. These two minerals are imported primarily from Brazil and Canada.

Scientists believe that niobium's abundance in Earth's crust is about 20 parts per million. That makes it about as abundant as **nitrogen** and **lithium**, and slightly more abundant than **lead**.

Isotopes

Only one naturally occurring isotope of niobium exists: niobium-93. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty-four radioactive isotopes of niobium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of niobium have any practical application.

Extraction

The first step in preparing niobium metal is to separate its compounds from tantalum in an ore. The niobium compounds are then heated in air to change them to niobium oxide (Nb_2O_5). The niobium oxide is then heated with charcoal (**carbon**) to produce free metal:

$$2Nb_2O_5 + 5C \rightarrow 5CO_2 + 4Nb$$

Uses

Niobium is used primarily in making alloys. For example, the addition of niobium to steel greatly increases its strength. One use of such steel is in the construction of nuclear reactors. Nuclear reactors are devices in which the energy of nuclear reactions is converted to electricity. Niobium steel is used because it keeps its strength at the very high temperatures produced there.

The demand for niobium steel has increased. One reason is its increased use in airplanes and space vehicles. Some skateboards also include niobium steel components.

Another popular use of niobium alloys is in the making of jewelry. These alloys are lightweight and hypoallergenic. The term hypoallergenic means that they do not cause skin reactions. People who wear pierced earrings or similar forms of jewelry will not develop skin problems from niobium alloy jewelry.

Niobium alloys are also used in the construction of superconducting magnets. A superconducting material is one that has no resistance to an

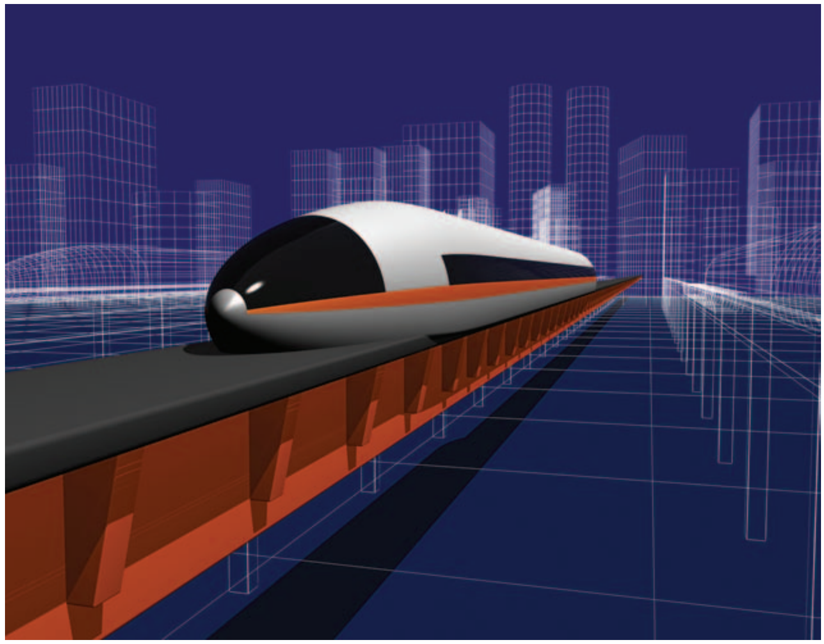
Skateboards often include niobium steel components.

electric current. Once an electric current begins to flow in such a material, it continues to flow practically forever.

The most powerful magnets in the world are those made with superconducting materials. Scientists are continually looking to improve the strength of such magnets.

Compounds

Niobium diselenide ($NbSe_2$) is sometimes used as a lubricant at high temperatures. It does not break down at temperatures up to about 2372°F (1300°C). Niobium silicide ($NbSi_2$) is used as a refractory material. A refractory material is one that can withstand very high temperatures.

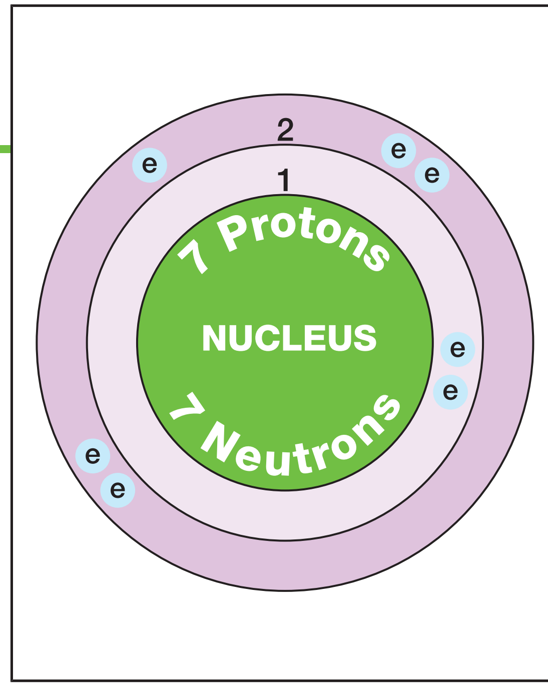


Niobium alloys are used in superconducting materials. They are used in applications ranging from magnetic resonance imaging (MRI) to levitation trains, like the prototype pictured here. Such trains use magnetic levitation and are capable of reaching high speeds. IMAGE COPYRIGHT 2009, MARTIN TRAJKOVSKI. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Health Effects

Neither niobium nor its compounds are known to pose serious health effects for humans and animals.

Nitrogen



Key Facts

Symbol: N

Atomic Number: 7

Atomic Mass: 14.0067

Family: Group 15 (VA); nitrogen

Pronunciation: NYE-tru-jun

Overview

Nitrogen is the first member in Group 15 (VA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Nitrogen is in a family group named after itself. Other elements in the nitrogen family are **phosphorus**, **arsenic**, **antimony**, and **bismuth**.

Nitrogen is one of the most interesting of all chemical elements. It is not a very active element. It combines with relatively few other elements at room temperature. Yet, the compounds of nitrogen are enormously important both in living organisms and in industrial applications. Five of the top 15 chemicals produced are compounds of nitrogen or the element itself. How does such an inactive element end up with so many important compounds?

Nitrogen makes up more than three-quarters of Earth's atmosphere. It is also found in a number of rocks and minerals in Earth's surface. It ranks about number 32 among the elements in terms of abundance in the earth.

Nitrogen was discovered by a number of chemists at about the same time, approximately 1772. But it was not until the early part of the 20th

WORDS TO KNOW

Anhydrous ammonia: Dry ammonia gas.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nitrogen fixation: The process of converting nitrogen as an element to a compound that contains nitrogen.

Periodic table: A chart that shows how the chemical elements are related to each other.

Proteins: Compounds that are vital to the building and growth of cells.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

century, when chemists learned how to make compounds of nitrogen, that these compounds became so widely used in a number of important applications.

By far the most notable use of nitrogen is in the production of ammonia (NH_3). Ammonia is used to make other compounds, such as ammonium sulfate ($(NH_4)_2SO_4$), ammonium nitrate (NH_4NO_3), urea ($CO(NH_2)_2$), and nitric acid (HNO_3). These compounds are used primarily to make synthetic fertilizers. Both elemental nitrogen and nitrogen compounds have a number of important industrial uses.

Discovery and Naming

Gases were poorly understood by chemists until the late 1700s. What is air "made of?" That question is difficult to answer for a number of reasons. First, air cannot really be "seen." In fact, it took chemists many years to figure out how to capture air so that they could study it. Also, is ordinary "air" an element or a compound? For many centuries, philosophers said that air was an element. They could not imagine how anything as basic as air could be made of other materials.

Also, is ordinary air different from other kinds of "airs" seen in nature? For example, "air" sometimes comes bubbling out of the ground near oil wells. Today, scientists know that type of "air" is methane gas (CH_4). But early chemists were not sure how "oil air" differed from ordinary air.

Some important breakthroughs in the study of air occurred in the 1770s. The key was a simple experiment that science students still do today. The experiment begins with an empty bottle being turned upside down in a pan of water. The air in the bottle cannot get out.

If a burning candle is placed inside the bottle with the trapped air, the water rises just a bit. Why does this happen? Early chemists thought that a part of the air was used up as the candle burns. Today, they know that part of the air is **oxygen** gas. Another part of the air is left behind. That part does not disappear when the candle burns. This simple experiment shows that air is composed of (at least) two different elements: oxygen and something else.

Who's Who of Nitrogen Research One of the first people to discover the other unknown element was Scottish physician and chemist Daniel Rutherford (1749–1819). Rutherford carried out an experiment like the candle-in-a-bottle research just described.

Some of the greatest chemists of the time were working on this problem at the same time that Rutherford made his discovery. English chemist Henry Cavendish (1731–1810) probably discovered nitrogen before Rutherford did, but did not publish his findings. And in science, the first person to publish the results of an experiment usually gets credit for the work.

It seems likely that English chemist Joseph Priestley (1733–1804) and Swedish chemist Carl Wilhelm Scheele (1742–1786) also discovered nitrogen in the early 1770s.

Chemists debated about the name of this new element for some time. Antoine-Laurent Lavoisier (1743–1794), a French chemist who is often called the "father of modern chemistry," preferred the name azote meaning "without life." Lavoisier chose this name because nitrogen does not support breathing, the way oxygen does.

The modern name of nitrogen was first suggested in 1790 by French chemist Jean Antoine Claude Chaptal (1756–1832). This name made sense to chemists when they realized that the new gas was present in both nitric acid and nitrates. Thus, nitrogen means "nitrate and nitric acid" *(nitro-)* and "origin of" *(-gen).*

Physical Properties

Nitrogen is a colorless, odorless, tasteless gas with a density of 1.25046 grams per liter. By comparison, the density of air is about 1.29 grams per liter. Nitrogen changes from a gas into a liquid at a temperature of –320.42°F (–195.79°C). It changes from a liquid to a solid at a temperature of –346.02°F (–210.01°C). When it freezes, it becomes a white solid that looks like snow. Nitrogen is slightly soluble in water. About two liters of nitrogen can be dissolved in 100 liters of water.

Chemical Properties

At room temperature, nitrogen is a very inactive gas. It does not combine with oxygen, **hydrogen**, or most other elements. Nitrogen will combine with oxygen, however, in the presence of lightning or a spark. The electrical energy from either of those sources causes nitrogen and oxygen to form nitric oxide:

$$N_2 + O_2 \xrightarrow{\text{electrical energy}} 2NO$$

Nitric oxide is more active than free nitrogen. For example, nitric oxide combines with oxygen and water in the atmosphere to make nitric acid. When it rains, nitric acid is carried to the earth. There it combines with metals in Earth's crust. Compounds known as nitrates and nitrites are formed.

Changing nitrogen as an element to nitrogen in compounds is called nitrogen fixation. The reaction between nitrogen and oxygen in the air when lightning strikes is an example of nitrogen fixation.

Certain bacteria have developed methods for fixing nitrogen. These bacteria live on the root hairs of plants. They take nitrogen out of air dissolved in the ground and convert it to compounds, such as nitrates. Those nitrates are used to make protein molecules, compounds vital to the building and growth of cells.

Plants, humans, and other animals do not have the ability to fix nitrogen. All living organisms on Earth depend on soil bacteria to carry out this process. Plants can grow because the bacteria fix nitrogen for them. They use the fixed nitrogen to make proteins. Humans and other animals can survive because they eat plants. They also depend on the soil bacteria that allow plants to make proteins. So all living creatures rely on soil bacteria to fix their nitrogen for them and, therefore, to survive.

Occurrence in Nature

Nitrogen is a fairly common element in Earth's crust. It occurs primarily as nitrates and nitrites. Nitrogen is by far the most important element in Earth's atmosphere. It makes up 78.084 percent of the atmosphere.

Isotopes

Two naturally occurring isotopes of nitrogen exist: nitrogen-14 and nitrogen-15. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Ten radioactive isotopes of nitrogen are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of nitrogen has any important commercial use. However, nitrogen-15 is used quite often in tracer studies. A tracer is a radioactive isotope whose presence in a system can be detected. Normally, tracer studies use radioactive isotopes. These isotopes give off radiation that can be detected with instruments. Nitrogen-15 is used for a different reason. A compound made with nitrogen-15 will weigh just a little bit more than one made with nitrogen-14. There are simple chemical methods for detecting whether a heavier compound or a lighter one is present in a system. Thus, nitrogen-15 can be used to trace the path of nitrogen through a system.

Extraction

Nitrogen is almost always made from liquid air. Liquid air is made by cooling normal atmospheric air to very low temperatures. As the temperature drops, the gases contained in air turn into liquids. At –297.33°F (–182.96°C), oxygen changes from a gas into a liquid. At –320.42°F (–195.79°C), nitrogen changes from a gas into a liquid. And so on. Eventually, all the gases in air can be made to liquefy (change into a liquid).

The reverse process also takes place. Suppose liquid air in a container warms up slowly. When its temperature reaches –320.42°F (–195.79°C), liquid nitrogen changes back to a gas. A container can be put into place to catch the nitrogen as it boils off the liquid air. When the temperature reaches –297.33°F (–182.96°C), oxygen changes from a liquid back to a gas. Another container can be put into place. The escaping oxygen can be collected. All of the gases in atmospheric air can be produced by this method.

Large amounts of nitrogen gas are produced in this way. In fact, nitrogen is second only to sulfuric acid in terms of production. In the early 2000s, more than 8.85 million metric tons (about 9.8 million short tons) of nitrogen gas were produced in the United States alone.

Uses

Nitrogen gas is used where an inert atmosphere is needed. An inert atmosphere is one that does not contain active elements. Ordinary air is not an inert atmosphere. It contains oxygen. Oxygen tends to react with other elements.

Suppose an ordinary lightbulb were filled with air. When the bulb is turned on, an electric current runs through the metal filament (wire) inside the bulb. The filament gets very hot, begins to glow, and gives off light.

But a hot metal wire will react quickly with oxygen in ordinary air. The metal combines with oxygen to form a compound of the metal. The metal compound will not conduct an electric current. The bulb will "burn out" very quickly.

An easy solution to that problem is to use nitrogen instead of ordinary air in the lightbulb. Nitrogen does not react with other elements very well, even when they get hot. The filament can get very hot, but the metal of which it is made will not combine with nitrogen gas. The nitrogen gas is an inert atmosphere for the bulb.

Another use for inert atmospheres is in protecting historic documents. Suppose the Declaration of Independence were simply left on top of a table for people to see. The paper and ink in the document would soon begin to react with oxygen in the air. They would both begin to decay. Before long, the document would begin to fall apart.

Instead, important documents like the Declaration of Independence are kept in air-tight containers filled with nitrogen gas. The documents are protected from oxygen and other gases in the air with which they might react. Although nitrogen gas provides an inert atmosphere for many purposes, other gases—especially argon—do an even better job.

Fairly simple methods are now available for changing nitrogen gas into liquid nitrogen. Liquid nitrogen is used to freeze other materials.

Liquid nitrogen is used to freeze foods such as TV dinners. Many frozen foods commonly found in grocery stores are produced this way.

The temperature of the nitrogen has to be reduced to –320.42°F (–195.79°C) for this change to occur.

Today, it is possible to buy large containers of liquid nitrogen. The liquid nitrogen can be used, then, to freeze other materials. For example, foods can be frozen simply by dipping them into large vats of liquid nitrogen. Many frozen foods in a grocery store are usually produced this way. Liquid nitrogen can also be used to keep foods cold when they are being transported from one place to another.

Compounds

Nitrogen is the starting point for an important group of compounds. First, nitrogen is combined with hydrogen to make ammonia (NH_3). The production of ammonia is sometimes called industrial nitrogen fixation.

The formation of ammonia from nitrogen and hydrogen is very difficult to accomplish. The two elements do not easily combine. Finding a way to make nitrogen and hydrogen combine was one of the great scientific discoveries of the 20th century.

That discovery was made by German chemist Fritz Haber (1868–1934) in 1905. He found that nitrogen and hydrogen would combine

Nitrogen's Role in the Oklahoma City Bombing

On April 19, 1995, a bomb exploded at the Alfred P. Murrah Federal Building in Oklahoma City, Oklahoma. The devastating impact of the explosion destroyed the building within eight seconds. Each of the nine floors collapsed on top of one another. The bomb killed 168 people and injured hundreds more. The nation was stunned to learn that the attack had not been committed by international terrorists, but by a domestic terrorist, American Timothy McVeigh.

While searching the home of McVeigh's accomplice (a partner in a crime), Terry Nichols, investigators found a receipt for ammonium nitrate. This nitrogen compound is most commonly purchased by farmers. They use it as a fertilizer for their crops. But it can also be used as an explosive. The amount on the receipt was for 2,000 pounds. Since neither Nichols nor McVeigh was farming at the time the fertilizer was purchased, there was no real reason to purchase such a large amount of fertilizer.

Investigators determined that an ammonium nitrate bomb did, indeed, destroy the Murrah Building. The explosion resulted from a mixture of 4,800 pounds of ammonium nitrate and fuel oil from 20 plastic drums.

In June 1997, McVeigh was found guilty of all 11 charges against him, including eight counts of first-degree murder of federal agents. He was sentenced to death later that month and was put to death for his crime on June 11, 2001.

if they were heated to a very high temperature with a very high pressure. He also found that a catalyst was needed to make the reaction occur. The catalyst he used was **iron** metal, though other metals are sometimes used. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction.

The significance of Haber's discovery was soon apparent. World War I began in 1914 in Europe. Very soon, Germany was no longer able to get nitrates from Chile. Nitrates were essential to the war effort for making explosives. But ships carrying nitrates from Chile to Germany were usually not able to get across the Atlantic Ocean.

However, nitrates can be made from ammonia using the Haber process. Germany was then able to make all the ammonia it needed. The ammonia was converted to nitrates for explosives. So a lack of nitrates from Chile did not stop the German war machine. Instead, Germany went on fighting for another four years against countries such as France and Great Britain, who were later joined by the United States.

Ammonia consistently ranks among the top 10 chemicals in the United States. The most important use of ammonia is in synthetic

The bomb used to destroy the federal building in Oklahoma City in 1995 was made of ammonium nitrate. The bomb killed 168 people, including more than a dozen children, while injuring 500 others. AP IMAGES.

fertilizers. A synthetic fertilizer is a mixture of compounds used to make plants grow better. Most farmers use huge amounts of synthetic fertilizer every year to ensure large crops.

In 2008, about 89 percent of ammonia use in the United States was in fertilizer. This included anhydrous ammonia. Anhydrous means "without water." Anhydrous ammonia is simply ammonia gas. It is stored in large tanks. Farmers inject anhydrous ammonia directly into the ground to produce strong and healthy plants.

Ammonia is also found in many household cleaners, especially glass-cleaning and grease-cutting products.

The largest producer of ammonia in the world is China, which makes four times as much ammonia as the next leading producers (India and Russia). Other large producers are the United States, Trinidad and Tobago, Indonesia, Ukraine, Canada, Germany, Saudi Arabia, and Pakistan.

Ammonia can also be converted into other nitrogen compounds. For example, it can be combined with nitric acid (HNO_3) to form ammonium nitrate (NH_4NO_3). And it can be combined with sulfuric acid (H_2SO_4) to make ammonium sulfate ($(NH_4)_2SO_4$):

$$\mathbf{NH_3 + HNO_3 \rightarrow NH_4NO_3}$$

$$\mathbf{2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4}$$

In the early 2000s, about 6.6 million short tons (6.0 million metric tons) of ammonium nitrate and about 2.9 million short tons (2.6 million metric tons) of ammonium sulfate were produced as fertilizers. These two compounds ranked number 14 and number 21 among chemicals produced in the United States.

Ammonium nitrate and ammonium sulfate both have other uses also. For example, ammonium nitrate is used to make explosives, fireworks, insecticides and herbicides (chemicals that kill insects and weeds), and rocket fuel. Ammonium sulfate is also used in water treatment systems, as a food additive, in the tanning of leather, in fireproofing materials, and as a food additive.

Yet another important compound of nitrogen is nitric acid (HNO_3). Nitric acid is made by reacting ammonia with oxygen:

$$\mathbf{NH_3 + 2O_2 \quad heat \rightarrow HNO_3 + H_2O}$$

Nitric acid usually ranks about number 13 among chemicals produced in the United States. The major use of nitric acid is to make ammonium nitrate as a synthetic fertilizer. Nitric acid is also used to make explosives, dyes, certain kinds of synthetic rubber and plastics, and in the preparation of metals.

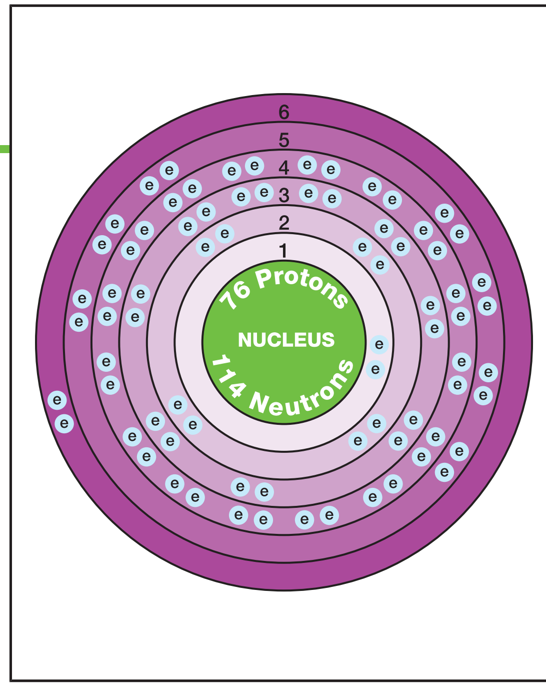
Health Effects

Nitrogen is absolutely essential to all living organisms. It is an important part of all protein molecules. Proteins are the building material in all kinds of cells. They are also used for many other functions. For example, all living organisms use hormones to send chemical messages from one cell to another. Hormones are proteins.

Nitrogen is also used to make nucleic acids. Nucleic acids have many important functions in living organisms. They store the organism's genetic information, which is the set of instructions that tell every cell what its job in the organism is. It passes on that information from one generation to the next.

However, according to the U.S. Geological Survey (USGS) in 2009, recent studies indicate that various alpine and pristine lakes are being impacted by increasing levels of nitrogen emissions. Such emissions come from several sources: agriculture, energy production, and vehicle emissions. Scientists are studying the situation to learn how much the added nitrogen is impacting ecosystems, water quality, and other important issues.

Osmium



Key Facts

Symbol: Os

Atomic Number: 76

Atomic Mass: 190.23

Family: Group 8 (VIIIB); transition metal; platinum group

Pronunciation: OZ-mee-um

Overview

Osmium is an element in Group 8 (VIIIB) of the periodic table. The periodic table is a chart showing how chemical elements are related to one another. Osmium is also a member of the **platinum** family. This family consists of five other elements: **ruthenium**, **rhodium**, **palladium**, **iridium**, and platinum. These elements often occur together in Earth's crust. They also have similar physical and chemical properties, and they are used in alloys.

Osmium was discovered in 1804 by English chemist Smithson Tennant (1761–1815). Tennant found the new element in an ore of platinum.

Osmium is a very rare element and has few commercial uses. Osmium tetroxide (OsO_4) is more widely used, however, because it is so active.

Discovery and Naming

Platinum metal (atomic number 78) was known to chemists as early as 1741. Over the next 60 years, however, scientists discovered that the substance they knew as "platinum" was usually a mixture of substances.

WORDS TO KNOW

Alloy: An alloy is a mixture of two or more metals that has properties different from those of the individual metals.

Aqua regia: A mixture of hydrochloric and nitric acids that dissolves many materials that are not dissolved by either acid by itself.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactivity: Having a tendency to break apart and give off some form of radiation.

Toxic: Dangerous.

These substances proved to be new elements. Osmium was one of the new elements discovered in impure platinum.

In the early 1800s, Smithson Tennant was studying platinum. He found that a black powder remained when platinum was dissolved in aqua regia. Aqua regia is a mixture of hydrochloric and nitric acids. The term aqua regia means "royal water." It often dissolves materials that either acid by itself does not dissolve.

In 1804, Tennant announced that the black powder was actually a mixture of two new elements. He called them iridium and osmium. He suggested osmium's name because of the unusual smell of the compound he was working with, osmium tetroxide. Osmium comes from the Greek word *osme,* meaning "odor."

Physical Properties

Osmium is a bluish-white, shiny metal with a melting point of about 5,400°F (3,000°C) and a boiling point of about 9,900°F (5,500°C). Its density is 22.5 grams per cubic centimeter. These numbers are the highest of any platinum metal. They are also among the highest of all elements.

Osmium is unworkable as a metal. It cannot be melted and shaped like most metals. Because it is unworkable, it has very few practical uses.

Chemical Properties

Osmium is dissolved by acids or by aqua regia only after long periods of exposure to the liquids. When heated, the metal combines with **oxygen** to form osmium tetroxide (OsO_4). Osmium tetroxide is very toxic and the only important commercial compound of osmium.

Occurrence in Nature

Osmium is very rare. Its abundance is thought to be about 0.001 parts per million (one part per billion). That places the element among the half dozen least abundant elements in Earth's crust.

The most common ore of osmium is osmiridium. The element also occurs in all ores of platinum.

Isotopes

There are seven naturally occurring isotopes of osmium. The most abundant are osmium-192, osmium-190, and osmium-189. These three isotopes make up 41 percent, 26.4 percent, and 16.1 percent of natural osmium, respectively. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Two of the naturally occurring isotopes of osmium are radioactive: osmium-184 and osmium-186. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. In addition to the two naturally occurring radioactive isotopes of osmium, 33 radioactive isotopes have been prepared in the laboratory. None of these isotopes has any significant practical application.

Extraction

Osmium is obtained when platinum metal is extracted from its ores.

Uses

Osmium metal has few uses. It is sometimes added to platinum or iridium to make them harder. The osmium-platinum alloy is harder than pure platinum. Some alloys of osmium and platinum are used to make

Osmium is often added to platinum to create an alloy used in pen points. IMAGE COPYRIGHT 2009, PAULPALADIN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

specialized laboratory equipment. Also, some of the best pen points are made of osmium-platinum alloys. An alloy is made by melting or mixing two or more metals.

Finely divided osmium metal is also used as a catalyst. A catalyst is a substance used to speed up a chemical reaction. The catalyst does not undergo any change itself during the reaction. The process for making ammonia from **hydrogen** and **nitrogen** sometimes uses osmium as a catalyst.

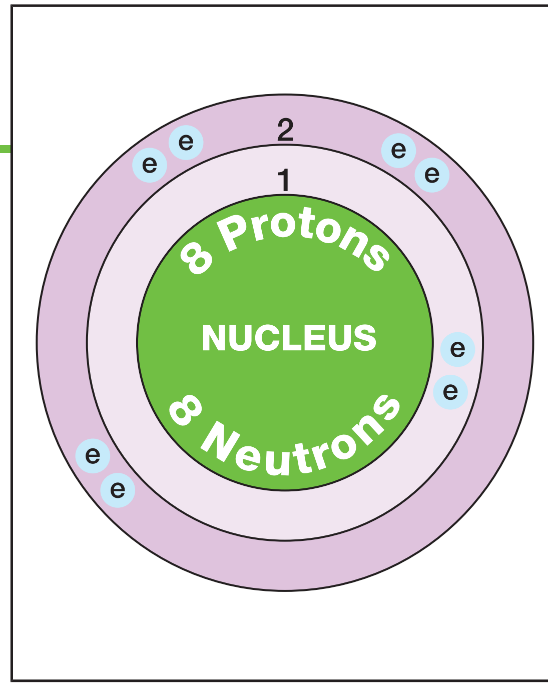
Compounds

Osmium tetroxide (OsO_4) is in demand for use as a catalyst for research purposes. The problem is that this compound of osmium is very dangerous to use. It is shipped in small glass containers called ampules. The ampules carry no labels, nor are they marked with ink. The label and ink would react violently with osmium tetroxide. Users are instructed to open and use an ampule containing osmium tetroxide with great care.

Health Effects

Some compounds of osmium are extremely dangerous. They irritate the respiratory passage (throat, lungs, etc.), the skin, and the eyes. They must be handled with extreme care. This caution is especially important for the most widely used compound of osmium, osmium tetroxide.

Oxygen



Overview

Oxygen is the first element in Group 16 (VIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The elements in Group 16 are said to belong to the chalcogen family. Other elements in this group include **sulfur**, **selenium**, **tellurium**, and **polonium**. The name chalcogen comes from the Greek word *chalkos,* meaning "ore." The first two members of the family, oxygen and sulfur, are found in most ores.

Oxygen is by far the most abundant element in Earth's crust. Nearly half of all the atoms in the earth are oxygen atoms. Oxygen also makes up about one-fifth of Earth's atmosphere. Nearly 90 percent of the weight of the oceans is due to oxygen. In addition, oxygen is thought to be the third most abundant element in the universe and in the solar system.

The discovery of oxygen is usually credited to Swedish chemist Carl Wilhelm Scheele (1742–1786) and English chemist Joseph Priestley (1733–1804). The two discovered oxygen at nearly the same time in 1774, working independently of each other.

Oxygen is necessary for the survival of all animal life on Earth. Animals breathe in oxygen and breathe out carbon dioxide. One important

Key Facts

Symbol: O

Atomic Number: 8

Atomic Mass: 15.9994

Family: Group 16 (VIA); chalcogen

Pronunciation: OK-si-jun

WORDS TO KNOW

Allotropes: Forms of an element with different physical and chemical properties.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Rusting: A process by which a metal combines with oxygen.

use of oxygen is in medicine. People who have trouble breathing are given extra doses of oxygen. In many cases, this "extra oxygen" keeps people alive after they would otherwise have died.

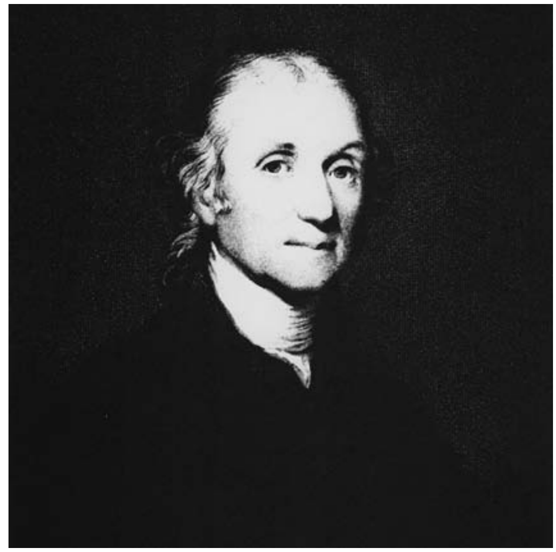
But oxygen has many commercial uses also. The most important use is in the manufacture of metals. More than half of the oxygen produced in the United States is used for this purpose. Oxygen usually ranks among the top five chemicals produced in the United States each year. The gas is prepared almost entirely from liquid air.

Discovery and Naming

What is air? Ancient peoples thought deeply about that question. And that should not be surprising. It is easy to see how essential air is to many processes. Objects cannot burn without air. Human life cannot survive without air. In fact, ancient peoples thought air must be an "element." But they used the word "element" differently than modern scientists do. To ancient people, an element was something that was very important and basic. Air fit that description, along with fire, water, and earth.

They often thought of air as an element in the modern sense—that it was as simple a material as could be found. Yet, some early scholars believed otherwise. For example, some Chinese scholars, as early as the eighth century CE, thought of air as having two parts. They called these parts the *yin* and *yang* of air. The properties of the Chinese yin and yang can be compared to the properties of oxygen and **nitrogen**.

The first person in Western Europe to describe the "parts" of air was Italian artist and scientist Leonardo da Vinci (1452–1519). Leonardo pointed out that air is not entirely used up when something is burned in it. He said that air must consist, therefore, of two parts: one part that is consumed in burning and one part that is not.



Joseph Priestley.

For many years, Leonardo's ideas were not very popular among scholars. One problem was that early chemists did not have very good equipment. It was difficult for them to collect samples of air and then to study it.

In the early 1700s, chemists began to find out more about air, but in a somewhat roundabout way. For example, in 1771 and 1772, Scheele studied the effect of heat on a number of different compounds. In one experiment, he used silver carbonate (Ag_2CO_3), mercury carbonate ($HgCO_3$), and magnesium nitrate ($Mg(NO_3)_2$). When he heated these compounds, he found that a gas was produced. He then studied the properties of that gas. He found that flames burned brightly in the gas. He also found that animals could live when placed in the gas. Without knowing it, Scheele had discovered oxygen.

About two years later, Joseph Priestley conducted similar experiments by heating mercury(II) oxide (HgO) in a flame. The compound broke down, producing liquid mercury metal and a gas:

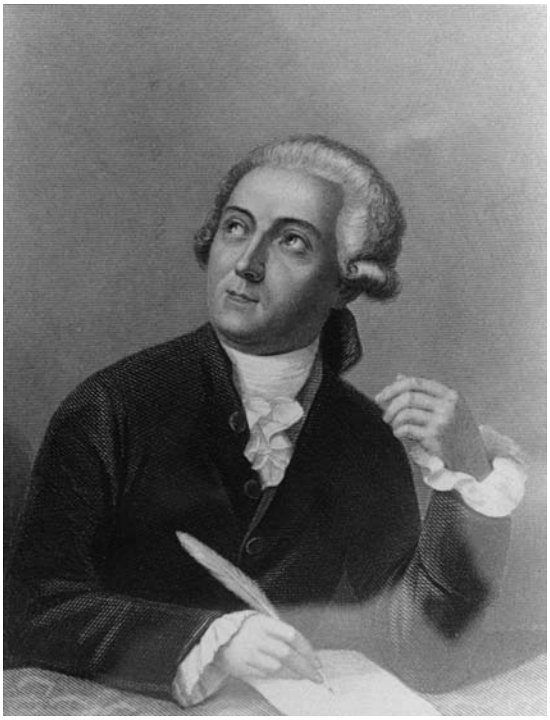
$$\mathbf{2HgO \quad heat \rightarrow 2Hg + O_2}$$

When Priestley tested the new gas, he found the same properties that Scheele had described.

Priestley even tried breathing the new gas he had produced. His description of that experience has now become famous:

> The feeling of it [the new gas, oxygen] to my lungs was not sensibly dif ferent from that of common air, but I fancied that my breast felt pecu liarly light and easy for some time afterwards. Who can tell but that, in time, this pure air may become a fashionable article in luxury? Hitherto only two mice and myself have had the privilege of breathing it.

Some people think Scheele should get credit for discovering oxygen. He completed his experiments earlier than did Priestley. But his publisher was very slow in printing Scheele's reports. They actually came out after



Antoine-Laurent Lavoisier.
LIBRARY OF CONGRESS.

Priestley's reports. So most historians agree that Scheele and Priestley should share credit for discovering oxygen.

Neither Scheele nor Priestley fully understood the importance of their discovery. That step was taken by French chemist Antoine-Laurent Lavoisier (1743–1794). Lavoisier was the first person to declare that the new gas was an element. He was also the first person to explain how oxygen is involved in burning.

In addition, Lavoisier suggested a name for the gas. That name, oxygen, comes from Greek words that mean "acidic" *(oxy-)* and "forming" *(-gen).* Lavoisier chose the name because he thought that all acids contain oxygen. Therefore, the new element was responsible for "forming acids." In this one respect, however, Lavoisier was wrong. All acids do not contain oxygen, although some do.

Physical Properties

Oxygen is a colorless, odorless, tasteless gas. It changes from a gas to a liquid at a temperature of –297.33°F (–182.96°C). The liquid formed has a slightly bluish color to it. Liquid oxygen can then be solidified or frozen at a temperature of –361.2°F (–218.4°C). The density of oxygen is 1.429 grams per liter. By comparison, the density of air is about 1.29 grams per liter.

Oxygen exists in three allotropic forms. Allotropes are forms of an element with different physical and chemical properties. The three allotropes of oxygen are normal oxygen, or diatomic oxygen, or dioxygen; nascent, atomic, or monatomic oxygen; and ozone, or triatomic oxygen. The three allotropes differ from each other in a number of ways.

First, they differ on the simplest level of atoms and molecules. The oxygen that we are most familiar with in the atmosphere has two atoms in every molecule. Chemists show this by writing the formula as O_2. The small "2" means "two atoms per molecule."

By comparison, nascent oxygen has only one atom per molecule. The formula is simply O, or sometimes (O). The parentheses indicate that

The Father of Modern Chemistry

Antoine-Laurent Lavoisier is often called the father of modern chemistry. He was given that title for a number of reasons. The most important reason is the explanation he discovered for the process of combustion (burning).

Prior to Lavoisier's research, chemists thought that a burning object gave off a substance to the air. They called that substance phlogiston. When wood burned, for example, chemists said that phlogiston escaped from the wood to the air.

Lavoisier showed that this idea was incorrect. When something burns, it actually combines with oxygen in the air. Combustion, Lavoisier said, is really just oxidation (the process by which something combines with oxygen).

This discovery gave chemists a whole new way to look at chemical changes. The phlogiston theory gradually began to die out. Many of the ideas used in modern chemistry began to develop.

Lavoisier led an unusually interesting life. He was an avid chemist who carried out many experiments. But he also had a regular job as a tax collector. His job was to visit homes and businesses to collect taxes. This did not make him a very popular man.

Lavoisier also made some important enemies early in his life. One of these enemies was Jean-Paul Marat (1743–1793). Marat thought of himself as a scientist and applied for membership in the French Academy of Scientists. Lavoisier voted against Marat's application. He said that Marat's research was not very good.

Less than a decade later, Lavoisier had reason to regret that decision. Marat had become a leader in the French Revolution (1774–1815). He accused Lavoisier of plotting against the revolution. He also said that Lavoisier was carrying out dangerous secret experiments.

These accusations were not true. But Marat was now a very powerful man. He was able to have Lavoisier convicted of the charges against him. On May 8, 1794, Lavoisier was beheaded and buried in an unmarked grave. Some people have said that Lavoisier's death was the worst single consequence of the French Revolution.

nascent oxygen does not exist very long under normal conditions. It has a tendency to form dioxygen:

$$\mathbf{O + O \rightarrow O_2}$$

That is, dioxygen is the normal condition of oxygen at room temperature.

The third allotrope of oxygen, ozone, has three atoms in each molecule. The chemical formula is O_3. Like nascent oxygen, ozone does not exist for very long under normal conditions. It tends to break down and form dioxygen:

$$\mathbf{2O_3 \rightarrow 3O_2}$$

Ozone does occur in fairly large amounts under special conditions. For example, there is an unusually large amount of ozone in Earth's upper atmosphere. That ozone layer is important to life on Earth. It shields out harmful radiation that comes from the sun. Ozone is also sometimes found closer to Earth's surface. It is produced when gasoline is burned in cars and trucks. It is part of the condition known as air pollution. Ozone at ground level is not helpful to life, and may cause health problems for plants, humans, and other animals.

The physical properties of ozone are somewhat different from those of dioxygen. It has a slightly bluish color as both a gas and a liquid. It changes to a liquid at a temperature of –169.4°F (–111.9°C) and from a liquid to a solid at –315°F (–193°C). The density is 2.144 grams per liter.

Chemical Properties

Oxygen's most important chemical property is that it supports combustion. That is, it helps other objects to burn. The combustion (burning) of charcoal is an example. Charcoal is nearly pure **carbon** (C):

$$\mathbf{C + O_2 \rightarrow CO_2}$$

Oxygen also combines with elements at room temperature. Rusting is an example. Rusting is a process by which a metal combines with oxygen. When iron rusts, it combines with oxygen:

$$\mathbf{4Fe + 3O_2 \rightarrow 2Fe_2O_3}$$

Oxygen also reacts with many compounds. Decay is an example. Decay is the process by which once-living material combines with oxygen. The products of decay are mainly carbon dioxide (CO_2) and water (H_2O):

$$\mathbf{dead\ matter + O_2 \rightarrow CO_2 + H_2O}$$

(The chemical formula for "dead matter" is too complicated to use here.)

Oxygen itself does not burn. A lighted match in a container of pure oxygen burns much brighter, but the oxygen does not catch fire.

Occurrence in Nature

Oxygen occurs mainly as an element in the atmosphere. It makes up 20.948 percent of the atmosphere. It also occurs in oceans, lakes, rivers, and ice caps in the form of water. Nearly 89 percent of the weight of water is oxygen. Oxygen is also the most abundant element in Earth's crust. Its abundance is estimated at about 45 percent in the earth. That makes it almost twice as abundant as the next most common element, **silicon**.

Oxygen occurs in all kinds of minerals. Some common examples include the oxides, carbonates, nitrates, sulfates, and phosphates. Oxides are chemical compounds that contain oxygen and one other element. Calcium oxide, or lime or quicklime (CaO), is an example. Carbonates are compounds that contain oxygen, carbon, and at least one other element. Sodium carbonate, or soda, soda ash, or sal soda (Na_2CO_3), is an example. It is often found in detergents and cleaning products.

Nitrates, sulfates, and phosphates also contain oxygen and other elements. The other elements in these compounds are nitrogen, sulfur, or **phosphorus** plus one other element. Examples of these compounds are **potassium** nitrate, or saltpeter (KNO_3); magnesium sulfate, or Epsom salts ($MgSO_4$); and calcium phosphate ($Ca_3(PO_4)_2$).

Isotopes

There are three naturally occurring isotopes of oxygen: oxygen-16, oxygen-17, and oxygen-18. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Ten radioactive isotopes of oxygen are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of oxygen has any commercial use.

Extraction

Oxygen is made from liquid air. Liquid air is made by cooling normal atmospheric air to very low temperatures. As the temperature drops, the gases contained in air turn into liquids. At –297.33°F (–182.96°C), oxygen changes from a gas into a liquid. At –320.42°F (–195.79°C), nitrogen changes from a gas into a liquid. And so on. Eventually, all the gases in air can be made to liquefy (change into a liquid).

But the reverse process also takes place. Suppose liquid air in a container warms up slowly. When its temperature reaches –320.42°F (–195.79°C), liquid nitrogen changes back to a gas. A container can be put into place to catch the nitrogen as it boils off the liquid air. When the temperature reaches –297.33°F (–182.96°C), oxygen changes from a liquid back to a gas. Another container can be put into place. The escaping oxygen can be collected. Oxygen with a purity of 99.995 percent can be made by this method. It is the only method by which oxygen is made for commercial purposes.

Uses

Many people are familiar with oxygen to help preserve lives. In some cases, people are not able to breathe on their own. Conditions such as emphysema damage the lungs. Oxygen cannot pass through the lungs into the bloodstream. One way to treat this condition is to force oxygen into the lungs with a pump.

The same method is used to treat other medical conditions. For example, carbon monoxide poisoning occurs when carbon monoxide gas

Standard firefighting equipment includes compressed air tanks to help firefighters breathe in smoke-filled situations. IMAGE COPYRIGHT 2009, M. NORRIS. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

gets into the bloodstream. Auto exhaust, poorly maintained oil furnaces, and wood fires produce carbon monoxide. The carbon monoxide replaces oxygen in the blood. Cells get carbon monoxide instead of oxygen. But they cannot use carbon monoxide, so they begin to die. Forcing oxygen into the blood can reverse some of the damage. In high enough amounts, it can force the carbon monoxide out of the blood and cells can recover.

Oxygen has other interesting uses. For example, it is used in rocket fuels. It is combined with hydrogen in the rocket engines. When hydrogen and oxygen combine, they give off very large amounts of energy. The energy is used to lift the rocket into space.

The unmanned Saturn *rocket, shortly after takeoff on January 22, 1968. The combination of oxygen and hydrogen creates enough energy to lift the rocket into space.* NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA).

Metal production accounts for the greatest percentage of oxygen use. For example, oxygen is used to burn off carbon and other impurities that are in iron to make steel. A small amount of these impurities may be desirable in steel, but too much makes it brittle and unusable. The carbon and other impurities are burned off in steel-making by blasting oxygen through molten iron.

Two chemical changes that take place during steel-making are shown below:

$$2C + O_2 \rightarrow CO_2$$

$$Si + O_2 \rightarrow SiO_2$$

The carbon dioxide escapes from the steel-making furnace as a gas. The silicon dioxide (SiO_2) forms slag. Slag is a crusty, metallic material that is scraped off after the steel is produced. Other impurities removed by a blast of oxygen are sulfur, phosphorus, **manganese**, and other metals.

Oxygen is also used in the production of such metals as **copper**, **lead**, and **zinc**. These metals occur in the earth in the form of sulfides, such as copper sulfide (CuS), lead sulfide (PbS), and zinc sulfide (ZnS). The first step in recovering these metals is to convert them to oxides:

$$2CuS + 3O_2 \rightarrow 2CuO + 2SO_2$$

$$2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$$

$$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$$

The oxides are then heated with carbon to make the pure metals:

$$2CuO + C \rightarrow 2Cu + CO_2$$

$$2PbO + C \rightarrow 2Pb + CO_2$$

$$2ZnO + C \rightarrow 2Zn + CO_2$$

Another use of oxygen is in high-temperature torches. The oxyacetylene torch, for example, produces heat by burning acetylene gas (C_2H_2) in pure oxygen. The torch can produce temperatures of 5,400°F (3,000°C) and cut through steel and other tough alloys.

Oxygen is also used in the chemical industry as a beginning material in making some very important compounds. Sometimes, the steps to get from oxygen to the final compound are lengthy. As an example, ethylene gas (C_2H_4) can be treated with oxygen to form ethylene oxide (CH_2CH_2O):

$$2CH_2H_4 + O_2 \rightarrow 2CH_2H_4O$$

About 60 percent of ethylene oxide produced is made into ethylene glycol ($CH_2CH_2(OH)_2$). Ethylene glycol is used in antifreeze and as a starting point in making polyester fibers, film, plastic containers, bags, and packaging materials.

Compounds

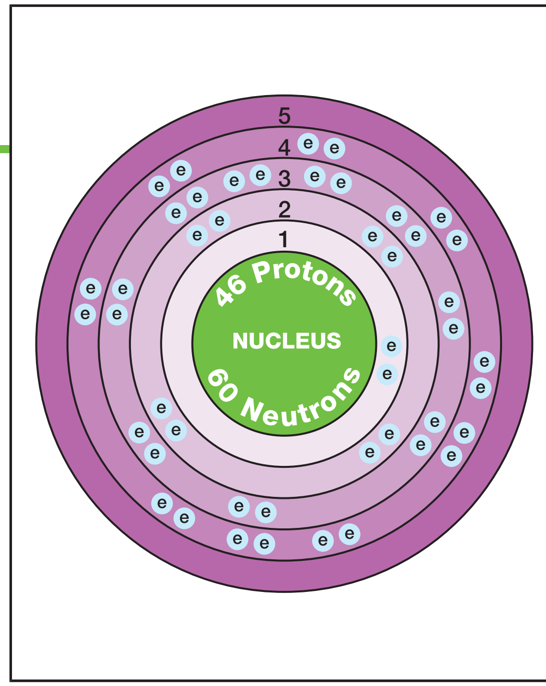
Thousands of oxygen compounds have important commercial uses. Many of these compounds are discussed under other elements.

Health Effects

Nearly all organisms require oxygen—bacteria, plants, and animals. Humans, for example, can go weeks without food. They can survive for many days without water. But they cannot survive more than a few minutes without oxygen.

Oxygen is used by the cells of animal bodies. It is used to oxidize chemicals and produce energy that cells need to stay alive. Without oxygen, cells begin to die in minutes.

Palladium



Key Facts

Symbol: Pd

Atomic Number: 46

Atomic Mass: 106.42

Family: Group 10 (VIIIB); transition metal; platinum group

Pronunciation: puh-LAY-dee-um

Overview

Palladium is found in Row 5, Group 10 (VIIIB) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Palladium, **ruthenium**, **rhodium**, **osmium**, **iridium**, and **platinum** make up the platinum group of metals. These metals are also sometimes called the noble metals. That term reflects the fact that the six elements are not very reactive. The elements in row 5 of the periodic table typically have one or more electrons in the fifth orbital. Palladium is an exception, which is the reason that no electrons are shown in the element's outermost orbital, as shown in the diagram at the top of this page.

Palladium was discovered along with rhodium in 1803 by English chemist William Hyde Wollaston (1766–1828). Wollaston had been studying platinum ores, probably taken from South America.

Like the other platinum metals, palladium is quite rare. It also has a beautiful shiny finish that does not tarnish easily. These properties make it desirable in making jewelry and art objects. These uses are its most important applications.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Native: Not combined with any other element.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An element that breaks apart and gives off some form of radiation.

Discovery and Naming

As early as the 1700s, Brazilian miners described a number of platinum-like metals. They called them by such names as *prata* (silver), *ouro podre* (worthless or spoiled gold), and *ouro branco* (white gold). These names may or may not have matched the materials that were actually present in the metals. For example, a substance the miners called *platino* (platinum) was probably a combination of **gold** and palladium.

In the early 1800s, Wollaston received samples of some of these metals. He decided to analyze them. During his work, he found that a sample of platinum ore contained other metals as well. These metals turned out to be two new elements—rhodium and palladium. The name palladium was taken from Pallas, an asteroid that had been discovered at about the same time.

Chemists later found palladium in other South American ores. A sample of *ouro podre*, for example, turned out to be about 86 percent gold, 10 percent palladium, and 4 percent silver.

Physical Properties

Palladium is a soft, silver-white metal. It is both malleable and ductile. Malleable means capable of being hammered into thin sheets. Ductile means capable of being drawn into thin wires. The malleability of palladium is similar to that of gold. It can be hammered into sheets no more than about a millionth of a centimeter thick.

An interesting property of palladium is its ability to absorb (soak up) **hydrogen** gas like a sponge. When a surface is coated with finely divided palladium metal, the hydrogen gas passes into the space between palladium atoms. Palladium absorbs up to 900 times its own weight in hydrogen gas.

Chemical Properties

Palladium has been called "the least noble" of the noble metals because it is the most reactive of the platinum group. It combines poorly with **oxygen** under normal conditions but will catch fire if ground into powder. Palladium does not react with most acids at room temperature but will do so when mixed with most hot acids. The metal will also combine with **fluorine** and **chlorine** when very hot.

Occurrence in Nature

The abundance of palladium in Earth's crust is estimated to be about 1 to 10 parts per trillion. That makes it one of the 10 rarest elements found in Earth's crust. It usually occurs in native form, meaning "not combined with any other element." Palladium is usually found with platinum and other members of the noble metal group.

As of 2008, Russia and South Africa produced about 82 percent of the palladium mined in the world. Other countries that produce the metal include Canada, the United States, and Zimbabwe.

Isotopes

There are six naturally occurring isotopes of palladium: palladium-102, palladium-104, palladium-105, palladium-106, palladium-108, and palladium-110. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-eight radioactive isotopes of palladium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

No isotope of palladium has an important commercial use.

Extraction

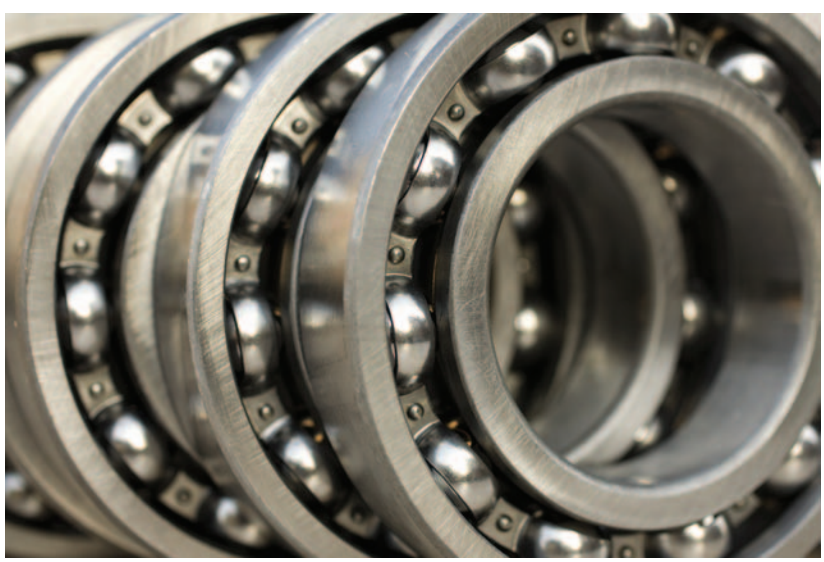
Palladium is removed from platinum ores after platinum and gold have been removed. The metal is converted to palladium chloride ($PdCl_2$) and then purified as pure palladium.

According to the U.S. Geological Survey (USGS), the cost of palladium reached a seven-year high in early 2008 of $585 per troy ounce before leveling off.

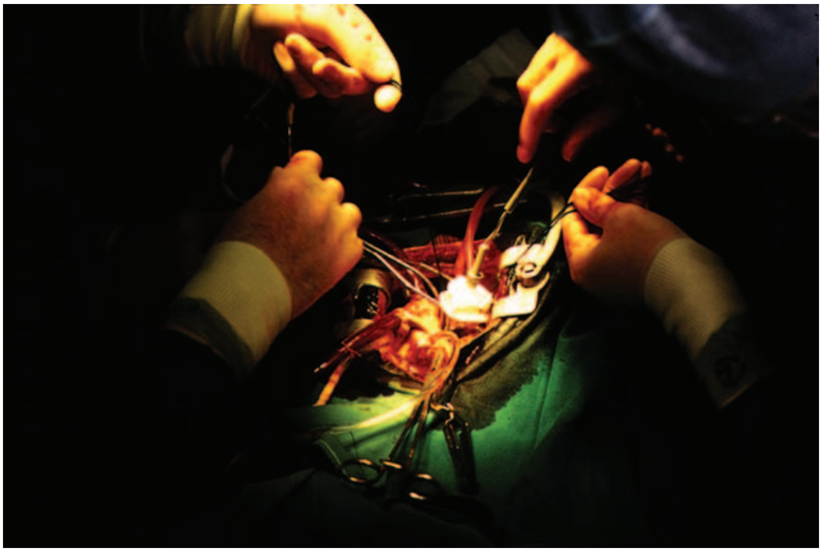
Uses

Palladium has two primary uses: as a catalyst and in making jewelry and specialized alloys. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself. Palladium catalysts are used in breaking down petroleum to make high quality gasoline and other products. It is also used in the production of some essential chemicals, such as sulfuric acid (H_2SO_4), which is used in paper and fabric production. The catalytic converters used in automobiles today may also contain a palladium catalyst. A catalytic converter is a device added to a car's exhaust system. It helps the fuel used in the car burn more efficiently.

An alloy is made by mixing two or more melted metals. The solid mixture has properties different from those of the individual metals. Palladium is commonly alloyed with gold, **silver**, and **copper**. The alloys



Palladium alloys are used to make ball bearings. IMAGE COPYRIGHT 2009, PETAR IVANOV ISHMIRIEV. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.



Palladium alloys are commonly used in surgical instruments, such as those used here during open-heart surgery. © MARTIN DOHRN/NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

are used in a variety of products, such as ball bearings, springs, balance wheels of watches, surgical instruments, electrical contacts, and astronomical mirrors. Palladium alloys are also used quite widely in dentistry.

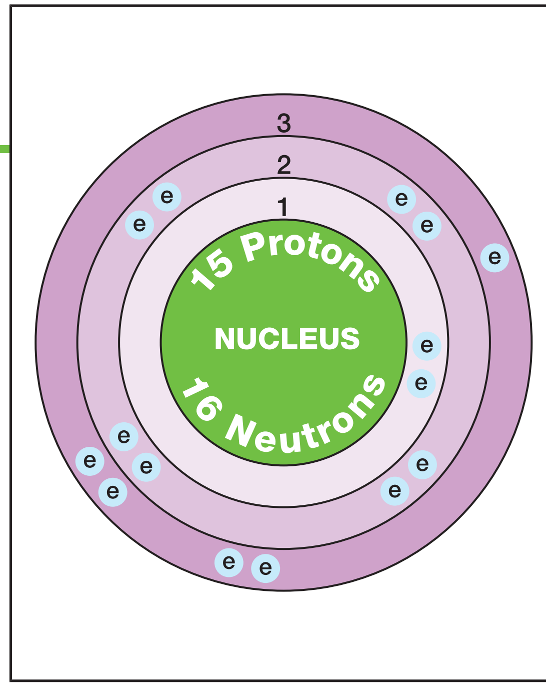
Compounds

Relatively few palladium compounds are commercially important.

Health Effects

There is no evidence of serious health effects from exposure to palladium or its compounds.

Phosphorus



Key Facts

Symbol: P

Atomic Number: 15

Atomic Mass: 30.973762

Family: Group 15 (VA); nitrogen

Pronunciation: FOS-fer-us

Overview

Phosphorus is found in Group 15 (VA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Phosphorus is part of the **nitrogen** family along with nitrogen, **arsenic**, **antimony**, and **bismuth**.

Phosphorus was first discovered in 1669 by German physician Hennig Brand (ca. 1630–1692). Brand is somewhat famous in chemistry. He is sometimes called the last of the alchemists. Alchemy was a kind of pre-science that existed from about 500 BCE to about the end of the 16th century. Alchemists wanted to find a way of changing **lead**, **iron**, and other metals into **gold**. They also wanted to find a way of having eternal life. Alchemy contained too much magic and mysticism to be a real science. But it developed a number of techniques and produced many new materials that were later found to be useful in modern chemistry.

Brand was convinced that the key to changing metals into gold could be found in urine. He decided to look for the "magic substance" in urine that could change lead into gold. In the process of heating and purifying urine, he obtained phosphorus. The discovery was important because it

WORDS TO KNOW

Alchemy: A kind of pre-science that existed from about 500 BCE to about the end of the 16th century.

Allotropes: Forms of an element with different physical and chemical properties.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Halogen: One of the elements in Group 17 (VIIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Phosphor: A material that gives off light when struck by electrons.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Sublimation: The process by which a solid changes directly to a gas when heated, without first changing to a liquid.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

was the first time someone had discovered an element not known to ancient peoples. In that regard, Brand was the first person who could be called the discoverer of an element.

Phosphorus is a fascinating element that occurs in at least three very different forms. If left exposed to the air, it catches fire on its own. It also glows in the dark. Today, its most important use is in the manufacture of phosphoric acid (H_3PO_4). Phosphoric acid, in turn, is used to manufacture fertilizers and a number of other important products.

Discovery and Naming

Phosphorus and its compounds may have been known before Brand's discovery. Old manuscripts refer to materials that glow in the dark. The word used for such materials today is phosphorescent. Early Christians made use of "perpetual lamps" that glowed in the dark. The lamps may have contained phosphorus or one of its compounds.

Still, Brand was the first to record the process of making pure phosphorus. No one knows how he decided that urine might contain a chemical that could be used to turn lead into gold. His experiments to find such a chemical were, of course, a failure. But he made an accidental discovery along the way. That discovery was a material that glowed in the dark: phosphorus.

Scientists were fascinated when they heard of Brand's discovery. They tried to repeat his research. Some tried to talk him into selling his discovery to kings and princes. The new element seemed to be a way of getting rich and becoming famous.

But Brand was never interested in these ideas. Instead, he gave away all of the phosphorus he prepared. Other scientists soon began to experiment with the element. One of the first discoveries they made was how dangerous phosphorus is. One scientist wrote that a servant left some phosphorus on top of his bed one day. Later that night, the bed covers burst into flame. The phosphorus had caught fire by itself!

Eventually, Brand's method of making phosphorus became widely known. The element joined iron, gold, **silver**, arsenic, and the handful of other elements known to early chemists. Little is known about what happened to Brand after his discovery. In fact, there is no record of where or when he died.

Physical Properties

Phosphorus exists in at least three allotropic forms. Allotropes are forms of an element with different physical and chemical properties. The three main allotropes are named for their colors: white phosphorus (also called yellow phosphorus), red phosphorus, and black phosphorus (also called violet phosphorus). These allotropes have different physical and chemical properties.

White phosphorus is a waxy, transparent solid. Its melting point is 111°F (44.1°C) and its boiling point is 536°F (280°C). It has a density of 1.88 grams per cubic centimeter. If kept in a vacuum, it sublimes if exposed to light. Sublimation is the process by which a solid changes directly to a gas when heated, without first changing to a liquid. White phosphorus is phosphorescent. It gives off a beautiful greenish-white glow. It does not dissolve well in water, although it does dissolve in other liquids, such as benzene, chloroform, and **carbon** disulfide. White phosphorus sometimes appears slightly yellowish because of traces of red phosphorus.

Red phosphorus is a red powder. It can be made by heating white phosphorus with a catalyst to 464°F (240°C). A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself. Without a catalyst, red phosphorus sublimes at 781°F (416°C). Its density is 2.34 grams per cubic centimeter. It does not dissolve in most liquids.

Black phosphorus looks like graphite powder. Graphite is a form of carbon used in "lead" pencils. Black phosphorus can be made by applying

Dry and wet red phosphorus solids. © CHARLES D. WINTERS, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

extreme pressure to white phosphorus. It has a density of 3.56 to 3.83 grams per cubic centimeter. One of its interesting properties is that it conducts an electric current in spite of being a non-metal.

Chemical Properties

White phosphorus is the form that occurs most commonly at room temperatures. It is very reactive. It combines with **oxygen** so easily that it catches fire spontaneously (automatically). As a safety precaution, white phosphorus is stored under water in chemical laboratories.

Phosphorus combines easily with the halogens. The halogens are the elements that make up Group 17 (VIIA) of the periodic table. They include **fluorine**, **chlorine**, **bromine**, **iodine**, and **astatine**. For example, the reaction between phosphorus and chlorine is:

$$2P + 3Cl_2 \rightarrow 2PCl_3$$

Phosphorus also combines with metals to form compounds known as phosphides:

$$3Mg + 2P \rightarrow Mg_3P_2 \text{ (magnesium phosphide)}$$

Occurrence in Nature

The abundance of phosphorus in Earth's crust is estimated to be 0.12 percent, making it the 11th most common element. It usually occurs as a phosphate. A phosphate is a compound that contains phosphorus, oxygen, and at least one more element. An example is **calcium** phosphate, $Ca_3(PO_4)_2$.

The only important commercial source of phosphorus is phosphate rock. Phosphate rock is primarily calcium phosphate. As of 2008, China was the largest producer of phosphate rock in the world, followed by the United States. In that year, 34.1 million short tons (30.9 million metric tons) of phosphate rock were mined in the United States at a value of about $3.5 billion. The price of phosphate rock surged in late 2007 and early 2008 as agricultural demand for it rose. According the to U.S. Geological Survey (USGS), the cost more than doubled between 2007 and 2008 in the United States.

More than 85 percent of phosphate rock mined in the United States comes from North Carolina and Florida. Smaller amounts are also mined in Idaho and Utah. Other major producers of phosphate rock are Morroco and Western Sahara, Russia, Tunisia, Brazil, Jordan, Syria, Israel, Egypt, South Africa, and Australia.

Isotopes

Only one naturally occurring isotope of phosphorus exists: phosphorus-31. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Seventeen radioactive isotopes of phosphorus are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope, phosphorus-32, has applications in medicine, industry, and tracer studies. A tracer is a radioactive isotope whose presence in a system can easily be detected. The isotope is injected into the system where it gives off radiation. The radiation is followed by means of detectors placed around the system.

Phosphorus-32 is especially useful in medical studies, because phosphorus occurs in many parts of the body. Radioactive phosphorus can be used as a tracer to study parts of the body as well as chemical changes inside the body. Radioactive phosphorus can also determine how much blood is in a person's body. It can also help locate the presence of tumors in the brain, eyes, breasts, and skin. Finally, it is sometimes used to treat certain forms of cancer. Radiation given off by phosphorus-32 may kill cancer cells and help slow or stop the disease.

Phosphorus-32 is important in a variety of scientific studies. For example, it is added to tires when they are made. Then, the radiation it gives off can be studied as the tires are used. This information tells where the tire wears out and how long it takes to wear out.

Extraction

It is possible to make pure phosphorus from phosphate rock. The rock is mixed with sand and coke (pure carbon). The mixture is then heated in an electric furnace. An electric furnace is a device for producing very high temperatures. Pure phosphorus is produced in this reaction. It escapes from the mixture as a vapor (gas). The cooled vapor solidifies into white phosphorus. The reaction is:

$$Ca_3(PO_4)_2 + 3SiO_2 + 5C \rightarrow 3CaSiO_3 + 5CO + 2P$$

This reaction is not very important because pure phosphorus has few uses. The most important compounds of phosphorus are all made from phosphate rock or calcium phosphate. Therefore, the most important step in producing "phosphorus" is simply to separate pure calcium phosphate from phosphate rock. This can be done fairly easily.

Uses and Compounds

In 2008, more than 95 percent of all the phosphate rock mined in the United States was used in the manufacture of fertilizer and animal feed supplements. Modern farmers use enormous amounts of synthetic (artificial) fertilizer on their crops. This synthetic fertilizer contains nitrogen, phosphorus, and **potassium**, the three elements critical to growing plants. These elements normally occur in the soil, but may not be present in large enough amounts. Adding them by means of synthetic fertilizer helps plants grow better. Most farmers add some form of synthetic fertilizer to their fields every year. This demand for synthetic fertilizers accounts for the major use of phosphorus compounds.

People sprinkle fertilizer on plants to help them grow faster. Synthetic fertilizer contains nitrogen, phosphorus, and potassium ingredients. IMAGE COPYRIGHT 2009, SARKA. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

The second most important use of phosphate compounds is in making detergents. The compound most often used in detergents is called sodium tripolyphosphate, or STPP ($Na_5P_3O_{10}$).

STPP adds a number of benefits to a detergent. For example, it can kill some bacteria and prevent washers from becoming corroded (rusted) and clogged. The most important function in detergents, however, is as a water-softening agent.

Natural water often contains chemicals that keep soaps and detergents from sudsing. They reduce the ability of soaps and detergents to clean clothes. STPP has the ability to capture these chemicals. It greatly improves the ability of soaps and detergents to make suds and clean clothes. STPP was first used in a detergent in 1947. That detergent brought about a revolution in clothes cleaning.

Sodium tripolyphosphate (STPP) can create problems for the environment. After detergents have been used, they are flushed away in wastewater, ending up in rivers and streams and, eventually, in lakes. And that's just fine for the algae that live in those lakes. Algae are tiny green plants that use phosphorus as they grow. As more detergents get into lakes, the amount of STPP increases. That means there is more phosphorus in a lake and that, in turn, means that algae begin to grow much faster.

In some cases, there is so much STPP and phosphorus in a lake that algae grow out of control, clogging the lake with algae and other green plants. The lake slowly turns into a swamp, and finally into a meadow. The lake disappears!

Many people became concerned about this problem in the 1960s. They demanded that less STPP be used in detergents. A number of cities and states banned the sale of STPP detergents. STPP production had grown rapidly from 1.10 billion pounds in 1955 to 2.44 billion pounds in 1970. But then production began to drop off. By the mid-1990s, production had dropped well below a billion pounds a year, and by the early 2000s, reached about 500 million pounds a year.

Phosphorus and its compounds have other uses. These uses account for about 10 percent of all the phosphorus produced. For example, the compounds known as phosphorus pentasulfide (P_2S_5) and phosphorus sesquisulfide (P_4S_3) are used to make ordinary wood and paper safety matches. These compounds coat the tip of the match. When the match is scratched on a surface, the phosphorus pentasulfide or phosphorus sesquisulfide bursts into flame. It ignites other chemicals on the head of the match.

Another compound of phosphorus with a number of uses is phosphorus oxychloride ($POCl_3$). This compound is used in the manufacture of gasoline additives, in the production of certain kinds of plastics, as a fire retardant agent, and in the manufacture of transistors for electronic devices.

Two phosphorus compounds are used to make the coating found on the tips of safety matches. IMAGE COPYRIGHT 2009, BORISLAV TOSKOV. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Health Effects

Phosphorus is essential to the health of plants and animals. Many essential chemicals in living cells contain phosphorus. One of the most important of these chemicals is adenosine triphosphate (ATP). ATP provides the energy to cells they need to stay alive and carry out all the tasks they have to perform. Phosphorus is critical to the development of bones and teeth.

Nucleic acids also contain phosphorus. Nucleic acids are chemicals that perform many functions in living organisms. For example, they carry the genetic information in a cell. They tell the cell what chemicals it must make. It also acts as the "director" in the formation of those chemicals.

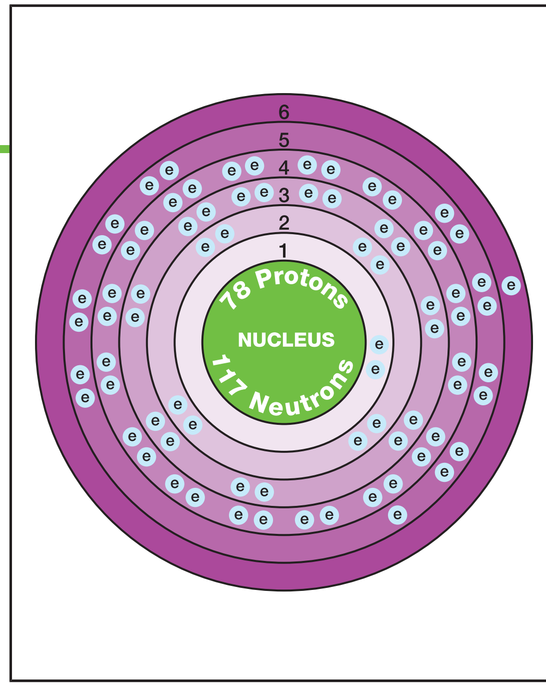
The daily recommended amount of phosphorus for humans is one gram. It is fairly easy to get that much phosphorus every day through meat, milk, beans, and grains.

However, elemental phosphorus is extremely dangerous. Elemental phosphorus is phosphorus as an element, not combined with other elements. Swallowing even a speck of white phosphorus produces severe diarrhea with loss of blood; damage to the liver, stomach, intestines, and circulatory system (blood flow system); and coma. Swallowing a piece of white phosphorus no larger than 50 to 100 milligrams (0.0035 ounce) can even cause death.

Handling white phosphorus is dangerous as well. It causes serious skin burns.

Interestingly, red phosphorus does not have the same effects. It is considered to be relatively safe. It is dangerous only if it contains white phosphorus mixed with it.

Platinum



Overview

Platinum is a transition metal in Group 10 (VIIIB) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Platinum is also a member of a group of metals named after itself. Other platinum metals include **ruthenium**, **rhodium**, **palladium**, **osmium**, and **iridium**. They are found in Rows 5 and 6 of Groups 8 through 10 in the periodic table. Platinum is also considered to be a precious metal. A precious metal is one that is rare and desirable.

The platinum group metals are sometimes referred to as the noble metals. That term comes from the fact that they are all relatively inactive. They do not combine with or interact with most other elements or compounds. This chemical inactivity accounts for some of the uses of the platinum metals. For example, platinum is often used to make laboratory equipment because it will not react with materials that come into contact with the equipment.

The primary use of platinum and other platinum metals is as catalysts. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself. For example, the catalytic converter in an automobile's exhaust system may contain a platinum metal.

Key Facts

Symbol: Pt

Atomic Number: 78

Atomic Mass: 195.084

Family: Group 10 (VIIIB); transition metal; platinum group

Pronunciation: PLAT-num

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Discovery and Naming

The first known reference to platinum can be found in the writings of Italian physician, scholar, and poet Julius Caesar Scaliger (1484–1558). Scaliger apparently saw platinum while visiting Central America in 1557. He referred to a hard metal that the native people had learned to use, but the Spanish had not. The metal had been called *platina* ("little silver") by the native people. The name was given to the material because it got in the way of mining **silver** and **gold**. Since the native people knew of no use for the platina, they thought of it as a nuisance.

The first complete description of platinum was given by the Spanish military leader Don Antonio de Ulloa (1716–1795). While serving in South America from 1735 to 1746, de Ulloa collected samples of platinum. He later wrote a report about the metal, describing how it was mined and used. De Ulloa is often given credit for discovering platinum on the basis of the report he wrote.

Reports of the new element spread through Europe. Scientists were fascinated by its physical properties. It was not only beautiful, but resistant to corrosion (rusting). Many people saw that it could be used in jewelry and art objects, as with gold and silver. Demand for the metal began to grow, leading to what was then called the "Platinum Age in Spain."

Physical Properties

Platinum is a silver-gray, shiny metal that is both malleable and ductile. Malleable means capable of being hammered into thin sheets. Platinum

Huge demand for platinum jewelry caused the "Platinum Age in Spain." The metal is still widely used today in rings, earrings, and other jewelry, such as this platinum ring set with sapphires and diamonds. IMAGE COPYRIGHT 2009, KDEDESIGN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

can be hammered into a fine sheet no more than 100 atoms thick, thinner than **aluminum** foil.

Ductile means the metal can be drawn into thin wires. Platinum has a melting point of about 3,223°F (1,773°C) and a boiling point of about 6,921°F (3,827°C). Its density is 21.45 grams per cubic centimeter, making it one of the densest elements.

Chemical Properties

Platinum is a relatively inactive metal. When exposed to air, it does not tarnish or corrode. It is not attacked by most acids, but will dissolve in aqua regia. Aqua regia is a mixture of hydrochloric and nitric acids. It often reacts with materials that do not react with either acid separately. Platinum also dissolves in very hot alkalis. An alkali is a chemical with properties opposite those of an acid. Sodium hydroxide ("common lye") and limewater are examples of alkalis.

An unusual property of platinum is that it will absorb large quantities of **hydrogen** gas at high temperatures. The platinum soaks up hydrogen the way a sponge soaks up water.

Occurrence in Nature

The platinum metals are often found together in nature. In fact, one of the problems in producing platinum is finding a way of separating it from the other platinum metals. Unlike gold, however, these metals do not occur in masses large enough to mine. Instead, they are usually obtained as by-products from mining other metals, such as **copper** and **nickel**.

Platinum is one of the rarest elements. Its abundance is estimated to be about 0.01 parts per million in Earth's crust. The world's largest supplier of platinum by far is South Africa. In 2008, that nation produced 153,000 kilograms of platinum, 77 percent of the total world production. The next largest producer was Russia, followed by Canada, Zimbabwe, and the United States. Most of the platinum in the United States comes from the Stillwater and East Boulder Mines in Montana.

Isotopes

Six naturally occurring isotopes of platinum exist: platinum-190, platinum-192, platinum-194, platinum-195, platinum-196, and platinum-198. Of these, only platinum-190 is radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-seven artificially radioactive isotopes of platinum have also been produced. These isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

No radioactive isotope of platinum has any commercial application.

Extraction

The major challenge in obtaining pure platinum is separating it from other platinum metals. The first step in this process is to dissolve the mixture in aqua regia. Platinum dissolves in aqua regia, and other platinum metals do not. Platinum metal can then be removed from the aqua regia in a form known as platinum sponge. Platinum sponge is a sponge-like material of black platinum powder. Finally, the powder is heated to very high temperatures and melted to produce the pure metal.

According to the U.S. Geological Survey (USGS), the cost of platinum reached a record high in early 2008 of $2,275 per troy ounce before leveling off.

Uses

If asked, most people would probably name jewelry as the most important use of platinum. And the metal *is* used for that purpose. It is hard, beautiful, corrosion-resistant—ideal for making bracelets, earrings, pins, rings, watch bands, and other types of jewelry.

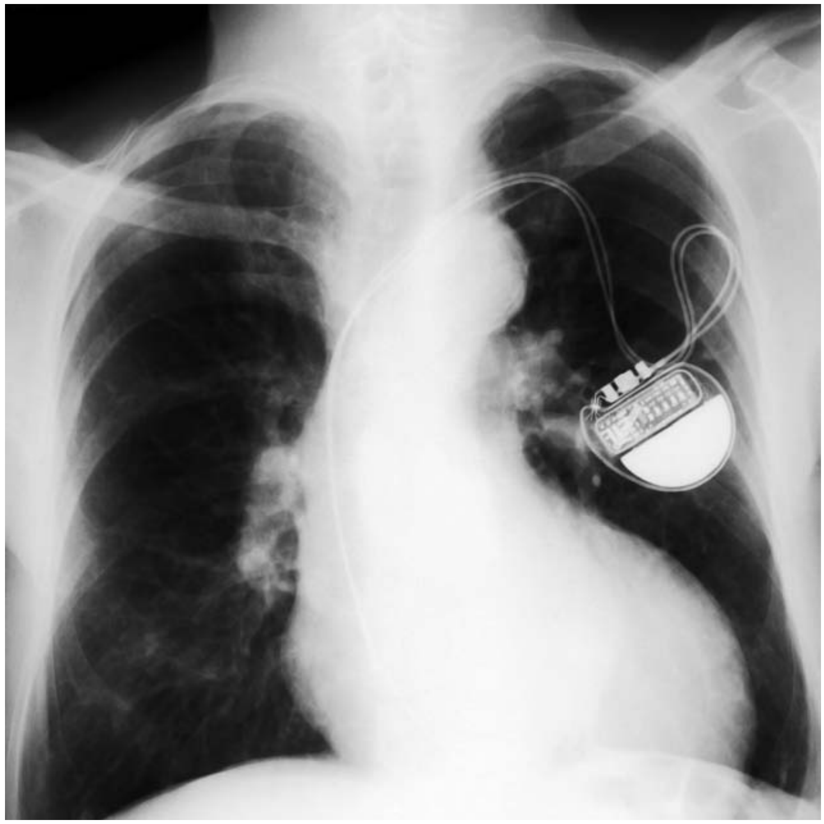
However, jewelry is not the most important use of platinum—the making of catalysts is. For example, platinum catalysts are widely used in the modern petroleum industry. Crude oil from the ground must be treated before it can be converted to gasoline, fuel oil, and other petroleum products. The molecules must be broken apart, rearranged, and put back together again in new patterns. Platinum is one of the most important catalysts in making these reactions happen.

Platinum catalysts are also used to make compounds that end up as fertilizers, plastics, synthetic fibers, drugs and pharmaceuticals, and dozens of other everyday products. For example, platinum is used in the manufacture of nitric acid (HNO_3). Nitric acid is used to produce ammonia, which, in turn, is used to make fertilizers.

Probably the best-known use of platinum as a catalyst is in cars. Many automobiles have a catalytic converter in the exhaust system. A catalytic converter is a device that helps gasoline burn more completely. It reduces the amount of pollutants released to the air. Most catalytic converters contain platinum or other platinum metals.

Platinum is used in other parts of a car or truck. Certain types of spark plugs, for example, may contain platinum. Overall, the greatest single use of platinum in the United States is in the manufacture of automobiles and trucks.

Many uses of platinum depend on its chemical inactivity. For example, some people need to have artificial heart pacemakers implanted into their chests. An artificial pacemaker is a device that makes sure the heart beats in a regular pattern. It usually replaces a body part that performs that function but has been damaged. Artificial pacemakers are usually



An X-ray shows the placement of a pacemaker. Such pacemakers are usually made out of platinum. IMAGE COPYRIGHT 2009, DARIO SABLJAK. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

made out of platinum. The platinum protects the pacemaker from corroding or being destroyed by acids inside the body.

Platinum is also used in small amounts in alloys. For example, **cobalt** alloyed with platinum makes a powerful magnet. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The platinum-cobalt magnet is one of the strongest magnets known.

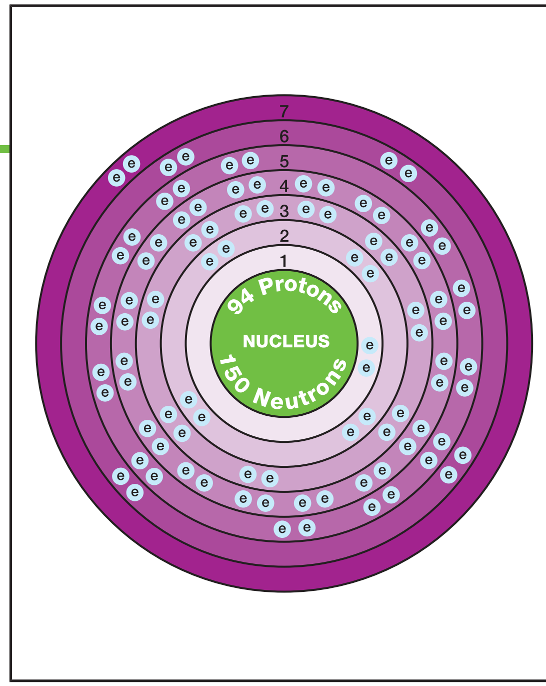
Compounds

Relatively few platinum compounds are commercially important.

Health Effects

Platinum dust and some platinum compounds can have mild health effects. If inhaled, they can cause sneezing, irritation of the nose, and shortness of breath. If spilled on the skin, they can cause a rash and skin irritation.

Plutonium



Key Facts

Symbol: Pu

Atomic Number: 94

Atomic Mass: [244]

Family: Actinoid; transuranium element

Pronunciation: plu-TOE-nee-um

Overview

Plutonium is a synthetic (artificial) element. It exists naturally only in the smallest imaginable amounts. Plutonium was first prepared artificially by a team of researchers at the University of California at Berkeley (UCB) in 1941. News of this discovery was not released, however, until 1946. This delay was caused by the need for secrecy about scientific developments during World War II (1939–1945).

Plutonium is a member of the actinoid family. The actinoids occur in Row 7 of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. The actinoids get their name from element 89, **actinium**, which is sometimes considered the first member of the family. Plutonium is also called a transuranium element. The term transuranium means "beyond **uranium**." Elements with atomic numbers greater than that of uranium (92) are called transuranium elements.

Plutonium has two important uses. First, some of its isotopes will undergo nuclear fission. Nuclear fission is a process in which an element is bombarded with neutrons. The element breaks apart into simpler elements, releasing large amounts of energy. Plutonium has been used to

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear fission: A process in which neutrons collide with the nucleus of a uranium atom causing it to split apart with the release of very large amounts of energy.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

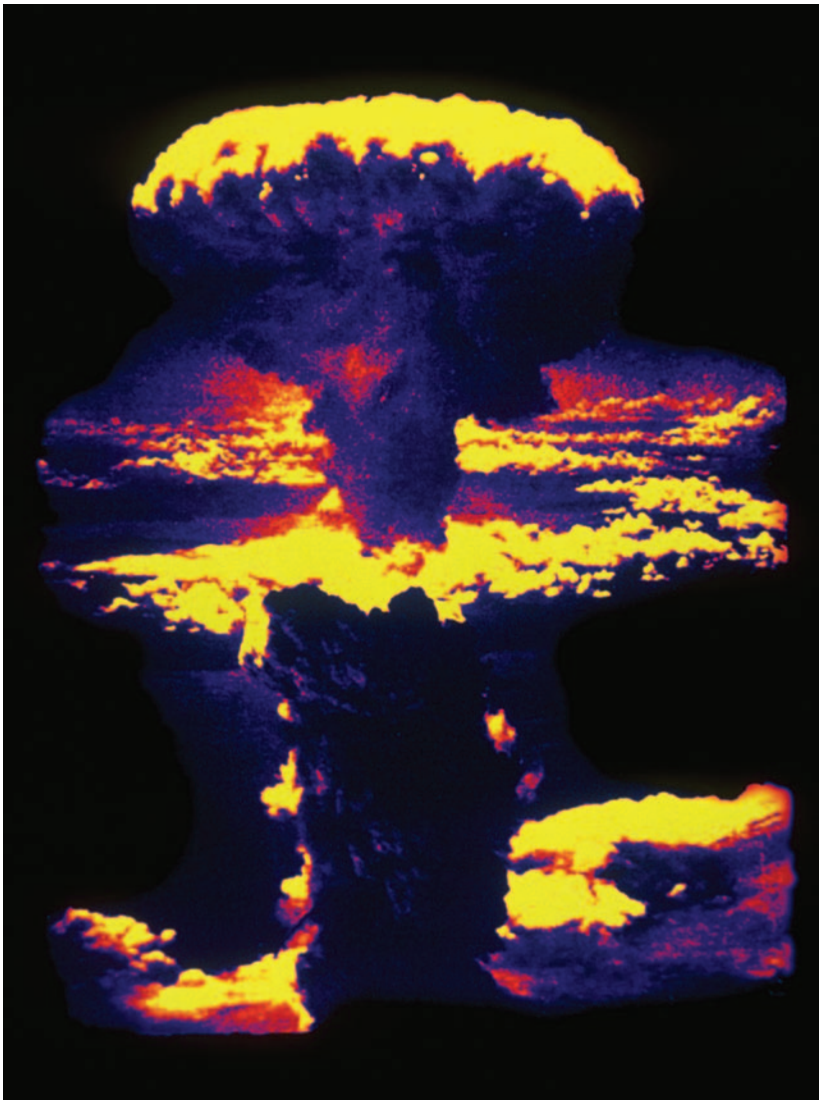
make nuclear weapons (such as atomic bombs) and in nuclear power plants to produce electricity. Plutonium has also been used as a portable energy supply in space probes and other space vehicles.

Discovery and Naming

In 1940, American physicists Edwin McMillan (1907–1991) and Philip Abelson (1913–2004) discovered the first transuranium element, **neptunium** (atomic number 93). The neptunium they produced was radioactive. They predicted it would break down to form a new element, atomic number 94. But McMillan and Abelson were called away to do research on the atomic bomb. They suggested to a colleague, Glenn Seaborg (1912–1999), that he continue their research on neptunium.

Seaborg and his associates picked up where McMillan and Abelson had left off. They eventually proved that element 94 did exist. The proof came in an experiment they conducted in a particle accelerator at UCB. A particle accelerator is sometimes called an "atom smasher." It is used to cause small particles, such as protons, to move at very high speeds. The particles then collide with targets, such as **gold**, **copper**, or **tin**. When struck by the particles, the targets break apart, forming new elements and other particles.

Seaborg's team suggested the name plutonium for the new element, in honor of the planet Pluto. The two elements just before plutonium in the periodic table had also been named for planets: uranium for Uranus and neptunium for Neptune.



Plutonium is used to make nuclear weapons. Here, a computer-enhanced image shows the mushroom-cloud that occurred after the U.S. military released an atomic bomb on Nagasaki, Japan, on August 9, 1945, in an effort to end World War II. © SCOTT CAMAZINE/ THE NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Glenn Seaborg later went on to find a number of other elements. One of those elements, atomic number 106, was named seaborgium in his honor. (See **transfermium elements** entry in this volume.)

Physical Properties

Plutonium is a silvery-white metal with a melting point of 1,183°F (639.5°C) and a density of 19.816 grams per cubic centimeter, nearly 20 times the density of water.

The United States first tested its nuclear bomb capabilities in a desert-region of New Mexico on July 16, 1945. When the atomic bomb was detonated, a huge crater formed. The heat from the plutonium-based bomb melted the desert sands, which then solidified, forming a glassy residue. The resulting mineral (pictured here) was named trinitite after the site (named Trinity) of the test.

Chemical Properties

Plutonium is highly reactive and forms a number of different compounds.

Occurrence in Nature

Scientists now know that very small amounts of plutonium occur in Earth's crust. It is formed in ores of uranium. When uranium breaks down, it sometimes forms plutonium in very small quantities. Scientists believe that the abundance of plutonium in the earth is about one quintillionth parts per million.

Isotopes

Thirty-two isotopes of plutonium with measured half lives are known to exist. All of these isotopes are radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

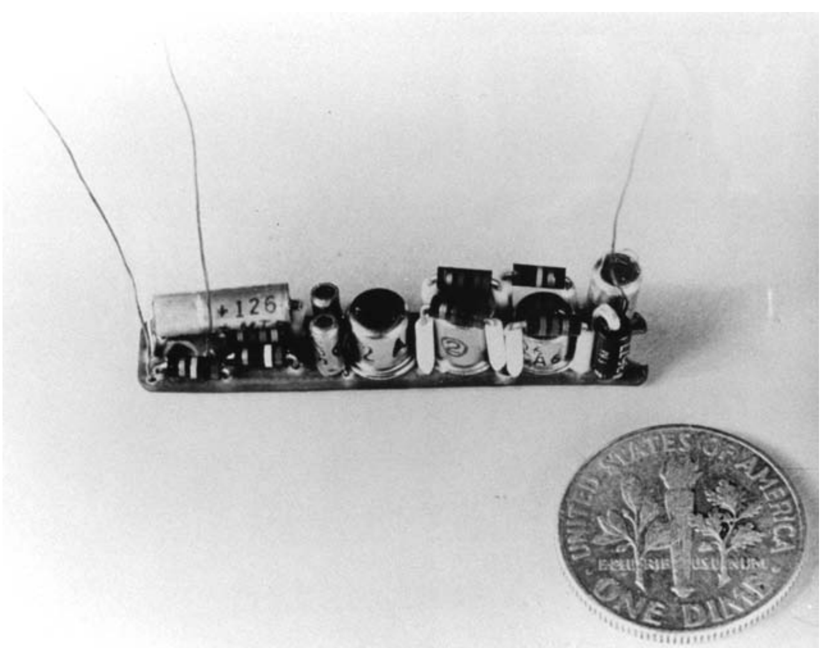
The most stable isotopes of plutonium are plutonium-242 and plutonium-244. The half lives of these two isotopes are 373,300 years and 80,800,000 years respectively. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. Consider the isotope plutonium-242, with its half life of 373,300 years. In 373,300 years (one half life), only half of a sample prepared today would still be plutonium-242. The rest would have broken down into a new isotope.

Extraction

Plutonium is extracted from natural sources only rarely and only for the purposes of research.

Uses

The most important uses of plutonium depend on two of its properties. First, the radiation given off by plutonium occurs as heat. In fact, plutonium gives off so much heat that the metal feels warm to the touch. If a large piece of plutonium is placed into water, the heat released can cause the water to boil.



Plutonium generators have been used in artificial pacemakers. Here, a historic cardiac pacemaker, fueled by radioactive plutonium-238, is shown. Its size is shown in relation to a dime. LIBRARY OF CONGRESS.

Understanding the Fuel-Making Process

The production of plutonium fuel (plutonium-239) is a fascinating story. When nuclear reactors were first built, they all used uranium-235 as a fuel. Of the three naturally occurring isotopes of uranium, only uranium-235 will undergo fission.

But the uranium used in a nuclear reactor is never pure uranium. Instead, it is natural uranium with an increased amount of uranium-235. The uranium is said to be "enriched" with uranium-235. But a lot of the main isotope of uranium, uranium-238, remains mixed with the uranium-235.

Fission of uranium-235 occurs when neutrons are fired into the reactor. Neutrons are subatomic particles with no electric charge. They cause uranium-235 to break apart, giving off energy. That energy is then used to make electricity.

But neutrons also collide with uranium-238 isotopes in the reactor. This isotope does not undergo fission, but does undergo another kind of change. It soaks up neutrons and changes into plutonium-239:

uranium-238 + neutrons → plutonium-239

The plutonium that is formed can be removed from the reactor. It is then purified and re-used as fuel in another nuclear reactor.

What an amazing process this is! One could compare it to the burning of coal to make electricity. In a coal-fired power plant, coal is burned to boil water. Steam runs turbines that make electricity, but when the coal burns up, it's gone.

In a nuclear reactor, the breakdown of uranium-235 atoms gives off energy like the burning of coal. Over time, most of the uranium-235 atoms are used up. But while this is happening, a new fuel is being made! Atoms of plutonium-239 are being produced from atoms of uranium-238. Some reactors are operated primarily to make plutonium, not to make electricity. These reactors are called breeder reactors because they generate new fuel as they operate.

This property makes plutonium a good choice for certain thermoelectric generator applications. A thermoelectric generator is a device that converts heat into electricity. Plutonium generators are not practical on a large scale basis. But they are very desirable for special conditions. For example, they have been used to provide electrical power on space probes and space vehicles.

They have also been used in artificial pacemakers for people with heart conditions. The isotope most commonly used for this application is plutonium-238 because the radiation it gives off does not pose a threat to people's health. In spite of the relative safety of the plutonium-238, pacemakers made with other materials are now preferred.

Plutonium is also used as a fuel in nuclear power plants and in making nuclear weapons (atomic bombs). The isotope used for this purpose is plutonium-239. It is used because it will undergo nuclear fission. Very few isotopes will undergo nuclear fission. Two isotopes of uranium, uranium-233 and uranium-235, are among these. But uranium-233 does not occur at all in nature and uranium-235 occurs in only very small amounts.

By contrast, plutonium-239 can be made fairly easily in nuclear power reactors. It is a by-product, or "waste product," of these reactors. It can be removed from the reactor, purified, and then re-used to make electrical power.

Compounds

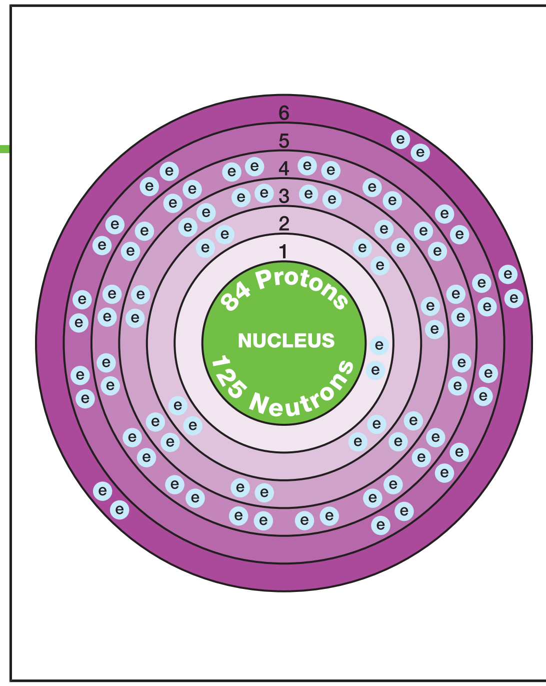
No plutonium compounds have any commercial application.

Health Effects

Plutonium is one of the most toxic elements known. In the body, it tends to concentrate in bones. One of its most serious health effects on a long-term basis is bone cancer.

Scientists who work with plutonium do not handle the metal directly. Instead, they use remote control devices. They always stand behind special shielding to protect themselves from the radiation produced by plutonium.

Polonium



Key Facts

Symbol: Po

Atomic Number: 84

Atomic Mass: [209]

Family: Group 16 (VIA); chalcogen

Pronunciation: puh-LO-nee-um

Overview

Polonium was discovered in 1898 by Polish-French physicist Marie Curie (1867–1934) and her husband, Pierre Curie (1859–1906). They were looking for the source of radioactivity in a naturally occurring ore called pitchblende. Radioactivity is the process by which materials give off energy and change into new materials.

Polonium is the heaviest element in the chalcogen family. It is in Group 16 (VIA) in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. The other chalcogen elements are **oxygen**, **sulfur**, **selenium**, and **tellurium**.

Polonium is a relatively rare element. The pitchblende studied by the Curies contained only about 100 micrograms (millionths of a gram) of polonium per metric ton of ore. The element can now be prepared artificially in a particle accelerator, or "atom smasher." A particle accelerator is a machine in which small particles such as protons, are accelerated (speeded up) to very high speeds. These speeds approach the speed of light—186,000 miles per second (300,000 kilometers per second). The particles collide with targets, such as **gold**, **copper**, or **tin**. When struck by the particles, the targets break apart, forming new elements and other particles.

WORDS TO KNOW

Alpha particles: Tiny, atom-sized particles that can destroy cells.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Particle accelerator ("atom smasher"): A machine used to cause small particles, such as protons, to move at very high speeds.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactivity: Having the tendency to break apart and give off some form of radiation.

Toxic: Poisonous.

Polonium has a few commercial uses. For example, it is used to remove static electrical charges in certain industrial operations. The element is highly toxic.

Discovery and Naming

In 1898 French physicist Antoine-Henri Becquerel (1852–1908) discovered a new form of radiation that was similar to light rays. It was found in a **uranium** ore called pitchblende.

Becquerel's discovery encouraged many scientists to learn more about this radiation. Among these scientists were the Curies. They decided to study pitchblende to learn what was giving off radiation. They knew uranium was one source of the radiation, but the amount of radiation they found was too great to come from uranium only.

The Curies purchased pitchblende by the ton. They slowly purified the ore, getting rid of sand, clay, and other materials in the ore. After months of work, they finally isolated an element that had never been seen before. Marie Curie suggested the name polonium, in honor of her homeland, Poland. Polonium is hundreds of times more radioactive than uranium.

Physical Properties

Polonium metal has a melting point of 489°F (254°C), a boiling point of 1,764°F (962°C), and a density of 9.4 grams per cubic centimeter, nearly 10 times that of water.

Chemical Properties

Polonium has chemical properties like the elements above it in the periodic table, especially selenium and tellurium. Polonium's chemical properties are of interest primarily to research chemists. Under most circumstances, scientists are more interested in polonium as a radioactive material.

Occurrence in Nature

Polonium is produced in nature when other radioactive elements break down. It is so rare, however, that all the polonium needed is now made in particle accelerators.

Isotopes

Polonium has 43 isotopes, all of which are radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

A radioactive isotope is one that breaks apart and gives off some form of radiation. About the only isotope of any use is polonium-210.

Extraction

Polonium occurs so rarely and has so few uses that it is extracted from natural ores only for the purpose of research.

Uses

Polonium releases a great deal of energy during its radioactive breakdown. This property has led to the development of compact heat sources for specialized purposes, such as use on space probes (see photo on page 448).

Radiation is used to remove static electricity from photographic film. Static electricity consists of electric charges that collect on the outside of a surface. When photographic film is exposed, electrostatic charges can reduce the clarity of a picture. The radiation polonium releases creates electrical charges in the air around it. These charges combine with those on the film, neutralizing them and preventing damage to the film.

Compounds

There are no compounds of polonium of practical interest. Some polonium compounds are prepared for the purpose of research.

The energy released by polonium during its radioactive breakdown is used in compact heat sources in space probes. This is the **Mariner 10**, *launched November 3, 1973, on the first trip to the planet Mercury.* NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA).

Health Effects

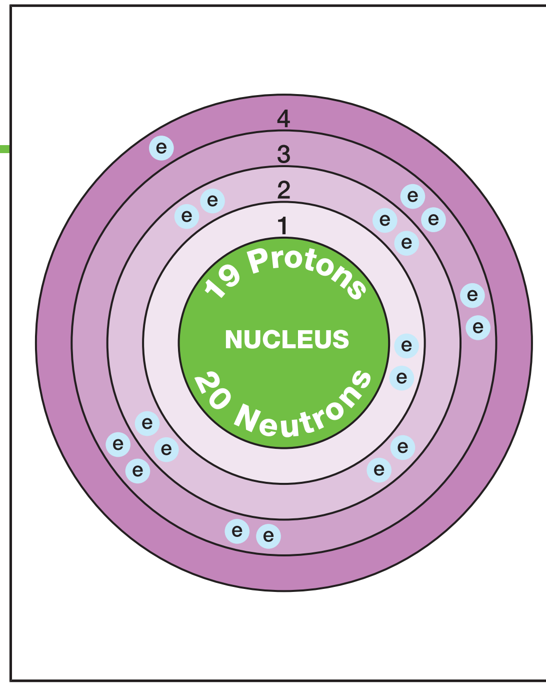
Polonium is an extremely dangerous substance. When it breaks down, it gives off alpha particles. These particles are tiny, atom-sized particles that can destroy cells. Polonium is considered to be more than 100 billion times more dangerous than hydrogen cyanide. The maximum suggested exposure to the element is no more than about seven one-hundred-billionths of a gram.

Polonium has been found in the tobacco used in cigarettes and other products. The amount of polonium taken in by a smoker is approximately equal to that taken in from all other sources. Polonium must be added, therefore, to the list of harmful chemicals inhaled during smoking.

The September 2008 article "Waking a Sleeping Giant: The Tobacco Industry's Response to the Polonium-210 Issue," which appeared in the *American Journal of Public Health*, discussed radioactivity in cigarettes and tobacco companies's efforts to try to rid their products of it. The authors claim that the companies covered up the problem for more than 40 years.

The severe health effects of exposure to Polonium-210 became front-page news in 2006 when former Russian spy Alexander Litvinenko died. Litvinenko (44), who had sought political asylum in Great Britain in 2000, fell ill in November of 2006 and died several weeks later due to severe radiation poisoning. The source of the poisoning was a mystery and his death was investigated as a murder.

Potassium



Key Facts

Symbol: K

Atomic Number: 19

Atomic Mass: 39.0983

Family: Group 1 (IA); alkali metal

Pronunciation: poe-TAS-see-um

Overview

Potassium is one of the alkali metals. The alkali metals are the elements that make up Group 1 (IA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. The alkali metals also include **lithium**, **sodium**, **rubidium**, **cesium**, and **francium**. They are among the most active metals.

Potassium is so active that it never occurs free in nature. It always occurs in compounds, combined with other elements. It was first prepared in pure form in 1807 by English chemist Sir Humphry Davy (1778–1829). Davy used a new method of isolating elements that he had invented called electrolysis. In electrolysis, an electric current is passed through a molten (melted) compound. The electrical current breaks the compound into its elements.

There are very few uses for potassium as a pure element. However, compounds of potassium have many important applications, the most important of which is as a fertilizer.

Discovery and Naming

Early humans were familiar with potash, a potassium compound that forms when wood burns. Wood ashes were washed with water to dissolve

WORDS TO KNOW

Alkali metal: An element in Group 1 (IA) of the periodic table.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how the chemical elements are related to each other.

Potash: A potassium compound that forms when wood burns.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

the potash. It was then recovered by evaporating the water. Potash was often called vegetable alkali. That name comes from the origin of the material ("vegetable" plants that contain wood) and the most important property of the material, alkali. The word alkali means a strong, harsh chemical that can be used for cleaning. Common household lye is a typical alkali.

The chemical name for potash is potassium carbonate (K_2CO_3). Early humans also knew about a similar substance called mineral alkali. This material was made from certain kinds of rocks. But it also had alkali properties. "Mineral alkali" was also called soda ash. The modern chemical name for soda ash is sodium carbonate (Na_2CO_3).

For many centuries, people had trouble telling "vegetable alkali" and "mineral alkali" apart. The two materials looked and acted very much alike. For example, they could both be used as cleaning materials. The main difference between them was the source from which they came. It was not until the 18th century that chemists understood the difference between potash (vegetable alkali) and soda ash (mineral alkali).

By the late 1700s, chemists were reasonably sure that both potash and soda ash contained elements they had never seen. They tried to think of ways to break these compounds down into their elements. The first method that Davy tried was to pass an electric current through a water solution of one compound or the other. But no new element was ever formed. What Davy did not know was how active the elements potassium and sodium are. Both elements are freed when an electric current is passed through a water solution of potash or soda ash. But as soon as the element is formed, it reacts immediately with the water. The free element can never be recovered by this method.

Then Davy thought of another way to separate potash and soda ash into their elements. He decided to use no water in his experiment. Instead, he melted a sample of potash and a sample of soda ash. Then he passed an electric current through the molten (melted) substances. He was amazed to see a tiny liquid droplet of metal formed in each case. The droplet was the first piece of potassium and sodium ever to be seen by a human.

Davy had his first success with potassium using this approach on October 6, 1807. A few days later he repeated his experiment with soda ash and produced pure sodium metal. Davy named these two elements after their much older names: potassium for "potash" and sodium for "soda ash."

Physical Properties

Potassium is a soft, silvery-white metal with a melting point of 145°F (63°C) and a boiling point of 1,420°F (770°C). Its density is 0.862 grams per cubic centimeter, less than that of water (1.00 grams per cubic centimeter). That means that potassium metal can float on water. As noted in "Chemical Properties," though, that's not a good idea.

The melting point of potassium is very low for a metal. It will melt over the flame of a candle.

Chemical Properties

Like the other alkali metals, potassium is very active. It reacts with water violently and gives off **hydrogen** gas:

$$2K + 2H_2O \rightarrow 2KOH + H_2$$

So much heat is produced in this reaction that the hydrogen gas actually catches fire and may explode. Floating potassium metal on the surface of water is not a good idea! In that instance, the potassium would skip along the surface of the water. The skipping is caused by hydrogen gas produced in the reaction pushing the metal around. The potassium would soon catch fire, burn, and, perhaps, explode.

Potassium reacts readily with all acids and with all non-metals, such as **sulfur**, **chlorine**, **fluorine**, **phosphorus**, and **nitrogen**.

Occurrence in Nature

Potassium is the eighth most abundant element in Earth's crust. Its abundance is estimated to be about 2.0 to 2.5 percent. It is just slightly less abundant than its alkali cousin, sodium.

Potassium occurs widely in many different minerals. Some of the most important of these minerals are sylvite, or potassium chloride (KCl); sylvinite, or sodium potassium chloride (NaCl • KCl); carnallite, or potassium magnesium chloride ($KCl \cdot MgCl_2$); langbeinite, or potassium magnesium sulfate ($K_2SO_4 \cdot 2MgSO_4$); and polyhalite, or **calcium** magnesium potassium sulfate ($2CaSO_4 \cdot MgSO_4 \cdot K_2SO_4$).

Isotopes

There are three naturally occurring isotopes of potassium: potassium-39, potassium-40, and potassium-41. Potassium-40 is radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Eighteen artificial radioactive isotopes of potassium with measured half lives are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Artificially radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Potassium-40 is of special interest to scientists. Potassium is widely distributed in nature in plants, animals, and rocks. Thus, nearly everything on Earth contains at least a tiny amount of radioactive potassium-40. That includes the human body! About 0.012 percent of the potassium in the human body is radioactive potassium-40. However, the isotope does not give off enough radiation to cause any harm.

Radioactive potassium-40 in rocks can be used to measure the age of objects. When the isotope gives off radiation, it breaks down to an isotope of **argon**:

potassium-40 loses radiation→ argon-40

A scientist can analyze a rock to see how much potassium-40 and how much argon-40 it contains. The older the rock, the more argon-40 and the less potassium-40 it contains. The younger the rock, the more potassium-40 and the less argon-40 it contains.

One might wonder why argon gas does not escape into the atmosphere. The answer is that the argon gas is trapped within the solid rock. It is released only when the potassium-dating process is conducted.

Extraction

Potassium metal is produced by combining potassium chloride with sodium metal at high temperatures. But this method is of little interest because potassium metal has few uses.

The word "potash" is still a widely used term for potassium compounds taken from the earth. But it no longer means potassium carbonate to most people. It can mean potassium sulfate (K_2SO_4), potassium chloride (KCl), potassium nitrate (KNO_3), potassium hydroxide (KOH), or potassium oxide (K_2O). People cling to the term "potash" because it is the term used in the manufacture of fertilizers. And fertilizers are far and away one of the most important uses of potassium compounds today.

An important source of potash in the United States is in New Mexico, where sylvinite (KCl • NaCl) and langbeinite ores are produced. In 2008, according to the U.S. Geological Survey (USGS), New Mexico mines were responsible for some 77 percent of U.S. producer sales. Potash is also produced from huge long-buried salt mine blocks formed

Aerial view of a potash mine in southern Saskatchewan, Canada. IMAGE COPYRIGHT 2009, ANDRE NANTEL. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Potash in the Colonies

Potash was a widely used material in Colonial America. People used the compound to make soap, glass, and dozens of other products. At the time, potash was easy to get. All one had to do was burn a tree and collect potash from its ashes.

The only problem was that a single tree does not produce much potash. To get all the potash a family might need, one might have to burn dozens or hundreds of trees. Colonists did not worry too much about this problem. America in the 1700s was covered with trees and did not yet suffer the effects of industrial pollution. Few people thought about or cared about saving the environment. If they ran out of trees, they just moved farther west.

One can imagine what America would have looked like if Colonists continued this practice. Fortunately, they did not. In the 1780s, French chemist Nicolas Le Blanc (1742–1806) invented an inexpensive method for making soda ash. Le Blanc's method used salt, or sodium chloride (NaCl); limestone, or calcium carbonate ($CaCO_3$); and coal (pure carbon). These three materials are all common and inexpensive. The Le Blanc method of making soda ash is quick, easy, and cheap. Before long, soda ash had become one of the least expensive chemicals made artificially. In the United States, trees were no longer burned to get potash. People could use inexpensive soda ash in place of potash.

when ancient seas evaporated (dried up). In Michigan, for example, potash is obtained by passing water into these mines. The water dissolves the potash and returns to the surface. There it is allowed to evaporate. When the water has all evaporated, potash remains behind.

The United States produced about $895 million worth of potash in 2008. Other large producers of potash include Canada, Russia, Belarus, Germany, Israel, China, and Jordan.

Uses

Potassium metal is sometimes used as a heat exchange medium. A heat exchange medium is a material that picks up heat in one place and carries it to another place. Potassium metal is sometimes used as a heat exchange medium in nuclear power plants. There, heat is produced at the core or center of the reactor. Liquid potassium is sealed into pipes surrounding the core. As heat is given off, it is absorbed (taken up) by the potassium. The potassium is then forced through the pipes into a nearby room. In that room, the potassium pipes are wrapped around pipes filled with water. The heat in the potassium warms the water. Eventually the water

Potassium bicarbonate, also known as baking soda, has many uses. For example, baking soda is used as a leavening agent—an ingredient that makes cookies, muffins, and other baked goods rise and expand as they are cooked instead of remaining flat. IMAGE COPYRIGHT 2009, TOBIK. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

gets hot enough to boil. It changes into steam and is used to operate devices that generate electricity.

Compounds

By far the most important compound of potassium is potassium chloride (usually referred to as "potash"). At least 85 percent of that compound is used to make synthetic (artificial) fertilizers in the United States. The figure is even higher worldwide—93 percent. The chemical industry is also a primary user of potash resources.

Many other potassium compounds are commercially important, although no use begins to compare with the amount of potash used for fertilizers. Some examples of other important potassium compounds are:

- potassium bicarbonate, or baking soda ($KHCO_3$): baking powders; antacid (for upset stomach); food additive; soft drinks; fire extinguishers
- potassium bisulfite ($KHSO_3$): food preservative (but not in meats); bleaching of textiles and straw; wine- and beer-making; tanning of leathers
- potassium bitartrate, or cream of tartar ($KHC_4H_4O_6$): baking powder; "tinning" of metals; food additive
- potassium bromide (KBr): photographic film; engraving

- potassium carbonate, or potash (K_2CO_3): specialized glasses and soaps; food additive
- potassium chromate (K_2CrO_4): dyes and stains (bright yellowish-red color); explosives and fireworks; safety matches; tanning of leather; fly paper
- potassium fluorosilicate (K_2SiF_6): specialized glasses, ceramics, and enamels; insecticide
- potassium hydroxide, or caustic potash (KOH): paint remover; manufacture of specialized soaps; fuel cells and batteries; bleaching; food additive; herbicide
- potassium nitrate, or nitre, or saltpeter (KNO_3): explosives, fireworks, matches, rocket fuel; manufacture of glass; curing of foods
- potassium pyrophosphate, or tetrapotassium pyrophosphate, or TKPP ($K_4P_2O_7$): soaps and detergents
- potassium sodium tartrate, or Rochelle salt ($KNaC_4H_4O_6$): baking powder; medicine; silvering of mirrors

Potassium bicarbonate is an additive in some fire extinguishers. IMAGE COPYRIGHT 2009, ROB BYRON. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Health Effects

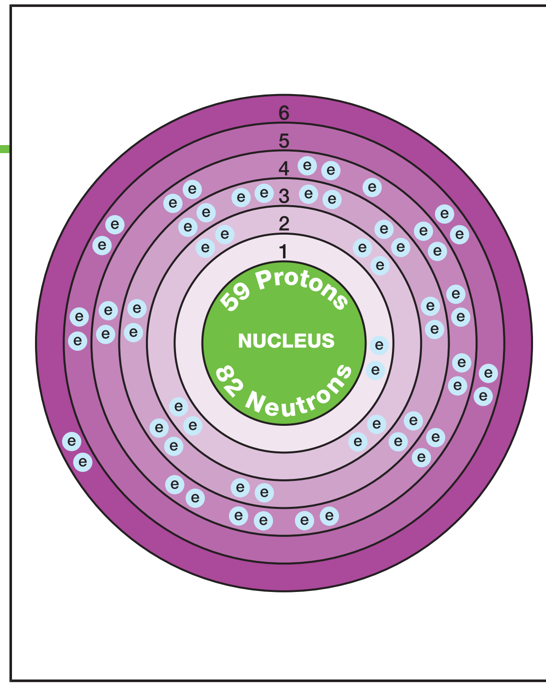
Potassium is essential to both plant and animal life. It is one of the three primary nutrients, or macronutrients, required by plants. Plants require relatively large amounts of potassium in order to grow and remain healthy.

Potassium plays a number of important roles in the human body also. It helps control the proper balance of fluids in cells and body fluids. It is involved in the transmission of chemical messages between nerve cells and in the contraction of muscles. Potassium also helps in the digestion of food and in the proper function of the eyes. In many of these reactions, potassium and sodium work together to keep these functions performing properly.

The average human who weighs 150 pounds (70 kilograms) has 5 ounces (140 grams) of potassium in his or her body. Normal daily intake of potassium is about 3.3 grams (0.1 ounce). Since potassium occurs in all plants, humans normally do not have any problems getting enough of the element in their daily diet.

Researchers continue to study the benefits of potassium. Areas of medical study include potassium's role in improving heart health and bone health, as well as in reducing high blood pressure. Foods rich in potassium include bananas, broccoli, fish (such as tuna and salmon), green leafy vegetables, melons, potatoes, raisins, and tomatoes.

Praseodymium



Key Facts

Symbol: Pr

Atomic Number: 59

Atomic Mass: 140.90765

Family: Lanthanoid (rare earth metal)

Pronunciation: PRAY-zee-oh-DIM-ee-um

Overview

During the late 1830s and early 1840s, Swedish chemist Carl Gustav Mosander (1797–1858) was studying two puzzling minerals, ceria and yttria. Both minerals had been discovered more than 50 years earlier in remote parts of Sweden. The minerals were puzzling because they seemed to consist of a mixture of new elements. Mosander eventually showed that one of the elements in ceria produced pink compounds. He called the new element didymium.

A few years after didymium was discovered, Austrian chemist Carl Auer (Baron von Welsbach) (1858–1929) made a correction to Mosander's research. Didymium was not a pure element, Auer announced, but a combination of two other new elements. He called these elements **neodymium** and praseodymium.

Praseodymium lies in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Fifteen of the elements that make up Row 6 are sometimes called the rare earth metals. But the term is not very accurate. The rare earth elements are not especially rare in Earth's crust. They were given this name because they have very similar properties. This similarity makes them difficult to

WORDS TO KNOW

Allotropes: Forms of an element with different physical and chemical properties.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to each other.

Pyrophoric: Gives off sparks when scratched.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

separate from each other. A better name for these rare earth elements is the lanthanoids. This name comes from **lanthanum**, element 57.

Praseodymium is a typical metal, somewhat similar to **aluminum**, **iron**, or **magnesium**. It is quite expensive to prepare and does not have many practical uses.

Discovery and Naming

Mosander had been educated as a physician and a pharmacist. In the early 1830s, he was put in charge of the minerals collection at the Stockholm Academy of Sciences. He became very interested in two minerals that had been discovered in Sweden many years before, yttria and cerite. He devoted much study to the composition of these two minerals.

In 1841, Mosander announced that he had obtained two new elements from cerite. He called these elements lanthanum and didymium. He was correct about lanthanum being a new element, but he was wrong about didymium. This new "element" turned out to be a mixture of two other new elements, now called neodymium and praseodymium.

The man who made this discovery was Auer. He selected these two names because they mean "new twin" (neodymium) and "green twin" (praseodymium). The elements were called "twins" because they were both so much like lanthanum.

The praseodymium prepared by Auer was not very pure. It was contaminated with other elements. The first really pure sample of praseodymium was not made until 1931.

Physical Properties

Praseodymium is a soft, malleable, ductile metal with a yellowish, metallic shine. Malleable means capable of being hammered into a thin sheet. Ductile means capable of being made into thin wires. Praseodymium has a melting point of 1,710°F (930°C) and a boiling point of about 5,800°F (3,200°C). Its density is 6.78 to 6.81 grams per cubic centimeter. Two allotropes of praseodymium exist. Allotropes are forms of an element with different physical and chemical properties. One allotrope, the "alpha" form, changes into a second allotrope, the "beta" form, at about 1,472°F (800°C).

Chemical Properties

When it becomes moist, praseodymium reacts with **oxygen** in air to form praseodymium oxide. Praseodymium oxide (Pr_2O_3) forms as a greenish-yellow scale (like rust) on the surface of the metal. To protect praseodymium for this reaction, it is stored under mineral oil or covered with a plastic wrap.

Like many other metals, praseodymium also reacts with water and with acids. In these reactions, **hydrogen** gas is released.

Occurrence in Nature

Praseodymium is one of the more common lanthanoids. It is thought to occur with an abundance of about 3.5 to 5.5 parts per million in Earth's crust. It occurs primarily with the other rare earth elements in two minerals, monazite and bastnasite.

Isotopes

Only one naturally occurring isotope of praseodymium is known: praseodymium-141. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-seven radioactive isotopes of praseodymium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. None of the radioactive isotopes has any commercial use.

Extraction

The first step in obtaining praseodymium is to treat monazite, bastnasite, or another ore to separate the lanthanoids from each other. The various elements are then changed to compounds of **fluorine**, such as praseodymium fluoride (PrF_3). Praseodymium metal can then be obtained by passing an electric current through molten (melted) praseodymium fluoride:

$$2PrF_3 \xrightarrow{\text{electric current}} 2Pr + 3F_2$$

or by making it react with an active metal:

$$3Na + PrF_3 \rightarrow 3NaF + Pr$$

It is one of the least expensive rare earths. In 2007, praseodymium oxide sold for about $75 per kilogram.

Uses

One of the oldest uses for praseodymium is in the manufacture of misch metal. Misch metal is pyrophoric, meaning that the metal gives off sparks when it is scratched. The most common use of misch metal is in lighter flints and tracer bullets. When a metal wheel is rubbed across misch metal in a cigarette lighter, the metal gives off sparks. Those sparks then set fire to lighter fluid, giving a flame to light a cigarette.

Like other lanthanoids, praseodymium is also used to give color to glass, ceramics, enamels, and other materials. The characteristic color provided by compounds of praseodymium is a bright yellow.

A related use of praseodymium is in carbon arc lamps, like those used in the motion picture industry. When an electric current is passed through a carbon arc, the arc gives off a brilliant white light. The addition of a small amount of praseodymium gives a brilliant yellow cast to the light.

Praseodymium is also a component of didymium glass. Didymium glass contains a mixture of rare earth elements, including lanthanum, praseodymium, neodymium, **samarium**, **cerium**, and **gadolinium**. This glass is used to make welder's goggles. It helps protect the welder's eyes from the intense light produced during welding.

In recent years, praseodymium is one of the rare earth elements used in some hybrid cars.

An African American woman during World War II wears welders' goggles. Praseodymium is a component of the glass used in safety goggles. LIBRARY OF CONGRESS.

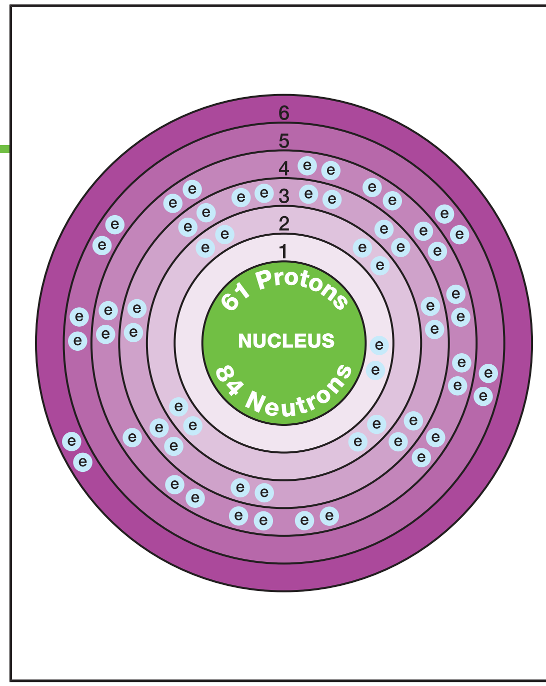
Compounds

Relatively few compounds of praseodymium have any commercial uses.

Health Effects

The health effects of praseodymium are not well known. Exposure to the metal or its compounds may cause irritation of the skin, eyes, and respiratory (breathing) system. As a safety measure, chemists treat the metal as if it were toxic and handle it with caution.

Promethium



Key Facts

Symbol: Pm

Atomic Number: 61

Atomic Mass: [145]

Family: Lanthanoid (rare earth metal)

Pronunciation: pruh-MEE-thee-um

Overview

Promethium is one of the most fascinating of all chemical elements. It has never been found on Earth's surface. Scientists know of it only because it can be prepared artificially in particle accelerators ("atom smashers") and in other unusual reactions. Its existence was predicted as early as 1902, but its discovery was not confirmed until 1945.

All of the known isotopes of promethium are radioactive. That is, they break down and give off radiation spontaneously.

At one time, promethium was strictly a laboratory curiosity. Today, however, it has a number of limited practical industrial applications.

Discovery and Naming

In the late 1860s, Russian chemist Dmitri Mendeleev (1834–1907) discovered the periodic law. The periodic law provides a way of organizing the chemical elements to show how they are related to each other. It is usually represented by a table with 18 columns and 7 rows. Each chemical element belongs in one of the boxes of the periodic table.

By about 1900, most of the chemical elements had been discovered, but a few empty boxes remained on the periodic table. Chemists

WORDS TO KNOW

Atomic fission: The process in which large atoms break apart producing large amounts of energy and smaller atoms.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements that make up Row 6 of the periodic table between barium and hafnium.

Luminescence: The property of giving off light without giving off heat.

Periodic law: A way of organizing the chemical elements to show how they are related to each other.

Radioactivity: Having the tendency to break apart and give off some form of radiation.

Spectrum (plural spectra): The pattern of light given off by a glowing object, such as a star.

wondered why those boxes were still empty. In 1902, Czech chemist Bohuslav Brauner predicted that there should be an element between **neodymium** (number 60) and **samarium** (number 62). Chemists began searching for the element based on the characteristics of the elements around it.

In 1924, Italian chemists Luigi Rolla and Rita Brunetti claimed to have found element 61. They suggested the name florentium for their home town of Florence. At about the same time, scientists at the University of Illinois also announced the discovery of element 61. They proposed the name illinium for Illinois.

Gradually, scientists began to believe that element 61 was radioactive. A radioactive element is one that breaks apart and gives off some form of radiation. One way to make radioactive elements is to fire very small particles at atoms. The particles stick in the atoms and make them radioactive. In the late 1930s, scientists at Ohio State University thought they had found element 61. They suggested the name cyclonium, after the kind of particle accelerator they used to make the element, a cyclotron.

None of the "discoveries"—from Italy, Illinois, or Ohio—could be confirmed by other scientists. A great debate went on for many years as to whether element 61 had really been found or not. Finally, the problem was solved. During World War II (1939–1945), scientists at the Oak Ridge Laboratory in Oak Ridge, Tennessee, were studying the materials formed during atomic fission. Atomic fission is the process in which large atoms break apart, releasing large amounts of energy and smaller atoms. The smaller atoms are called fission products.

The Oak Ridge scientists proved that element 61 was present in fission products of **uranium**. They named it promethium, after the Greek god Prometheus. According to legend, Prometheus stole fire from the gods and brought it to Earth for human use.

Physical Properties

Promethium is a silver-white metal with a melting point of 2,120°F (1,160°C) and a boiling point estimated at about 5,400°F (3,000°C). Its density is 7.2 grams per cubic centimeter. The physical properties of promethium are of less interest to scientists than its radioactive properties.

Chemical Properties

Promethium behaves like other rare earth elements. The chemical properties of promethium are of less interest to scientists than its radioactive properties.

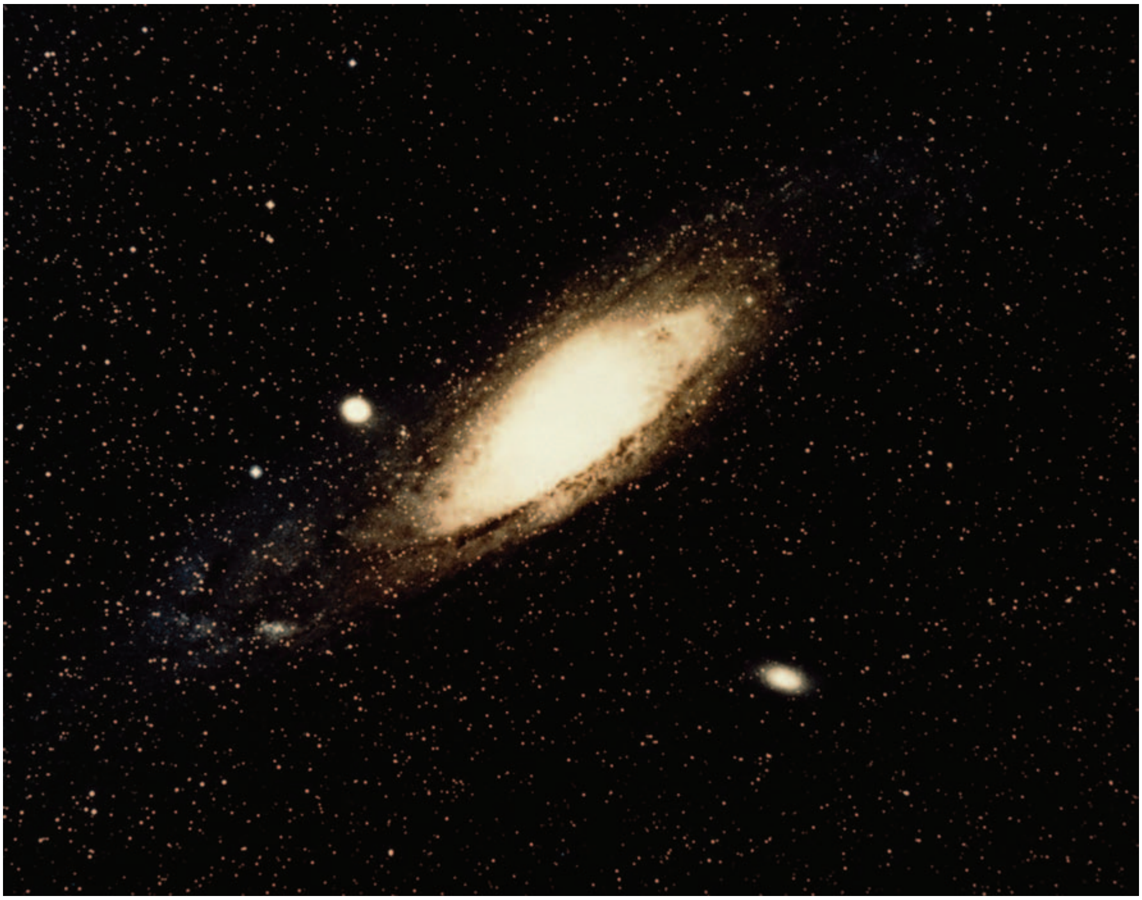
Occurrence in Nature

Promethium has never been found in Earth's crust. It has been observed, however, in the spectra of some stars in the galaxy of Andromeda. The spectrum (plural: spectra) of a star is the light given off by the star.

Isotopes

Forty isotopes of promethium with measured half lives are known. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The only isotope generally available is promethium-147, with a half life of 2.6234 years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. That means for promethium-147 that after 2.6234 years, only half of a 100-gram sample, for example, or 50 grams, will be left. Another isotope, promethium-145, has a longer half life of 17.7 years.



The Andromeda galaxy. Promethium has been observed in the spectra of some stars in this galaxy. PHOTODISC/ROYALTY FREE.

Extraction

Promethium is not found in Earth's surface.

Uses and Compounds

Promethium has limited uses. It can be used as a source of power. The radiation it gives off provides energy, similar to that from a battery. A promethium battery can be used in places where other kinds of batteries would be too heavy or large to use, as on satellites or space probes. Such batteries are far too expensive for common use, however.

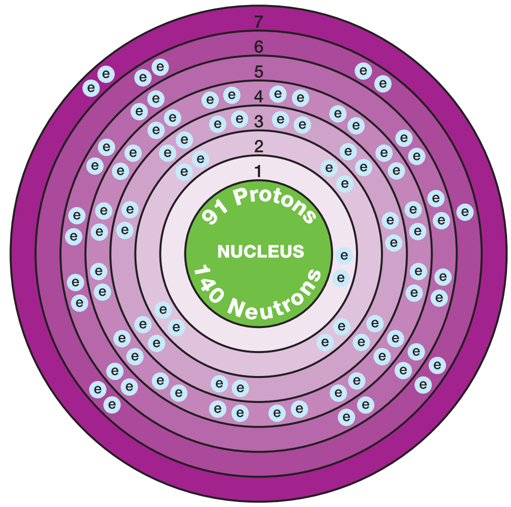
Promethium is also used to measure the thickness of materials. For example, suppose thin sheets of metal are being produced on a conveyor belt. A sample of promethium metal is placed above the metal and a detector is placed below. The detector counts the amount of radiation passing through the metal. If the metal sheet becomes too thick, less radiation passes through. If the sheet becomes too thin, more radiation passes through. The detector reports when the sheet of metal is too thick or too thin. It can automatically stop the conveyor belt when this happens.

Some compounds of promethium are luminescent. Luminescence is the property of giving off light without giving off heat. The light of a firefly is an example of luminescence. Promethium compounds are luminescent because of the radiation they give off.

Health Effects

Like all radioactive materials, promethium must be handled with great care. The radiation it produces can have serious health effects on humans and animals.

Protactinium



Overview

Protactinium is one of the rarest elements on Earth. It is formed when **uranium** and other radioactive elements break down. For many years, the only supply of protactinium of any size was kept in Great Britain. The British government had spent $500,000 to extract about 4 ounces (125 grams) of the element from about 65 short tons (60 metric tons) of radioactive waste. Relatively little is known about the properties of the element, and it has no commercial uses.

Protactinium belongs in the actinoids series in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another.

Key Facts

Symbol: Pa

Atomic Number: 91

Atomic Mass: 231.03588

Family: Actinoid

Pronunciation: pro-tack-TIN-ee-um

Discovery and Naming

Scientists first learned about radioactive elements toward the end of the 19th century. Radioactive elements are elements that break apart all by themselves. They give off radiation—somewhat similar to light or X rays—and change into new elements. Radiation is energy transmitted in the form of electromagnetic waves or subatomic particles.

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radiation: Energy transmitted in the form of electromagnetic waves or subatomic particles.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Radioactive family: A group of radioactive elements and isotopes that are related to each other.

For example, the element uranium is radioactive. It emits radiation over very long periods of time. It begins to change into other elements. One of those elements is protactinium.

Many naturally occurring isotopes are radioactive. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Many of the radioactive isotopes that occur in nature are related to each other. For example, when uranium-235 breaks apart, it forms a new isotope, **thorium**-231. But thorium-231 is radioactive also. It breaks apart to form protactinium-231. And protactinium-231 is also radioactive. It breaks apart to form **actinium**-227. This series goes on for 14 more steps until a stable isotope is finally formed.

This process often goes on for a dozen steps or more. Finally, an isotope is formed that is not radioactive. The chain—or "family" of radioactive isotopes—comes to an end.

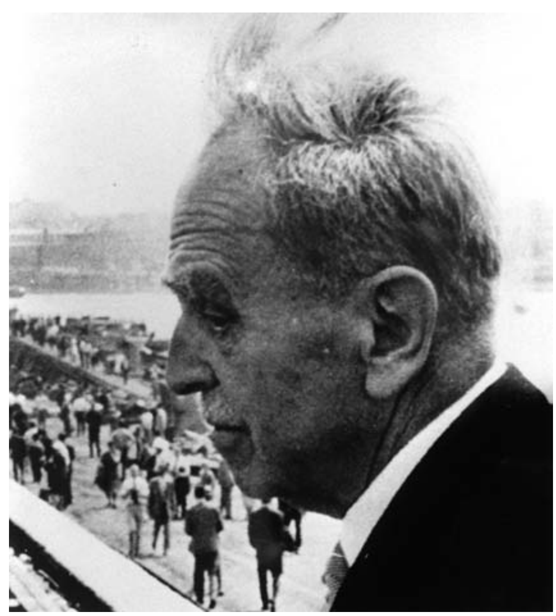
During the early 1900s, scientists were trying to understand these radioactive families. They were trying to identify all the elements found in a family. In doing so, they sometimes found new elements. Such was the case with element number 91. Many scientists had been looking for element number 91 for some time. There was an empty box in the periodic table for element 91. That meant that a new element was yet to be found. Some scientists decided to look in the radioactive families for that element.

In 1913 German-American physicist Kasimir Fajans (1887–1975) and his colleague, O. H. Göhring, claimed to have found element number 91. They suggested the name brevium for the element. They chose the name because the half life of the isotope they found was very short ("brief"). It was only 1.175 minutes.

The half life of a radioactive element is the time it takes for half of a sample of the element to break down. That means that 10 grams of the isotope they studied would break down very quickly. Only 5 grams would be left after 1.175 minutes. Then 2.5 grams (half of 5 grams) would be left after another 1.175 minutes, and 1.25 grams (half of 2.5 grams) after another 1.175 minutes, and so on. Until the discovery by Fajans and Göhring, the element had been known as uranium-X_2. That name came from the element's position in one of the radioactive families.

In 1918, another isotope of element number 91 was discovered by German physicists Lise Meitner (1878–1968) and Otto Hahn (1879–1968). This isotope had a half life of 32,500 years. It was much easier to study than the isotope discovered by Fajans and Göhring.

The new element was originally given the name protoactinium, meaning "first actinium." It comes from the way the element breaks down. Its first product is the element actinium. In 1949, the element's name was changed slightly to its current form, protactinium.



German chemist Otto Hahn was involved in early work with protactinium. LIBRARY OF CONGRESS.

Breaking New Ground: Lise Meitner Until recently, science has often been a difficult occupation for women. Male scientists once assumed that women did not have the mental powers to do good research. Women who became famous scientists usually had to be outstanding in their own field, and they had to overcome the strange prejudices of their male colleagues.

No one knew more about discrimination in science than Lise Meitner. Meitner was born in Vienna, Austria, on November 7, 1878. She learned about the work of Marie Curie while in high school and decided to pursue a career in science. She earned her Ph.D. degree in physics in 1906.

After working as a nurse during World War I (1914–18), Meitner took a job at the University of Berlin. At first, she had to overcome huge obstacles. Her superior would not allow her to work in a laboratory if men were present. He had a tiny laboratory built for her in a closet.

Meitner persevered, however. She eventually became a professor of physics at the school and also served as co-director of the Kaiser Wilhelm Institute in Berlin. The other co-director at this famous research institution was Otto Hahn, the physicist with whom Meitner worked throughout most of her career.

Meitner's career took an unexpected turn in the 1930s. When Nazi leader Adolf Hitler (1889–1945) came to power in Germany, he began to rid the universities of anyone who was Jewish. Although Meitner had been baptized as a Christian, she came from a Jewish family. She soon realized that her life would be in danger if she remained in Berlin. So she escaped from Germany in 1938 and took a position in Copenhagen, Denmark.

Austrian chemist Lise Meitner. She discovered an isotope of protactinium and helped explain the process of nuclear fission. LIBRARY OF CONGRESS.

Meitner and Hahn found protactinium while searching through the products of a nuclear reaction that had only recently been discovered. In fact, the ability of Hahn and Meitner to unravel the nature of that reaction proved to be even more important than the discovery of protactinium.

The reaction in question was one that occurs when neutrons (tiny particles that occur in atoms) are fired at uranium atoms. The reaction had been carried out by a number of scientists, but only Meitner and Hahn figured out what had actually taken place. In 1939, they wrote a paper explaining the reaction. They said that neutrons caused uranium atoms to fission, or split apart.

Meitner and Hahn had described for the first time one of the most important reactions in all of human history: nuclear fission. Nuclear fission later became the basis for weapons, such as the atomic bomb, and useful applications, such as nuclear power plants. For his role in this discovery, Hahn was awarded a share of the 1944 Nobel Prize in Chemistry. Meitner, who had contributed at least as much as Hahn, never received a Nobel Prize for her work. Scholars are still debating the reasons that Meitner's brilliant work was ignored by the Nobel Prize committee in 1944. However, in 1966 she shared the Enrico Fermi Award with Hahn and Fritz Strassman. In 1997, several decades after Meitner's death, element 109 was officially named Meitnerium in her honor.

Physical Properties

Protactinium is a bright shiny metal. When exposed to air, it combines easily with **oxygen** to form a whitish coating of protactinium oxide. Its melting point is 2,840°F (1,560°C) and its density about 15.37 grams per cubic centimeter, more than 15 times the density of water.

Chemical Properties

Protactinium forms compounds with the halogens (**fluorine**, **chlorine**, **bromine**, and **iodine**) and with **hydrogen**. But these compounds have not been studied in detail.

Occurrence in Nature

The amount of protactinium in Earth's crust is too small to estimate accurately. Its most common ore, pitchblende, contains about 0.1 part per million of protactinium.

Isotopes

Twenty-nine isotopes of protactinium with measured half lives are known. All are radioactive. (A more detailed explanation of protactinium isotopes can be found in the "Discovery and Naming" section.)

Extraction

Protactinium does not occur naturally.

Uses and Compounds

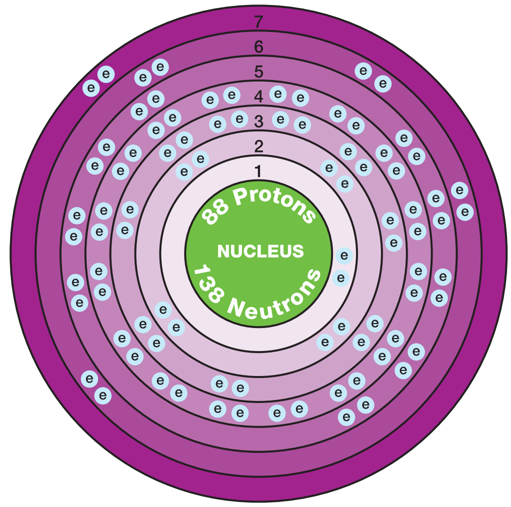
Neither protactinium nor its compounds have any commercial uses. It can be purchased in small amounts from the Oak Ridge National

Laboratory in Oak Ridge, Tennessee. In the early 2000s, it price was about $300 per gram.

Health Effects

Protactinium is very radioactive and highly dangerous. Researchers who work with it must take extreme caution to protect themselves from its radiation.

Radium



Key Facts

Symbol: Ra

Atomic Number: 88

Atomic Mass: [226]

Family: Group 2 (IIA); alkaline earth metal

Pronunciation: RAY-dee-um

Overview

Radium is a radioactive element in Group 2 (IIA) and Row 7 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Radium was discovered in 1898 by Marie Curie (1867–1934) and her husband, Pierre Curie (1859–1906). It was found in an ore of **uranium** called pitchblende. The alkaline earth metals also include **beryllium**, **magnesium**, **calcium**, **strontium**, and **barium**.

Radium is luminescent, meaning it gives off radiation that can be seen in the dark. Its radioactive properties account for its relatively few uses.

Discovery and Naming

The discovery of radium is one of the most interesting stories in science. The story has been told over and over again in books, articles, and motion pictures, and on television.

The story begins with the research of French physicist Antoine-Henri Becquerel (1852–1908). In 1896, Becquerel made a discovery about the ore called pitchblende. Pitchblende contains the element uranium. Becquerel found that pitchblende gives off radiation that acts much like light.

WORDS TO KNOW

Alkaline earth metal: An element found in Group 2 (IIA) of the periodic table.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

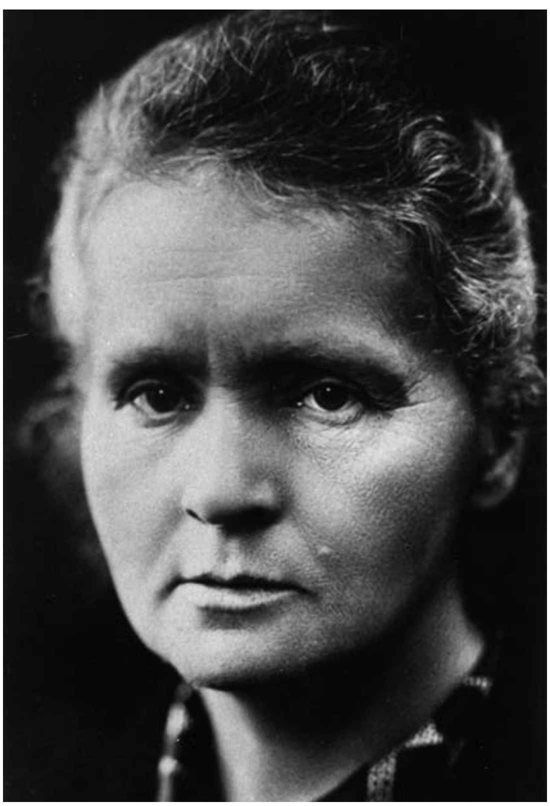
Radiation: Energy transmitted in the form of electromagnetic waves or subatomic particles.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

The main difference is that the radiation from pitchblende is not visible to the human eye.

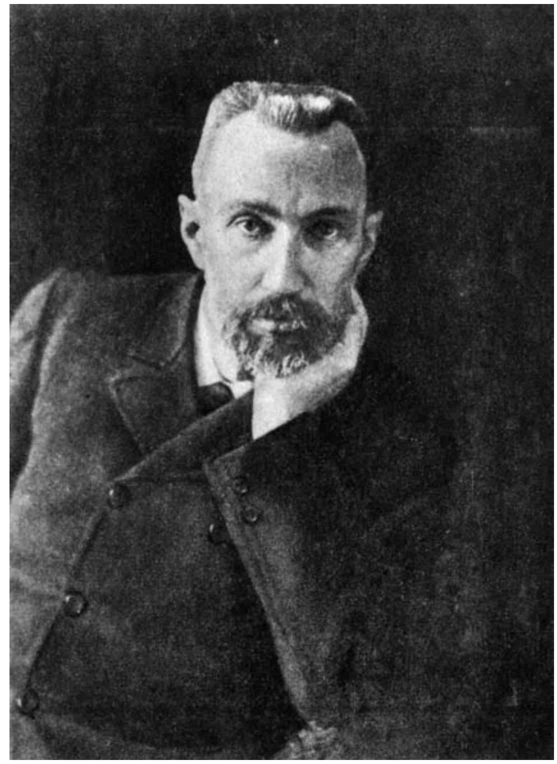
Becquerel's discovery caused great excitement among scientists. Many physicists stopped their own research and began to study this new curiosity. One of those who did so was a graduate student named Marie Sklodowska Curie. Marie had been born in Warsaw, Poland, as Marya Sklodowska. In 1891, she moved to Paris, France, to study physics. Three years later she met another physicist, Pierre Curie. The two were married in 1895.

Polish-French physicist Marie Curie. LIBRARY OF CONGRESS.



The Curies were especially interested in learning more about pitchblende. What was in the ore that was giving off radiation, they asked. To answer this question, they purified huge amounts of the natural ore. Eventually, they isolated a new element that gave off radiation much more intensely than did the pitchblende itself. The Curies named the new element **polonium**.

But they were not finished with their research. They thought at least one other element might be in the pitchblende. So they continued the process of purification. In 1898, they isolated a second new element. They called this element radium. They chose this name because the element gives off such intense radiation. It took the Curies another four years to prepare one gram of the element. To do so, they had to sift through more than seven metric tons of pitchblende!



French physicist Pierre Curie.
LIBRARY OF CONGRESS.

Physical Properties

Radium is a brilliant white metal with a melting point of 1,300°F (700°C) and a boiling point of 3,159°F (1,737°C). Its density is 5.5 grams per cubic centimeter.

Chemical Properties

Radium combines with most non-metals, including **oxygen**, **fluorine**, **chlorine**, and **nitrogen**. It also reacts with acids with the formation of **hydrogen** gas. Radium's chemical properties are of much less interest than its radioactivity, however.

Occurrence in Nature

The amount of radium in Earth's crust is very small. Its abundance has been estimated to be about 0.0000001 parts per million. It occurs not only in pitchblende, but in all ores that contain uranium. It is formed when uranium gives off radiation and breaks down.

Isotopes

Four naturally occurring isotopes of radium are known. They are radium-223, radium-224, radium-226, and radium-228. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

A total of 37 isotopes of radium with measured half lives are known, all of which are radioactive.

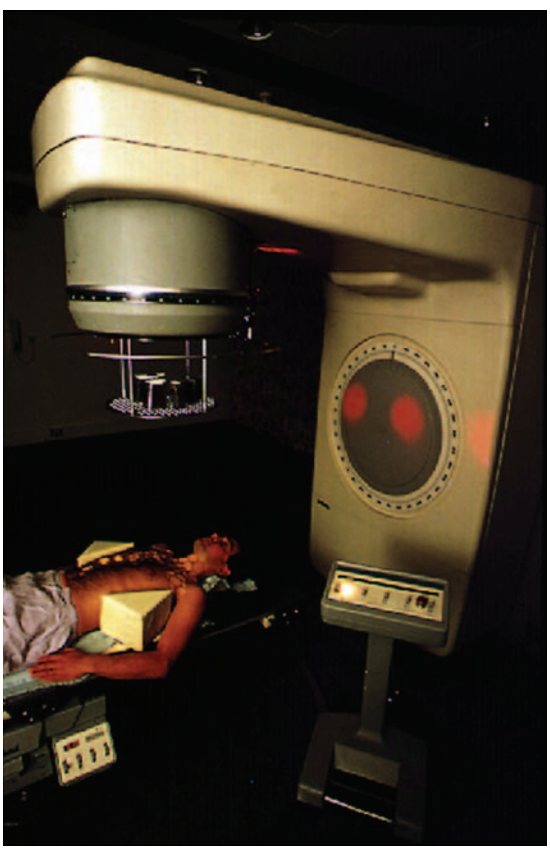
Only radium-226 has any commercial applications. It has a half life of 1,620 years. After that period of time, only half of the original sample would remain. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. The other three isotopes have half lives of only a few days or years. These short half lives make it difficult to work with the isotopes.

The only isotope now used very often, radium-226, is generally not used directly. Instead, it is used to make **radon** gas. Radon gas is one of the products formed when radium breaks down. The radon gas is easier and safer to work with than the radium itself.

Extraction

The process by which radium is obtained is similar to that used by the Curies. The metal is separated from other substances found in pitchblende by a long series of chemical reactions.

A man undergoes radiation treatment. © MARTIN DOHRN/ SCIENCE PHOTO LIBRARY, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.



Uses and Compounds

Because of its history, radium is a very interesting and important element. But radium and its compounds have relatively few uses. In fact, no more than about 5 pounds (2 kilograms) of radium is made each year. The small amount of radium that is available is used for medical purposes. The radium is used to produce **radon** gas, which, in turn, is used to treat cancer. Radiation given off by radium is sometimes used to study the composition of metals, plastics, and other materials.

Radium was once used in paint that was applied on the hands and numbers of clocks and watches. The visible radiation it emitted made it possible to read the numbers in the dark. But the radiation proved very harmful to the people who applied the radium paint to the watches and clocks.

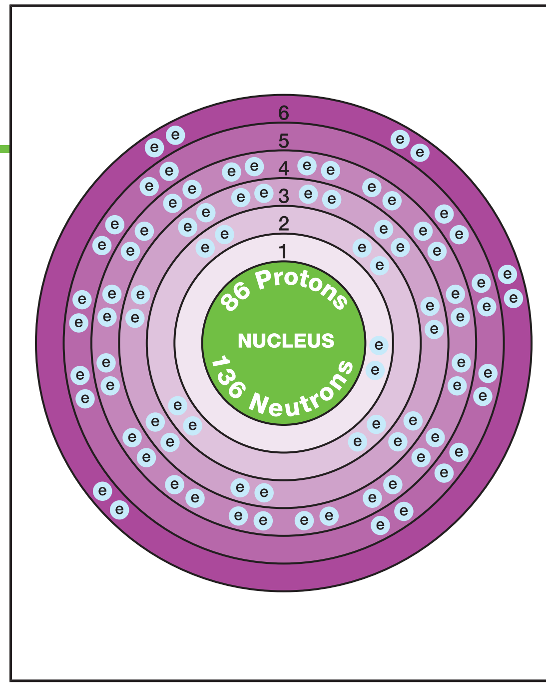
The technique that the painters used included making a sharp point on their brushes by twirling the brush between their lips. They then dipped the brush into radioactive radium paint. The dipping and twirling sequence ultimately caused the painters to get a lot of radium on their lips. This resulted in many cases of lip and mouth cancer among those painters. So radium is no longer used on clocks and watches.

Health Effects

Like all radioactive materials, radium is a dangerous substance to handle. The radiation it gives off can kill living cells. This property is desirable in treating cancer. Killing cancer cells can help a patient recover from the disease. But great care must be taken in using radium for this purpose. Its radiation can also kill healthy cells. People who work with radium must be careful to avoid getting the element on their skin, swallowing it, or inhaling its fumes.

Marie Curie herself eventually died from working with radium. She developed leukemia and died in 1934.

Radon



Overview

Radon is the last member of the noble gas family. The noble gases are the elements that make up Group 18 (VIIIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. The noble gases get their name because they are inactive chemically. They combine with other substances under only extreme conditions. Their tendency to avoid contact with other elements was seen by early chemists as "royal" or "noble" behavior. The noble gases are also called the inert gases.

Radon is a radioactive element. A radioactive element is one that gives off radiation and breaks down to form a different element. Radon is formed when heavier radioactive elements, like **uranium** and **thorium**, break down. In turn, radon breaks down to form lighter elements, such as **lead** and **bismuth**.

Radon is a well-known air pollutant today. It is formed in rocks and soil where uranium is present. As a gas, radon tends to drift upward out of the ground. If a house or building has been built above soil containing uranium, radon may collect in the structure. The U.S. Environmental Protection Agency (EPA) regards the presence of radon in homes and offices as a serious health problem.

Key Facts

Symbol: Rn

Atomic Number: 86

Atomic Mass: [222]

Family: Group 18 (VIIIA); noble gas

Pronunciation: RAY-don

WORDS TO KNOW

Half life: The time it takes for half of a sample of a radioactive element to break down.

Inert: Incapable of reacting with other substances.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Noble gas: An element in Group 18 (VIIIA) of the periodic table.

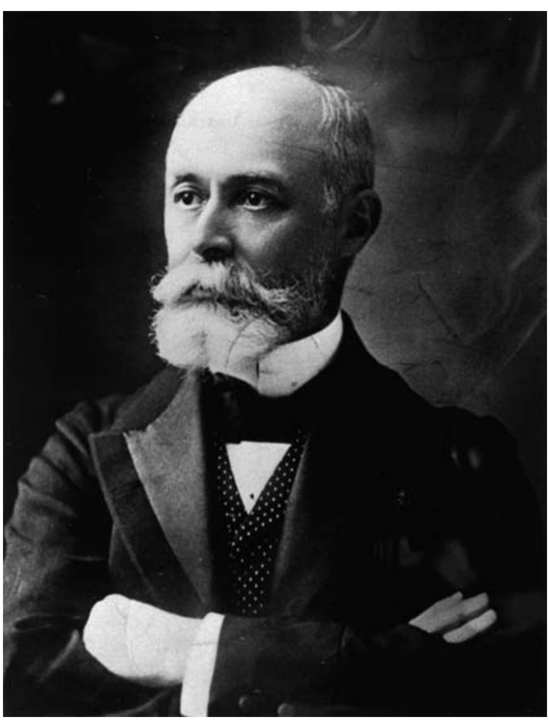
Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Discovery and Naming

Radioactivity was discovered in 1896 by French physicist Antoine-Henri Becquerel (1852–1908). Becquerel observed that a photographic plate was exposed even in the dark when placed next to an ore called pitchblende. The explanation for this phenomenon was offered two years later by a colleague of Becquerel's, Polish-French chemist Marie Curie (1867–1934). Curie said that something in the pitchblende was giving off radiation. The radiation was similar to light in some ways. But it was also different, since it could not be seen. Curie suggested the name of radioactivity for this behavior.

French physicist Antoine-Henri Becquerel. LIBRARY OF CONGRESS.



Over the next decade, many scientists worked to find out more about radioactive materials. Curie and her husband, Pierre Curie (1859–1906), isolated two new radioactive elements, **polonium** and **radium**. In 1900, German physicist Friedrich Ernst Dorn (1848–1916) found a third radioactive element: radon.

Dorn found this element because of an observation made by Curie. When radium is exposed to air, the air becomes radioactive. The Curies did not study this phenomenon further. However, Dorn did. Eventually he discovered that radium produces a gas when it breaks apart. The radioactive gas escapes into the air. The radioactivity of air exposed to radium is caused by this gas.

At first, Dorn called this radioactive gas radium "emanation." The term emanation refers to something that has been given off. Radium emanation, then, means something given off by radium. Dorn also considered the name of niton for the gas. This name comes from the Latin word *nitens,* which means "shining." Eventually, however, scientists decided on the modern name of radon. The name is a reminder of the source from which the gas comes, *rad*ium.

The proper location of radon in the periodic table was determined by Scottish chemist Sir William Ramsay (1852–1916). Ramsay was also involved in the discovery of three other noble gases: **neon**, **krypton**, and **xenon**. In 1903, Ramsay was able to determine the atomic weight of radon. He showed that it belonged beneath xenon in Group 18 (VIIIA) of the periodic table.

Credit for the discovery of radon is often given to other scientists as well. In 1899, Robert B. Owens announced the presence of a radioactive gas that he named thoron. In 1903, French chemist André Louis Debierne (1874–1949) made a similar discovery. He named the gas actinon. Certainly, some credit for the discovery of element 86 can be shared among all these scientists.

Physical Properties

Radon is a colorless, odorless gas with a boiling point of –79.2°F (–61.8°C). Its density is 9.72 grams per liter, making it about seven times as dense as air. It is the densest gas known. Radon dissolves in water and becomes a clear, colorless liquid below its boiling point. At even lower temperatures, liquid radon freezes. As a solid, its color changes from yellow to orangish-red as the temperature is lowered even more. It is a dramatic sight since it also glows because of the intense radiation being produced.

Chemical Properties

Radon was long thought to be chemically inert. The term inert means incapable of reacting with other substances. In the early 1960s, however, a number of chemists found ways of making compounds of the noble gases. They did so by combining a noble gas with a very active element. The element generally used was **fluorine**, the most active chemical element. The result was the formation of noble gas compounds. The first radon compound to be produced was radon fluoride (RnF).

Occurrence in Nature

The abundance of radon in air is too small to be estimated. Some radon is always present because it is formed during the breakdown of uranium and radium. The abundance of radon in Earth's crust is estimated to be the lowest of any chemical element.

Isotopes

Thirty-nine isotopes of radon with measured half lives are known. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope. At least 30 other radioactive isotopes of radon have been produced artificially.

All isotopes of radon have short half-lives and do not remain in the atmosphere very long. The half life of a radioactive element or isotope is the time it takes for half of a sample of the element or isotope to break down. The radon isotope with the longest half life is radon-222 at only 3.8235 days. If 10 grams of radon-222 were prepared today, only 5 grams would remain 3.8235 days from now. After another 3.8235 days, only 2.5 grams would be left. Within a month, it would be difficult to detect any of the isotope.

A handheld Geiger counter, used to detect radiation, is shown. Together with an isotope of radon, leaks can be located. IMAGE COPYRIGHT 2009, JOE WHITE. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Extraction

Radon is produced during the breakdown of radium. It is obtained commercially by the following method. A compound of radium is placed under water. Gases given off by the radium compound are collected in a glass tube. **Oxygen**, **nitrogen**, water vapor, carbon dioxide, and other gases are removed from the gas in the tube. The gas that remains is pure radon.

The Dangers of Radon Gas

Radon gas is in many people's homes and they don't even know it. People can't see or smell it, but it is dangerous nonetheless. It can cause cancer among those exposed to it.

Radon is produced naturally when uranium breaks down. Uranium is a radioactive element that occurs naturally in Earth's crust. It is a fairly common element and could be in the ground below some people's homes.

When uranium breaks down, it produces many different elements, including radium, thorium, bismuth, and lead. None of these elements is a threat since they all remain in the ground. But uranium also forms radon when it breaks down. And radon is a gas. It can float upward, out of the earth, and into the basement of your home.

In some respects, radon is a serious health hazard. It gives off radiation that can kill cells. But radon does not have a very long half life. It breaks down and disappears fairly quickly.

The problem is that it breaks down into elements that are solid. These solids include polonium-214, polonium-218, and lead-214. These elements are more of a threat to your health. If you inhale them, they may stick to the lining of your lungs. While there, they give off radiation. The radiation can kill or damage cells. The final result of radon escaping into a building can be a variety of respiratory problems. Respiratory problems are those affecting the lungs and other parts of the system used for breathing. The most serious of these respiratory problems is lung cancer.

According to the U.S. Environmental Protection Agency (EPA) in 2010, radon gas in people's homes may cause as many as 20,000 deaths due to lung cancer annually. This makes radon the second-leading cause of this disease in the United States, after smoking. The people most in danger from radon are those who also smoke. Smokers are threatened both by radon and by cigarette smoke.

The EPA has studied the problem of radon in homes and offices. The agency estimates that 1 in 15 U.S. homes has radon levels that are too high. Radon can enter homes in a variety of ways, including through cracks in walls and floors as well as via the water supply.

Fortunately, it's easy to find out if radon is lurking in your home. Radon test kits can be purchased at little cost and are easy to use. If radon is present, some simple steps can be taken to reduce the danger. For example, any cracks in the foundation of a house can be sealed. By doing so, radon gas will be prevented from seeping into the house. Also, some method for circulating air should always be available. This includes a fan or an air conditioner. In an effort to increase awareness, the EPA observes National Radon Action Month (NRAM) in January.

Uses

The uses for radon all depend on the radiation it gives off. That radiation cannot be seen, smelled, tasted, or detected by any other human sense. However, a number of instruments, including the Geiger counter, have been invented for detecting this radiation. A Geiger counter is a device that makes a clicking sound or flashes a light when radiation passes through it.

One use of radon based on this principle is in leak detection. An isotope of radon is added to a flow of gas or liquid through a tube. A Geiger counter can be passed along the outside of the tube. If radiation is present, the Geiger counter makes a sound or flashes a light. The presence of radiation indicates a leak in the tube. This principle is applied in many other systems to study materials that cannot actually be seen.

Radon was once commonly used to treat cancer too. The radiation it gives off kills cancer cells. However, the element must be used with great care because radiation can kill healthy cells as well. In fact, the bad side-effects of radiation therapy are caused by the killing of healthy cells by radiation. Today, radon is not as widely used for the treatment of cancer. More efficient isotopes have been found that are easier and safer to use.

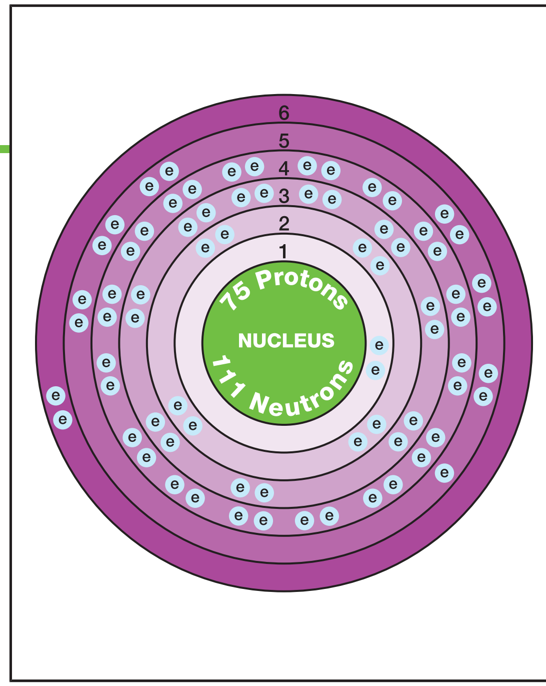
Compounds

Chemists are trying to make compounds of radon, but the task is difficult. One compound that *has* been made is radon fluoride. In any event, such compounds are laboratory curiosities and have no commercial uses.

Health Effects

Because of the radiation it produces, radon is a highly dangerous material. It is used only with great caution. Radon is especially dangerous because it is inhaled, exposing fragile tissues to penetrating radiation.

Rhenium



Key Facts

Symbol: Re

Atomic Number: 75

Atomic Mass: 186.207

Family: Group 7 (VIIB); transition metal

Pronunciation: REE-nee-um

Overview

Rhenium was discovered by a German research team that included Walter Noddack (1893–1960), Ida Tacke (1896–1979), and Otto Berg. These scientists knew that there were several empty boxes in the periodic table that represented elements that had not yet been discovered. The periodic table is a chart that shows how chemical elements are related to one another. In 1925, the German team announced that they had found two elements. They were correct about one (element number 75) but wrong about the other (element number 43).

Rhenium is one of the rarest elements in the world. At one time it sold for about $5,000,000 a pound ($10,000,000 a kilogram). It is no longer that expensive, although it is still very costly.

Rhenium has some unusual properties. For example, it is one of the most dense elements known. It also has one of the highest boiling points of all elements.

The primary uses of rhenium are in alloys that are used at very high temperatures or exposed to a great deal of wear.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into thin wires.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive: Having a tendency to break apart and give off some form of radiation.

Superalloy: An alloy made of iron, cobalt, or nickel that has special properties, such as the ability to withstand high temperatures and attack by oxygen.

Toxic: Poisonous.

Discovery and Naming

At the beginning of the 1920s, chemists knew they were approaching a milestone. They had already isolated 87 chemical elements. But they knew that five more were waiting to be discovered. How did they know? Every element has a space in the periodic table. An empty space meant that an element was missing. In 1920, five empty spaces were still left in the periodic table.

Chemists worldwide were searching for these five elements. In 1925, Noddack, Tacke, and Berg reported that they had found two of those elements: numbers 43 and 75. They called the first element masurium, after the region called Masurenland in eastern Germany. They named element number 75 rhenium, after the Rhineland, in western Germany. Rhenium was the last naturally occurring element to be discovered.

When a discovery like this is announced, other chemists try to repeat the experiments. They see if they get the same results as those reported. In this case, the German team turned out to be half right. Scientists were able to confirm the existence of element 75. They were not able to confirm the Germans' discovery of element 43. In fact, it was another decade before element 43 (**technetium**) was actually discovered.

Physical Properties

Rhenium is a ductile, malleable, silvery metal. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. It has a density of 21.02 grams per cubic centimeter, a melting point of 5,760°F (3,180°C), and a boiling point of 10,170°F (5,630°C). These numbers are among the highest to be found for any of the chemical elements.

Chemical Properties

Rhenium is a moderately stable metal. It does not react with **oxygen** and some acids very readily. But it does react with strong acids such as nitric acid (HNO_3) and sulfuric acid (H_2SO_4).

Occurrence in Nature

The U.S. Geological Survey (USGS) estimates that about 17,000 pounds (7,700 kilograms) of rhenium were produced in the United States in 2008. The metal was obtained from mines in Arizona, Montana, Nevada, New Mexico, and Utah as the by-product of **copper** mining. Another 110,670 pounds (50,200 kilograms) were imported from other countries. Approximately $91 million of rhenium was consumed in 2008. The largest rhenium producers in the world that year were Chile, Kazakhstan, the United States, and Peru. The principal ores of rhenium are molybdenite, gadolinite, and columbite.

Rhenium is one of the rarest elements in the world. Its abundance is thought to be about one part per billion.

Isotopes

Two isotopes of rhenium occur in nature: rhenium-185 and rhenium-187. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The more abundant of the two isotopes, rhenium-187, is radioactive. A radioactive isotope is one that breaks apart and gives off some form of radiation. The half life of rhenium-187 is about 43.5 billion years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. For example, of a 100-gram sample of rhenium-187, only half that amount, or 50 grams, would be left after 43.5 billion years. The other 50 grams would have broken down and changed into another isotope. In addition to rhenium-187, 41 other radioactive isotopes are known to scientists.

Extraction

Ores containing rhenium are first roasted, or heated in air, to convert them to rhenium oxide (ReO_3 or Re_2O_7). **Hydrogen** gas is then passed over the rhenium oxide. The hydrogen converts the rhenium oxide to the pure metal:

$$ReO_3 + 3H_2 \rightarrow 3H_2O + Re$$

Uses

About 70 percent of all rhenium consumed in the United States is used in the manufacture of superalloys and other metallurgical processes. Metallurgy is the art and science of working with metals. A superalloy is an alloy made of **iron**, **cobalt**, or **nickel**. It has special properties, such as the ability to withstand high temperatures and attack by oxygen. Superalloys are widely used in making jet engine parts and gas turbine engines.

The heating element found in some household electric stoves is made from rhenium alloys.

Alloys containing rhenium also have many other applications. They are used in making devices that control temperatures (like the thermostat in your home), heating elements (like those on an electric stove), vacuum tubes (like those in a television set), electromagnets, electrical contacts, metallic coatings, and thermocouples. A thermocouple is used like a thermometer for measuring very high temperatures.

About 20 percent of the rhenium consumed in the United States is used as a catalyst in the petroleum industry. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself. Rhenium catalysts are used in the reactions by which natural petroleum is broken down into more useful fragments, such as gasoline, heating oil, and diesel oil.

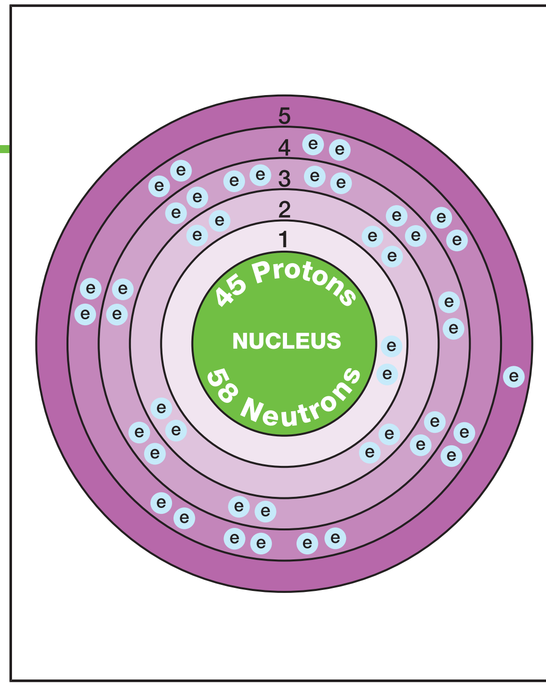
Compounds

Very few compounds of rhenium have any commercial applications.

Health Effects

Complete studies on the health effects of rhenium are not available. For that reason, it should be assumed to be toxic and be handled with caution.

Rhodium



Key Facts

Symbol: Rh

Atomic Number: 45

Atomic Mass: 102.90550

Family: Group 9 (VIIIB); transition metal; platinum group

Pronunciation: RO-dee-um

Overview

Rhodium is considered to be a precious metal. A precious metal is one that is rare and valued. Other precious metals are **gold**, **silver**, and **platinum**. Rhodium is also classified as a member of the platinum group of metals. The platinum group includes five other metals that often occur together in nature: **ruthenium**, **palladium**, **osmium**, **iridium**, and platinum.

Rhodium falls in the center of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Elements in groups 3 through 12 are called the transition metals.

Rhodium was discovered by English chemist and physicist William Hyde Wollaston (1766–1828) in about 1804. He discovered the metal in an ore that apparently came from South America. The rhodium compound he first discovered was a beautiful rose color.

Rhodium is used primarily to make alloys with other metals. These alloys are used for specialized industrial purposes and in jewelry.

Discovery and Naming

In the early 1800s, Wollaston was studying an ore of platinum. Although scientists don't know for sure, they believe the platinum ore came from South

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

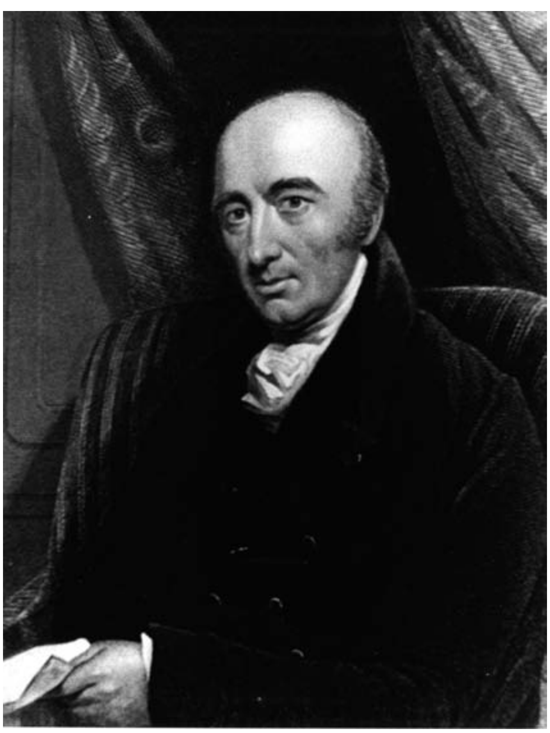
Precious metal: A metal that is rare, desirable, and, therefore, expensive.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Thermocouple: A device for measuring very high temperatures.

America. Wollaston analyzed the ore and found that he could produce a beautiful rose-colored compound from it. He showed that the pink compound contained a new element. Wollaston suggested the name "rhodium" for the new element because of this rose color. The Greek word for rose is *rhodon.*

English chemist and physicist William Hyde Wollaston discovered rhodium. LIBRARY OF CONGRESS.



Physical Properties

Rhodium is a silver-white metal. It has a melting point of 3,571°F (1,966°C) and a boiling point of about 8,100°F (4,500°C). Its density is 12.41 grams per cubic centimeter. Two of the metal's special properties are its high electrical and heat conductivity. That means that heat and electricity pass through rhodium very easily.

Chemical Properties

Rhodium is a relatively inactive metal. It is not attacked by strong acids. When heated in air, it combines slowly with **oxygen**. It also reacts with **fluorine**, **chlorine** and **bromine** when very hot. It forms compounds such as rhodium fluoride (RhF_3) and rhodium chloride ($RhCl_3$)

Occurrence in Nature

Rhodium is one of the rarest elements on Earth. Its abundance is estimated to be 0.0001 parts per million. That would place it close to the bottom of the list of elements in terms of abundance. Compounds of rhodium are usually found in combination with platinum and other members of the platinum group. Its most common ores are rhodite, sperrylite, and iridosmine.

Isotopes

Only one naturally occurring isotope of rhodium is known: rhodium-103. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty-one radioactive isotopes of rhodium are also known to scientists. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the isotopes of rhodium have any commercial or other use.

Extraction

Rhodium is usually obtained as a by-product in the recovery of platinum from its ores. Rhodium is separated by a series of chemical and physical reactions from other platinum metals with which it occurs. The mixture of metals is treated with various acids and other chemicals that dissolve some metals, but not others. Rhodium is one of the first metals to be removed from such a mixture.

The cost of pure rhodium metal has fluctuated dramatically in recent years. According to the U.S. Geological Survey (USGS), the price of rhodium reached a record high price in early 2008 of $10,100 per troy ounce before leveling off.

Uses

Most of the rhodium metal sold in the United States is used to make alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals.

Rhodium is often added to platinum to make an alloy. Rhodium is harder than platinum and has a higher melting point. So the alloy is a better material than pure platinum.

Most rhodium alloys are used for industrial or research purposes, such as laboratory equipment and thermocouples. A thermocouple is a device for measuring very high temperatures. Rhodium alloys are also used to coat mirrors and in searchlights because they reflect light very well. Rhodium is sometimes alloyed with other precious metals in the manufacture of jewelry and art objects.

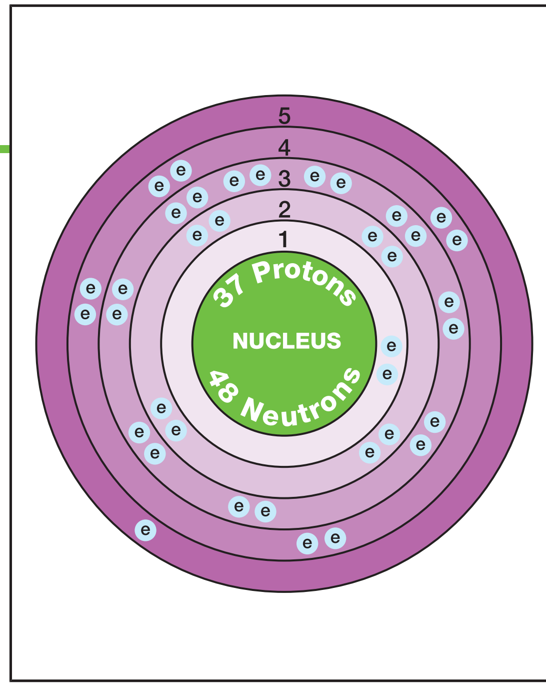
Compounds

Compounds of rhodium are used as catalysts. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself. As an example, rhodium sesquioxide (Rh_2O_3) is sometimes used as a catalyst for the hydrogenation of oils. Hydrogenation is the process by which liquid oils are converted to semi-solids.

Health Effects

There are few studies of the health effects from rhodium or its common compounds. Powdered rhodium metal is considered to be an irritant to the skin, eyes, and respiratory system. There has been no research on the long-term effects of exposure to rhodium or its compounds. Elements without information about toxicity are usually treated as if they are poisonous.

Rubidium



Key Facts

Symbol: Rb

Atomic Number: 37

Atomic Mass: 85.4678

Family: Group 1 (IA); alkali metal

Pronunciation: roo-BID-ee-um

Overview

Rubidium is a soft, silvery metal. It is one of the most active chemical elements. Rubidium is a member of the alkali family. The alkali family consists of elements in Group 1 (IA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Other Group 1 (IA) elements include **lithium**, **sodium**, **potassium**, **cesium**, and **francium**. Rubidium was discovered in 1861 by German chemists Robert Bunsen (1811–1899) and Gustav Kirchhoff (1824–1887).

Rubidium is used to make atomic clocks. An atomic clock is a device for keeping very exact time. A radioactive isotope of rubidium is also used to measure the age of very old objects. In general, however, rubidium and its compounds have few practical uses.

Discovery and Naming

Rubidium is one of four elements discovered by spectroscopy. Spectroscopy is the process of analyzing the light produced when an element is heated. Every element produces a very specific series of colored lines called a spectrum (plural: *spectra*).

WORDS TO KNOW

Alkali metal: An element in Group 1 (IA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Spectroscope: A device for analyzing light produced when an element is heated.

Spectroscopy: The process of analyzing light produced when an element is heated.

Spectroscopy is a very useful technique for chemists. Sometimes only a very small amount of an element in a sample can be tested. And that amount may be too small to see or weigh easily. But the element can still be detected by heating the sample. The element will give off its characteristic line spectrum. The line spectrum shows that the element is present.

Bunsen and Kirchhoff used a spectroscope to find rubidium in a mineral called lepidolite. The mineral had been discovered in the 1790s by a Jesuit priest, Abbé Nicolaus Poda (1723?–1798) of Neuhaus, Germany. When Bunsen and Kirchhoff heated a sample of lepidolite, they found two new lines in the spectrum. They reported that:

> The magnificent dark red color of these new rays of the new alkali metal led us to give this element the name rubidium and the symbol Rb from *rubidus,* which, with the ancients, served to designate the deepest red.

Physical Properties

Rubidium is a soft, silvery metal. It has a melting point of 102°F (39°C) and a boiling point of 1,270°F (688°C). Its density is 1.532 grams per cubic centimeter, about one and a half times that of water.

Chemical Properties

Rubidium is one of the most active elements. It catches fire when exposed to **oxygen** in the air. For that reason, it must be stored completely submerged in kerosene. Rubidium also reacts vigorously with water. It produces **hydrogen** gas that catches fire and burns. Rubidium combines violently with the halogens (**fluorine**, **chlorine**, **bromine**, and **iodine**).

Occurrence in Nature

Rubidium is a relatively abundant element at about 35 to 75 parts per million. This makes it about as abundant as **nickel**, **chromium**, **zinc**, and **copper**.

The most common ores of rubidium are lepidolite, carnallite, and pollucite. Rubidium is also found in seawater and in mineral springs.

According to the U.S. Geological Survey (USGS), the United States does not mine rubidium. Instead, it is imported from Canada. Other countries with limited rubidium resources include Afghanistan, Chile, China, France, Germany, Namibia, Peru, the United States, and Zambia.

Sample of rubidium stored in hydrogen. © RUSS LAPPA/ SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Isotopes

Two naturally occurring isotopes of rubidium exist: rubidium-85 and rubidium-87. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Rubidium-87 is a radioactive isotope. A radioactive isotope is one that breaks apart and gives off some form of radiation. Some radioactive isotopes occur naturally. Others can be produced artificially by firing very small particles at atoms. These particles stick in the atoms and make them radioactive. In addition to rubidium-87, 35 artificial radioactive isotopes of rubidium are also known.

Rubidium-87 is used to estimate the age of very old rocks. Many kinds of rocks contain two rubidium isotopes, rubidium-85 and rubidium-87. When rubidium-87 breaks down in the rock, it changes into a new isotope, **strontium**-87. Any rock that contains rubidium-87 also contains some strontium-87.

Rocks that contain rubidium usually contain strontium as well. One of the isotopes of strontium found in these rocks is strontium-86. It is not radioactive.

Consider a rock that contains both rubidium and strontium. It will contain two isotopes of strontium. One is naturally occurring strontium-86, and the other is radioactive strontium-87, which is produced when the rock's rubidium-87 breaks down.

The amount of strontium-87 in the rock depends on how long it has been there. The longer the rock has been in place, the longer rubidium-87 has had to break down and the longer strontium-87 has had to form. But the amount of strontium-86 does not change. It is not produced by rubidium-87.

To determine the age of a rock, then, scientists measure the amount of strontium-87 compared to the amount of strontium-86. The higher the ratio of strontium-87 to strontium-86, the longer the rock has been in existence. This method for measuring the age of rocks has been used to measure the age of Earth and the age of meteorites.

Extraction

A common method for producing rubidium is to pass an electrical current through molten (melted) rubidium chloride:

$$2RbCl \xrightarrow{\text{electric current}} 2Rb + Cl_2$$

Uses and Compounds

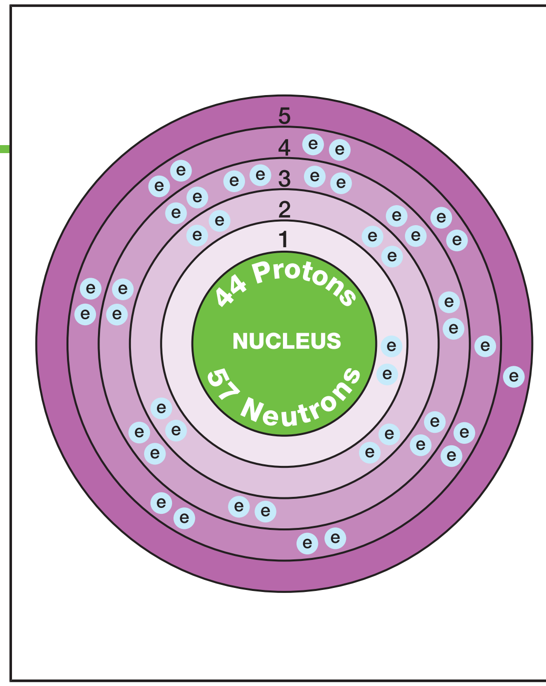
There are relatively few commercial uses for rubidium or its compounds. Rubidium is used to make atomic clocks. But these clocks are used only for very specialized purposes where very precise timekeeping is important. Rubidium is also used to make photocells. A photocell is a device for converting light energy into electrical energy. But other members of the alkali family are still preferred for this application.

One application of photocells is in motion detectors for security alarm systems. A beam of light is emitted by a special device so that it strikes the photocell precisely, producing a tiny electric current. If something or someone "breaks" (interrupts) the beam, the current stops flowing and an alarm sounds.

Health Effects

Rubidium metal is a dangerous element to work with because it is so active chemically. However, no health hazards have been associated with any rubidium compounds.

Ruthenium



Overview

Ruthenium is a member of the platinum group of metals. The elements in this group are named after the best known member of the group, **platinum**. The group is found in the middle of the periodic table, in Groups 8, 9, and 10, and Rows 5 and 6. The periodic table is a chart that shows how chemical elements are related to one another. The platinum metals tend to be somewhat rare and valuable. They are also called precious metals. The platinum metals also tend to have bright, shiny surfaces and high melting points, boiling points, and densities.

Credit for the discovery of ruthenium is often given to Polish chemist Jedrzej Sniadecki (1768–1838). Sniadecki announced the discovery of the element in 1808. He suggested the name vestium for the element, after the asteroid Vesta. Other chemists were not able to confirm Sniadecki's work, however. As a result, the element was rediscovered twice more in later years.

The primary uses of ruthenium are in alloys and as catalysts for industrial processes.

Key Facts

Symbol: Ru

Atomic Number: 44

Atomic Mass: 101.07

Family: Group 8 (VIIIB); transition metal; platinum group

Pronunciation: roo-THEE-nee-um

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Aqua regia: A mixture of hydrochloric and nitric acids.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactivity: Having a tendency to break apart and give off some form of radiation.

Discovery and Naming

Sniadecki discovered element 44 in 1808 while working with platinum ores from South America. After he published his results, other chemists tried to find the element as well. They were unsuccessful. Sniadecki became discouraged, dropped his claims of discovery, and did no further research on the element.

About 20 years later, the discovery of element 44 was announced again. This time, the discoverer was Russian chemist Gottfried W. Osann. Once more, other chemists could not repeat Osann's results. There was disagreement as to whether the element had been found.

Finally, in 1844, Russian chemist Carl Ernst Claus (also known as Karl Karlovich Klaus; 1796–1864) gave positive proof of a new element in platinum ores. Many authorities now call Claus the discoverer of the element. Claus suggested calling the element ruthenium, after the ancient name of Russia, *Ruthenia.* Osann had suggested that name as well.

Physical Properties

Ruthenium is a hard, silvery-white metal with a shiny surface. Its melting point is about 4,200 to 4,400°F (2,300 to 2,450°C) and its boiling point is about 7,100 to 7,500°F (3,900 to 4,150°C). Its density is 12.41 grams per cubic centimeter, more than 12 times the density of water.

Chemical Properties

Ruthenium metal is relatively unreactive. It does not dissolve in most acids or in aqua regia. Aqua regia is a mixture of hydrochloric and nitric acids. It often reacts with materials that do not react with either acid separately. Ruthenium does not react with **oxygen** at room temperatures either. At higher temperatures, however, it does combine with oxygen.

Occurrence in Nature

Ruthenium is one of the rarest elements in Earth's crust. Its abundance is estimated at about 0.0004 parts per million. This makes it one of the six least abundant elements on Earth.

Like other members of the platinum family, ruthenium occurs in platinum ores. It is obtained from those ores and from the mineral osmiridium by purification of the natural material.

Isotopes

Seven stable isotopes of ruthenium are known. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-two radioactive isotopes of ruthenium are also known. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Ruthenium-106 is used for medical purposes. When ruthenium-106 breaks down, it gives off a form of radiation called beta rays. These beta rays act somewhat like X rays. They attack and kill cancer cells. As an example, ruthenium-106 has been used to treat certain forms of eye cancer.

Extraction

Ruthenium is obtained by separating it from other platinum metals, such as platinum, **palladium**, and **osmium**, with which it occurs. These metals are usually obtained as by-products during the refining of **nickel** metal. They are then separated from each other by a series of chemical reactions.

According to the U.S. Geological Survey (USGS), the cost of ruthenium was estimated to be approximately $340 per troy ounce in 2008, up considerably from $64 in 2004.

Uses

One important use of ruthenium is in the manufacture of alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Ruthenium adds two properties to an alloy. First, it makes the alloy hard. Second, it makes the alloy resistant to attack by oxygen and other materials.

Ruthenium is most often combined with platinum or palladium in alloys. Electrical contacts, devices for measuring very high and very low temperatures, and medical instruments are often made from ruthenium alloys. Ruthenium is also used in alloys with other platinum family metals to make jewelry and art objects. This use is limited, however, because of the high cost of ruthenium metal.

Ruthenium can also be alloyed with other metals. It is sometimes added to **titanium** to make that metal more resistant to corrosion (rusting). Only 0.1 percent of ruthenium in titanium makes titanium 100 times more corrosion resistant.

A second important use of ruthenium is in catalysts. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself. Ruthenium catalysts may provide a way of changing light energy into electrical energy. The process is similar to photosynthesis, in which green plants change sunlight into stored chemical energy.

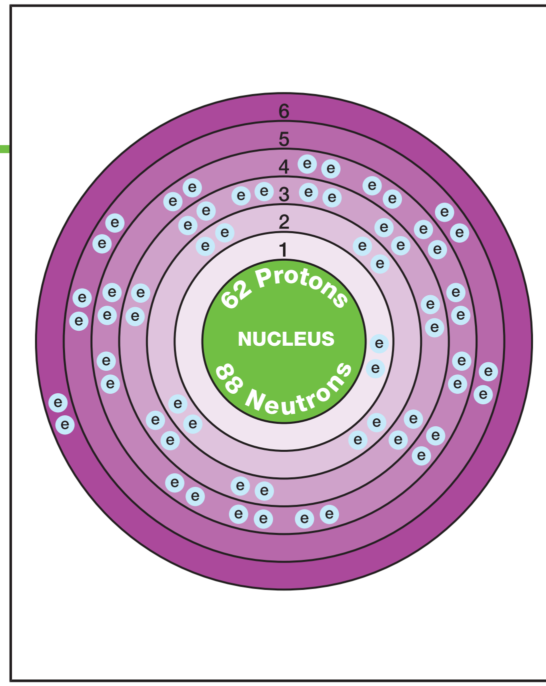
Ruthenium is often combined with platinum or palladium in alloys to make medical instruments. IMAGE COPYRIGHT 2009, JOSEPH. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Compounds

No compounds of ruthenium have any important commercial application.

Health Effects

Ruthenium metal appears to have only mild effects, such as irritation of the skin, on the human body. Most compounds of ruthenium that have been studied, however, appear to be far more dangerous to human health. For example, ruthenium tetroxide (RuO_4) is not only highly explosive, but also very irritating to the skin, eyes, and respiratory tract (mouth, throat, and lungs).



Samarium

Overview

Samarium is one of the rare earth elements found in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The rare earth metals are not really very rare in Earth's surface. The name comes from the fact that these elements were once very difficult to separate from each other. For a long time, chemists knew very little about the individual elements. A more correct name for these rare earth elements is the lanthanoid series. It is named after the element **lanthanum**, the first element in the series.

Samarium looks and behaves like most other metals, but it has relatively few uses. One of the most important is in the manufacture of very powerful magnets. Compounds of samarium are also used to color glass and in television tubes.

Key Facts

Symbol: Sm

Atomic Number: 62

Atomic Mass: 150.36

Family: Lanthanoid (rare earth metal)

Pronunciation: suh-MARE-ee-um

Discovery and Naming

The study of chemical elements during the 19th century was frustrating. Each time a new element was announced, questions were immediately raised. Was the element really a new element? Or was it a mixture of two or more new elements?

WORDS TO KNOW

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

The discovery of samarium grew out of this kind of frustration. In 1880, French chemist Paul-émile Lecoq de Boisbaudran (1838–1912) was studying a substance known as didymium. Earlier chemists believed didymium might be a new element. Boisbaudran said that at least two new elements were present in didymium.

At nearly the same time, French chemist Jean-Charles-Galissard de Marignac (1817–1894) was also studying didymium. He was able to separate didymium into two parts, which he called didymium and samarium. He announced that samarium was a new element.

Marignac's research appeared to be satisfactory for nearly 20 years. Then, another French chemist, Eugène-Anatole Demarçay (1852–1904), found that samarium could itself be broken into two parts. He called the new elements samarium and **europium**. Because of this long history, credit for the discovery of samarium is usually given to Boisbaudran, Marignac, Demarçay, or to all three chemists.

The name samarium was taken from a mineral in which it occurs, samarskite. The name of the mineral, in turn, comes from the last name of a Russian mine official, Colonel Samarski.

Physical Properties

Samarium is a yellowish metal with a melting point of 1,962°F (1,072°C) and a boiling point of about 3,450°F (1,900°C). Its density is 7.53 grams per cubic centimeter. Samarium is the hardest and most brittle of the rare earth elements.

Chemical Properties

Samarium is a fairly reactive metal. It tends to combine with many other substances under relatively mild conditions. For example, it reacts with water to release **hydrogen** gas. It also combines easily with **oxygen** and will ignite (catch fire) at about 300°F (150°C).

Occurrence in Nature

As with other rare earth elements, the primary sources of samarium are the mineral monazite and bastnasite. It is also found in samarskite, cerite, orthite, ytterbite, and fluorspar.

Samarium is regarded as a relatively abundant lanthanoid. It occurs to the extent of about 4.5 to 7 parts per million in Earth's crust. That makes it about as common as **boron** and two other lanthanoids, **thulium** and **gadolinium**.

Isotopes

There are seven naturally occurring isotopes of samarium: samarium-144, samarium-147, samarium-148, samarium-149, samarium-150, samarium-152, and samarium-154. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Three of samarium's naturally occurring isotopes are radioactive—samarium-147, samarium-148, and samarium-149. A radioactive isotope is one that breaks apart and gives off some form of radiation. Twenty-eight additional radioactive isotopes of samarium have been made in the laboratory.

One radioactive isotope of samarium, samarium-153, is used in medicine. Patients with bone cancer often have very severe pain. The isotope samarium-153 can help relieve that pain. It in injected in the form of a drug known as Quadramet. Quadramet was approved by the U.S. Food and Drug Administration (FDA) for this purpose in March 1997.

Extraction

Samarium can be obtained by heating samarium oxide (Sm_2O_3) with barium or lanthanum metal:

$$2Ba + Sm_2O_3 \rightarrow Ba_2O_3 + 2Sm$$

A compound of samarium is used as a catalyst in the manufacture of ethanol, which is produced at plants such as the one pictured here. IMAGE COPYRIGHT JIM PARKIN, 2007. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Uses

Samarium has some uses similar to those of other rare earth elements. For example, it can be added to glass for color or special optical (light) properties. It is also used to make lasers for special applications. A laser is a device for producing very bright light of a single color. The color produced by the laser depends on the elements it contains.

One of the most important uses of samarium is in the manufacture of very powerful magnets. Samarium is combined with the metal **cobalt** to make samarium-cobalt, or SmCo, magnets. They are among the strongest magnets known. They also have other desirable properties. For example, they can be used at high temperatures and do not react easily with substances around them. SmCo magnets are widely used in motors, such as those used to power specialized kinds of airplanes.

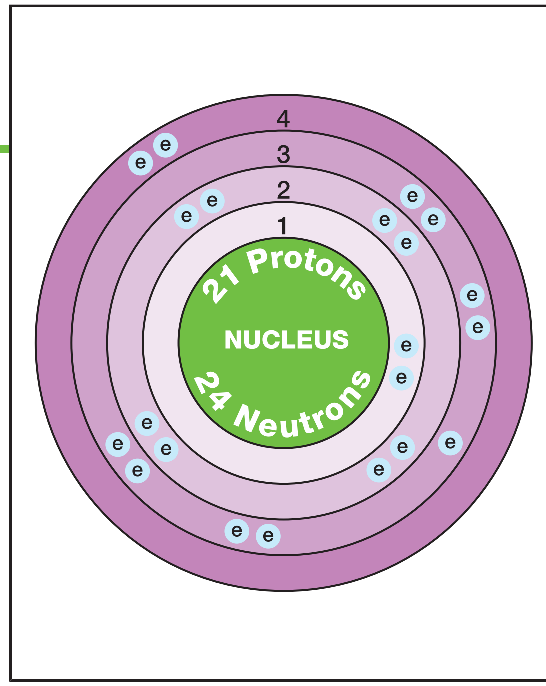
Compounds

The only compound of samarium with any commercial applications is samarium oxide (Sm_2O_3). This compound is used in the manufacture of special kinds of glass, as a catalyst in the manufacture of ethanol (ethyl alcohol), and in nuclear power plants as a neutron absorber.

Health Effects

Samarium metal poses a threat to workers who may come into contact with it and its fumes. When inhaled, those fumes may damage the lungs and, over long periods of time, affect the liver. Very little information is available on the health hazards of samarium compounds, although they are suspected of being irritants to the skin, eyes, and respiratory system.

Scandium



Key Facts

Symbol: Sc

Atomic Number: 21

Atomic Mass: 44.955912

Family: Group 3 (IIIB); transition metal

Pronunciation: SCAN-dee-um

Overview

The existence of scandium was predicted nearly 10 years before it was actually discovered. The prediction was made by Russian chemist Dmitri Mendeleev (1834–1907). Mendeleev developed the periodic table based on his periodic law. The periodic table is a chart that shows how chemical elements are related to one another. The table originally had a number of empty boxes for elements that had not been discovered but were believed to exist. Chemists were able to search for these elements based on the properties of the elements around the empty boxes. Scandium was found in 1879 by Swedish chemist Lars Nilson (1840–1899). It is a transition metal, appearing in Group 3 (IIIB).

Scandium is a moderately abundant element. However, it tends to be spread out throughout the earth rather than concentrated in a few places. This makes it difficult to isolate. In fact, scandium is classified as a rare earth element. Rare earth elements are not really "rare." However, they are difficult to extract from the earth. They were also difficult to separate from each other.

Scandium has few commercial uses. It is sometimes combined with other metals to make alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Periodic table: A chart that shows how the chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Rusting: A process by which a metal combines with oxygen.

individual metals. Scandium alloys are now being used in various kinds of sporting equipment and in other applications.

Discovery and Naming

In 1869, Mendeleev made one of the great discoveries in the history of chemistry, the periodic law. The periodic law shows how the chemical elements are related to each other. The most common way of representing the periodic law is in a chart called the periodic table.

Mendeleev's original periodic table contained only about 60 elements. That was the total number of elements known in 1869. When he drew his first periodic table, Mendeleev found some empty places. What did those empty places mean?

Mendeleev made a prediction that the empty places in the periodic table stood for elements that had not yet been discovered. He said one could tell what those elements were going to be like by examining their position in the periodic table. For example, element number 21 would be like **boron**, Mendeleev predicted. Boron was the element above number 21 in Mendeleev's chart. He called the missing element (number 21) ekaboron, or "similar to boron."

Chemists were fascinated by Mendeleev's prediction. Could he really tell them how to look for a new element? And could he tell them what that element would be like?

One of the chemists who took up the challenge was Lars Nilson. He analyzed two minerals known as gadolinite and euxenite, in search of the missing element. By 1879, he announced the discovery of "ekaboron."

The Scientist Who Discovered Scandium

Lars Nilson was born in the Swedish town of Östergötland on May 27, 1840. He entered the University of Upsala at the age of 19, intending to study biology, chemistry, and geology. He found university work difficult because he was in very poor health. He often suffered from bleeding in the lungs.

Yet, he persevered and was ready to receive his doctoral degree in 1865. Then he received word that his father was seriously ill. Instead of finishing his university work, he returned home. He took charge of the farm and helped his sick father for many months. At the end of that time, he made a surprising discovery. His illness had disappeared. He was healthy enough to return to Upsala and earn his degree.

In 1879, Nilson made the discovery for which he is most famous. He was studying a mineral known as erbia. The mineral was a complex mixture of many elements. Many chemists throughout Europe were trying to find out exactly what elements were present in erbia.

Nilson found a new element in erbia that no one had yet seen. He found that the element had properties very similar to those predicted by the Russian chemist Dmitri Mendeleev. Only 10 years earlier, Mendeleev had discovered the periodic law and used that law to predict the existence of three elements that had not yet been discovered. One of these elements exactly matched the element found by Nilson.

He suggested the name scandium, in honor of Scandinavia, the region in which Nilson's homeland of Sweden is located.

Nilson's discovery was very important in chemistry. It showed that Mendeleev's periodic law was correct. The law *did* show how elements are related to each other. It *could* be used to describe elements that had not even been discovered!

The substance discovered by Nilson was not pure scandium metal, but a compound of scandium and **oxygen**—scandium oxide (Sc_2O_3). It is quite difficult to produce pure scandium metal from scandium oxide. In fact, it was not until 1937 that the metal was isolated. Then, it was another 20 years before a large sample (weighing one pound) was produced. Today, companies that use scandium often buy the oxide rather than the pure metal. In 2008, scandium oxide of 99.9995 percent purity cost about $3,260 per kilogram.

Physical Properties

Scandium metal is a silvery-white solid with a slight pink or yellow tint when exposed to air. It has a melting point of 2,800°F (1,538°C) and a boiling point of about 4,900°F (2,700°C). Its density is 2.99 grams per cubic centimeter.

Chemical Properties

Scandium is similar to other rare earth elements chemically. It reacts readily with acids, but does not react easily with oxygen in the air.

Occurrence in Nature

The abundance of scandium is thought to be about 5 to 6 parts per million in Earth's crust. Interestingly, the element seems to be much more abundant in the sun and some stars than it is on Earth.

Scandium is thought to occur in more than 800 different minerals. Its most important ores are the minerals thortveitite and wolframite. It is also found in minerals containing other rare earth elements, such as monazite, bastnasite, and gadolinite.

In the United States, scandium is obtained from the waste products of other mining operations. It is also imported from countries such as China, Russia, and Ukraine. According to the U.S. Geological Survey (USGS), scandium was not mined in the United States in 2008.

Isotopes

Only one naturally occurring isotope of scandium is known: scandium-45. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Seventeen radioactive isotopes of scandium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

There are no commercial uses for any radioactive isotope of scandium.

Extraction

Pure scandium metal can be made by reacting scandium fluoride (ScF_3) with another active metal, such as **calcium** or **zinc**:

$$3Ca + 2ScF_3 \rightarrow 3CaF_2 + 2Sc$$

Uses

There are relatively few commercial uses for scandium or its compounds. It is sometimes used to make alloys for special purposes. Scandium metal is lighter than most other metals. It is also resistant to corrosion (rusting) and has a high melting point. These properties make scandium alloys especially desirable for use in sporting equipment, such as baseball bats, lacrosse sticks, and bicycle frames.

These alloys may also have some applications in the aerospace industry. These applications are not yet well developed, however, because of the high cost of the metal.

Scandium alloys are also used in specialized lamps. The presence of scandium produces light that is very similar to that of natural sunlight.

Compounds

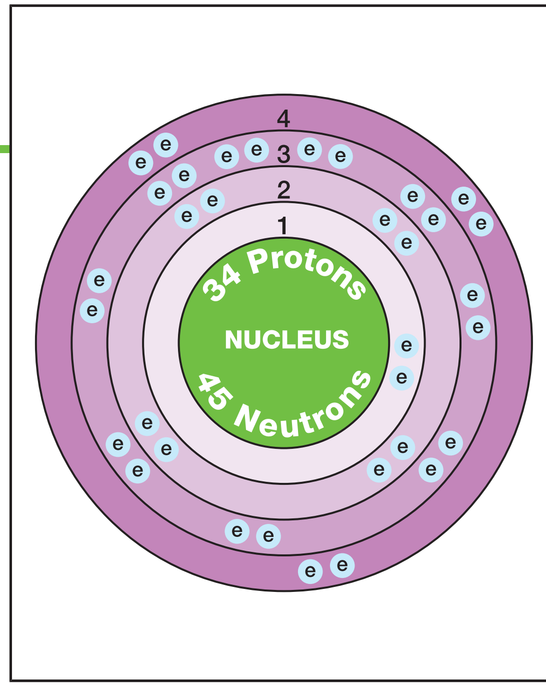
None of the compounds of scandium has any important commercial use.

Scandium alloys are used in bicycle frames. IMAGE COPYRIGHT 2009, SIRKO HARTMANN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Health Effects

Relatively little is known about the health effects of scandium metal and its compounds. Exposure to scandium dust or most of its compounds is thought to produce irritation of the skin, eyes, and respiratory system. No long-term serious effects of exposure to scandium or its compounds have as yet been found.

Selenium



Key Facts

Symbol: Se

Atomic Number: 34

Atomic Mass: 78.96

Family: Group 16 (VIA); chalcogen

Pronunciation: suh-LEE-nee-um

Overview

Selenium is a member of the chalcogen family. The chalcogens are elements in Group 16 (VIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Other chalcogens are **oxygen**, **sulfur**, **tellurium**, and **polonium**. The name chalcogen comes from the Greek word *chalkos,* meaning "ore." The first two members of the family, oxygen and sulfur, are found in most ores.

Selenium is a metalloid. A metalloid is an element that has some characteristics of a metal and some of a non-metal.

Selenium and tellurium are often associated with each other. They tend to occur together in Earth and have somewhat similar properties. They have many uses in common. In recent years, some important new uses have been found for selenium. It has been used in the manufacture of plain paper photocopiers and laser printers, in photovoltaic cells that convert sunlight into electricity, and in X-ray systems for medical applications.

Discovery and Naming

Selenium was discovered in 1818 by Swedish chemists Jöns Jakob Berzelius (1779–1848) and J. G. Gahn (1745–1818). The men were studying the

WORDS TO KNOW

Allotropes: Forms of an element with different physical and chemical properties.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Amorphous: Without crystalline shape.

Chalcogen: Elements in Group 16 (VIA) of the periodic table.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Metalloid: An element that acts like a metal sometimes and like a non-metal other times.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

chemicals used in making sulfuric acid at a plant where they had just become part-owners. Among these chemicals they found a material that they thought was the element tellurium. Tellurium had been discovered some 30 years earlier, mixed with some gold deposits in Hungary.

Tellurium is a rare element. Berzelius decided to study the sample more carefully. He took it back to his laboratory in Stockholm. There, he found that he and Gahn had been mistaken. The substance was similar to tellurium, but it also had different properties. They realized they had found a new element. Berzelius suggested naming the element selenium, from the Greek word *selene,* for "moon." The name seemed a good choice because the element tellurium is named after the Latin word *tellus* for "Earth." Just as Earth and the Moon go together, so do tellurium and selenium.

Physical Properties

Selenium exists in a number of allotropic forms. Allotropes are forms of an element with different physical and chemical properties. One allotrope of selenium is an amorphous red powder. Amorphous means "without crystalline shape." A lump of clay is an example of an amorphous material. A second allotrope of selenium has a bluish, metallic appearance. A number of other allotropes have properties somewhere between these two forms.

The amorphous forms of selenium do not have specific melting points. Instead, they gradually become softer as they are heated. They may also change from one color and texture to another.

Selenium pellets. © RICH TREPTOW, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

The crystalline (metallic) form of selenium has a melting point of 423°F (217°C) and a boiling point of 1,260°F (685°C). Its density is 4.5 grams per cubic centimeter.

Some of the most important physical characteristics of selenium are its electrical properties. For example, selenium is a semiconductor. A semiconductor is a substance that conducts an electric current better than non-conductors, but not as well as conductors. Semiconductors have many very important applications today in the electronics industry. Selenium is often used in the manufacture of transistors for computers, cellular phones, and hand-held electronic games.

Selenium is also a photoconductor, a material that changes light energy into electrical energy. Furthermore, it becomes better at making this conversion as the light intensity or brightness increases.

Chemical Properties

Selenium is a fairly reactive element. It combines easily with **hydrogen**, **fluorine**, **chlorine**, and **bromine**. It reacts with nitric and sulfuric acids.

It also combines with a number of metals to form compounds called selenides. An example is **magnesium** selenide (MgSe). One of selenium's interesting properties is its reaction with oxygen. It burns in oxygen with a bright blue flame to form selenium dioxide (SeO_2). Selenium dioxide has a characteristic odor of rotten horseradish.

Occurrence in Nature

Selenium is a very rare element. Scientists estimate its abundance at about 0.05 to 0.09 parts per million. It ranks among the 25 least common elements in Earth's crust. It is widely distributed throughout the crust. There is no ore from which it can be mined with profit. Instead, it is obtained as a by-product of mining other metals. It is now produced primarily from **copper**, **iron**, and **lead** ores. As of 2008, the major producers of selenium in the world were Japan, Belgium, and Canada. The actual amount of selenium produced in the United States was not reported as it is considered a trade secret.

Isotopes

There are six naturally occurring isotopes of selenium: selenium-74, selenium-76, selenium-77, selenium-78, selenium-80, and selenium-82. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

One naturally occurring isotope of selenium is radioactive: selenium-82. Its half life is very long, more than 100 quadrillion years. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. Twenty-two radioactive isotopes of selenium with known half lives have also been discovered.

Only one radioactive isotope of selenium is used commercially, selenium-75. This isotope is used to study the function of two organs in the body, the pancreas and the parathyroid gland. (The pancreas helps with digestion and the parathyroid gland releases hormones.) The radioactive selenium is injected into the bloodstream. It then goes primarily to one or both of these two organs. The isotope gives off radiation when it reaches these organs. A technician can tell whether the organs are functioning properly by the amount and location of radiation given off.

Extraction

Selenium is obtained as a by-product from other industrial processes. For example, when copper is refined, small amounts of selenium are produced as by-products. This selenium can be removed from the copper-refining process and purified. Selenium is also obtained as a secondary product during the manufacture of sulfuric acid.

Uses

One of the most important uses of selenium is in glass-making. The addition of selenium to glass can have one of two opposite effects. First, it will cancel out the green color that iron compounds usually add to glass. If a colorless glass is desired, a little selenium is added to neutralize the effects of iron. Second, selenium will add its own color—a beautiful ruby red—if that is wanted in a glass product. Selenium is also added to glass used in architecture. The selenium reduces the amount of sunlight that gets through the glass.

The production of chemicals and pigments (coloring agents) is another major use of the selenium produced. The addition of selenium to paints, plastics, ceramics, and glazes adds any one of a number of possible colors, ranging from light orange to deep red.

Selenium is also used in electronics products, such as plain-paper photocopiers and laser printers. However, some newer models have phased out selenium. The element is also used to make photovoltaic ("solar") cells. When light strikes selenium, it is changed into electricity. A solar cell is a device for capturing the energy of sunlight on tiny pieces of selenium. The sunlight is then changed into electrical energy. Currently, that process is not very efficient. Too much sunlight is lost without being converted into electricity. More efficient solar cells will be able to make use of all the free sunlight that strikes the planet every day.

In the United States, selenium is also used in a variety of applications, including agriculture and metallurgy. Metallurgy refers to the art and science of working with metals. One agricultural use involves the

Selenium has been used in photocopiers and laser printers. IMAGE COPYRIGHT 2009, ARFO. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

addition of selenium to soil or feed to ensure that animals get enough of the element they need in their daily diets.

Compounds

Very few compounds of selenium have any important practical applications. One exception is selenium sulfide (SeS_2). This compound is used to treat seborrhea, or "oily skin." It is sometimes added to shampoos for people with especially oily hair. Another compound, selenium diethyldithiocarbonate ($Se[SC(S)N(C_2H_5)_2]_4$), is used as a vulcanizing ("toughening") agent for rubber products.

Health Effects

Selenium has some rather interesting nutritional roles. It is essential in very small amounts for the health of both plants and animals. Animals that do not have enough selenium in their diets may develop weak muscles. But large doses of selenium are dangerous. In some parts of California, for example, selenium has been dissolved out of the soil by irrigation systems. When lakes accumulate unusually high levels of selenium, birds and fish in the area often develop health problems.

Selenium's Role in Making Photocopies

Hundreds of years ago, making a copy of a document was a long and difficult process. Some people devoted their lives to making copies of important historical documents. Each copy had to be written out by hand. The process was not only dull and tedious, but resulted in numerous errors.

Even 40 years ago, copying was slow and difficult. For a time, people used carbon paper to make copies while writing or typing. But every error had to be corrected on every copy, which made some copies messy and difficult to read. The mimeograph machine made it possible to reproduce dozens of copies in a few minutes, but required handwritten or typed originals. The final product was printed in purple but was not very stylish.

With the invention of the photocopier, copies could be made by placing the original document on a glass cover and pushing a button. For many years, most photocopiers were only available at businesses and were very expensive. Very few people had such machines at home. Much has changed since then.

Although selenium is gradually being phased out of newer machines, it has played an important role in photocopiers. Here's how it works. An essential part of a photocopier is a drum-shaped unit or a wide moving belt. Fine selenium powder is spread on the surface of the drum or the belt. An electric charge is then applied to the selenium.

Another part of the photocopy machine consists of a set of mirrors. When the machine's "Copy" button is pushed, a bright light shines on the page being copied. The light reflects off the white parts of the page. But it is not reflected off the dark parts, such as text or images. The light reflects off the mirrors to the drum or belt.

Selenium is important because when light strikes the charged selenium, the charge disappears. The sections on the drum or belt struck by light have no charge. The sections *not* struck by light continue to have a charge.

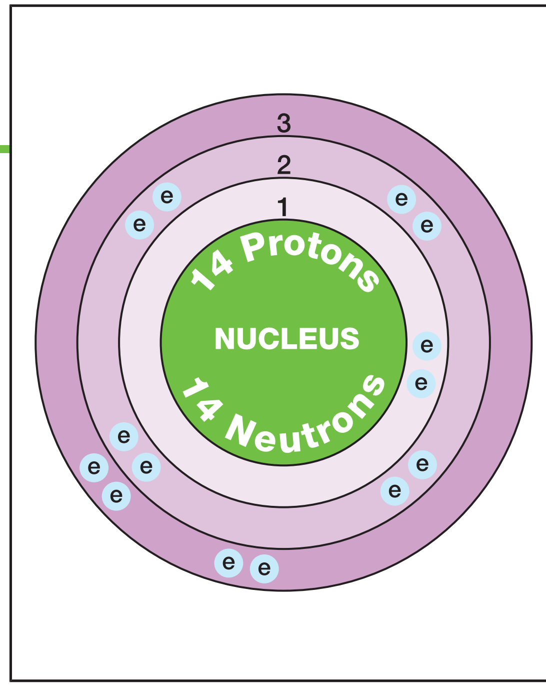
Next, a toner is spread out over the surface of the drum or belt. A toner is usually finely divided carbon. It sticks to the areas that still carry an electric charge. But it does not stick to the selection without a charge.

Finally, a piece of paper is pressed against the drum or belt. The toner sticks to the paper. A blast of heat causes the carbon to melt and stick tightly to the paper. A copy of the original document is produced by the machine.

A serious selenium problem occurred at the Kesterson Reservoir in Northern California. In the late 1970s, scientists found that birds nesting in the reservoir were developing genetic deformities. They traced the problem to high levels of selenium in the water. A large artificial lake was built and the birds were moved to the artificial lake. They were no longer allowed to nest in the dangerous waters of the reservoir.

In the early 21st century, the problems of selenium in the environment have yet to be resolved. Some biologists warn that levels of the element permitted by the U.S. Environmental Protection Agency (EPA) are still too high and pose a threat to birds, fish, and other organisms. Other biologists say the selenium standards are too severe, creating an undue burden on industries.

Silicon



Key Facts

Symbol: Si

Atomic Number: 14

Atomic Mass: 28.0855

Family: Group 14 (IVA); carbon

Pronunciation: SIL-i-con

Overview

Silicon is a member of Group 14 (IVA) in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Silicon is also part of the **carbon** family. Other carbon family elements include carbon, **germanium**, **tin**, and **lead**. Silicon is a metalloid, one of only a very few elements that have characteristics of both metals and non-metals.

Silicon is the second most abundant element in Earth's crust, exceeded only by **oxygen**. Many rocks and minerals contain silicon. Examples include sand, quartz, clays, flint, amethyst, opal, mica, feldspar, garnet, tourmaline, asbestos, talc, zircon, emerald, and aquamarine. Silicon never occurs as a free element. It is always combined with one or more other elements as a compound.

By the early 1800s, silicon was recognized as an element. But chemists had serious problems preparing pure silicon because it bonds (attaches) tightly to oxygen. It took chemists many years to find out how to separate silicon from oxygen. That task was finally accomplished in 1823 by Swedish chemist Jöns Jakob Berzelius (1779–1848).

Silicon's most important application is in electronic equipment. Silicon is one of the best materials from which to make transistors and

WORDS TO KNOW

Abrasive: A powdery material used to grind or polish other materials.

Allotropes: Forms of an element with different physical and chemical properties.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Metalloid: An element that acts like a metal sometimes and like a non-metal other times.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Refractory: A material that does not conduct heat well.

computer chips that store information. The total weight of silicon used for this purpose is relatively small. Much larger amounts are used, for example, to make metal alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals.

Discovery and Naming

In one sense, humans have always used silicon. Nearly every naturally occurring rock or mineral contains some silicon. So when ancient peoples built clay huts or sandstone temples, they were using compounds of silicon.

But no one thought about silicon as an element until the 19th century. Then, a number of chemists tried to separate silicon from the other elements with which it is combined in the earth. English scientist Sir Humphry Davy (1778–1829) developed a technique for separating elements that bond tightly to each other. He melted compounds containing these elements and passed an electric current through them. The technique was successful for producing free or elemental **sodium**, **potassium**, **calcium**, and a number of other elements for the first time. But he failed with silicon.

Berzelius also tried to isolate silicon using a method similar to that of Davy's. He mixed molten (melted) potassium metal with a compound known as potassium silicon fluoride (K_2SiF_6). The procedure was successful in producing pure silicon.

$$4K + K_2SiF_6 \xrightarrow{\text{heat and electricity}} 6KF + Si$$

Scottish chemist Thomas Thomson (1773–1852) suggested the name silicon for the new element. The name is based on the Latin word for "flint," *silex* (or *silicis*). Thomson added the ending *-on* because the new element was so much like bor*on* and carb*on.* Thus, the new element's name was accepted as silicon.

Some interesting studies were done on silicon over the next few years. German chemist Friedrich Wöhler (1800–1882) produced a series of compounds known as silanes. These compounds contain silicon, **hydrogen**, and, sometimes, other elements. The simplest silane is silicon tetrahydride (SiH_4). This compound is also called silane.

A group of compounds known as the siloxanes were produced at about the same time. The siloxanes are made up of silicon, oxygen, and an organic group. Organic compounds contain carbon.

Silanes and siloxanes were not discovered in the search for the answer to any practical question. Chemists were just curious about the kinds of compounds they could make with silicon. But many years later, chemists made some interesting discoveries. Both groups of compounds do have some very important practical uses. For example, the compounds known as silicones are a form of the siloxanes.

Physical Properties

Silicon is a metalloid, an element with properties of both metals and nonmetals. Silicon exists in two allotropic forms. Allotropes are forms of an element with different physical and chemical properties. One allotrope is in the form of shiny, grayish-black, needle-like crystals, or flat plates. The second allotrope has no crystal structure and usually occurs as a brown powder.

The melting point of silicon is 2,570°F (1,410°C) and the boiling point is 4,270°F (2,355°C). Its density is 2.33 grams per cubic centimeter. Silicon has a hardness of about 7 on the Mohs scale. The Mohs scale is a way of expressing the hardness of a material. It runs from 0 (for talc) to 10 (for diamond).

Silicon is a semiconductor. A semiconductor is a substance that conducts an electric current better than a non-conductor—like glass or rubber—but not as well as a conductor—like **copper** or **aluminum**. Semiconductors have important applications in the electronics industry.

Chemical Properties

Silicon is a relatively inactive element at room temperature. It does not combine with oxygen or most other elements. Water, steam, and most acids have very little affect on the element. At higher temperatures, however, silicon becomes much more reactive. In the molten (melted) state, for example, it combines with oxygen, **nitrogen**, **sulfur**, **phosphorus**, and other elements. It also forms a number of alloys very easily in the molten state.

Occurrence in Nature

Silicon is the second most abundant element in Earth's crust. Its abundance is estimated to be about 27.6 percent of the crust. It ranks second only to oxygen. Some authorities believe that more than 97 percent of the crust is made of rocks that contain compounds of silicon and oxygen.

Silicon has been detected in the sun and stars. It also occurs in certain types of meteorites known as aerolites or "stony meteorites." Meteorites are rock-like chunks that fall to Earth's surface from outside Earth's atmosphere.

Silicon never occurs as a free element in nature. It always occurs as a compound with oxygen, **magnesium**, calcium, phosphorus, or other elements. The most common minerals are those that contain silicon dioxide in one form or another. These minerals are known as silicates.

Ordinary sand is nearly pure silicon dioxide. Sand dunes in Death Valley National Park in California are shown here.

Isotopes

There are three naturally occurring isotopes of silicon: silicon-28, silicon-29, and silicon-30. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Eleven radioactive isotopes of silicon are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of silicon has any commercial use.

Silicon Valley

Santa Clara Valley, south of San Francisco, California, is called Silicon Valley due to the vast number of high tech companies located there. The area has produced many computers, semiconductor chips, and other products using silicon for many years. It is also home to many Internet-based companies and other electronics firms.

Various companies associated with the high-tech revolution have operated or continue to operate businesses in Silicon Valley. For example, International Business Machines (IBM) built its Pacific headquarters in San Jose in 1943. Since that time, the Silicon Valley has been home to corporations such as Apple, eBay, Google, Hewlett-Packard, Intel, Lockheed, San Disk, Sun Microsystems, Yahoo!, and many others.

Extraction

Silicon is prepared by heating silicon dioxide with carbon. Carbon replaces the silicon in the compound. The silicon formed is 96 to 98 percent pure.

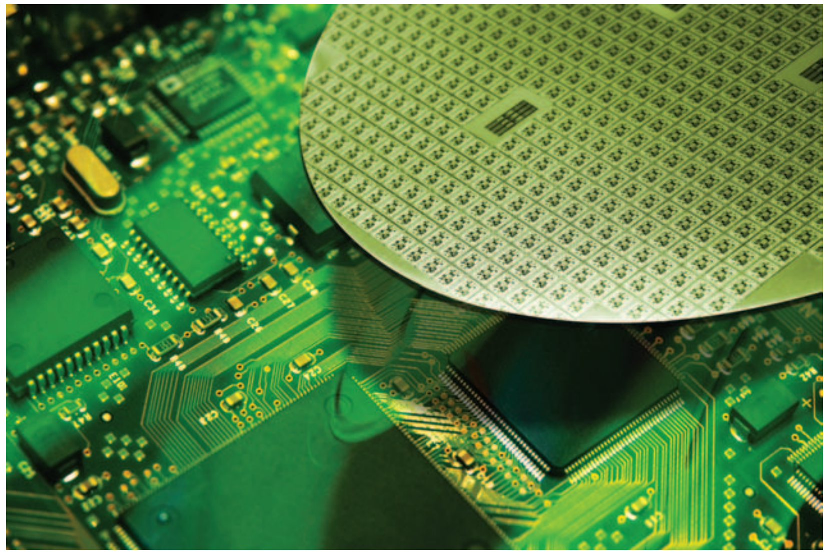
$$SiO_2 + C \xrightarrow{heat} CO_2 + Si$$

Many applications of silicon require a very pure product. Methods have been developed to produce silicon that is at least 99.97 percent pure silicon. This form of silicon is called hyperpure silicon.

According to the U.S. Geological Survey (USGS), about $87 billion of silicon metal and alloys were produced in the United States in 2008. That figure doesn't include semiconductor-grade silicon, however.

Uses

Perhaps the best known use of silicon is in electronic devices. Hyperpure silicon is used in transistors and other components of electronic devices. It is also used to make photovoltaic (solar) cells, rectifiers, and parts for computer circuits. A photovoltaic cell is a device that converts sunlight into electrical energy. A rectifier is an electrical device for changing one



A circular wafer of silicon carrying many individual integrated circuits is shown. IMAGE COPYRIGHT 2009, JOANCHANG. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

kind of electric current (alternating current, or AC) into another kind of electric current (direct current, or DC).

The largest single use of silicon, however, is in making alloys. The most important silicon alloys are those made with **iron** and steel, aluminum, and copper. When silicon is produced, in fact, scrap iron and metal are sometimes added to the furnace. As soon as the silicon is produced, it reacts with iron and steel to form ferrosilicon. Ferrosilicon is an alloy of iron or steel and silicon. It is used for two major purposes. First, it can be added to steel to improve the strength and toughness of the steel. Second, it can be added during the steel-making process to remove impurities from the steel that is being made. In 2008, the leading producers of ferrosilicon were China, Norway, Russia, South Africa, and the United States.

The aluminum industry uses large amounts of silicon in alloys. These alloys are used to make molds and in the process of welding. Welding is a process by which two metals are joined to each other. Alloys of silicon, aluminum, and magnesium are very resistant to corrosion (rusting). They are often used in the construction of large buildings, bridges, and transportation vehicles such as ships and trains.

Compounds

A number of silicon compounds have important uses. Silicon dioxide (sand) is used in the manufacture of glass, ceramics, abrasives, as a food additive, in water filtration systems, as an insulating material, in cosmetics and pharmaceuticals (drugs), and in the manufacture of paper, rubber, and insecticides. Each of these applications could be the subject of a very long discussion in and of itself. For example, humans have made glass for thousands of years. Today, dozens of different kinds of glass are produced, each with special properties and uses. But almost without exception, they all contain silicon dioxide.

Another important group of silicon compounds is the silicones. The silicones have an amazing range of uses. These uses include toys (such as putty and superballs), lubricants, weatherproofing materials, adhesives (glues), foaming agents, brake fluids, cosmetics, polishing agents, electrical insulation, materials to reduce vibration, shields for sensitive equipment, breast implants, and parts for automobile engines.

In recent years, many companies have begun to produce cooking and baking tools using silicone. Such products include baking sheets, muffin and cake pans, oven mitts, cooking spoons, spatulas, and other utensils. Many cooks like the silicone bakeware because it offers a nonstick surface, withstands a range of temperatures (from being put into the freezer or into a hot oven), and remains flexible.

Another important compound is silicon carbide (SiC). Silicon carbide is also known as carborundum. It is one of the hardest substances known,

Many cooking and bakeware products are now being made out of silicone. IMAGE COPYRIGHT 2009, CRISFERRA. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

with a hardness of about 9.5 on the Mohs scale. Carborundum is widely used as an abrasive, a powdery material used to grind or polish other materials. Carborundum also has refractory properties. A refractory material can withstand very high temperatures by reflecting heat. Refractory materials are used to line the inside of ovens that maintain very high temperatures.

Health Effects

Information on the health effects of silicon is limited. Some studies show that silicon may be needed in very small amounts by plants and some animals. One study showed, for example, that chickens that did not receive silicon in their diet developed minor health problems. Overall, silicon probably has no positive or negative effects on human health.

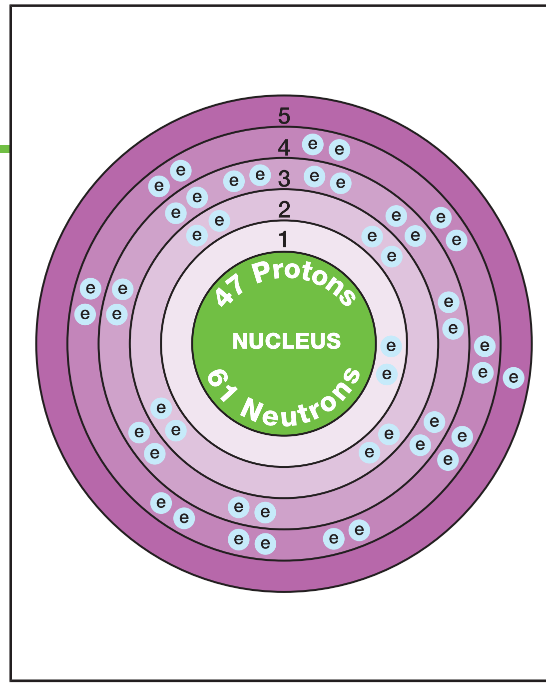
However, a serious health problem called silicosis is associated with silicon dioxide (SiO_2). Silicon dioxide occurs in many forms in the earth. Ordinary sand is nearly pure silicon dioxide.

In some industries, sand is ground up into a very fine powder that gets into the air. As workers inhale the dust, it travels through their mouths, down their throats, and into their lungs. Silicon dioxide powder can block the tiny air passages in the lungs through which oxygen and carbon dioxide pass. When this happens, silicosis results.

Silicosis is similar to pneumonia. The person finds it difficult to breathe. The longer one is exposed to silicon dioxide dust, the worst the problem gets. In the worst cases, silicosis results in death because of the inability to breathe properly.

Silicone The safety of silicone breast implants is also a matter of debate. Such implants were banned by the U.S. Food and Drug Administration (FDA) in the early 1990s due to concerns that the implants could lead to cancer or connective tissue disease. But in 2006, the FDA began allowing several companies to offer silicone-gel breast implants again. This followed the agency's thorough review of various medical studies on the product's safety. When removing the ban, the FDA stated that "there is no convincing evidence that breast implants are associated with either of these diseases." However, the FDA and implant makers agreed to continue monitoring such studies.

Silver



Key Facts

Symbol: Ag

Atomic Number: 47

Atomic Mass: 107.8682

Family: Group 11 (IB); transition metal

Pronunciation: SIL-ver

Overview

Chemists classify silver as a transition metal. The transition metals are elements between Groups 2 and 13 in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. More than 40 elements, all metals, fall within the transition metal range.

Silver is also classified as a precious metal. Precious metals are not very abundant in Earth's crust. They are attractive and not very chemically active. These properties make the metal desirable in jewelry, coins, and art. About a half dozen metals near silver in the periodic table are also precious metals. These include **gold**, **platinum**, **palladium**, **rhodium**, and **iridium**.

Silver has been used by humans for thousands of years. It often occurs as a free element in nature. It can also be extracted from its ores fairly easily. These properties made it easy for early humans to learn about silver.

The three most important uses of silver today are in a variety of industrial applications; in the making of coins, jewelry, and art objects; and in photography.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Amalgam: An alloy of mercury and at least one other metal.

Ductile: Capable of being drawn into thin wires.

Electrolysis: A process by which a compound is broken down by passing an electric current through it.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Silver plating: A process by which a very thin layer of silver metal is laid down on top of another metal.

Toxic: Poisonous.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

Silver was probably discovered after gold and **copper**. Gold and copper often occur as free elements in nature. They have very distinctive colors, which made it easy for early humans to find these metals.

Silver also occurs as a free metal, but much less often than gold or copper. At some point, humans learned to extract silver from its ores. But that discovery must have occurred very early on in human history. Archaeologists (scientists who study ancient civilizations) have found silver objects dating to about 3400 BCE in Egypt. Drawings on some of the oldest pyramids show men working with metal, probably extracting silver from its ores.

Other early cultures also used silver. Written records from India describe the metal as far back as about 900 BCE. Silver was in common use in the Americas when Europeans first arrived.

The Bible contains many references to silver. The metal was used as a way of paying for objects. It also decorated temples, palaces, and other important buildings. The Bible also contains sections that describe the manufacture of silver.

The word silver goes back to at least the 12th century. It seems to have come from an old English word used to describe the metal, *seolfor.*

The symbol for silver (Ag), however, comes from its Latin name, *argentum.* The name may have originated from the Greek word *argos,* meaning "shiny" or "white."

Physical Properties

Silver is a soft, white metal with a shiny surface. It is one of the most ductile and most malleable of all metals. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. Silver has two other unique properties. It conducts heat and electricity better than any other element. It also reflects light very well.

Silver's melting point is 1,762°F (961.5°C) and its boiling point is about 3,600 to 4,000°F (2,000 to 2,200°C). Its density is 10.49 grams per cubic centimeter, more than 10 times the density of water.

Chemical Properties

Silver is a very inactive metal. It does not react with **oxygen** in the air under normal circumstances. It does react slowly with **sulfur** compounds in the air, however. The product of this reaction is silver sulfide (Ag_2S), a black compound. The tarnish that develops over time on silverware, jewelry, and other silver-plated objects is silver sulfide.

Silver does not react readily with water, acids, or many other compounds. It does not burn except as silver powder.

Occurrence in Nature

Silver is a fairly rare element in Earth's crust. Its abundance is estimated to be about 0.1 parts per million. It is also found in seawater. Its abundance there is thought to be about 0.01 parts per million.

Silver usually occurs in association with other metal ores, especially those of **lead**. The most common silver ores are argentite (Ag_2S); cerargyrite, or "horn silver" ($AgCl$); proustite ($3Ag_2S \cdot As_2S_3$); and pyrargyrite ($Ag_2S \cdot Sb_2S_3$).

As of 2008, the largest producers of silver in the world are Peru, Mexico, China, Chile, Australia, Poland, and the United States. The largest state producers are Alaska and Nevada. According to the U.S. Geological Survey (USGS), the nation mined approximately 1,235 short tons (1,120 metric tons) of silver, valued at $570 million, that year.

In the American Southwest, silver jewelry—featuring turquoise, coral, mother of pearl, and other stones—is popular. Many silver bracelets, rings, and earrings are created by Native American silversmiths. IMAGE COPYRIGHT 2009, DOUGLAS KNIGHT. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Isotopes

Two naturally occurring isotopes of silver exist: silver-107 and silver-109. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fifty-six radioactive isotopes of silver are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of silver has any commercial use.

Extraction

Ores rich in silver disappeared long ago due to mining. Today, silver usually comes from ores that contain very small amounts of the metal. These amounts can range from about a few thousandths of an ounce per ton of ore to 100 ounces per ton. The metal is most commonly produced as a by-product of mining for other metals. After the primary metal has been removed, the waste often contains small amounts of silver. These wastes are treated with chemicals that react with the silver. The silver can then be extracted by electrolysis. Electrolysis is a process by which a compound is broken down by passing an electric current through it.

Uses and Compounds

One of the major uses of silver in the United States is in the creation of coins, medals, jewelry, and silverware. In many cases, silver is used in alloys with gold. Gold is highly desired for coins and jewelry. But it is much too soft to use in its pure form. Adding silver to gold, however, makes an alloy that is much stronger and longer lasting. Most "gold" objects today are actually alloys, often alloys of silver and gold.

Another product that uses silver is photographic film. Pure silver is first converted to a compound: silver chloride (AgCl), silver bromide (AgBr), or silver iodide (AgI). The compound is then used to make photographic film. Use of photographic film has decreased as many photographers have switched to digital cameras. However, some photographers still prefer to use 35mm film cameras and some hospitals still use x-ray film containing silver.

Silver is also used to make electrical and electronic equipment. It is actually the most desirable of all metals for electrical equipment.

A popular coin to collect is the Morgan Silver Dollar, which was minted in the United States between 1878 and 1904 and again in 1921. IMAGE COPYRIGHT 2009, KENNETH V. PILON. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Electricity flows through silver more easily than it does through any other metal. In most cases, however, metals such as copper or **aluminum** are used because they are less expensive. But sometimes, an electrical device is so important that cost is not a consideration. For example, electrical devices on spacecraft, satellites, and aircraft must work reliably and efficiently. The cost of using silver is not as important as it would be in a home appliance. Thus, silver is used for electrical wiring and connections in these devices.

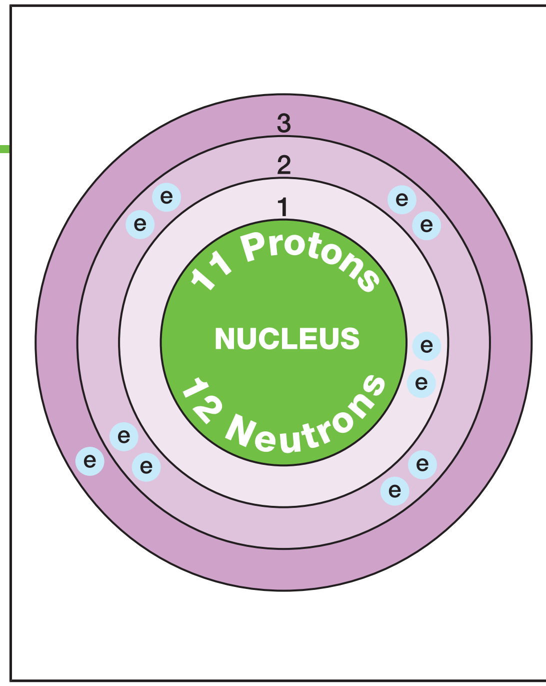
In some cases, silver plating solves a practical problem where the more expensive silver would work best. Silver plating is the process by which a very thin layer of silver metal is laid down on top of another metal. Silver is so malleable that it can be hammered into sheets thinner than a sheet of paper. Silver this thin can be applied to another metal. Then the other metal takes on some of the properties of the silver coating. For example, it may work very well as a reflector because silver is such a good reflector. It does not matter if the second metal is a good reflector or not. The silver coating serves as the reflecting surface in the combination.

Small amounts of silver are used in a variety of other products. For example, it is used in dental amalgams. An amalgam is an alloy in which mercury is one of the metals used. Silver amalgams work well for filling decayed teeth. They are non-toxic and do not break down or react with other materials very readily. Silver is also used in specialized batteries, cell phone covers, circuit boards, and Radio Frequency Identification Devices (RFIDs).

Health Effects

Silver is a mildly toxic element. The metal and its compounds can cause irritation of the skin, eyes, and respiratory system. They can cause a condition known as argyria or argyrosis, in which the skin or eyes turn blue. Breathing in silver dust can have serious long-term health effects also. The highest recommended exposure for silver dust is 0.1 milligrams per cubic meter of air.

Sodium



Key Facts

Symbol: Na

Atomic Number: 11

Atomic Mass: 22.98976928

Family: Group 1 (IA); alkali metal

Pronunciation: SO-dee-um

Overview

Most people have never seen sodium metal. But it is almost impossible not to see many compounds of sodium every day. Ordinary table salt, baking soda, baking powder, household lye, soaps and detergents, aspirin and other drugs, and countless other consumer products are sodium products.

Sodium is a member of the alkali metals family. The alkali family consists of elements in Group 1 (IA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Other Group 1 (IA) elements are **lithium**, **potassium**, **rubidium**, **cesium**, and **francium**. The members of the alkali metals family are among the most active elements.

Compounds of sodium have been known, of course, throughout human history. But sodium metal was not prepared until 1807. The reason is that sodium attaches itself very strongly to other elements. Its compounds are very difficult to break apart. It was not until 1807 that English chemist Sir Humphry Davy (1778–1829) found a way to extract sodium from its compounds.

Sodium metal itself has relatively few uses. It reacts with other substances easily, sometimes explosively. However, many sodium compounds have a variety of uses in industry, medicine, and everyday life.

WORDS TO KNOW

Amalgam: An alloy of mercury and at least one other metal.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into thin wires.

Heat exchange medium: A material that picks up heat in one place and carries it to another place.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

Discovery and Naming

Sodium carbonate, or soda (Na_2CO_3), was probably the sodium compound best known to ancient peoples. It is the most common compound of sodium found in nature.

This fact explains why glass was one of the first chemical products made by humans. Glass is made by heating sodium carbonate and **calcium** oxide (lime) together. When the mixture cools, it forms the hard, clear, transparent material called glass. Glass was being manufactured on a large scale in Egypt as early as 1370 BCE.

The Egyptians called soda *natron.* Much later, the Romans used a similar name for the compound, *natrium.* These names explain the chemical symbol used for sodium, Na.

The name sodium probably originated from an Arabic word *suda,* meaning "headache." Soda was sometimes used as a cure for headaches among early peoples. The word *suda* also carried over into Latin to become *sodanum,* which also means "headache remedy."

In the early 1800s, Davy found a way to extract a number of active elements from their compounds. Sodium was one of these elements. Davy's method involved melting a compound of the active element, then passing an electric current through the molten (melted) compound. Davy used sodium hydroxide (NaOH) to make sodium.

Physical Properties

Sodium is a silvery-white metal with a waxy appearance. It is soft enough to be cut with a knife. The surface is bright and shiny when first cut, but quickly becomes dull as sodium reacts with **oxygen** in the air. A thin film of sodium oxide (Na_2O) forms on the surface of the metal.

Sodium's melting point is 208.1°F (97.82°C) and its boiling point is 1,618°F (881.4°C). Its density is slightly less than that of water, 0.968 grams per cubic centimeter. Sodium is a good conductor of electricity.

Chemical Properties

Sodium is a very active element. It combines with oxygen at room temperature. When heated, it combines very rapidly, burning with a brilliant golden-yellow flame.

Sodium also reacts violently with water. The effect is fascinating. When sodium metal is first placed into water, it floats. But it immediately begins to react with water, releasing hydrogen gas:

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

A great deal of energy is released in this reaction. The energy produced is sufficient to set fire to the hydrogen gas. So much heat is released by the burning hydrogen that the sodium melts. It turns into a tiny ball of liquid sodium. The burning hydrogen gas causes the ball of sodium to go sizzling across the surface of the water.

Sodium is so active that it is normally stored under a liquid with which it does not react. Kerosene or naphtha are liquids commonly used for this purpose.

Sodium also reacts with most other elements and with many compounds. It reacts with acids to produce hydrogen gas. It also dissolves in **mercury** to form a sodium amalgam. An amalgam is an alloy of mercury and at least one other metal.

Occurrence in Nature

Sodium never occurs as a free element in nature. It is much too active. It always occurs as part of a compound. The most common source of sodium in Earth is halite. Halite is nearly pure sodium chloride (NaCl). It is also called rock salt.

Halite can be found in underground deposits similar to coal mines. Those deposits were formed when ancient oceans evaporated (dried

Natural salt crystals. IMAGE COPYRIGHT 2009, SHI YALI. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

up), leaving sodium chloride behind. Earth movements eventually buried those deposits. Now they can be mined to remove the sodium chloride.

Sodium chloride can also be obtained from seawater and brine. Brine is similar to seawater, but it contains more dissolved salt. Removing sodium chloride from seawater or brine is easy. All that is needed is to let the water evaporate. The sodium chloride is left behind. It only needs to be separated from other chemicals that were also dissolved in the water.

Isotopes

There is only one naturally occurring isotope of sodium: sodium-23. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Sixteen radioactive isotopes of sodium with measured half lives are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Two radioactive isotopes of sodium—sodium-22 and sodium-24—are used in medicine and other applications. They can be used as tracers to follow sodium in a person's body. A tracer is a radioactive isotope whose presence in a system can easily be detected. The isotope is injected into the system at some point. Inside the system, the isotope gives off radiation. That radiation can be followed by means of detectors placed around the system.

Sodium-24 also has non-medical applications. For example, it is used to test for leaks in oil pipe lines. These pipe lines are usually buried underground. It may be difficult to tell when a pipe begins to leak. One way to locate a leak is to add some sodium-24 to the oil. If oil leaks out of the pipe, so does the sodium-24. The leaking oil may not be visible, but the leaking sodium-24 is easily detected. It is located by instruments that are designed to detect radiation.

Extraction

One way to obtain pure sodium metal is by passing an electric current through molten (melted) sodium chloride:

$$2NaCl \xrightarrow{\text{electric current}} 2Na + Cl_2$$

This method is similar to the one used by Humphry Davy in 1808.

But there is not much demand for sodium metal. Sodium compounds are much more common. A second and similar method is used to make a compound known as sodium hydroxide (NaOH). The sodium hydroxide is then used as a starting point for making other sodium compounds.

The method for making sodium hydroxide is called the chlor-alkali process. The name comes from the fact that both chlorine and an alkali metal (sodium) are produced at the same time. In this case, an electric current is passed through a solution of sodium chloride dissolved in water:

$$2NaCl + 2H_2O \xrightarrow{\text{electric current}} Cl_2 + H_2 + 2NaOH$$

Three useful products are obtained from this reaction: chlorine gas (Cl_2), hydrogen gas (H_2), and sodium hydroxide (NaOH). The chlor-alkali process is one of the most important industrial processes used today.

Uses

Sodium metal has a relatively small, but important, number of uses. For example, it is sometimes used as a heat exchange medium in nuclear power plants. A heat exchange medium is a material that picks up heat in one place and carries it to another place. Water is a common heat exchange medium. Some home furnaces burn oil or gas to heat water that travels through pipes and radiators in the house. The water gives off its heat through the radiators.

Sodium does a similar job in nuclear power plants. Heat is produced by nuclear fission reactions at the core (center) of a nuclear reactor. In a nuclear fission reaction, large atoms break down to form smaller atoms. As they do so, large amounts of heat energy are given off.

Liquid sodium is sealed into pipes that surround the core of the reactor. As heat is generated, it is absorbed (taken up) by the sodium. The sodium is then forced through the pipes into a nearby room. In that room, the sodium pipes are wrapped around pipes filled with water. The heat in the sodium converts the water to steam. The steam is used to operate devices that generate electricity.

Another use of sodium metal is in producing other metals. For example, sodium reacts with **titanium** tetrachloride ($TiCl_4$) to produce titanium metal:

$$4Na + TiCl_4 \rightarrow 4NaCl + Ti$$

Sodium is also used to make artificial rubber. (Real rubber is made from the collected sap of rubber trees and is expensive.) The starting material for artificial rubber is usually a small molecule. The small molecule reacts with itself over and over again. It becomes a much larger molecule called a polymer. The polymer is the material that makes up the artificial rubber. Sodium metal is used as a catalyst in this reaction. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself.

Sodium is also used to make lightbulbs. Sodium is first converted to a vapor (gas) and injected into a glass bulb. An electric current is passed through a wire or filament in the gas-filled bulb. The electric current causes the sodium vapor to give off a yellowish glow. Many street lamps are sodium vapor lamps. Their advantage is that they do not produce as much glare (or light pollution) as do ordinary lights.

Compounds

Almost all sodium compounds dissolve in water. When it rains, sodium compounds dissolve and are carried into the ground. Eventually, the compounds flow into rivers and then into the oceans. The ocean is

Northwest Utah is the site of the Bonneville Salt Flats—an area covered with a hard, flat, salt crust that formed in ancient times. Located near I-80, the salt flats cover 46 square miles (119 square kilometers) and are mainly comprised of sodium chloride (common table salt). The flat landscape, which is home to the Bonneville Speedway, has helped many auto racers set speed records for nearly 100 years.

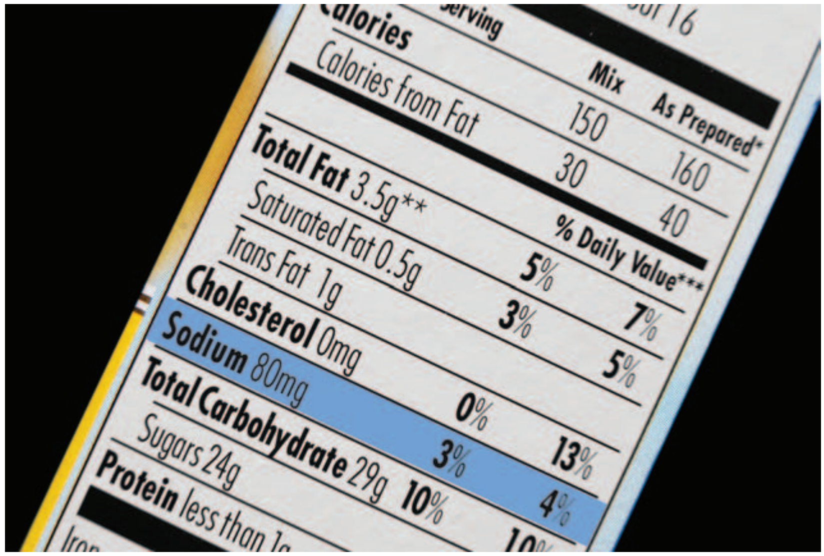
salty partly because sodium compounds have been dissolved for many centuries.

But that means that finding sodium compounds on land is somewhat unusual. They tend to be more common in desert areas because deserts experience low rainfall. So sodium compounds are less likely to be washed away. Huge beds of salt and sodium carbonate are sometimes found in desert areas.

Dozens of sodium compounds are used today in all fields. Some of the most important of these compounds follow.

Sodium chloride (NaCl): The most familiar use of sodium chloride is as a flavor enhancer in food. It is best known as table salt. Large amounts of sodium chloride are also added to prepared foods, such as canned, bottled, frozen, and dried foods. One purpose of adding sodium chloride to these foods is to improve their flavors. But another purpose is to prevent them from decaying. Sodium chloride kills bacteria in foods. It has been used for hundreds of years as a food preservative. The "pickling" or "salting" of a food, for example, means the adding of salt to that food to keep it from spoiling.

This process is one reason people eat so much salt in their foods to-day. Most people eat a lot of prepared foods. Those prepared foods



Food nutrition labels specify the sodium content of packaged foods. This information is especially helpful to people who need to watch or restrict how much sodium they consume. IMAGE COPYRIGHT 2009, BRITTANY COURVILLE. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

contain a lot of salt. People are often not aware of all the salt they take in when they eat such foods.

Sodium chloride is also the starting point for making other sodium compounds. In fact, this application is probably the number one use for sodium chloride.

Sodium carbonate (Na_2CO_3): Sodium carbonate is also known by other names, such as soda, soda ash, sal soda, and washing soda. It is also used as the starting point in making other sodium compounds. A growing use is in water purification and sewage treatment systems. The sodium carbonate is mixed with other chemicals that react to form a thick, gooey solid. The solid sinks to the bottom of a tank, carrying impurities present in water or wastewater.

Sodium carbonate is also used to make a very large number of commercial products, such as glass, pulp and paper, soaps and detergents, and textiles.

Sodium bicarbonate ($NaHCO_3$): When sodium bicarbonate is dissolved in water, it produces a fizzing reaction. That reaction can be used in many household situations. For example, the fizzy gas can help bread batter rise. The "rising" of the batter is caused by bubbles released when sodium bicarbonate (baking soda) is added to milk in the batter.

Certain kinds of medications, such as antacids, also include sodium bicarbonate. The fizzing is one of the effects of taking certain antacids that helps settle the stomach. Sodium bicarbonate is also used in mouthwashes, cleaning solutions, wool and silk cleaning systems, fire extinguishers, and mold preventatives in the timber industry.

Examples of lesser known compounds are as follows:

- sodium alginate ($NaC_6H_7O_6$): a thickening agent in ice cream and other prepared foods; manufacture of cement; coatings for paper products; water-based paints
- sodium bifluoride (KHF_2): preservative for animal specimens; antiseptic (germ-killer); etching of glass; manufacture of tin plate
- sodium diuranate, or "**uranium** yellow" ($Na_2U_2O_7$): used to produce yellowish-orange glazes for ceramics
- sodium fluorosilicate (Na_2SiF_6): used to make "fluoride" toothpastes that protect against cavities; insecticides and rodenticides (rat-killers); moth repellent; wood and leather preservative; manufacture of laundry soaps and "pearl-like" enamels
- sodium metaborate ($NaBO_2$): herbicide
- sodium paraperiodate ($Na_3H_2IO_6$): helps tobacco to burn more completely and cleanly; helps paper products retain strength when wet
- sodium stearate ($NaOOCC_{17}H_{35}$): keeps plastics from breaking down; waterproofing agent; additive in toothpastes and cosmetics
- sodium **zirconium** glycolate ($NaZrH_3(H_2COCOO)_3$): deodorant; germicide (germ-killer); fire-retardant

A common compound of sodium, sodium bicarbonate, produces a fizzing reaction. It is an ingredient in medications, such as some antacids that are taken after they are dissolved in water. IMAGE COPYRIGHT 2009, DMITRIY SHIRONOSOV. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Health Effects

Sodium has a number of important functions in plants, humans, and animals. In humans, for example, sodium is involved in controlling the amount of fluid present in cells. An excess or lack of sodium can cause cells to gain or lose water. Either of these changes can prevent cells from carrying out their normal functions.

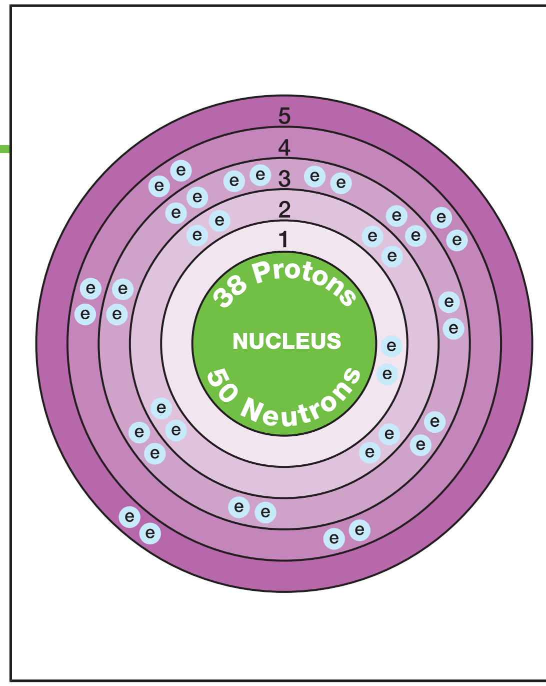
Sodium is also involved in sending nerve messages to and from cells. These impulses control the way muscles move. Again, an excess or lack of sodium can result in abnormal nerve and muscle behavior. Sodium is also needed to control the digestion of foods in the stomach and intestines.

People sometimes talk about the amount of "sodium" in their diet. Or they may refer to the amount of "salt" in their diet. The two terms are similar, but not exactly alike. In the body, sodium occurs most often as sodium chloride. A common name for sodium chloride is salt.

In its dietary guidelines, the U.S. Department of Health and Human Services (HHS) recommends that people "[c]onsume less than 2,300 mg (approximately 1 tsp of salt) of sodium per day." The HHS advises middle-aged and older adults, African Americans, and those with hypertension (high blood pressure) to consume a lower amount (1,500 mg or less) daily due to the negative health effects of sodium on these groups of people. The HHS directs people to "[c]hoose and prepare foods with little salt. At the same time, consume potassium-rich foods, such as fruits and vegetables."

However, many people take in much higher levels of sodium than recommended every day. This fact concerns health experts for a variety of reasons. Too much sodium can affect the body's ability to digest fats, for example. It can also lead to hypertension. A person with high blood pressure may be at risk for stroke, heart attack, or other major health problems. Many people are often surprised when reading the sodium content on nutritious labels because they didn't realize how much sodium is in some prepared foods.

Strontium



Key Facts

Symbol: Sr

Atomic Number: 38

Atomic Mass: 87.62

Family: Group 2 (IIA); alkaline earth metal

Pronunciation: STRONT-she-um

Overview

Strontium is a member of the alkaline earth metals. The alkaline earth metals make up Group 2 (IIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Other alkaline metals include **beryllium**, **magnesium**, **calcium**, **barium**, and **radium**. Strontium occupies a middle position in the family. Chemically, it is more active than calcium or magnesium, above it in the periodic table. But it is less active than barium, below it in Group 2.

The existence of strontium was first recognized in 1790 by Irish physician Adair Crawford (1748–1795). However, the element was not prepared in pure form until nearly 20 years later by English chemist Humphry Davy (1778–1829).

One of the major uses of strontium has been in the production of color cathode ray tubes (CRTs) used in televisions and computer monitors. However, changes in electronics technology and the popularity of flat-panel screens (which use far less or even no strontium) have led to decreased strontium demand for this purpose in the United States and Europe. However, strontium is also used in the manufacture of ceramics and specialty glass. One of its radioactive isotopes is used in industry and medical studies.

WORDS TO KNOW

Alkaline earth metal: An element found in Group 2 (IIA) of the periodic table.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

Discovery and Naming

Adair Crawford was trained as a physician. However, he was also interested in chemical research. For a period of time, he was on the staff at St. Thomas's Hospital in London, England, and a professor of chemistry at Woolwich University.

In 1790, he began studying certain minerals that were on display at St. Thomas's. These minerals were thought to be a form of baryte. Baryte is a mineral from which the element barium is obtained.

But Crawford found that some of the minerals did not behave as he expected. They did not have the properties of barium minerals. He concluded that the minerals contained a new element. He called the element strontia. He named it after a **lead** mine in Strontia, Scotland, from which the samples came.

Strontia was later found to be a compound of strontium and **oxygen**. In 1808, Davy found a way to produce pure strontium metal. He passed an electric current through molten (melted) strontium chloride. The electric current broke the compound into its two elements:

$$\mathbf{SrCl_2 \quad electric\ current \rightarrow Sr + Cl_2}$$

Physical Properties

Strontium is a silvery-white, shiny metal. When exposed to air, it combines with oxygen to form a thin film of strontium oxide (SrO). The film gives the metal a yellowish color.

Strontium has a melting point of about 1,395°F (757°C) and a boiling point of 2,491°F (1,366°C). Its density is 2.6 grams per cubic centimeter, about two and a half times the density of water.

Chemical Properties

Strontium is so active it must be stored under kerosene or mineral oil. In this way, the metal does not come into contact with air. In a finely divided or powdered form, strontium catches fire spontaneously and burns vigorously. Strontium is active enough to combine even with **hydrogen** and **nitrogen** when heated. The compounds formed are strontium hydride (SrH_2) and strontium nitride (Sr_3N_2). Strontium also reacts with cold water and with acids to release hydrogen gas:

$$\mathbf{Sr + 2H_2O \rightarrow Sr(OH)_2 + H_2}$$

Occurrence in Nature

Strontium is a relatively abundant element in Earth's crust. It ranks about 15th among the elements found on Earth. That makes it about as abundant as **fluorine** and its alkaline earth partner, barium.

The most common minerals containing strontium are celestine and strontianite. Celestine contains primarily strontium sulfate ($SrSO_4$), while strontianite contains mostly strontium carbonate ($SrCO_3$). Important world sources of strontium are Spain, China, Mexico, Turkey, and Argentina. No strontium has been mined in the United States since 1959.

Isotopes

Four isotopes of strontium occur in nature. They are strontium-84, strontium-86, strontium-87, and strontium-88. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-seven radioactive isotopes of strontium with measured half lives are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of strontium, strontium-90, is of special interest. It is a toxic substance, which, at one time, was the cause of great concern because of its connection to atomic bomb testing.

Toxic Skies: Strontium-90 in the Atmosphere

Strontium-90 is a radioactive isotope produced during the explosion of atomic weapons, such as an atomic bomb. In the 1950s and 1960s, the United States, the Soviet Union, China, and a few other nations tested atomic bombs in the atmosphere. Whenever one of these bombs exploded, some strontium-90 was thrown high into the atmosphere. After a short time, the strontium-90 settled to the ground where it was absorbed by growing plants. When cattle, sheep, and other domestic animals ate the plants, they also took strontium-90 into their bodies.

Strontium is just below calcium on the periodic table. That means that strontium behaves in much the same way that calcium does. Calcium eaten by humans and animals goes primarily to building bones and teeth. TV advertisements frequently recommend that young children drink milk. That's because milk contains calcium. It is used to build bones and teeth in growing children.

So any strontium that enters an animal's body is also used to build bones and teeth. The bad news is that strontium-90 is radioactive. It gives off radiation that kills or damages living cells. It can also cause those cells to begin growing out of control. Out-of-control cells lead to cancer. Strontium-90 in bones and teeth is a built-in time bomb. As long as it remains in the body, it has the potential for causing cancer in people and animals.

The threat posed by strontium-90 is one reason that nations agreed to begin testing nuclear weapons underground. It also helped world leaders realize that they needed to stop the testing of nuclear weapons entirely. It led in some degree to the agreements signed in the 1980s among the United States, Soviet Union, and other nations to give up atomic bomb testing entirely, although some testing has continued. In 2009, the issue was renewed when North Korea announced nuclear tests.

Today, strontium-90 has a number of useful applications. For example, it is used to monitor the thickness of materials such as metal sheeting. The sheeting is carried along on a conveyor belt beneath a small container of strontium-90. The isotope gives off radiation, some of which passes through the metal sheeting. The thicker the sheeting, the less radiation gets through. The thinner the sheeting, the more radiation gets through. A radiation detector is placed below the conveyor belt. The detector measures the amount of radiation passing through the sheeting. An inspector monitors the reading and makes adjustments to the manufacturing equipment to maintain the right thickness.

Strontium-90 is used for a number of other industrial applications, all based on the same principle. For instance, strontium-90 is used to measure the density of silk and tobacco products.

Strontium-90 has medical applications. For example, it is used to control pain. People who have cancer of the bone often experience terrible pain. At one time, the only treatment was medication. But those drugs often had unpleasant side-effects, such as nausea, dizziness, or depression.

Injecting strontium-90 into a person's body is an alternative to the use of drugs. The strontium-90 deposits in the bones, just as the calcium does. Within bones, the isotope stops pain signals being sent to the brain.

There are other medical applications for radioactive strontium isotopes. Strontium-90 is used to treat a variety of eye disorders. And strontium-85 and strontium-87m are used to study the condition of bones in a person's body.

Strontium compounds provide the red color in certain kinds of fireworks. IMAGE COPYRIGHT 2009, VADIM VOLODIN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Extraction

Most strontium metal is still obtained by the method used by Davy. An electric current is passed through molten (melted) strontium chloride.

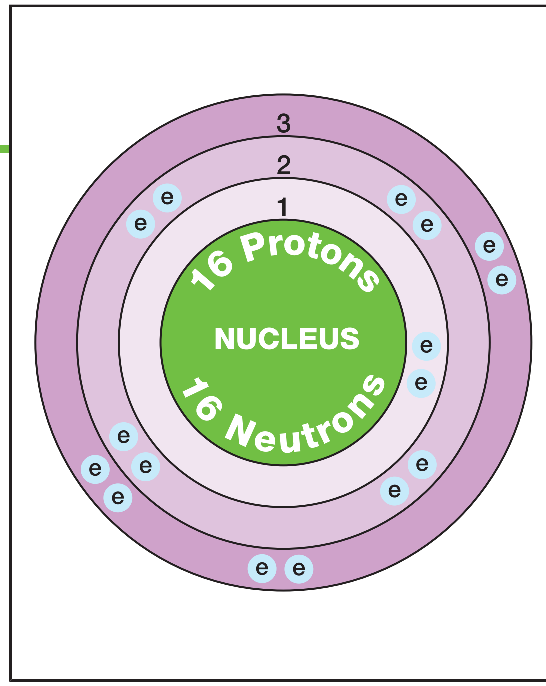
Uses and Compounds

Strontium and its compounds have relatively few commercial uses. The pure metal is sometimes combined with other metals to form alloys. An alloy is made by melting and mixing two or more metals. The mixture has different properties than the individual metals. Compounds of strontium are sometimes used to color glass and ceramics. They give a beautiful red color to these materials. Strontium compounds also provide the brilliant red color of certain kinds of fireworks.

Health Effects

Most strontium compounds are regarded as harmless to plants and animals. A few, such as strontium chloride ($SrCl_2$) and strontium iodide (SrI_2), are somewhat toxic.

Sulfur



Overview

Sulfur belongs to the chalcogen family. Other members of the family are **oxygen**, **selenium**, **tellurium**, and **polonium**. These elements make up Group 16 (VIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other.

The term chalcogen comes from two Greek words meaning "ore forming." An ore is a naturally occurring mineral used as a source for an element. Many ores are compounds of a metal and oxygen or a metal and sulfur. Compounds that contain two elements, one of which is sulfur, are called sulfides. For example, a beautiful gold-colored mineral is called pyrite, or "fool's gold," because it looks so much like real gold. Pyrite is iron sulfide (FeS_2).

Sulfur was known to ancient peoples. Its physical and chemical properties are very distinctive. It often occurs as a brilliant yellow powder. When it burns, it produces a clear blue flame and a very strong odor.

Sulfur, also spelled as sulphur, is a very important element in today's world. Its most important use is in the manufacture of sulfuric acid (H_2SO_4). There is more sulfuric acid made than any other chemical in the world. It has an enormous number of important uses.

Key Facts

Symbol: S

Atomic Number: 16

Atomic Mass: 32.065

Family: Group 16 (VIA); chalcogen

Pronunciation: SUL-fur

WORDS TO KNOW

Chalcogen: Elements in Group 16 (VIA) of the periodic table.

Frasch method: A method for removing sulfur from underground mines by pumping hot air and water down a set of pipes.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Superheated water: Water that is hotter than its boiling point, but that has not started to boil.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

Vulcanization: The process by which soft rubber is converted to a harder, longer-lasting product.

Discovery and Naming

Sulfur must have been well known to ancient peoples. They sometimes referred to it as brimstone. Sulfur sometimes occurs in bright yellow layers on the top of the earth. It has a sharp, offensive odor. When it burns, it gives off a strong, suffocating smell. The odor is like that produced when a match is struck.

The Bible mentions brimstone in a number of places. For example, Sodom and Gomorrah were two towns destroyed by God for the wicked ways of their citizens: "The Lord rained upon Sodom and upon Gomorrah brimstone and fire."

But ancient people certainly did not think about sulfur the way modern chemists do. In fact, they used the word "element" to talk about anything that was basic. Some ancient Greek philosophers, for example, thought that everything consisted of four elements: earth, fire, water, and air. Other philosophers thought there were only two elements: sulfur and **mercury**.

But early thinkers were often confused as to what they meant by the word "sulfur." They often were talking about anything that burned and gave off large amounts of smoke. To them, "sulfur" was really a "burning substance." It took centuries for scientists to identify sulfur as an element.

Physical Properties

Sulfur exists in two allotropic forms. Allotropes are forms of an element with different physical and chemical properties. The two forms of sulfur are known as α-form and β-form (the Greek letters alpha and beta, respectively). Both allotropes are yellow, with the α-form a brighter yellow and the β-form a paler, whitish-yellow. The α-form changes to the β-form at about 202°F (94.5°C). The α-form can be melted at 235°F (112.8°C) if it is heated quickly. The β-form has a melting point of 246°F (119°C). The boiling point of the α-form is 832.3°F (444.6°C).

The two allotropes have densities of 2.06 grams per cubic centimeter (α-form) and 1.96 grams per cubic centimeter (β-form). Neither allotrope will dissolve in water. Both are soluble in other liquids, such as benzene (C_6H_6), **carbon** tetrachloride (CCl_4), and carbon disulfide (CS_2).

Another allotrope of sulfur is formed when the element is melted. This allotrope has no crystalline shape. It looks like a dark brown, thick, melted plastic.

Chemical Properties

Sulfur's most prominent chemical property is that it burns. When it does so, it gives off a pale blue flame and sulfur dioxide (SO_2) gas. Sulfur dioxide has a very obvious strong, choking odor.

Sulfur also combines with most other elements. Sometimes it combines with them easily at room temperature. In other cases, it must be heated. The reaction between **magnesium** and sulfur is typical. When the two elements are heated, they combine to form magnesium sulfide (MgS):

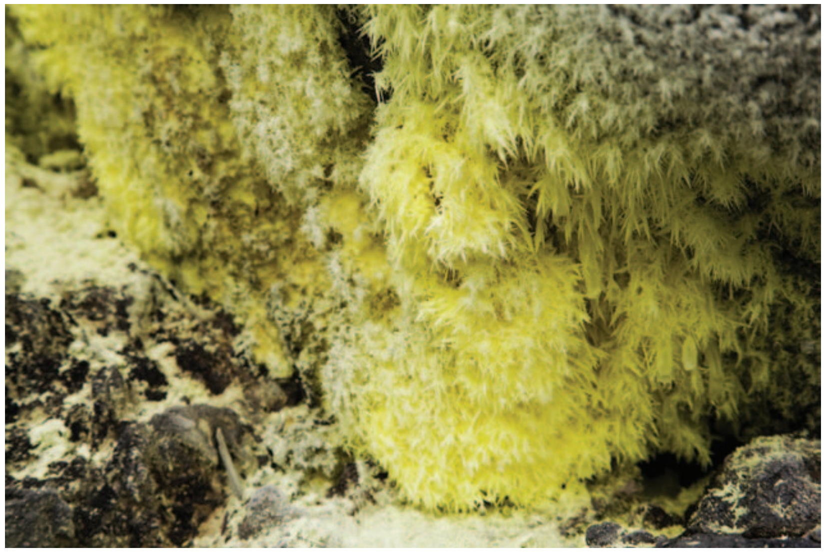
$$\mathbf{Mg + S \xrightarrow{heated} MgS}$$

Sulfur also combines with **hydrogen** gas:

$$\mathbf{H_2 + S \xrightarrow{heated} H_2S}$$

The compound formed in this reaction is hydrogen sulfide (H_2S). Hydrogen sulfide has one of the best known odors of all compounds. It smells like rotten eggs. Hydrogen sulfide is added to natural gas (methane) used in homes for cooking and heating. Methane is odorless, so the unique smell of hydrogen sulfide makes it easy to know when there is a methane leak.

A chemical reaction involving sulfur. © LAWRENCE MIGDALE/ SCIENCE SOURCE/NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.



Sulfur crystals, like those pictured here on the Kilauea Volcano in Hawaii, form as sulfur vapors escape from volcanic vents. IMAGE COPYRIGHT 2009, LITTLESAM. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Occurrence in Nature

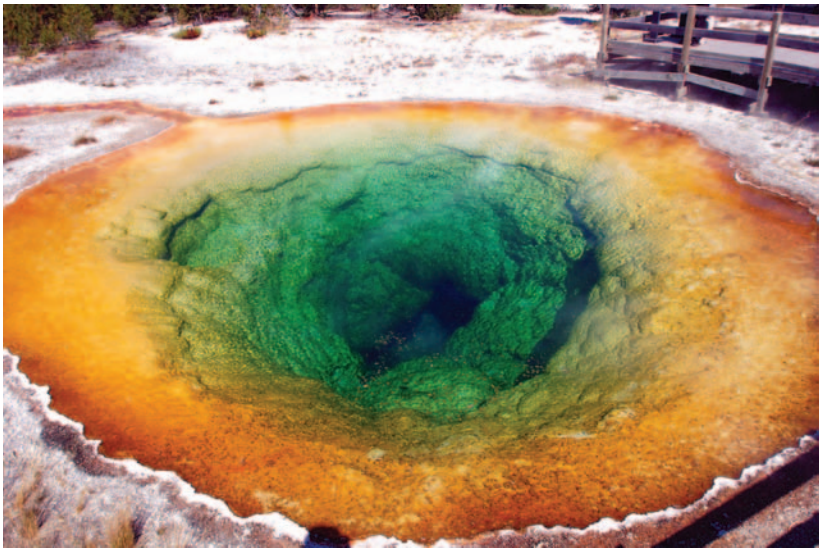
At one time, sulfur occurred in layers along Earth's surface. They were easy for humans to find and take. Deposits like these are more difficult to find today. One place they still occur is in the vicinity of volcanoes. Sulfur is released from volcanoes as a gas. When it reaches the cold air, it changes back to a solid. It forms beautiful yellow deposits along the edge of a volcano.

Large supplies of sulfur still occur underground. They are removed by the Frasch process.

Sulfur also occurs in a number of important minerals. Some examples are barite, or barium sulfate ($BaSO_4$); celestite, or **strontium** sulfate ($SrSO_4$); cinnabar, or mercury sulfide (HgS); galena, or **lead** sulfide (PbS); pyrites, or **iron** sulfide (FeS_2); sphalerite, or **zinc** sulfide (ZnS); and stibnite, or **antimony** sulfide (Sb_2S_3).

The abundance of sulfur in Earth's crust is thought to be about 0.05 percent. It ranks about number 16 among the elements in terms of their abundance in the earth. It is more abundant than carbon, but less abundant than barium or strontium.

As of 2008, the largest producers of sulfur in the world were the United States, Canada, China, Russia, and Japan. That year, the United States produced about 9.26 million short tons (8.4 million metric tons) of elemental sulfur. It was mined in 29 states and the U.S. Virgin Islands.



The distinctive rotten-egg smell of sulfur permeates many thermal areas of Yellowstone National Park in Wyoming.

According to the U.S. Geological Survey (USGS), shipments totaled nearly $1 billion. The total reflected a dramatic increase in the cost from the previous year.

Isotopes

There are four naturally occurring isotopes of sulfur: sulfur-32, sulfur-33, sulfur-34, and sulfur-36. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fourteen radioactive isotopes of sulfur are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of sulfur, sulfur-35, is used commercially. In medicine, the isotope is used to study the way fluids occur inside the body. It also has applications in research as a tracer. A tracer is a radioactive isotope whose presence in a system can easily be detected.

The isotope is injected into the system at some point. Inside the system, the isotope gives off radiation. That radiation can be followed by means of detectors placed around the system.

As an example, a company that makes rubber tires might want to know what happens to the sulfur added to tires. Sulfur-35 is added to rubber along with non-radioactive sulfur. Researchers follow the radioactive isotope in the tires to see what happens to the sulfur when the tires are used.

Similar applications of sulfur-35 involve studying sulfur in steel when it is made, seeing how sulfur affects the way engines operate, following what happens when proteins (which contain sulfur) are digested, and learning how drugs that contain sulfur are processed in the body.

Extraction

Like coal, sulfur sometimes occurs in thick layers underground. One way to remove sulfur would be to mine it the way coal is mined. But a much easier method for removing sulfur from the ground is the Frasch method.

Uses

Sulfur has relatively few uses as an element. One of the most important of those uses is in vulcanization. Vulcanization is the process of adding sulfur to rubber to make it stiff and hard. It keeps the rubber from melting as it gets warmer. The discovery of vulcanization by Charles Goodyear (1800–1860) in 1839 is one of the greatest industrial accomplishments of modern times.

Some powdered sulfur is also used as an insecticide. It can be spread on plants to kill or drive away insects that feed on the plants. By far the majority of sulfur is used, however, to make sulfur compounds. The most important of these is sulfuric acid (H_2SO_4).

Compounds

Nearly 90 percent of all sulfur produced is used to make sulfuric acid. Sulfuric acid is the number one chemical in the world in terms of the amount produced. In 2007, more than 39.8 million short tons (36.1 million metric tons) of sulfuric acid were produced in the United States alone.

The greatest portion of sulfuric acid is used to make fertilizers. The next most important use is in the petroleum industry. Other important

Understanding the Frasch Method

The Frasch method is one of the most famous mining systems ever invented. It was developed by German-American chemist Herman Frasch (1851–1914) in 1887.

The Frasch method is based on the low melting point of sulfur. The element melts at a temperature slightly higher than that of boiling water (212°F/100°C). Here is how the method works:

A set of three nested pipes (one inside each other) is sunk into the ground. The innermost pipe has a diameter of about 1 inch (2.5 centimeters). The middle pipe has a diameter of about 4 inches (10 centimeters). And the outer pipe has a diameter of about 8 inches (20 centimeters).

A stream of superheated water is injected into the outer pipe. Superheated water is water that is hotter than its boiling point, but that has not started to boil. Superheated water can be made by raising the pressure on the water. Its temperature can reach 320°F (160°C).

The superheated water passes down the outer pipe into the underground sulfur, causing it to melt. The molten (melted) sulfur forms a lake at the bottom of the pipe.

At the same time, a stream of hot air under pressure is forced down the innermost (1-inch) pipe. The hot air stirs up the molten sulfur and hot water at the bottom of the pipe. A foamy, soupy mixture of sulfur and water is formed. The mixture is forced upward through the middle pipe. When it reaches the surface, it is collected. The sulfur cools and separates from the water.

uses of sulfuric acid are in the treatment of **copper** ores; the production of paper and paper products; the manufacture of other agricultural chemicals; and the production of plastics, synthetic rubber, and other synthetic materials.

Sulfuric acid is also used in smaller amounts to make explosives, water treatment chemicals, storage batteries, pesticides, drugs, synthetic fibers, and many other chemicals used in everyday life.

Health Effects

The cleansing power of sulfur has been known for many centuries. At one time, ancient physicians burned sulfur in a house to cleanse it of impurities. Creams made with sulfur were used to treat infections and diseases. In fact, sulfur is still used to treat certain medical problems.

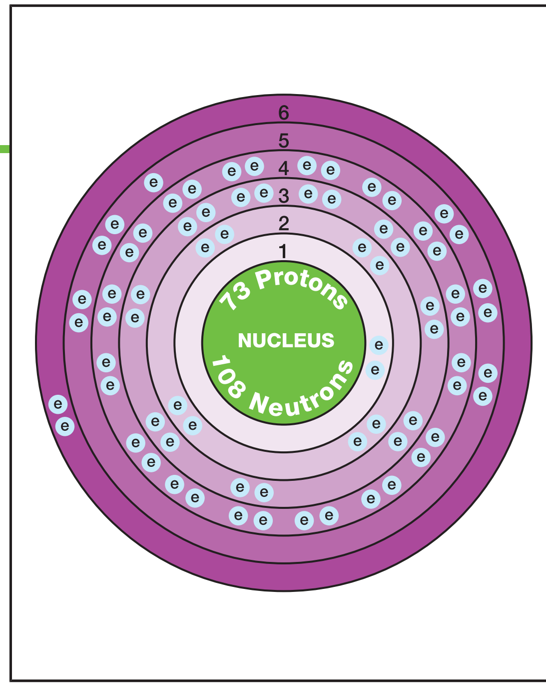
Sulfur is prepared in one of three forms. Precipitated sulfur (milk of sulfur) is made by boiling sulfur with lime. Sublimed sulfur (flowers of sulfur) is pure sulfur powder. And washed sulfur is sulfur treated with ammonia water. Washed sulfur is used to kill parasites (organisms that live on other organisms) such as fleas and ticks. It is also used as a laxative, a substance that helps loosen the bowels.

Sulfur is a macronutrient for both plants and animals. A macronutrient is an element needed in relatively large amounts to insure the good health of an organism. Sulfur is used to make proteins and nucleic acids, such as DNA. It also occurs in many essential enzymes. Enzymes are chemicals that make chemical reactions occur more quickly in cells. Humans usually have no problem getting enough sulfur in their diets. Eggs and meats are especially rich in sulfur.

A person who does not get enough sulfur in his or her diet develops certain health problems. These include itchy and flaking skin and improper development of hair and nails. Under very unusual conditions, a lack of sulfur can lead to death. Such conditions would be very rare, however.

Plants require sulfur for normal growth and development. When plants do not get enough sulfur from the soil, their young leaves start to turn yellow. Eventually, this yellowing extends to the whole plant. The plant may develop other diseases as a result.

Tantalum



Overview

Tantalum is a transition metal in Group 5 (VB) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Tantalum is one of the most inert metals known. An inert material is one that does not react with most other chemicals. Most metals, for example, dissolve in acids, but tantalum is not affected by acids or other strong chemicals. For this reason, tantalum is used to make chemical, medical, and dental equipment.

Credit for the discovery of tantalum goes to Swedish chemist and mineralogist Anders Gustaf Ekeberg (1767–1813). Ekeberg announced his discovery in 1802. However, chemists were uncertain about Ekeberg's new element for many years. They believed that another element, **niobium**, might be present along with tantalum. In fact, it was not until 50 years later that chemists could be sure that tantalum and niobium were really two different elements.

Key Facts

Symbol: Ta

Atomic Number: 73

Atomic Mass: 180.94788

Family: Group 5 (VB); transition metal

Pronunciation: TAN-tuh-lum

Discovery and Naming

In 1801, English chemist Charles Hatchett (1765–1847) discovered a new element that he named niobium. A year later, Ekeberg discovered

WORDS TO KNOW

Capacitor: An electrical device, somewhat like a battery, that collects and then stores up electrical charges.

Ductile: Capable of being drawn into thin wires.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Inert: Having little tendency to react with most other chemicals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to one another.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

a new element that he named tantalum. The two names are related. Niobium was named for the mythical daughter of Tantalus, Niobe.

Tantalus was a son of Zeus, the major Greek god. Zeus decided to punish his son for giving the gods' secrets to humans. He forced Tantalus to stand in a vat filled with water up to his chin. Whenever Tantalus bent to take a drink, the water dropped a little lower so he could never get his drink. Ekeberg said that his new element was like Tantalus. When placed in acid, it did not take up (react with) the acid.

Most chemists thought that the two men's discoveries were one and the same. The two elements reacted exactly like each other. They could not see how tantalum was different from niobium. For more than 40 years, the general belief was that Ekeberg and Hatchett had discovered the same element.

In 1844, however, German chemist Heinrich Rose (1795–1864) announced new evidence. He found that tantalic acid (H_3TaO_4) made from tantalum and niobic acid (H_3NbO_4) made from niobium were definitely different from each other. He confirmed that Ekeberg and Hatchett had really discovered two different elements.

Physical Properties

Tantalum is a very hard, malleable, ductile metal. Malleable means capable of being hammered into thin sheets. Ductile means capable of being drawn into thin wires. The metal has a silvery-bluish color when unpolished, but a bright silvery color when polished. It has a melting point of 5,425°F (2,996°C) and a boiling point of 9,804°F (5,429°C). It has the third highest melting point of all elements, after **tungsten** and **rhenium**. Tantalum's density is 16.69 grams per cubic centimeter, nearly 17 times the density of water.

Chemical Properties

Tantalum is one of the most unreactive metals. At room temperature, it reacts only with **fluorine** gas and certain fluorine compounds. Fluorine, a non-metal, is the most active element. At higher temperatures, tantalum becomes more active. Above about 300°F (150°C), it reacts with acids and alkalis. An alkali is the chemical opposite of an acid.

Occurrence in Nature

Tantalum ranks about number 50 among elements found in Earth's crust. It is slightly more common than tungsten, but less common than **arsenic**. Its abundance is probably about 1.7 parts per million in the earth. The element is most commonly found in the minerals columbite, tantalite, and microlite. It always occurs with niobium.

Most of the tantalum worldwide comes from Australia, Brazil, and Canada. Australia, China, and Brazil were the main suppliers of tantalum to the United States in 2008. According to the U.S. Geological Survey (USGS), Americans used approximately $190 million of tantalum that year.

Isotopes

There are two naturally occurring isotopes of tantalum: tantalum-180m and tantalum-181. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Tantalum-180m is radioactive. The suffix "m" means that the isotope is metastable, that is, it changes to a more stable state over time. A radioactive isotope is one that breaks apart and gives off some form of radiation. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. Tantalum-180m has a half life of more than one trillion years. It makes up about 0.01 percent of all natural tantalum.

Forty-two radioactive isotopes of tantalum have been made artificially. None of these isotopes has any commercial application.

Extraction

After tantalum ores are taken from the earth, they are converted to tantalum **potassium** fluoride (K_2TaF_7). Pure tantalum is then obtained from this compound by passing an electric current through it.

Tantalum alloys are used in artificial knees as well as hips and other joints. IMAGE COPYRIGHT 2009, VADIM KOZLOVSKY. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Uses

The primary use of tantalum metal is in making capacitors. A capacitor is an electrical device similar to a battery. It can be given an electrical charge, which it then stores until needed. Capacitors are essential parts of nearly all electrical circuits. Semiconductor circuits, like those used in transistors, require tiny capacitors the size of grains of rice. Tantalum is one of the best metals for this purpose. Different kinds of capacitors are made for many different applications. They are used in military weapons systems, aircraft, space vehicles, communication systems, computers, and medical applications. For example, the smallest hearing aids are likely to have a tantalum capacitor.

Tantalum is also used in many different alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Tantalum alloys are used in laboratory equipment, weights for very precise balances, fountain and ballpoint pen points, and tools that have to operate at high speeds and temperatures.

Another application for tantalum alloys is in medical and dental applications. The metal has no effect on body tissues. It is used in artificial hips, knees, and other joints. Pins, screws, staples, and other devices used to holds bones together are also made of tantalum alloys.

Compounds

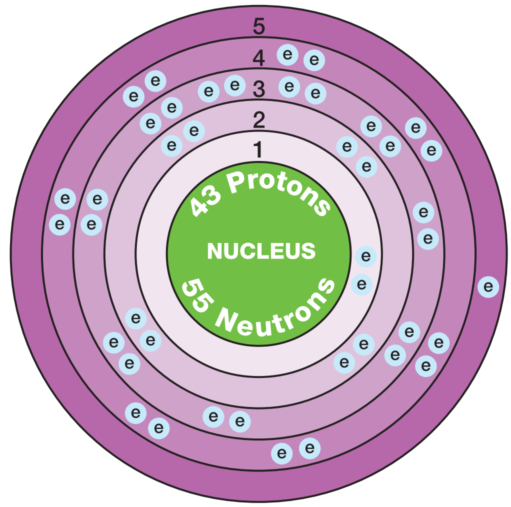
A few compounds of tantalum have some important uses. They are as follows:

- tantalum carbide (TaC): a very hard material used for cutting tools and dies
- tantalum disulfide (TaS_2): used in the form of a black powder, it acts as a solid lubricant, like powdered carbon
- tantalum oxide (Ta_2O_5): used in the preparation of special types of glass; used in specialized lasers (devices for producing a very bright light of a single color).

Health Effects

Tantalum and its compounds are not thought to pose a serious health hazards to humans and animals.

Technetium



Overview

Technetium is the only element below **uranium** that does not exist on Earth. It is a synthetic (human-made) element produced in a particle accelerator. For many years, chemists knew that an element with atomic number 43 must exist, based on an empty spot in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. By 1925, only five empty boxes remained. Five elements were still to be discovered.

A number of scientists tried to find those elements. In many cases, the results they announced were wrong. Such was the case with element 43. When the element's "discovery" was announced in 1925, chemists were excited, but no one else was able to repeat the discovery. An error had been made. In fact, it was not until more than 10 years later that the element was finally produced. Then, it was created in a particle accelerator and not found on Earth.

Today, technetium has very few—but very important—uses. It is used in finding out more about diseases and health problems. It is also used to make steel stronger.

Key Facts

Symbol: Tc

Atomic Number: 43

Atomic Mass: [98]

Family: Group 7 (VIIB); transition metal

Pronunciation: tek-NEE-she-um

WORDS TO KNOW

Diagnosis: Finding out what medical problems a person may have.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear reactor: A device in which neutrons are made to collide with atoms of uranium or plutonium.

Particle accelerator ("atom smasher"): A device used to cause small particles to move at very high speeds.

Periodic table: A chart that shows how chemical elements are related to each other.

Discovery and Naming

In the 1920s, a team of researchers were looking for elements with atomic numbers 43 and 75. This team consisted of German chemists Walter Noddack (1893–1960), Ida Tacke (1896–1979), and Otto Berg. In 1925, the team announced that they had found both elements. They named element 43 masurium, after the region called Masurenland in eastern Germany, and element 75 **rhenium**, after the Rhineland, in western Germany. Although they were correct about rhenium, they were wrong about masurium. No other chemist was able to reproduce masurium.

So, chemists kept looking for element 43. It was finally discovered in the products of a particle accelerator experiment at the University of California at Berkeley. A particle accelerator is sometimes called an atom smasher. It accelerates small particles, such as protons, to very high speeds. The particles then collide with elements such as **gold**, **copper**, or **tin**. When struck by the particles, the targets often form new elements.

Element 43 was found by Italian physicist Emilio Segrè (1905–1989) and his colleague Carlo Perrier. These researchers collected one ten-billionth of a gram of the element and studied some of its properties. They eventually gave the name technetium to the element, from the Greek word *technetos,* meaning "artificial." Technetium was the first element not found in the earth to be made artificially. It can now be made in much larger quantities, of at least two pounds (one kilogram) at a time.

Physical Properties

Technetium is a silver-gray metal with a melting point of 4,000°F (2,200°C) and a density of 11.5 grams per cubic centimeter, almost 12 times the density of water.

Chemical Properties

Technetium is placed between **manganese** and rhenium on the periodic table. That placement would lead chemists to believe that its properties are like those of the other two elements. Experiments have shown this to be true. It reacts with some acids, but not others. It also reacts with **fluorine** gas and with **sulfur** at high temperatures.

Occurrence in Nature

Some scientists believe that technetium will be found in very small amounts in Earth's crust along with other radioactive materials, such as uranium and **radium**. However, it has never been found on Earth. It has, however, been found in certain types of stars. Its presence can be detected by analyzing the light produced by these stars.

Isotopes

All 37 isotopes of technetium are radioactive. The most stable of these isotopes, technetium-97 and technetium-98, have half lives of 2.6 million years and 4.2 million years, respectively. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The half life of a radioactive element is the time it takes for half of a sample of the element to break down. After 2.6 million years, only 5 grams of a 10-gram sample of technetium-97 would remain. After another 2.6 million years, only half of that, or 2.5 grams, would be left.

Extraction

Technetium is produced in nuclear reactors. A nuclear reactor is a device in which uranium or **plutonium** is bombarded with neutrons. The neutrons

An Ideal Diagnostic Tool—Almost!

Technetium-99m is an almost ideal diagnostic tool. It has a half life of about six hours. After six hours, only half of it remains as technetium-99m. The rest has broken down into another element. After 24 hours, only 1/16th of the original isotope remains. It breaks down and disappears very quickly.

When injected into the body, technetium deposits in certain organs, such as the brain, liver, spleen, and kidney. It also deposits in the bones. Technetium-99m gives off radiation that can be detected very easily. The amount and location of the radiation indicates problems with an organ or bones. Technetium-99m sends out clear, easily observed signals for a short time. Then, it is eliminated from the body.

The only problem with technetium-99m is how to get it. If a doctor ordered technetium-99m from a supplier a great distance away, by the time the isotope arrived at the hospital, it would have almost completely broken down!

Instead, medical workers use a different isotope, molybdenum-99. When molybdenum-99 breaks down, it forms technetium-99m. But molybdenum-99 has a longer half life, almost three days.

When medical workers need technetium-99m, they bring in a container of molybdenum-99. They separate the technetium-99m as it is formed from the molybdenum-99. When molybdenum-99 is used in this way, it is called a "molybdenum cow."

cause the uranium or plutonium to fission, or split apart into smaller elements. One of the elements produced in this process is technetium. The technetium is collected from spent fuel rods, rods that contain the uranium or plutonium used in the reactor. The technetium removed from fuel rods is converted to ammonium pertechnate (NH_4TcO_4). That compound is then treated with **hydrogen** gas to obtain pure technetium metal.

Uses

Technetium is used in steel alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Technetium-steel alloys are very resistant to corrosion or reaction with **oxygen** and other materials. No more than 50 parts per million of technetium to steel produces this property. Technetium-steel has limited uses, however, because technetium is radioactive. People cannot be exposed to technetium-steel directly. Thus far, technetium-steel has no commercial uses.

Technetium is a popular diagnostic tool in medicine. The term diagnosis means to find out what medical problems a person may have.

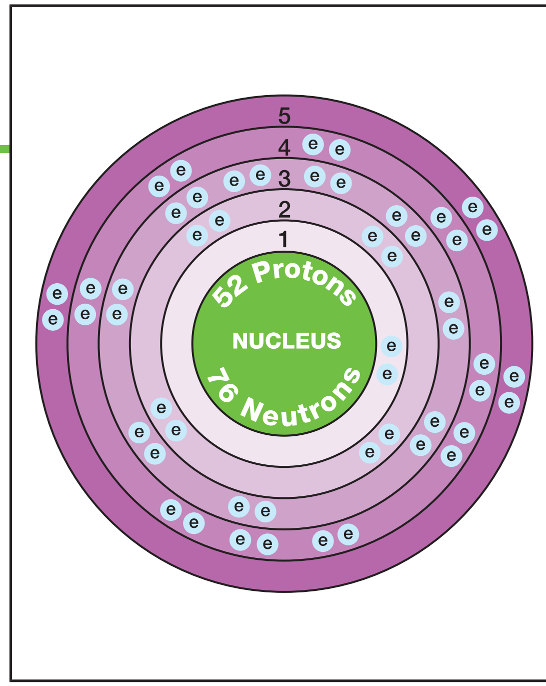
Compounds

There are no commercially important compounds of technetium.

Health Effects

Since all forms of technetium are radioactive, the element must be handled with great care. Radiation damages or kills living cells. A significant exposure produces radiation sickness.

Tellurium



Key Facts

Symbol: Te

Atomic Number: 52

Atomic Mass: 127.60

Family: Group 16 (VIA); chalcogen

Pronunciation: tuh-LUHR-ee-um

Overview

The elements that make up Group 16 (VIA) of the periodic table are sometimes called the *chalcogens.* This name comes from the Greek word for "ore forming," *chalkos.* The first two elements in the family, **oxygen** and **sulfur**, are often found in ores. Tellurium is the next to last member of that family. The periodic table is a chart that shows how chemical elements are related to one another.

The chalcogens are one of the most interesting families in the periodic table. The first member, oxygen, is a gas with very un-metal-like properties. The next two members of the family, sulfur and **selenium**, are solids, with increasingly metallic properties. Tellurium, near the bottom of the family, looks and behaves very much like most metals. The slow change of properties, from less metal-like to more metal-like, occurs in all families in the periodic table. But the change is seldom as dramatic as it is in the chalcogens.

Tellurium was discovered in 1782 by Austrian mineralogist Baron Franz Joseph Müller von Reichenstein (1740–c. 1825). The element seldom occurs in its pure state. It is usually found as a compound in ores of **gold**, **silver**, **copper**, **lead**, **mercury**, or **bismuth**. The most common

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Vulcanization: The process by which soft rubber is converted to a harder, longer-lasting product.

use of tellurium today is in specialized alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The majority of all tellurium consumed goes into alloys. The other two major uses of tellurium are in making chemicals and electrical equipment.

Discovery and Naming

Müller discovered tellurium while studying gold taken from a mine in the Börzsöny Mountains of Hungary. He had received the gold from a colleague who thought that it contained an impurity. The colleague was unable to identify the impurity, but thought it might be "unripe gold."

The concept of "unripe gold" was invented before the birth of modern chemistry. Earlier scientists—called alchemists—thought that gold "grew" in the earth in much the same way that plants grow. They thought gold went through various stages, from lead to mercury to silver to gold. These metals were thought to be the same material in various stages of growth.

This view of tellurium is reflected in some of its older names. It was also known as *aurum paradoxum* and as *metallum problematum.* The first name means "paradoxical gold," something that acts like gold, but really isn't. The second name means "the problem metal."

Müller held more modern views, however. He suspected that the impurity was not "unripe gold," but a new element. He conducted more than 50 tests on the new material over a three-year period. He came to have a clear understanding of the new element.

Many years later, Müller sent a sample of the new element to German chemist Martin Heinrich Klaproth (1743–1817). Klaproth confirmed Müller's discovery. He suggested the name tellurium, from the Latin word *tellus,* meaning "Earth."

Tellurium is often found with another element, selenium. That element was discovered 30 years later and named in honor of the moon. In Latin, the word for moon is *selene*.

Physical Properties

Tellurium is a grayish-white solid with a shiny surface. It has a melting point of 841.6°F (449.8°C) and a boiling point of 1,814°F (989.9°C). Its density is 6.24 grams per cubic centimeter. It is relatively soft. Although it has many metal-like properties, it breaks apart rather easily and does not conduct an electric current very well.

Chemical Properties

Tellurium does not dissolve in water. But it does dissolve in most acids and some alkalis. An alkali is a chemical with properties opposite those of an acid. Sodium hydroxide (common lye) and limewater are examples of alkalis.

Tellurium samples. © RUSS LAPPA/SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

Tellurium also has the unusual property of combining with gold. Gold normally combines with very few elements. The compound formed between gold and tellurium is called gold telluride (Au_2Te_3). Much of the gold found in the earth occurs in the form of gold telluride.

Occurrence in Nature

Tellurium is one of the rarest elements in Earth's crust. Its abundance is estimated to be about 1 part per billion. That places it about number 75 in abundance of the elements in the earth. It is less common than gold, silver, or **platinum**.

The most common mineral of tellurium is sylvanite. Sylvanite is a complex combination of gold, silver, and tellurium. Tellurium is obtained commercially today as a by-product in copper and lead refining.

Isotopes

Eight naturally occurring isotopes of tellurium are known. They are tellurium-120, tellurium-122, tellurium-123, tellurium-124, tellurium-125, tellurium-126, tellurium-128, and tellurium-130. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Three of the naturally occurring isotopes of tellurium are radioactive: tellurium-123, tellurium-128, and tellurium-130. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. Thirty-five additional radioactive isotopes of tellurium are also known.

None of the radioactive isotopes of tellurium have any commercial uses.

Extraction

More than 90 percent of the tellurium produced in the United States is obtained as a by-product of the refining of copper. The waste materials left over from this process are treated to obtain pure tellurium.

Uses and Compounds

The majority of tellurium produced today is used in alloys. Its most important alloy is a tellurium-steel alloy. It has better machinability than does steel without tellurium. Machinability means working with a metal: bending, cutting, shaping, turning, and finishing the metal, for example. Adding 0.04 percent tellurium to steel makes it much easier to work with.

Tellurium is also added to copper to improve machinability. Tellurium-copper alloys are also easier to work with than pure copper. And the essential ability of copper to conduct an electric current is not affected. Tellurium is also added to lead. Tellurium-lead alloys are more resistant to vibration and fatigue than pure lead. Metal fatigue is the tendency of a metal to wear out and eventually break down after long use.

Smaller amounts of tellurium are also used in the rubber and textile industries. It is important in the vulcanization of rubber, for example. Vulcanization is the process by which soft rubber is converted to a harder, longer-lasting product. Tellurium is also used as a catalyst in the manufacture of synthetic fibers. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself.

Tellurium has been used to improve picture quality in photocopiers and laser printers. IMAGE COPYRIGHT 2009, NORMAN POGSON. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Tellurium is also used in a variety of electrical devices. For example, it has been used to improve picture quality in photocopiers and printers. However, tellurium is being phased out in some of the newer machines.

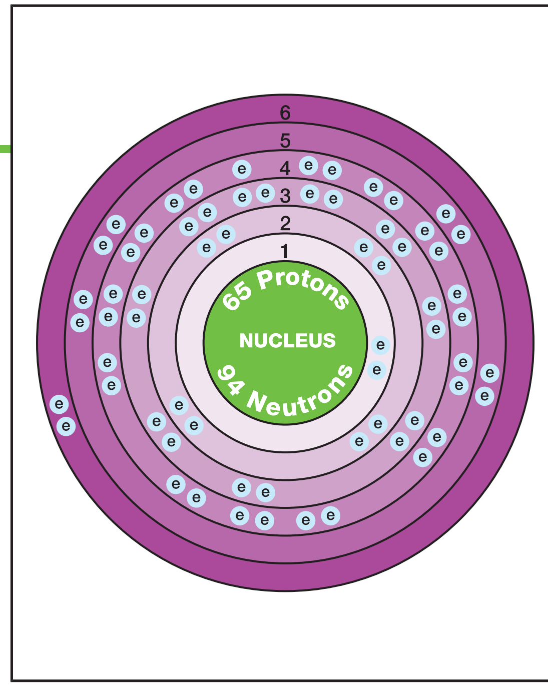
A compound of tellurium, **cadmium**, and mercury is also used in infrared detection systems. Infrared radiation is heat. It can be made visible with special glass. Some satellites orbiting Earth study forests, crops, and other plant life by measuring the infrared radiation they give off.

Finally, a very small amount of tellurium is used for minor applications, such as a coloring agent in glass and ceramics and in blasting caps for construction projects.

Health Effects

Tellurium is an irritant to the skin, eyes, and respiratory system. If taken internally, it can cause nausea, vomiting, and damage to the central nervous system. One interesting side effect is that it gives a garlicky-odor to the breath.

Terbium



Key Facts

Symbol: Tb

Atomic Number: 65

Atomic Mass: 158.92535

Family: Lanthanoid (rare earth metal)

Pronunciation: TER-bee-um

Overview

Terbium is classified as a rare earth element. The term is misleading because terbium is not especially rare in Earth's crust. It is more abundant than better known metals such as **silver** and **mercury**. Although the rare earth elements are not actually scarce, they were once very difficult to separate from each other. They have physical and chemical properties very similar to each other.

Today, chemists have developed methods for separating elements from each other. Terbium doesn't have a great many uses, but is easily available. One use is in television screens. It helps the screen display the colors more clearly. It is also used in some hybrid cars.

Although the term "rare earth" is still used, the more proper name for terbium and its cousins is the lanthanoids. The term lanthanoid comes from the element **lanthanum** in Row 6 of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another.

Discovery and Naming

Terbium was discovered during the great element hunt of the 1840s. That hunt began with a lucky discovery made in 1787. A lieutenant in

WORDS TO KNOW

Ductile: Capable of being drawn into thin wires.

Fuel cell: Any system that uses chemical reactions to produce electricity.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Malleable: Capable of being hammered into thin sheets.

Phosphor: A material that gives off light when struck by electrons.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Toxic: Poisonous.

the Swedish army, Carl Axel Arrhenius (1757–1824), discovered an unusual black rock near the town of Ytterby, Sweden. Arrhenius passed the rock on to a friend of his, chemist Johan Gadolin (1760–1852). Gadolin analyzed the sample to see what elements it contained.

Gadolin first discovered an entirely new mineral that he named yttria, after the town of Ytterby. This discovery, however, was only the first in a long chain of puzzling new findings.

In 1843, Swedish chemist Carl Gustav Mosander (1797–1858) demonstrated that yttria was really a mixture of three other minerals. He called those minerals erbia, terbia, and yttria. All three of these names also came from the town of Ytterby. The ending *-a* on these names means that they refer to minerals that occur in the earth. A mineral ending in *-a* usually refers to an element combined with **oxygen**. For example, soda is a combination of **sodium** and oxygen.

Mosander's research is long and complicated. Chemists did not have good equipment in the 1840s. They often made errors and were confused by their discoveries. For example, other chemists also studied the mineral yttria. When they did so, however, they got the names that Mosander used mixed up. They called his terbia "erbia" and his erbia "terbia."

Mosander is given credit for discovering terbium even though he never saw the pure element. In 1886, French chemist Jean-Charles-Galissard de Marignac (1817–1894) was the first person to prepare pure terbium.

Physical Properties

Terbium has the silver-gray luster typical of many metals. It is quite soft, however, and can be cut with a knife. It is also malleable and ductile, meaning it can be hammered into thin sheets and drawn into wires rather easily. The melting point of terbium is 2,473°F (1,356°C) and its boiling point is about 5,000°F (2,800°C). It has a density of 8.332 grams per cubic centimeter, more than eight times the density of water.

Chemical Properties

Like many of its rare earth cousins, terbium is not very active. It does not react with oxygen in the air very easily. It does react with water slowly, however, and will dissolve in acids.

Occurrence in Nature

Terbium is one of the rarest of the lanthanoids. It ranks about 55th among the elements in Earth's crust. It is about as abundant as **molybdenum** and **tungsten**, but more abundant than **iodine**, **silver**, and **gold**. Terbium occurs with other lanthanoids in minerals such as monazite, cerite, gadolinite, xenotime, and euxenite. In 2007, terbium oxide sold for about $850 per kilogram.

Isotopes

Only one isotope of terbium occurs in nature: terbium-159. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty-two radioactive isotopes of terbium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope, terbium-149, is used in medicine. The isotope is injected directly into cancer cells in a patient's body. The radiation given off kills the cancer cells. Terbium-149 is used because its radiation does not travel far, so it does not damage healthy cells. Therefore, it is safer to use than some other radioactive isotopes.

Extraction

The rare earth elements often occur together in the earth. A mineral like monazite may contain half a dozen or more different rare earth elements. The chemist's job, then, is to find a way to separate all these elements from each other.

Today, a standard procedure is available for separating the rare earth elements from each other. In this procedure, terbium usually ends up in the form of the compound terbium fluoride (TbF_3). Pure terbium metal may then be obtained by passing an electric current through the compound:

$$2TbF_3 \rightarrow 2Tb + 3F_2$$

Reacting calcium metal with terbium fluoride also produces free terbium:

$$3Ca + 2TbF_3 \rightarrow 3CaF_2 + 2Tb$$

Uses and Compounds

Probably the most common use of terbium and its compounds is in phosphors. A phosphor is a material that gives off light when struck by

Terbium is used in X-ray screens. This X ray shows the wrist and hand of a middle-aged woman. IMAGE COPYRIGHT 2009, LAURENT DAMBIES. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

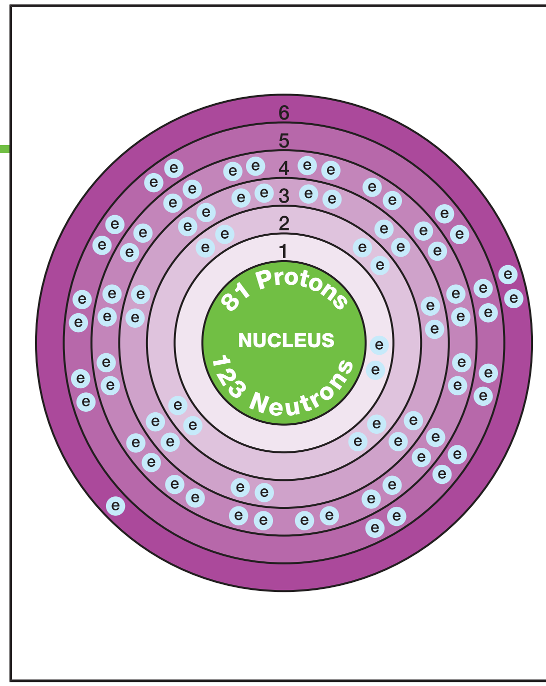
electrons. The back of a television screen is coated with different kinds of phosphors. When those phosphors are struck by electrons inside the television tube, they give off different colors of light. Phosphors that contain terbium give off a green light when struck by electrons. They are also used in X-ray screens to make very clear pictures.

Another use of terbium is in the manufacture of fuel cells. Any system that uses chemical reactions to produce electricity is a fuel cell. Fuel cells will probably be much more widely used as a source of electricity in the future. Terbium fuel cells operate effectively at very high temperatures.

Health Effects

Little research exists on the health effects of terbium. The information that is available suggests that it probably has few harmful effects on the human body and is not very toxic if ingested.

Thallium



Key Facts

Symbol: Tl

Atomic Number: 81

Atomic Mass: 204.3833

Family: Group 13 (IIIA); aluminum

Pronunciation: THA-lee-um

Overview

Thallium is a member of the **aluminum** family, Group 13 (IIIA) in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Thallium is also classified as a heavy metal, along with **mercury**, **cadmium**, and **lead**.

Thallium was first discovered by means of a spectroscope. A spectroscope is a device for analyzing the light produced when an element is heated. The spectrum (plural: *spectra*) of an element consists of a series of colored lines that are different for every element. The brightest lines in the spectrum of thallium are green, which accounts for its name. In Greek, the word *thallos* means "green twig." The green lines in thallium's spectrum look like green twigs.

Thallium is a rather uncommon element. Still, some of its compounds have important applications. For example, thallium sulfate (Tl_2SO_4) has long been used as a rodenticide (rat and mouse poison). One form of thallium is sometimes used to study the flow of blood in the body. It shows how well the heart is working.

Discovery and Naming

The spectroscope was invented in 1814 by German physicist Joseph von Fraunhofer (1787–1826). Forty years later, German chemists Robert

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactivity: Having the tendency to break apart and give off some form of radiation.

Rodenticide: A poison used to kill rats and mice.

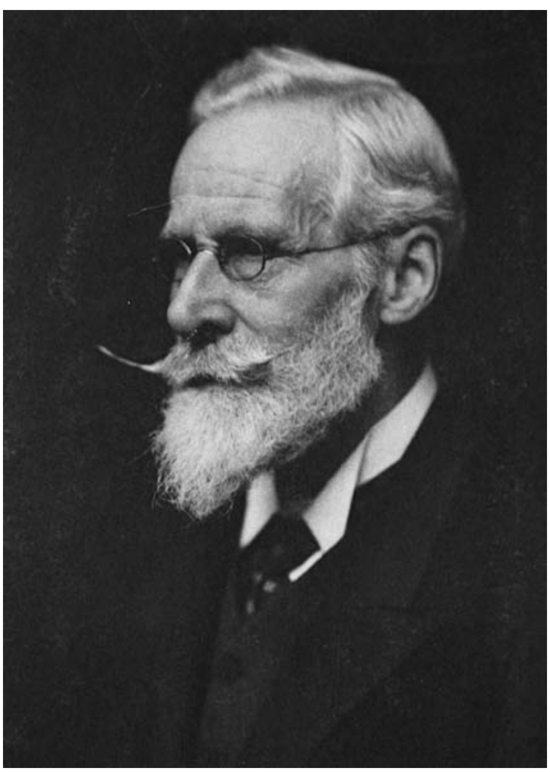
Spectroscope: A device for analyzing the light produced when an element is heated.

Superconductivity: The tendency for an electric current to continue flowing through a material forever once it has begun.

Toxic: Poisonous.

Bunsen (1811–1899) and Gustav Robert Kirchhoff (1824–1887) improved on the instrument and showed how it could be used to study chemical elements.

Sir William Crookes. LIBRARY OF CONGRESS.



Scientists were fascinated by the instrument. They could detect the presence of elements without actually seeing them. A mineral is made of many elements, each of which gives off its own series of colored (spectral) lines. The spectroscope is able to detect all the elements present in the mineral.

Within a period of four years after the work of Bunsen and Kirchhoff, four new elements were discovered: **cesium**, **rubidium**, thallium, and **indium**. All four elements are named after the color of their spectral lines. The discoverer of thallium was British physicist Sir William Crookes (1832–1919).

Interestingly, thallium was discovered at almost the same time by French chemist Claude-Auguste Lamy (1820–1878). Lamy discovered thallium the "old fashioned way," by separating one of its minerals in the laboratory. For a short time, there was a difference of opinion as to whether Lamy or Crookes was the "real" discoverer of thallium. Eventually, the decision was made in favor of Crookes.

Physical Properties

Thallium is a heavy, bluish-white metal that resembles lead, element 82. Thallium is very soft and melts easily. It is soft enough to be cut with an ordinary knife and will leave a mark on paper if rubbed across it.

Thallium has a melting point of 576°F (302°C) and a boiling point of 2,655°F (1,457°C). Its density is 11.85 grams per cubic centimeter, almost 12 times the density of water.

Chemical Properties

Thallium is a fairly active element. It reacts with acids and with **oxygen** in the air. When exposed to air, it forms a thin coating of thallium oxide (Tl_2O) that peels off easily. As the coating drops off, a new layer forms in its place.

Occurrence in Nature

Thallium is quite uncommon in Earth's crust. Its abundance is estimated to be about 0.7 parts per million. That puts it in the bottom half among the elements in terms of abundance. It is about as common as **iodine** or **tungsten**.

The most common minerals containing thallium are crookesite, lorandite, and hutchinsonite.

Isotopes

Two naturally occurring isotopes of thallium exist: thallium-203 and thallium-205. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Fifty-two radioactive isotopes of thallium have also been made. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

During a stress test, thallium-201 is injected into the patient's bloodstream to determine if his or her heart is working properly.

Thallium-201 is used by doctors to determine how well a person's heart is working. In many cases, the isotope is used as part of a stress test. Thallium-201 is injected into the patient's bloodstream as he or she exercises on a treadmill or bicycle. As soon as the exercise ends, the patient lies down. A large camera is passed over the body. The camera records the radiation given off by the isotope. This record shows whether the patient's heart is working properly or not.

Extraction

Thallium is obtained as a by-product of the recovery of lead and **zinc**. Gaseous compounds of the element formed during the recovery process are captured. They are then treated to obtain the pure metal.

Uses and Compounds

For many years, thallium sulfate (Tl_2SO_4) was used as a rodenticide. It worked well with rats and mice because it passes through their skin easily. Once inside their bodies, it causes death. Thallium sulfate is also colorless and odorless, so rats and mice were not aware the compound was present.

Unfortunately, thallium sulfate has the same effects on humans. Accidental poisoning, especially of young children, led thallium sulfate to be banned as a rodenticide in the United States in 1975. Today, safer compounds (for humans, not rats) are available for rodenticides.

Thallium is too expensive to have many practical applications. There are a few exceptions, however, that make use of special properties of the elements and its compounds. For example, thallium sulfide (Tl_2S) is sometimes used in photocells. Photocells are devices that convert light into electrical energy. In some kinds of light, thallium sulfide does not conduct electricity very well. But in other kinds of light, it conducts very well. Special photocells can be built to take advantage of this property.

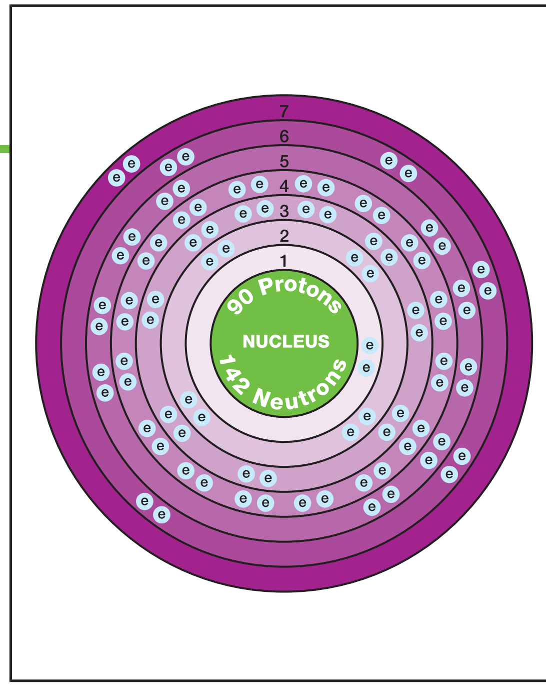
An alloy of thallium and **mercury** can be used to make low-temperature thermometers. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. The thallium-mercury alloy remains liquid at –76°F (–60°C). At that temperature, a mercury-only thermometer would freeze solid.

An interesting application of thallium is in superconducting materials. Superconductors have no resistance to the flow of electricity. Once an electrical current begins flowing in the material, it continues to flow forever. Thallium is also used in wireless communications.

Health Effects

Both thallium and its compounds are very toxic. A person exposed to the element or its compounds over long periods of time develops weakness, pain in the arms and legs, and loss of hair. A high dosage in a short time leads to different symptoms. These symptoms include nausea, vomiting, diarrhea, pain in the arms and legs, coma, convulsions, and even death. People who work with thallium use extreme caution to avoid coming into contact with the material.

Thorium



Key Facts

Symbol: Th

Atomic Number: 90

Atomic Mass: 232.03806

Family: Actinoid

Pronunciation: THOR-ee-um

Overview

Thorium is a member of the actinoid family. The actinoid elements are located in Row 7 of the periodic table. They have atomic numbers between 89 and 103. The periodic table is a chart that shows how chemical elements are related to one another. The actinoid series is named for element 89, **actinium**, the first element in the actinoid family.

Thorium was discovered in 1828 by Swedish chemist Jöns Jakob Berzelius (1779–1848). At the time, Berzelius did not realize that thorium was radioactive. That fact was discovered 70 years later, in 1898, by Polish-French physicist Marie Curie (1867–1934) and English chemist Gerhard C. Schmidt (1864–1949).

Thorium is a relatively common element with few commercial applications. There is some belief that it can someday be used in nuclear power plants, where nuclear reactions are used to generate electricity.

Discovery and Naming

In 1815, Jöns Jakob Berzelius was studying a new mineral found in the Falun district of Sweden. From his analysis, he concluded that he had

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Nuclear fission: A process in which neutrons collide with the nucleus of a uranium atom causing it to split apart with the release of very large amounts of energy.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

found a new element. He named the element thorium, in honor of the Scandinavian god Thor.

Ten years later, Berzelius announced that he had made an error. The substance he had found was not a new element, but the compound **yttrium** phosphate (YPO_4).

Shortly thereafter, Berzelius again reported that he had found a new element. This time he was correct. He chose to retain thorium as the name for this element.

At the time Berzelius made his discovery, the concept of radioactivity was unknown. Radioactivity refers to the process by which an element spontaneously breaks down and gives off radiation. In that process, the element often changes into a new element. One of the first scientists to study radioactivity was Marie Curie. She and Gerhard C. Schmidt announced at almost the same time in 1898 that Berzelius' thorium was radioactive.

Physical Properties

Thorium is a silvery white, soft, metal, somewhat similar to lead. It can be hammered, rolled, bent, cut, shaped, and welded rather easily. Its general physical properties are somewhat similar to those of **lead**. It has a melting point of about 3,300°F (1,800°C) and a boiling point of about 8,100°F (4,500°C). The density of thorium is about 11.7 grams per cubic centimeter, nearly 12 times the density of water.

Can Thorium Replace Uranium?

Uranium is one of the most important elements in the world. Why? One of its isotopes undergoes nuclear fission. Nuclear fission occurs when neutrons collide with the nucleus of a uranium atom. When that happens, the uranium nucleus splits apart. Enormous amounts of energy are released. That energy can be used for mass destruction in the form of atomic bombs, or used for peaceful energy production in nuclear power plants.

But there are two problems with using uranium for nuclear fission. First, of uranium's three isotopes (uranium-234, uranium-235, and uranium-238) only one of these isotopes—uranium-235—undergoes fission. The second problem is that this isotope of uranium is quite rare. Out of every 1,000 atoms of uranium, only seven are uranium-235. Tons of uranium ore must be processed and enriched to make tiny amounts of this critical isotope. It is difficult and extremely expensive.

Scientists know that another isotope of uranium, uranium-233, will also undergo fission. The problem is that uranium-233 does not occur in nature. So how can it be used to make nuclear power?

The trick is to start with an isotope of thorium-232, which has a very long half life of 14 billion years. If thorium-232 is bombarded with neutrons, it undergoes a series of nuclear changes, first to thorium-233, then to protactinium-233, and finally to uranium-233. The whole process takes about a month. At the end of the month, a supply of uranium-233 has been produced. This isotope of uranium has a fairly long half life, about 163,000 years. So once it has been made, it stays around for a long time. It can then be used for nuclear fission.

Scientists would like to find a way to use this process to make uranium-233 economically. Thorium is much more abundant than uranium. It would be far cheaper to make nuclear fuel with thorium than with uranium.

Unfortunately, no one has figured how to make the process work on a large scale. One nuclear reactor using thorium was built near Platteville, Colorado, in 1979. However, a number of economic and technical problems developed. After only 10 years of operation, the plant was shut down. The promise of thorium fission plants has yet to become reality.

Chemical Properties

Thorium is soluble in acids and reacts slowly with oxygen at room temperature. At higher temperatures, it reacts with **oxygen** more rapidly, forming thorium dioxide (ThO_2).

Occurrence in Nature

Thorium is a relatively abundant element in Earth's crust. Scientists estimate that the crust contains about 15 parts per million of the element. That fact is important from a commercial standpoint. It means that thorium is much more abundant than another important radioactive element, **uranium**. Uranium is used in nuclear reactors to generate electricity and in making nuclear weapons (atomic bombs). Some scientists believe that it may be possible to replace uranium with thorium to create nuclear fuel. With more thorium than uranium available, it would be cheaper to make electricity with thorium than uranium.

The most common ores of thorium are thorite and monazite. Monazite is a relatively common form of beach sand. It can be found, among other places, on the beaches of Florida. This sand may contain up to 10 percent thorium.

Isotopes

Twenty-nine isotopes of thorium are known. All are radioactive. The isotope with the longest half life is thorium-232. Its half life is about 14 billion years. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The half life of a radioactive element is the time it takes for half of a sample of the element to break down. After one half life (14 billion years), only 5 grams of a 10-gram sample of thorium-232 would be left. The remaining 5 grams would have broken down to form a new isotope.

Thorium fluoride helps produce the bright beam used in searchlights, such as those being used to illuminate this historical landmark. IMAGE COPYRIGHT 2009, PHILIP LANGE. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Extraction

The thorium in monazite, thorite, or other minerals is first converted to thorium dioxide (ThO_2). This thorium dioxide is then heated with calcium to get the free element:

$$ThO_2 + 2Ca \rightarrow 2CaO + Th$$

Uses and Compounds

Thorium and its compounds have relatively few uses. The most important thorium compound commercially is thorium dioxide. This compound has the highest melting point of any oxide, about 6,000°F (3,300°C). It is used in high-temperature ceramics. A ceramic is a material made from earthy materials, such as sand or clay. Bricks, tiles, cement, and porcelain are examples of ceramics. Thorium dioxide is also used in the manufacture of specialty glass and as a catalyst. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself.

The mantle in a portable gas lantern that produces a hot, white flame was once commonly made out of thorium dioxide. It was replaced, however, with safer substitutes, due to concerns of radioactivity.

The one device in which most people are likely to have seen thorium dioxide is in portable gas lanterns. These lanterns contain a gauzy material called a mantle. Gas passing through the mantle is ignited to produce a very hot, bright white flame. That flame provides the light in the lantern. The mantle in most lanterns was once made of thorium dioxide because it can get very hot without melting.

The thorium dioxide in a gas mantle is radioactive. But it is of no danger to people because the amount used is so small. Still, gas mantles in the United States are no longer made with thorium. Safer substitutes have been found.

Another thorium compound, thorium fluoride (ThF_4), is used in **carbon** arc lamps for movie projectors and searchlights. A carbon arc lamp contains a piece of carbon (charcoal) to which other substances (such as ThF_4) have been added. When an electric current is passed through the carbon, it gives off a bright white light. The presence of thorium fluoride makes this light even brighter.

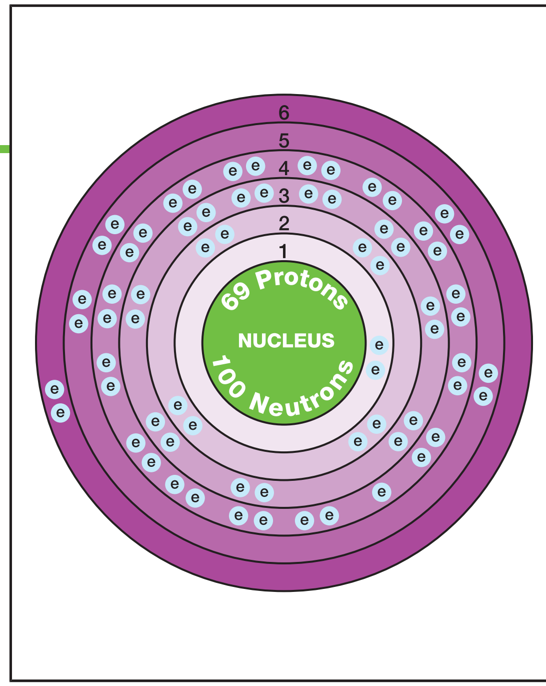
Health Effects

As with all radioactive materials, thorium is dangerous to the health of humans and other animals. It must be handled with great caution.

Living cells that absorb radiation are damaged or killed. Inhaling a radioactive element is especially dangerous because it exposes fragile internal tissues.

Use of thorium has decreased substantially in recent years. This is due to its radioactivity and the costs associated with monitoring its use and disposing of it safely.

Thulium



Overview

Thulium was given its name in honor of the earliest name for Scandinavia, Thule. The element was discovered and named by Swedish chemist Per Teodor Cleve (1840–1905) in 1879. Cleve made his discovery while studying the mineral erbia. Thulium was one of the many new elements found in a black rock discovered outside the town of Ytterby, Sweden, in 1787. The complete analysis of that rock took more than 100 years. In the process, nine new elements, including thulium, were discovered.

The chemical family to which thulium belongs is sometimes called the rare earth elements. That name is misleading. These elements are not really very rare. But they usually occur together in the earth, and they were once difficult to separate from each other. The more common chemical name for the group of rare earth elements is the lanthanoids. The name comes from element 57, **lanthanum**, the first element in the family. The family makes up Row 6 of the periodic table between barium and hafnium. The periodic table is a chart that shows how chemical elements are related to each other.

Key Facts

Symbol: Tm

Atomic Number: 69

Atomic Mass: 168.93421

Family: Lanthanoid (rare earth metal)

Pronunciation: THU-lee-um

WORDS TO KNOW

Ductile: Capable of being drawn into thin wires.

Gamma rays: A form of radiation similar to X rays.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Malleable: Capable of being hammered into thin sheets.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Stable: Not likely to react with other materials.

Toxic: Poisonous.

Discovery and Naming

In 1787, a Swedish army officer named Carl Axel Arrhenius (1757–1824) found a strange looking black rock outside the town of Ytterby, Sweden. He passed it along to Johan Gadolin (1760–1852), professor of chemistry at the University of Åbo in Finland. Gadolin discovered a new mineral in the rock, now known as yttria.

Gadolin had no idea how complicated yttria was. Various chemists worked for the next 100 years before they completely understood the mineral.

In 1879, Cleve was studying one of the new elements found in yttria. The element had been named erbium by an earlier researcher. Cleve realized that erbium was not really an element, but was made up of three other substances. Cleve called these substances **erbium**, **holmium**, and thulium.

The substance Cleve called thulium was not pure thulium, but a compound of thulium combined with other elements. Pure thulium was not produced until 1910 by American chemist Charles James (1880–1928).

Physical Properties

Thulium is a silvery metal that is so soft it can be cut with a knife. It is easy to work with and is both malleable and ductile. Malleable means capable of being hammered into thin sheets. Ductile means capable of being drawn into thin wires. Its melting point is 2,820°F (1,550°C) and its boiling point is 3,141°F (1,727°C). Its density is 9.318 grams per cubic centimeter, more than nine times the density of water.

Chemical Properties

Thulium is relatively stable in air. That is, it does not react easily with **oxygen** or other substances in the air. It does react slowly with water and more rapidly with acids.

Occurrence in Nature

Thulium compounds occur mixed with other rare earth compounds in minerals such as monazite, euxenite, and gadolinite. Monazite is about 0.007 percent thulium.

Thulium is probably the rarest of the lanthanoid elements. Its abundance is estimated at about 0.2 to 1 part per million in Earth's crust. This still makes it more abundant than **silver**, **platinum**, **mercury**, and **gold**.

Isotopes

Only one naturally occurring isotope of thulium exists: thulium-169. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty-six radioactive isotopes of thulium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Thulium-170, a radioactive isotope of thulium, has been used in portable X-ray machines for use in medical and dental procedures. This isotope gives off gamma radiation. Gamma radiation is very similar to X rays. They pass through soft tissues in the body like X rays. But they are blocked by bones and other thick materials. So a small amount of thulium-170 acts just like a tiny X-ray machine. It can be carried around more easily than can a big X-ray machine. Another radioactive isotope of thulium, thulium-171, may have some application as an energy source.

Extraction

Like many lanthanoids, pure thulium is made by treating its fluorine compound with calcium:

$$2TmF_3 + 3Ca \rightarrow 3CaF_2 + 2Tm$$

Because it is so rare, thulium is also very expensive. In 2007, thulium oxide sold for approximately $2,500 per kilogram.

Uses

Thulium is too expensive to have many commercial uses. One of the few applications is in lasers. A laser is a device that produces bright, focused light of a single color. Thulium lasers work well at high temperatures and need less cooling. Lasers containing thulium are used in satellites that take pictures of Earth's surface.

Lasers containing thulium are used in satellites that take pictures of Earth. Here, Intelsat VI *floats over the Earth.* PUBLIC DOMAIN.

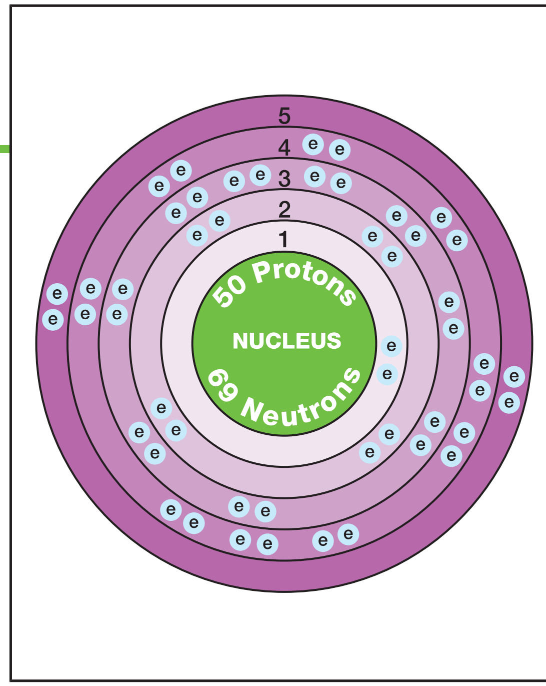
Compounds

There are no commercially important compounds of thulium.

Health Effects

Little information about the health effects of thulium is available. Evidence suggests that it may be a mild irritant to the skin, eyes, and respiratory system. It is probably not very toxic if ingested. People who work with the metal are advised to use good safety practices to avoid coming into contact with the metal any more than necessary.

Tin



Key Facts

Symbol: Sn

Atomic Number: 50

Atomic Mass: 118.710

Family: Group 14 (IVA); carbon

Pronunciation: TIN

Overview

Tin is a member of Group 14 (IVA) in the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Tin is also part of the carbon family. Other carbon family elements include **carbon**, **silicon**, **germanium**, and **lead**.

Tin is a highly workable metal that was once as valuable as **silver** for jewelry, coins, and special dishware. Today it is used in sheets in the construction of buildings and roofs, for soldering or joining metal parts, for storage containers, and in alloys like bronze and Babbitt metal.

Discovery and Naming

Tin, its alloys, and its compounds have been known to humans for thousands of years. A number of references to the element can be found in the Bible. Tin was apparently known to other civilizations also. For example, the sacred Hindu book *Rig-Veda,* written in about 1,500 BCE, mentions tin among other metals known to the Hindus.

The alloy of tin known as bronze was probably produced even earlier than the pure metal. An alloy is made by melting and mixing two or more metals. The mixture has properties that are different than any of the

WORDS TO KNOW

Allotropes: Forms of an element with different physical and chemical properties.

Bronze: An alloy of copper and tin.

Bronze Age: A period in human history ranging from about 3500 to 1000 BCE, when bronze was widely used for weapons, utensils, and ornamental objects.

Cassiterite: An ore of tin containing tin oxide, the major commercial source of tin metal.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Ore: A compound or mixture from which an element can be extracted for commercial profit.

Solder: An alloy of tin and lead with a low melting point used to join two metals to each other.

"Tin cry": A screeching-like sound made when tin metal is bent.

Tinplate: A type of metal consisting of a thin protective coating of tin deposited on the outer surface of some other metal.

metals alone. The Egyptians, Mesopotamians, Babylonians, and Peruvians were producing bronze as far back as 2000 BCE. The alloy was probably discovered accidentally when copper and tin compounds were heated together. Over time, a method for producing bronze with consistent composition was developed.

Bronze became popular among ancient peoples because it was harder and tougher than copper. Before the discovery of bronze, many metal items were made out of copper. But copper is soft and bends easily. Bronze is a much better replacement for copper in tools, eating utensils, and weapons. Bronze marked a significant advance in human civilization. This strong alloy improved transportation methods, food preparation, and quality of life during a period now known as the Bronze Age (3500–1000 BCE).

The origin of the name tin is lost in history. Some scholars believe it is named for the Etruscan god Tinia. During the Middle Ages, the metal was known by its Latin name, *stannum.* It is from this name that the element's symbol, Sn, is derived.

Physical Properties

The most common allotrope of tin is a silver-white metallic-looking solid known as the β-form (or "beta-form"). Allotropes are forms of an element with different physical and chemical properties. This "white tin" has a melting point of 450°F (232°C), a boiling point of 4,100°F (2,260°C), and a density of 7.31 grams per cubic centimeter, more than seven times the density of water.

One of tin's most interesting properties is its tendency to give off a strange screeching sound when it is bent. This sound is sometimes known as "tin cry." β-tin is both malleable and ductile. Malleable means capable of being hammered into thin sheets. Ductile means capable of being drawn into a thin wire. At temperatures greater than 390°F (200°C), tin becomes very brittle.

A second form of tin is α-tin (or "alpha-tin"), also known as "gray tin." Gray tin forms when white tin is cooled to temperatures less than about 55°F (13°C). Gray tin is a gray amorphous (lacking a crystalline shape) powder. The change from white tin to gray tin takes place rather slowly. This change is responsible for some peculiar and amazing changes

Tin sample. © RUSS LAPPA, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

in objects made from the element. For example, tin and its alloys are used in jewelry, kitchenware, serving cups, and other metallic objects. When these objects are cooled below 55°F (13°C) for long periods of time, the tin changes from a silvery, metallic material to a crumbly powder.

In the late 19th century, organ pipes in many cathedrals of Northern Europe were made of tin alloys. During the coldest winters, these pipes began to crumble as tin changed from one allotropic form to the other. The change was known as "tin disease." At the time, no one knew why this change occurred.

Chemical Properties

Tin is relatively unaffected by both water and oxygen at room temperatures. It does not rust, corrode, or react in any other way. This explains one of its major uses: as a coating to protect other metals. At higher temperatures, however, the metal reacts with both water (as steam) and oxygen to form tin(IV) oxide (SnO_2).

Similarly, tin is attacked only slowly by dilute acids such as hydrochloric acid (HCl) and sulfuric acid (H_2SO_4). Dilute acids are mixtures that contain small amounts of acid dissolved in large amounts of water. This property also makes tin a good protective covering. It does not react with acids as rapidly as do many other kinds of metals, such as iron, and can be used, therefore, as a covering for those metals.

Tin dissolves easily in concentrated acids, however, and in hot alkaline solutions, such as hot, concentrated **potassium** hydroxide (KOH). The metal also reacts with the halogens to form compounds such as tin chloride and tin bromide. It also forms compounds with **sulfur**, **selenium**, and **tellurium**.

Occurrence in Nature

Tin is not very abundant in nature. It ranks about 50th on the list of elements most commonly found in Earth's crust. Estimates are that the crust contains about 1 to 2 parts per million of tin.

By far the most common ore of tin is cassiterite, a form of tin oxide (SnO_2). An ore is a compound or mixture from which an element can be extracted for commercial profit. Cassiterite has been mined for thousands of years as a source of tin. During ancient times, Europe obtained most of its tin from the British Isles. As of 2008, the major producers of tin were China, Indonesia, Peru, Bolivia, and Brazil. No tin is mined or smelted

Shown here are the remains of a tin mine near St. Agnes, Cornwall, England. Many men, women, and young children worked in the mines. Such work was very dangerous. Falling rock and explosions killed some miners; others contracted diseases such as bronchitis, rheumatism, tuberculosis, and silicosis (black lung disease). The life expectancy of miners was short.

in the United States, although the nation is the major consumer of the metal.

Isotopes

Tin has 10 naturally occurring isotopes. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirty-six radioactive isotopes have also been discovered. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of tin have any commercial applications.

Extraction

Tin can be produced easily by heating cassiterite with charcoal (nearly pure carbon). In this reaction, the carbon reacts with and removes **oxygen** from the cassiterite, leaving pure tin behind.

$$SnO_2 + C \rightarrow Sn + CO_2$$

This reaction occurs so easily that people knew of the reaction thousands of years ago.

In order to obtain very pure tin, however, one problem must be solved. **Iron** often occurs in very small amounts along with tin oxide in cassiterite. Unless the iron is removed during the extraction process, a very hard, virtually unusable form of tin is produced. Modern systems of tin production, therefore, involve two steps. In one of those steps, impure tin is heated in the presence of oxygen to oxidize any iron in the mixture. In this reaction, iron is converted to iron(III) oxide, and metallic tin is left behind:

$$Sn + 4Fe + 3O_2 \rightarrow 2Fe_2O_3 + Sn$$

Uses

The largest amount of tin used in the United States goes to the production of solder (typically pronounced "SAH der" in the United States). Solder is an alloy, usually made of tin and lead, with a low melting point. It is used to join two metals to each other. For example, metal wires are attached to electrical devices by means of solder. Solder is also used by plumbers to seal the joint between two metal pipes.

Over the years, various toys were made out of tin. Pictured here is a tin soldier. IMAGE COPYRIGHT 2009, ALEXANDER SHINGAREV. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Solder is often applied by means of a soldering iron. A soldering iron consists of a steel bar through which an electric current runs. The electric current heats the bar as it passes through it. When a small piece of solder is placed on the tip of the soldering iron, it melts. The solder is then applied to the joint between two metals. When it cools, the bond is strong. In 2007, more than 50 percent of tin consumption was for solder.

Tin is also used in the manufacture of other alloys. Bronze, for example, is an alloy of tin and copper. It is used in a wide variety of industrial products, such as spark-resistant tools, springs, wire, electrical devices, water gauges, and valves.

One application of tin that was once important is in the manufacture of "tin foil." Tin

Before Plastic Toys There Were Tin Toys

Until World War II (1939–1945), most of the finest toys in the world were made of tin-plated metal. The earliest of these toys were made in the early 1800s. They were based on common objects and events, such as trains, horse-drawn carriages, sailing ships, soldiers, and people from everyday life.

During the first half of the 20th century, the most popular tin toy was the automobile. Toymakers made replicas of every type of car manufactured in the world. These toy cars ranged from the very simplest to the most detailed and elaborate.

Following World War II, plastic toys became much more popular, but tin toys were still made. Reflecting the times, these toys often represented space ships, robots, and other modern objects.

The manufacture of tin toys is no longer the large-scale business it was 100 years ago. However, toy-collecting has remained a fascinating hobby for adults and children around the world. Some antique collectors and dealers specialize in tin toys.

foil is a very thin sheet of tin used to wrap candies, tobacco, and other products. The tin protected the products from spoiling by exposure to air. Today, most tin foil is actually thin sheets of **aluminum** because aluminum is less expensive.

A very important application of tin is tinplating. Tinplating is the process by which a thin coat of tin is placed on the surface of steel, iron, or another metal. Tin is not affected by air, oxygen, water, acids, and bases to the extent that steel, iron, and other metals are. So the tin coating acts as a protective layer.

Perhaps the best known example of tin plating is in the production of food cans. Tin cans are made of steel and are covered with a thin layer of tin. Most food and drink cans today are made out of aluminum because it is cheaper.

Metals can be plated with tin in one of two ways. First, the metal to be plated can simply be dipped in molten (liquid) tin and then pulled out. A thin layer of liquid tin sticks to the base metal and then cools to form a thin coating. The second method is electroplating. In the process of electroplating, the base metal is suspended in a solution of tin sulfate, or a similar compound. An electric current passes through the solution, causing the tin in the solution to be deposited on the surface of the base metal.

Another tin alloy is Babbitt metal. Babbitt metal is a soft alloy made of any number of metals, including **arsenic**, **cadmium**, lead, or tin.

Babbitt metal is used to make ball bearings for large industrial machinery. The Babbitt metal is laid down as a thin coating on heavier metal, such as iron or steel. The Babbitt metal retains a thin layer of lubricating oil more efficiently than iron or steel.

Compounds

Some of the tin consumed in the United States is used in the production of tin compounds. Some of the most important of those compounds and their uses are as follows:

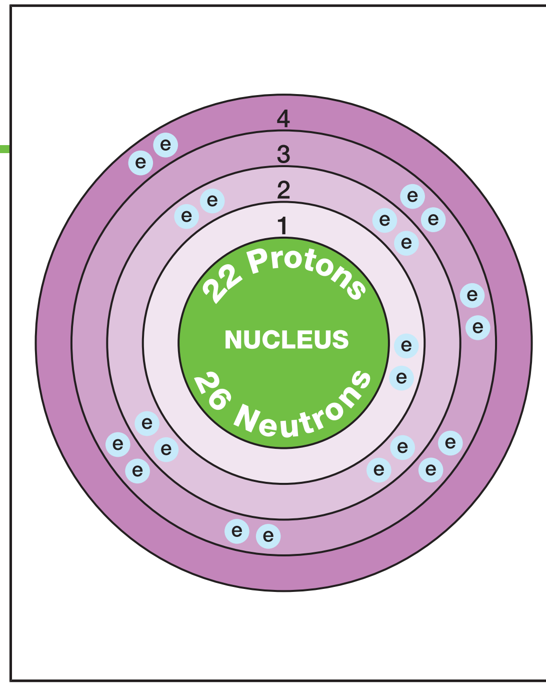
- tin chloride ($SnCl_2$): used in the manufacture of dyes, polymers, and textiles; in the silvering of mirrors; as a food preservative; as an additive in perfumes used in soaps; and as an anti-gumming agent in lubricating oils
- tin oxide (SnO_2): used in the manufacture of special kinds of glass, ceramic glazes and colors, perfumes and cosmetics, and textiles; and as a polishing material for steel, glass, and other materials
- tin chromate ($SnCrO_4$ or $Sn(CrO_4)_2$): brown or yellowish-brown compounds used as a coloring agent for porcelain and china
- tin fluoride (SnF_2) and tin pyrophosphate ($Sn_2P_2O_7$): used as toothpaste additives to help protect against cavities

Health Effects

Most compounds of tin are toxic (poisonous). Tin compounds are most likely to present a hazard when they get into the air. Then, they may be inhaled, after which they can cause problems such as nausea, diarrhea, vomiting, and cramps.

The U.S. government has set a standard of 2 milligrams per cubic meter of air for most tin compounds. For organic compounds of tin (those that contain the element carbon also), the limit is 0.1 milligram per cubic meter. Miners and factory workers are the people most likely to be exposed to these levels of tin. The amount of tin absorbed from canned foods is too small to be of concern to consumers.

Titanium



Key Facts

Symbol: Ti

Atomic Number: 22

Atomic Mass: 47.867

Family: Group 4 (IVB); transition metal

Pronunciation: ty-TAY-nee-um

Overview

Titanium is found in the middle of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Titanium is a transition metal and is part of Group 4 (IVB).

Titanium was one of the first elements to be discovered by modern chemists. The "modern" chemistry period begins after the middle of the 18th century. That period is chosen because it is the first time that the basic concepts of modern chemistry were developed.

Titanium was discovered by English clergyman William Gregor (1761–1817). Gregor studied minerals as a hobby. He did not think of himself as a chemist, and yet his research led to the discovery of titanium.

Titanium and its compounds have become very important in modern society. The metal is widely used in a variety of alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Titanium alloys are used in aircraft, spacecraft, jewelry, clocks, armored vehicles, and in the construction of buildings.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Biocompatible: Not causing a reaction when placed into the body.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Corrosive agent: A material that tends to vigorously react or eat away at something.

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to one another.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Slag: A mixture of materials that separates from a metal during its purification and floats on top of the molten metal.

Discovery and Naming

Gregor discovered titanium while he was studying a mineral found near his home. He was able to identify most components of the mineral, but he found one part that he could not identify. He decided it was a new substance, but did not continue his research. Instead, he wrote a report and left it to professional chemists to find out more about the material.

Today, we know that the material Gregor found is a mineral called ilmenite. Ilmenite is made of **iron**, **oxygen**, and titanium. Its chemical formula is $FeTiO_3$. Even though Gregor did not complete his study of ilmenite, he is usually given credit for the discovery of titanium.

Surprisingly, most chemists paid little attention to Gregor's report. Four years later, German chemist Martin Heinrich Klaproth (1743–1817) decided to study ilmenite. Klaproth believed that Gregor had been correct and that ilmenite truly did contain a new element. Klaproth suggested the name titanium, in honor of the Titans. The Titans were mythical giants who ruled Earth until they were overthrown by the Greek gods. Klaproth reminded everyone that Gregor should receive credit for having discovered the element.

Klaproth was never able to produce pure titanium from ilmenite, only titanium dioxide (TiO_2). It was not until 1825 that even impure

Titanium alloys are used in clocks. IMAGE COPYRIGHT 2009, R.MARTENS. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

titanium metal was produced. Swedish chemist Jöns Jakob Berzelius (1779–1848) accomplished this task.

Physical Properties

Pure titanium metal can exist as a dark gray, shiny metal or as a dark gray powder. It has a melting point of 3,051°F (1,677°C) and a boiling point of 5,931°F (3,277°C). Its density is 4.6 grams per cubic centimeter. Titanium metal is brittle when cold and can be broken apart easily at room temperature. At higher temperatures, it becomes malleable and ductile. Malleable means capable of being hammered into thin sheets. Ductile means capable of being drawn into thin wires.

Titanium has an interesting physical property. Small amounts of oxygen or **nitrogen** make it much stronger.

Chemical Properties

In general, titanium tends to be quite unreactive. It does not combine with oxygen at room temperature. It also resists attack by acids, **chlorine**, and other corrosive agents. A corrosive agent is a material that tends to react vigorously with other substances.

Titanium becomes more reactive at high temperatures. It can actually catch fire when heated in the presence of oxygen.

Occurrence in Nature

Titanium is a very common element. It is the ninth most abundant element in Earth's crust. Its abundance is estimated to be about 0.63 percent. That places titanium just above hydrogen and just below **potassium** among elements present in the earth.

The most common mineral sources of titanium are ilmenite, rutile, and titanite. Titanium is also obtained from iron ore slags. Slag is an earthy material that floats to the top when iron is removed from iron ore.

Isotopes

Five naturally occurring isotopes of titanium exist. They are titanium-46, titanium-47, titanium-48, titanium-49, and titanium-50. The most abundant of these is titanium-48. It makes up about 75 percent of all titanium found in nature. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Thirteen artificial isotopes of titanium for which half lives have been determined have also been made. These isotopes are all radioactive. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

None of the radioactive isotopes of titanium have any commercial applications.

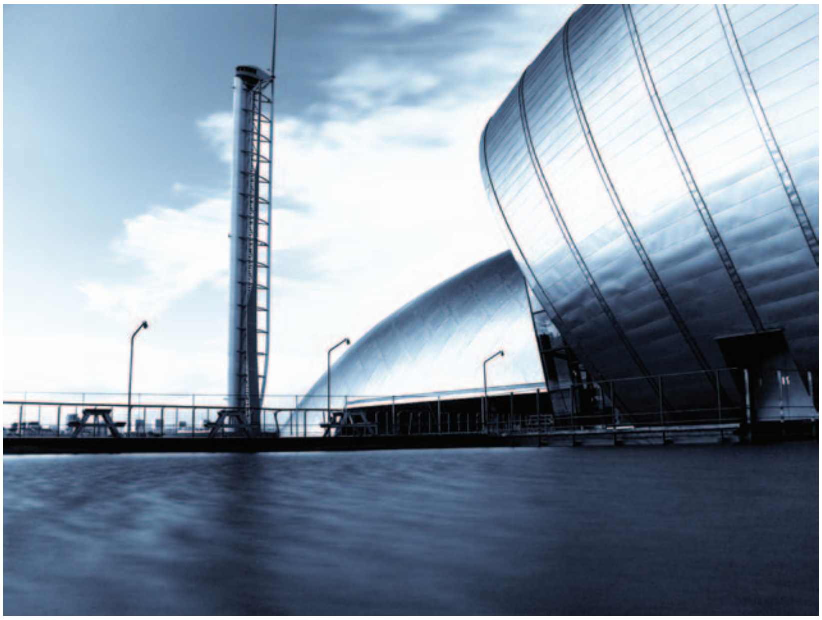
Extraction

The methods used to obtain titanium are similar to those used for other metals. One way to make the metal is to heat one of its compounds with another metal, such as **magnesium**:

$$\mathbf{2Mg + TiCl_4 \rightarrow Ti + 2MgCl_2}$$

Another approach is to pass an electric current through a molten (melted) compound of titanium:

$$\mathbf{TiCl_4 \quad electricity\rightarrow Ti + 2Cl_2}$$



Infrared picture of a building clad in titanium. IMAGE COPYRIGHT 2009, LAURENT DAMBIES. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Uses

By far the most important use of titanium is in making alloys. The metal is most commonly added to steel. It adds strength to the steel and makes it more resistant to corrosion (rusting). Titanium also has another advantage in alloys. Its density is less than half that of steel. So a steel alloy containing titanium weighs less, pound-for-pound, than does the pure steel alloy.

These properties explain why titanium steel is so desirable for spacecraft and aircraft applications. In fact, much of the titanium sold is used in aerospace applications. Titanium alloys are used in the airframes (bodies) and engines of aircraft and spacecraft.

Other uses are in armored vehicles, armored vests, and helmets; in jewelry, eyeglasses, bicycles, golf clubs, and other sports equipment; in specialized dental implants; in power-generating plants and other types of factories; and in roofs, faces, columns, walls, ceilings, and other parts of buildings.

Titanium alloys have also become popular in body implants, such as artificial hips and knees. These alloys are light, strong, long-lasting, and biocompatible. Biocompatible means that the alloy does not cause a reaction when placed into the body.

Titanium alloys are used in eyeglasses. IMAGE COPYRIGHT 2009, MLADEN MITRINOVIC. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Compounds

The most important compound of titanium is titanium dioxide (TiO_2). In 2008, about 1,650,000 short tons (1,500,000 metric tons) of this compound were produced in the United States. The amount produced totaled about $3.7 billion. Titanium dioxide is a dense white powder with excellent hiding power. That term means that anything beneath it cannot be seen well. This property accounts for the major use of titanium dioxide: making white paint. Titanium dioxide paint is a good choice for painting over old wallpaper or dark paints because it covers so well. In 2008, nearly 60 percent of the titanium dioxide produced in the United States was used in paints.

About 36 percent of all titanium dioxide used in the United States goes into paper and plastic materials. Titanium dioxide gives "body" to paper and makes it opaque (unable to see through it). Other uses are in floor coverings, fabrics and textiles, ceramics, ink, roofing materials, and catalysts in industrial operations. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself.

Another interesting compound is titanium tetrachloride ($TiCl_4$). Titanium tetrachloride is a clear, colorless liquid when kept in a sealed container. However, it changes dramatically when exposed to the air. It combines with moisture in the air to form a dense white cloud. Skywriters use titanium tetrachloride to form letters in the sky. The compound is also used to make smokescreens. Smoke effects used in motion pictures and television programs sometimes are produced with titanium tetrachloride.

Health Effects

Titanium appears to have no harmful effects on plants or humans. In powdered form, it may cause mild irritation of the skin, eyes, and respiratory system. It has also not been shown to have any role in maintaining good health.

Transfermium Elements

Overview

The term "transfermium" describes the elements with atomic numbers greater than 100. **Fermium** is element 100, so *trans*fermium means "beyond fermium." The transfermium elements are grouped together for a number of reasons. First, they are all prepared artificially. None of them has been found to occur in Earth's crust naturally. Second, they can be made with only the greatest difficulty. In fact, no more than a few atoms of some transfermium elements have been created so far. Third, very little is known about the transfermium elements. With only a few atoms to study, it is difficult to learn much about them.

Still, the transfermium elements are of great interest to chemists and physicists. They help answer questions about the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The transfermium elements are found at the very end of the periodic table. Scientists want to know if there is a limit to how heavy a chemical element can be. They also want to know what the properties of these very heavy elements will be like.

The following chart provides basic information about the transfermium elements that have been officially recognized and named.

Transfermium Elements

	Atomic Symbol	Atomic Number	Mass*
Mendelevium	Md	101	[258]
Nobelium	No	102	[259]
Lawrencium	Lr	103	[262]
Rutherfordium	Rf	104	[261]
Dubnium	Db	105	[262]
Seaborgium	Sg	106	[266]
Bohrium	Bh	107	[264]
Hassium	Hs	108	[277]
Meitnerium	Mt	109	[268]
Darmstadtium	Ds	110	[271]
Roentgenium	Rg	111	[272]
Copernicium	Cn	112	[285]

*Mass of the most stable isotope.

WORDS TO KNOW

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

"Magic number": The number of protons and/or neutrons in an atom that tend to make the atom stable (not radioactive).

Particle accelerator ("atom smasher"): A machine that makes very tiny particles, like protons or small atoms, move very fast.

Periodic table: A chart that shows how chemical elements are related to each other.

Transfermium element: Any element with an atomic number greater than 100.

A discussion of the names and symbols in the transfermium elements chart follows in the next section.

Discovery of the Elements

All transfermium elements are made in particle accelerators, or "atom smashers." A particle accelerator is a machine that makes particles move very fast. These particles may be as small as protons or positrons or as large as ions of atoms such as nickel and zinc. They often go nearly as fast as the speed of light. Light travels about 186,000 miles per second (300,000 kilometers per second).

These fast moving particles are then made to smash into atoms. If they hit an atom just right, they will stick to the atom, making it heavier. For example, when fast moving **neon** atoms strike atoms of **americium**, the following reaction can occur:

$$^{243}_{95}Am + ^{22}_{10}Ne \rightarrow ^{265}_{105}Db$$

The new element, dubnium (number 105), is produced.

This kind of experiment is easy to describe but very difficult to carry out. In fact, this research is carried out at only several laboratories in the world. One is the Joint Institute of Nuclear Research, in Dubna, Russia. The second is the Lawrence Berkeley Laboratory at the University of California at Berkeley in the United States. The third is the Institute for Heavy Ion Research in Darmstadt, Germany. All of these laboratories use large particle accelerators that cost millions of dollars. Dozens of scientists from many different countries work on each team.

Credit for discovery of a transfermium element is extremely complicated. In most cases, no more than a handful of atoms is produced in an atom smasher. For example, the Dubna group first claimed to have found element 104 in 1964, but many scientists doubted this report. Five years later, American scientists also reported making element 104. This time, the evidence was better.

Naming the Elements

One reason that scientists often argue over the discovery of an element is this: The group of scientists that discovers an element usually has the opportunity to suggest a name for it. For example, researchers at the Berkeley laboratory first discovered elements 97 and 98. They suggested naming those elements **berkelium** and **californium**, in honor of Berkeley, California, where the research was done.

Two men work on a particle accelerator. © PHILIPPE PLAILLY/EURELIOS/NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

The final decision about naming elements is made by a group called the International Union of Pure and Applied Chemistry (IUPAC). The decision can take a very long time. The IUPAC spent nearly 20 years trying to agree on names for elements 104, 105, and 106. Finally, in 1997, the IUPAC announced the official and final names for elements 101 through 109. Those names and their symbols are shown in the chart on page 627. The discoveries of elements 110 and 111 were confirmed in 2001 and 2003, respectively, and names were assigned to those two elements: darmstadtium and roentgenium. The most recent element discovered is number 112. In July 2009, IUPAC officially acknowledged the discovery of this element and agreed to name it copernicium in 2010.

The names chosen by the IUPAC honor either great scientists or places of importance. The meaning of the names is as follows:

- Mendelevium (Md): Named after Russian chemist Dmitri Mendeleev (1834–1907), who developed the periodic law and the periodic table
- Nobelium (No): Named after Swedish inventor Alfred Nobel (1833–1896), who provided funding for the Nobel Prizes when he died
- Lawrencium (Lr): Named after American physicist Ernest Orlando Lawrence (1901–1958), who invented one of the first particle accelerators and for whom the Lawrence Berkeley Laboratory is named
- Rutherfordium (Rf): Named after British physicist Ernest Rutherford (1871–1937), who made many important discoveries about atoms and radioactivity
- Dubnium (Db): Named after Dubna, the city in Russia where the Joint Institute for Nuclear Research is located
- Seaborgium (Sg): Named after American chemist Glenn Seaborg (1912–1999), who was involved in the discovery of 10 elements
- Bohrium (Bh): Named after Danish physicist Niels Bohr (1885–1962), who helped develop the modern theory of the atom
- Hassium (Hs): Named after the German state in which the Institute for Heavy Ion Research is located
- Meitnerium (Mt): Named after Austrian physicist Lise Meitner (1878–1968), who helped explain the process of nuclear fission (the splitting of atoms)

- Darmstadtium (Ds): Named after the city in which the Institute for Heavy Ion Research is located
- Roentgenium (Rg): Named after German scientist William Roentgen, discoverer of X rays
- Copernicium (Cn): Named after Polish astronomer Nicolaus Copernicus, who proposed the heliocentric theory of the universe.

Ernest O. Lawrence. Element 103, Lawrencium, is named after him. LIBRARY OF CONGRESS.

Claims for the discovery of six additional elements have also been made. Thus far, the IUPAC has not confirmed the discovery of these elements, nor has it assigned permanent names to the elements. It has, however, announced a system for giving temporary names to these elements that are Latin equivalents for their atomic numbers. The postulated elements are as follows:

- Ununtrium: Atomic symbol is Uut; atomic number is 113
- Ununquadium: Atomic symbol is Uuq; atomic number is 114
- Ununpentium: Atomic symbol is Uup; atomic number is 115
- Ununhexium: Atomic symbol is Uuh; atomic number is 116
- Ununoctium: Atomic symbol is Uuo; atomic number is 118
- Unbibium: Atomic symbol is Ubb; atomic number is 122

Ununtrium was first detected as a by-product of another nuclear reaction by a team of Dubna and Berkeley scientists in 2003 and was then synthesized by the team a year later. About eight atoms of the element have been detected, over which the isotope ununtrium-284 has the longest half life, about 500 ms (milliseconds).

Isotopes of ununquadium have been reported by Dubna researchers since 1998. In late 2009, a team at Lawrence Berkeley National Laboratory confirmed the existence of the new element. The isotope with the longest half life of the atoms thus far observed is ununquadium-289, with a half life of about 2.6 seconds.

Stability and "Magic" Numbers

The larger an atom is, the more unstable it tends to be. It seems that big atoms have trouble staying together. They tend to fall apart, giving off tiny particles like electrons and protons in the process. When they do so, they change into other, smaller atoms. This process is called radioactive decay.

All elements heavier than bismuth are radioactive. They have no stable isotopes. Does that mean that scientists will never find another stable element in the transfermium group? As they search for elements 117, 119, and beyond, will they always find radioactive isotopes only?

Some scientists think the answer is no. They believe that some very heavy elements may be stable. Their atoms may be able to stay together, as is the case with lighter elements. One of these elements may be number 114.

Scientists think that atoms are likely to be stable if they contain a certain "magic" number of protons and neutrons. Those magic numbers are 2, 8, 20, 28, 50, 82, 114, and 184. So an atom with 20 protons and 20 neutrons, for example, would be expected to be stable. And it is.

The joint Dubna-Berkeley research team reported the discovery of ununpentium in 2003. Of the 30 atoms thus far observed, the one with the longest half life is ununpentium-288, with a half life of about 100 ms.

About 30 atoms of ununhexium have been discovered by Dubna researchers, with the isotope ununhexium-293 having the longest half life of 60 ms.

In 2006, the Dubna-Berkeley research team reported that they had detected either three or four atoms of ununoctium, with a half life of about 0.89 ms (which is in doubt because of the limited number of atoms studied).

In April 2008, a research group from the Hebrew University in Jerusalem, under the direction of Amnon Marinov, reported the discovery of a few individual atoms of unbibium in natural thorium reserves. That report has been strongly criticized and no supporting evidence has been produced yet. If true, the results would be astounding. It would be the first time that a transfermium element had been found as a natural product.

Properties of the Elements

No one knows much about the properties of the transfermium elements. It isn't possible to see or touch or smell or taste any of these elements. There are often no more than a few dozen atoms to study.

In fact, it is quite amazing that scientists know much of anything about these elements. Yet, they do know a few things. In 1997, for example, the German team studied the properties of element 106, seaborgium, with only six atoms to work with! But they managed to watch how these atoms behaved as they slowly moved down a column of special material.

In some of the most recent research, scientists have determined that element 118 (ununoctium) is probably not an inert gas, as would be expected from its position in the periodic table but, under normal circumstances, a solid.

Of course, these elements have no known uses.

Isotopes

Most transfermium elements have more than one isotope. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The number of isotopes for which an atomic mass and half life are currently known for each element follows. The numbers may change as scientists discover new isotopes:

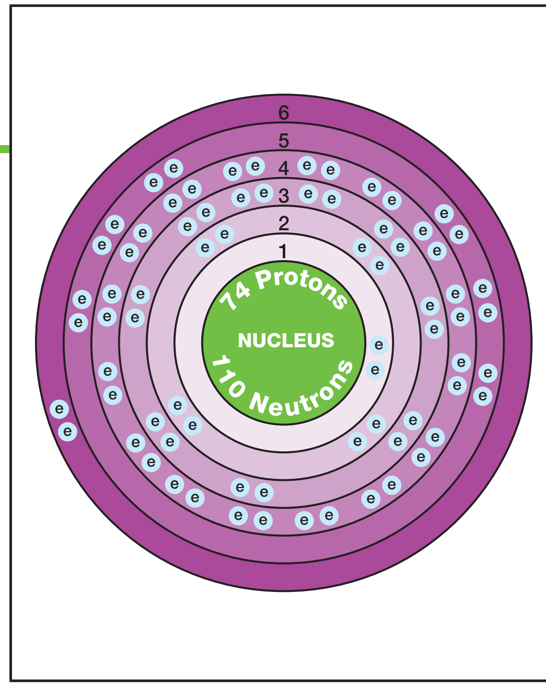
mendelevium: 13
nobelium: 14
lawrencium: 12
rutherfordium: 11
dubnium: 9
seaborgium: 9
bohrium: 8
hassium: 8
meitnerium: 5
darmstadtium: 6
roentgenium: 4
copernicium: 5

All of the isotopes of the transfermium elements are radioactive. A radioactive isotope is one that breaks apart and gives off some form of radiation.

In most cases, they have very short half lives. The half life of a radioactive isotope is the time it takes for half of a sample to break apart.

The half life of most transfermium isotopes is only a few seconds or less. The half life of dubnium-260, for example, is 1.6 seconds. That means that half of the atoms in a sample will break down in 1.6 seconds and change to some other element. The short half lives of the transfermium isotopes make them hard to study. They tend to break down almost as soon as they are formed. Scientists have very little time to observe them.

Tungsten



Key Facts

Symbol: W

Atomic Number: 74

Atomic Mass: 183.84

Family: Group 6 (VIB); transition metal

Pronunciation: TUNG-stun

Overview

Tungsten is a transition metal. The transition metals are a group of elements found in the middle of the periodic table. They occupy the boxes in Rows 4 through 7 between Groups 2 and 13. The periodic table is a chart that shows how chemical elements are related to one another.

These metals have very similar physical and chemical properties. One of tungsten's unusual properties is its very high melting point of 6,170°F (3,410°C). This is the highest melting point of any metal. Another of its important properties is its ability to retain its strength at very high temperatures. These properties account for tungsten's primary application, the manufacture of alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals.

Credit for the discovery of tungsten is often divided among three men—Spanish scientists Don Fausto D'Elhuyard (1755–1833) and his brother Don Juan José D'Elhuyard (1754–1796), and Swedish chemist Carl Wilhelm Scheele (1742–1786). Tungsten's chemical symbol, W, is taken from an alternative name for the element, wolfram.

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Aqua regia: A mixture of hydrochloric and nitric acids that often reacts with materials that do not react with either acid separately.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

The first mention of tungsten and its compounds can be traced to about 1761. German chemist Johann Gottlob Lehmann (1719–1767) was studying a mineral known as wolframite. He found two new substances in the mineral but did not recognize that they were new elements.

About 20 years later, Scheele also studied this mineral. From the mineral, he produced a white acidic powder. Scheele knew the powder was a new substance. But he could not isolate a pure element from it. Scheele's discovery was actually tungstic acid (H_2WO_4).

Tungsten metal was prepared for the first time in 1783 by the D'Elhuyard brothers. In 1777, they were sent to Sweden to study mineralogy. After their return to Spain, the brothers worked together on a number of projects. One project involved an analysis of wolframite. They produced tungstic acid like Scheele but went one step further. They found a way to obtain pure tungsten metal from the acid. For this work, they are generally given credit as the discoverers of tungsten.

The name tungsten is taken from the Swedish phrase that means "heavy stone." In some parts of the world, the element is still called by another name, wolfram. This name comes from the German expression *Wolf rahm,* or "wolf froth (foam)." The element's chemical symbol is taken from the German name rather than the Swedish name.

Physical Properties

Tungsten is a hard brittle solid whose color ranges from steel-gray to nearly white. Its melting point is the highest of any metal, 6,170°F (3,410°C) and its boiling point is about 10,600°F (5,900°C). Its density

Tungsten samples. © RUSS LAPPA/SCIENCE SOURCE, NATIONAL AUDUBON SOCIETY COLLECTION/PHOTO RESEARCHERS, INC.

is about 19.3 grams per cubic centimeter, almost 20 times the density of water. Tungsten conducts electrical current very well.

Chemical Properties

Tungsten is a relatively inactive metal. It does not combine with **oxygen** at room temperatures. It does corrode (rust) at temperatures above 700°F (400°C). It does not react very readily with acids, although it does dissolve in nitric acid or aqua regia. Aqua regia is a mixture of hydrochloric and nitric acids. It often reacts with materials that do not react with either acid separately.

Occurrence in Nature

Tungsten never occurs as a free element in nature. Its most common ores are the minerals scheelite, or calcium tungstate ($CaWO_4$) and wolframite, or **iron manganese** tungstate ($Fe,MnWO_4$). The abundance of tungsten in Earth's crust is thought to be about 1.5 parts per million. It is one of the more rare elements.

The largest producers of tungsten in the world are China (which produces the vast majority of the world's total), Russia, and Canada. A limited amount of tungsten concentrates were produced in the United States in 2008. Detailed information about the production and use of tungsten in the United States is not available. This information is withheld from the public to protect the companies' interests that produce and use tungsten.

Isotopes

Five naturally occurring isotopes of tungsten exist. They are tungsten-180, tungsten-182, tungsten-183, tungsten-184, and tungsten-186. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Two naturally occurring isotopes are radioactive: tungsten-183 and tungsten-184. Both have very long half lives, of more than 100 quadrillion years. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. Thirty-three radioactive isotopes of tungsten are known also.

None of the radioactive isotopes of tungsten has any important commercial use.

Extraction

Tungsten metal can be obtained by heating tungsten oxide (WO_3) with **aluminum**:

$$2Al + WO_3 \rightarrow W + Al_2O_3$$

It is also produced by passing **hydrogen** gas over hot tungstic acid (H_2WO_4):

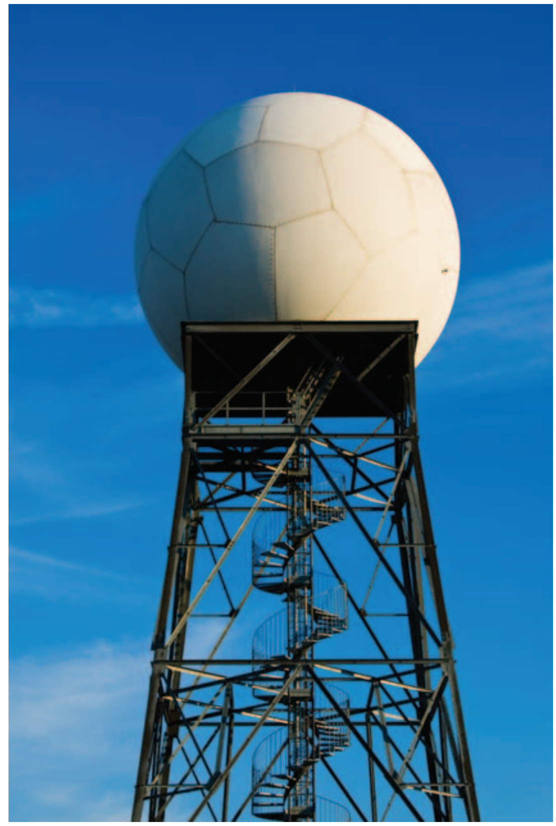
$$H_2WO_4 + 3H_2 \rightarrow W + 4H_2O$$

Uses

By far the most important use of tungsten is in making alloys. Tungsten is used to increase the hardness, strength, elasticity (flexibility), and tensile strength (ability to stretch) of steels. The metal is usually prepared in one of two forms. Ferrotungsten is an alloy of iron and tungsten. It usually contains about 70 to 80 percent tungsten. Ferrotungsten is mixed with other metals and alloys (usually steel) to make specialized alloys. Tungsten is also produced in powdered form. It can then be added to other metals to make alloys.

About 90 percent of all tungsten alloys are used in mining, construction, and electrical and metal-working machinery. These alloys are used to make high-speed tools; heating elements in furnaces; parts for aircraft and spacecraft; equipment used in radio, television, and radar; rock drills; metal-cutting tools; and similar equipment.

A small, but very important, amount of tungsten is used to make incandescent lights. The very thin metal wire that makes up the filament in these lights is made of tungsten. An electric current passes through the wire, causing it to get hot and give off light. It does not melt because of the high melting point of tungsten.



Tungsten alloys are used in radar equipment. Here, Doppler radar measures the speed and direction of local winds. IMAGE COPYRIGHT 2009, ANTHRO. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Compounds

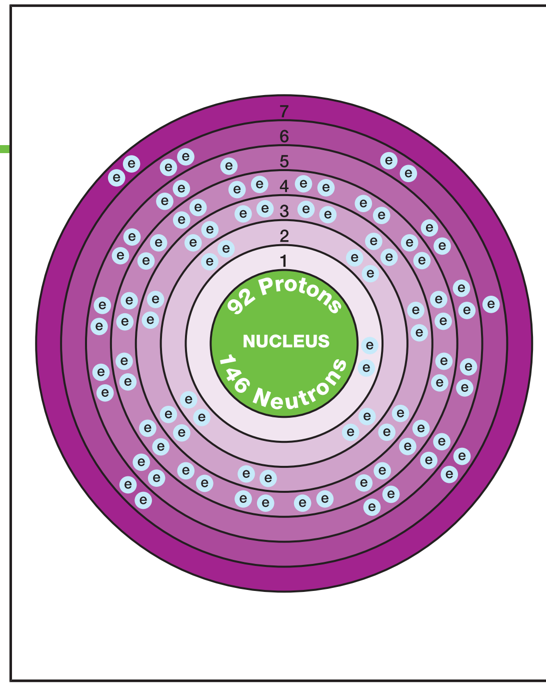
Probably the most important compound of tungsten is tungsten carbide (WC). Tungsten carbide has a very high melting point of 5,000°F (2,780°C). It is the strongest structural material. It is used to make parts for electrical circuits, cutting tools, cermets, and cemented carbide. A cermet is a material made of a ceramic and a metal. A ceramic is a clay-like material. Cermets are used where very high temperatures occur for long periods of time. For example, the parts of a rocket motor or a jet engine may be made from a cermet.

A cemented carbide is made by bonding tungsten carbide to another metal. The product is very strong and remains strong at high temperatures. Cemented carbides are used for rock and metal cutting. They can operate at 100 times the speed of similar tools made of steel.

Health Effects

Tungsten has no essential role in the health of plants, humans, or animals. In moderate amounts, it also presents virtually no health danger. Exposure to tungsten dust or fumes may cause mild irritation of the skin, eyes, and respiratory system.

Uranium



Overview

Uranium is the heaviest and last naturally occurring element in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Uranium occurs near the beginning of the actinoid family. The actinoid family consists of elements with atomic numbers 89 through 103.

At one time, uranium was considered to be a relatively unimportant element. It had a few applications in the making of stains and dyes, in producing specialized steels, and in lamps. But annual sales before World War II (1939–1945) amounted to no more than a few hundred metric tons of the metal and its compounds.

Then, a dramatic revolution occurred. Scientists discovered that one form of uranium will undergo nuclear fission. Nuclear fission is the process in which the nuclei of large atoms break apart. Large amounts of energy and smaller atoms are produced during fission. The first application of this discovery was in the making of nuclear weapons, such as the atomic bomb. After the war, nuclear power plants were built to make productive use of nuclear fission. Nuclear power plants convert the energy released by fission to electricity. Today, uranium is regarded as one of the most important elements for the future of the human race.

Key Facts

Symbol: U

Atomic Number: 92

Atomic Mass: 238.02891

Family: Actinoid

Pronunciation: yuh-RAY-nee-um

WORDS TO KNOW

Actinoid family: Elements with atomic numbers 89 through 103.

Ductile: Capable of being drawn into thin wires.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Mordant: A material that helps a dye stick to cloth.

Nuclear fission: A process in which neutrons collide with the nucleus of a uranium atom causing it to split apart with the release of very large amounts of energy.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Discovery and Naming

Credit for the discovery of uranium is usually given to German chemist Martin Klaproth (1743–1817). During the late 1780s, Klaproth was studying a common and well-known ore called pitchblende. At the time, scientists thought that pitchblende was an ore of **iron** and **zinc**.

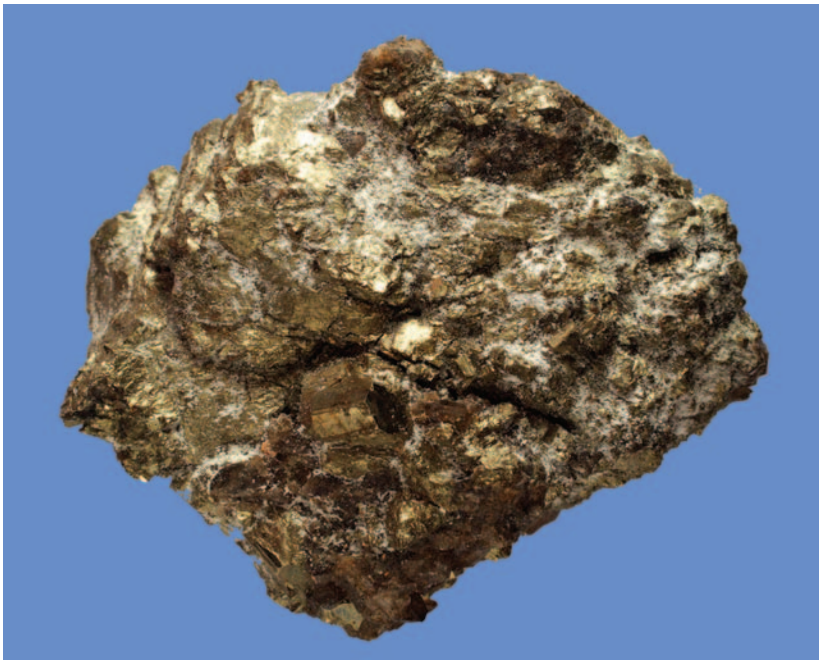
During his research, however, Klaproth found that a small portion of the ore did not behave the way iron or zinc would be expected to behave. He concluded that he had found a new element and suggested the name uranium for the element. The name was given in honor of Uranus, a planet that had been discovered only a few years earlier, in 1781.

For some time, scientists believed that Klaproth had isolated uranium. Eventually they realized he had found uranium oxide (UO_2), a compound of uranium. It was not until a half century later, in fact, that the pure element was prepared. In 1841, French chemist Eugène-Melchior Peligot (1811–1890) produced pure uranium from uranium oxide.

Early researchers did not know that uranium was radioactive. In fact, radioactivity was not discovered until 1898. Radioactivity is the tendency of an isotope or element to break down and give off radiation.

Physical Properties

Uranium is a silvery, shiny metal that is both ductile and malleable. Ductile means capable of being drawn into thin wires. Malleable means



Uranium ore sample. IMAGE COPYRIGHT 2009, KLETR. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

capable of being hammered into thin sheets. Its melting point is 2,070.1°F (1,132.3°C) and its boiling point is about 6,904°F (3,818°C). Its density is about 19.05 grams per cubic centimeter, 19 times the density of water.

Chemical Properties

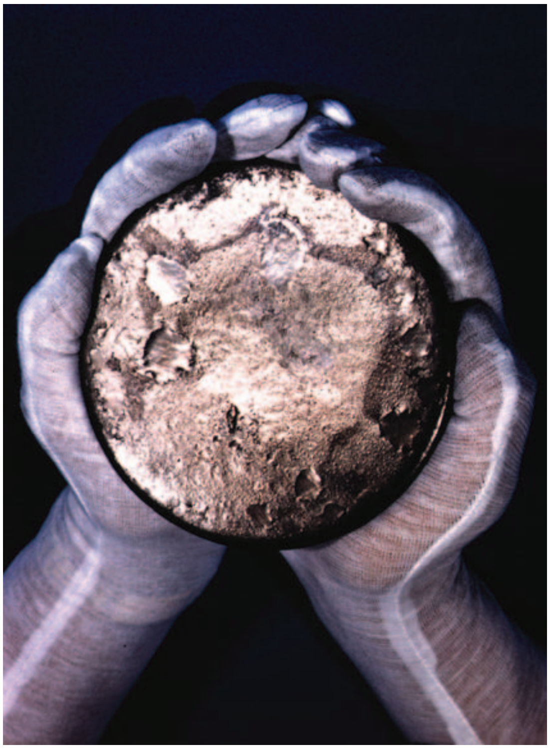
Uranium is a relatively reactive element. It combines with nonmetals such as **oxygen**, **sulfur**, **chlorine**, **fluorine**, **phosphorus**, and **bromine**. It also dissolves in acids and reacts with hot water. It forms many compounds that tend to have yellowish or greenish colors.

Occurrence in Nature

Uranium is a moderately rare element. Its abundance is estimated to be about 1 to 2 parts per million, making it about as abundant as bromine or **tin**. The most common ore of uranium is pitchblende, although it also occurs in other minerals, such as uraninite, carnotite, uranophane, and coffinite.

Isotopes

All 24 isotopes of uranium with measured half lives are radioactive. Three of these isotopes occur naturally: uranium-234, uranium-235,



A 9.5-pound button of uranium-235 is held. It was slated to be manufactured into a nuclear weapons component.
U.S. DEPARTMENT OF ENERGY

uranium-238. By far the most common is uranium-238, which makes up about 99.2756 percent of uranium found in Earth's crust. Uranium-238 also has the longest half life, about 4,468,000,000 years.

Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

The half life of a radioactive element is the time it takes for half of a sample of the element to break down. Imagine that Earth's crust contains 100 million tons of uranium-238 today. Only half of a uranium-238 sample would remain 4,468,000,000 years from now (one half life). The remainder would have changed into other isotopes.

Nearly 20 other isotopes of uranium have been made artificially.

Extraction

Uranium is mined in much the same way iron is. Uranium ore is removed from the earth, then treated with nitric acid to make uranyl nitrate ($UO_2(NO_3)_2$). This compound is converted to uranium dioxide (UO_2). Finally, uranium dioxide is converted to pure uranium metal with **hydrogen** gas:

$$UO_2 + 2H_2 \rightarrow 2H_2O + U$$

Uses and Compounds

Uranium compounds have been used to color glass and ceramics for centuries. Scientists have found that glass made in Italy as early as 79 CE was colored with uranium oxide. They have been able to prove that the coloring was done intentionally.

Creating Energy: Separating the Isotopes of Uranium

Suppose neutrons are fired at a big block of uranium metal. Would nuclear fission occur? Would this be the way to make an atomic bomb? Could this process be used in a nuclear power plant?

The answer to all these questions is no. Only one isotope of uranium undergoes nuclear fission, uranium-235. The most common isotope, uranium-238, does not undergo fission. There is no way to make a bomb or a nuclear power plant with a chunk of natural uranium metal.

To make a nuclear bomb or a nuclear power plant, it is first necessary to increase the percentage of uranium-235 in the metal. As a chunk of uranium metal contains more uranium-235, it is more likely to undergo nuclear fission.

In making a bomb or a power plant, then, the first step is to separate the isotopes of uranium from each other. The goal is to produce more uranium-235 and less uranium-238.

That goal sounds easy, but it is very difficult to do. All isotopes of uranium behave very much alike. They have the same chemical properties. The only way they differ from each other is by weight. An atom of uranium-238, for example, weighs about 1 percent more than an atom of uranium-235. That's not much of a difference.

Scientists separate these isotopes in a centrifuge. A centrifuge is a machine that spins containers of materials at very high speeds. They are like some of the rides at an amusement park. A person sits in a compartment at the end of a long arm. When the ride is turned on, the compartment spins around faster and faster.

In a centrifuge, heavier objects spin farther out than do lighter objects. A mixture of uranium-235 and uranium-238 can be separated slightly in a centrifuge. But the separation is not very good because the isotopes weigh almost the same amount.

In practice, a mixture of isotopes must be centrifuged many times. Each time, the separation gets better.

Scientists prepare enriched uranium by this method. Enriched uranium contains more uranium-235 and less uranium-238. Enriched uranium was used to make atomic bombs and is now used in nuclear power plants. It contains enough uranium-235 to allow nuclear fission to occur.

Some uranium compounds were used for this purpose until quite recently. In fact, a popular type of dishware known as "Fiesta Ware" made in the 1930s and 1940s sometimes used uranium oxide as a coloring material. Other glassware, ceramics, and glazes also contained uranium oxide as a coloring agent.

Uranium compounds have had other limited uses. For example, they have been used as mordants in dyeing operations. A mordant is a material that helps a dye stick to cloth. Uranium oxide has also found

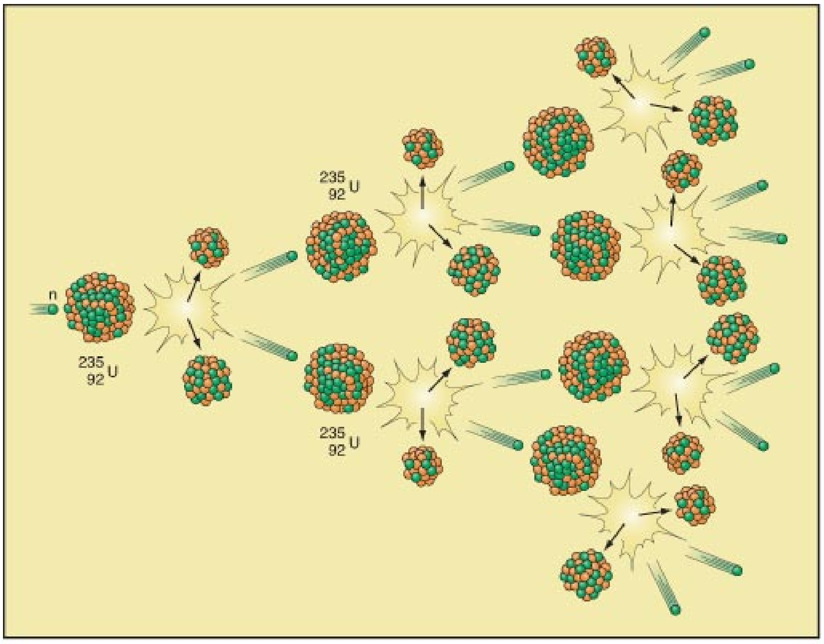
A nuclear explosion seen from space. PHOTODISC/ROYALTY FREE.

limited application as an attachment to filaments in lightbulbs. The compound reduces the speed at which an electric current enters the bulb. This reduces the likelihood of the filament heating too fast and breaking.

None of these applications is of very much importance today, however. By far the most important application for uranium is in nuclear weapons and nuclear power plants. The reason for this importance is that one isotope of uranium, uranium-235, undergoes nuclear fission.

Nuclear fission is the process by which neutrons are fired at a target. The target is usually made of uranium atoms. When neutrons hit the target, they cause the nuclei of uranium atoms to break apart. Smaller elements are formed and very large amounts of energy are given off.

When this reaction is carried out with no attempt to capture or control the energy, an enormous explosion takes place. This release of nuclear



A nuclear chain reaction showing the uninterrupted fission of ever-increasing numbers of uranium-235 atoms. GALE GROUP

energy accounts for the power of a nuclear weapon such as an atomic bomb. In reactors, the energy released during fission is used to boil water. Steam is produced and is converted to electricity. The controlled release of nuclear energy takes place in a nuclear power plant.

According to the International Atomic Energy Agency (IAEA) in January 2010, 436 nuclear reactors were in operation worldwide. The United States led with 104 reactors, followed by France at 59, Japan at 53, and Russia at 31. The U.S. Nuclear Regulatory Commission (NRC) reports that the 104 licensed units generate about 20 percent of the electricity used in the country. Most of the reactors are located in the eastern half of the United States.

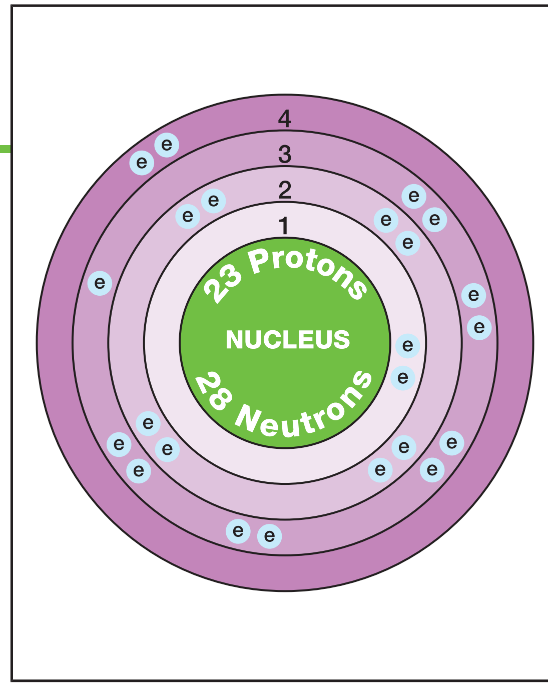
Many people believe nuclear power will be more important in the future as the world's supply of coal, oil, and natural gas will eventually run out.

Other people are concerned about the dangers of nuclear power. The radiation released and radioactive wastes produced by nuclear power plants have made them unpopular in the United States. It is not clear what the future of nuclear power plants in the United States will be.

Health Effects

Since it is a radioactive element, uranium must be handled with great care. In addition, it poses an exceptional risk in powdered form. In this form, it tends to catch fire spontaneously.

Vanadium



Key Facts

Symbol: V

Atomic Number: 23

Atomic Mass: 50.9415

Family: Group 5 (VB); transition metal

Pronunciation: vuh-NAY-dee-um

Overview

Vanadium is a transition metal that lies toward the middle of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. Groups 3 through 12 contain the transition metals.

Vanadium was discovered in 1801 by Spanish-Mexican metallurgist Andrés Manuel del Río (1764–1849). The element was re-discovered nearly 30 years later by Swedish chemist Nils Gabriel Sefström (1787–1845).

By far the most important application of vanadium today is in making alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Vanadium steel, for example, is more resistant to wear than ordinary steel. A potentially important use of vanadium is in the manufacture of batteries. These batteries show promise for use in electric cars.

Discovery and Naming

Andrés Manuel del Río was educated in France, Germany, and England, but moved to Mexico in 1794. There he became professor of mineralogy at the School of Mines in Mexico City. While studying minerals at the

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Battery: A device for changing chemical energy into electrical energy.

Catalyst: A substance used to speed up a chemical reaction without undergoing any change itself.

Ductile: Capable of being drawn into thin wires.

Fly ash: The powdery material produced during the production of iron or some other metal.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Metal: Elements that have a shiny surface, are good conductors of heat and electricity, can be melted, hammered into thin sheets, and drawn into thin wires.

Non-metal: Elements that do not have the properties of metals.

Slag: A mixture of materials that separates from a metal during its purification and floats on top of the molten metal.

School of Mines, he believed he had found a new element. He announced this discovery in 1801 and suggested the name panchromium, meaning "all colors." The new element formed compounds of many beautiful colors. Del Río later changed his mind and decided to call the element erythronium. The prefix *erytho-* means "red."

Del Río sent the mineral he was studying to colleagues in Europe for confirmation of his discovery. Unfortunately, they concluded that del Río's "new element" was **chromium**. Del Río's became discouraged and gave up his claim to the new element.

About 30 years later, however, del Río's element was discovered again. This time, the element was found by Sefström, who found the element in iron ore taken from a Swedish mine. He soon realized that his discovery was identical to that of del Río's. Vanadium was eventually named for the Scandinavian goddess of love, Vanadis.

Both Sefström and del Río saw vanadium only in the form of a compound, vanadium pentoxide (V_2O_5). It is very difficult to separate pure vanadium metal from this compound. It was not until 1887 that pure vanadium metal was isolated. English chemist Sir Henry Enfield Roscoe (1833–1915) found a way to separate pure vanadium from its oxide.

Physical Properties

Vanadium is a silvery-white, ductile, metallic-looking solid. Ductile means capable of being drawn into thin wires. Its melting point is about 3,500°F (1,900°C) and its boiling point is about 5,400°F (3,000°C). Its density is 6.11 grams per cubic centimeter, more than six times the density of water.

Chemical Properties

Vanadium is moderately reactive. It does not react with **oxygen** in the air at room temperature, nor does it dissolve in water. It does not react with some acids, such as hydrochloric or cold sulfuric acid. But it does become more reactive with hot acids, such as hot sulfuric and nitric acids.

Vanadium is special in that it acts like a metal in some cases, and as a non-metal in other cases. Metals are defined as elements that have a shiny surface, are good conductors of heat and electricity, can be melted, hammered into thin sheets, and drawn into thin wires. Non-metals generally do not have these properties.

Occurrence in Nature

Vanadium is a relatively abundant element, ranking about 20th among elements occurring in Earth's crust. Its abundance has been estimated

Vanadium is found in minerals such as vanadinite.

at about 100 parts per million. That makes it about as abundant as **chlorine**, chromium, and **nickel**.

Vanadium is found in a number of minerals, including vanadinite (see photo on page 651), carnotite, roscoelite, and patronite.

Commercially, however, it is obtained as a by-product of the manufacture of **iron**. Slag and fly ash are purified to remove the vanadium metal contained within them. Slag is a mixture of materials that separates from iron and floats on top of the molten metal. Fly ash is a powdery material produced during the purification of iron.

The vanadium obtained from slag and fly ash is usually in the form of ferrovanadium. Ferrovanadium is a mixture of iron and vanadium. It can be used in place of pure vanadium in making alloys. Ferrovanadium saves companies the cost of making pure vanadium metal.

Isotopes

Two naturally occurring isotopes of vanadium exist: vanadium-50 and vanadium-51. Vanadium-51 is much more common, making up about 99.75 percent of all naturally occurring vanadium.

Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Vanadium-50 is radioactive. It has a half life of about 600 quadrillion years. The half life of a radioactive element is the time it takes for half of a sample of the element to break down. Ten grams of vanadium-50 today would reduce by 5 grams after 600 quadrillion years. The other half would have broken down to form a new isotope. Eighteen radioactive isotopes made by artificial means are also known.

Extraction

Vanadium can be obtained in a variety of ways. For example, it can be produced by passing an electric current through molten (melted) vanadium chloride:

$$\mathbf{VCl_2 \quad \text{electric current} \rightarrow V + Cl_2}$$

It can also be made by combining calcium metal with vanadium oxide:

$$5Ca + V_2O_5 \rightarrow 2V + 5CaO$$

Uses

More than 90 percent of the vanadium consumed in the United States is used to make steel alloys. Steel containing vanadium is stronger, tougher, and more rust-resistant than steel without vanadium. An important application of such alloys is in space vehicles and aircraft. A common use of vanadium steel alloys is in tools used for cutting and grinding. Overall, about a third of all vanadium steel goes to building and heavy construction uses; less goes to transportation, machinery, and tool applications.

Compounds

The most important compound of vanadium commercially is vanadium pentoxide. Among its applications are as a catalyst for many industrial reactions, as a coloring material for glass and ceramics, and in the dyeing of textiles. A catalyst is a substance used to speed up a chemical reaction without undergoing any change itself.

An important newer use for vanadium pentoxide is in batteries. Scientists have worked for a very long time to make better batteries. Common automobile batteries are large and heavy. Batteries like these are

Wrenches made with a vanadium steel alloy. IMAGE COPYRIGHT 2009, STEVE COLLENDER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

too big and heavy for many applications. For example, they cannot be used in space probes and space vehicles. They simply weigh too much.

These batteries are also too large for use in electric cars. An electric car is powered by electricity rather than gasoline. A great deal of research is being done to create the most economical electric car.

A new vanadium pentoxide battery produces more electrical energy per pound than the lead storage batteries in cars today. They are also likely to cause fewer environmental disposal problems.

Some manufacturers think electric cars with vanadium pentoxide batteries are part of the world's transportation future. Drivers would bring these cars into a "battery filling station." The worn-out battery would be "pumped out" and replaced in a matter of minutes.

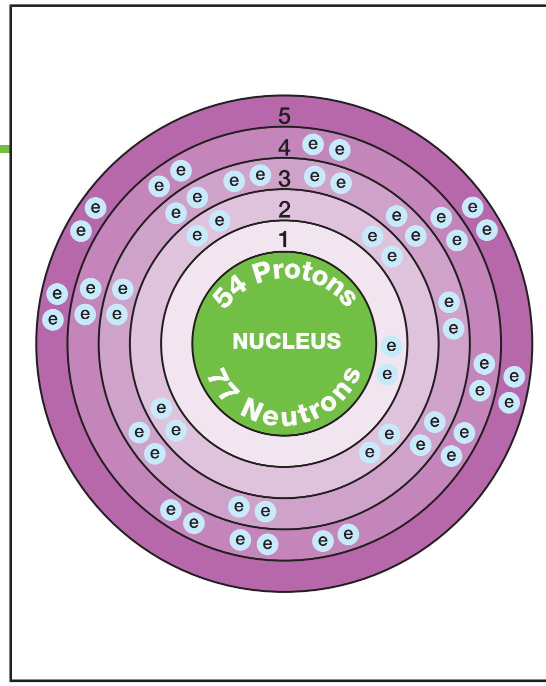
Health Effects

Vanadium occurs in living organisms in very small amounts. The total amount of vanadium in the human body is estimated to be less than 1 milligram (0.000035 ounce). It is found most commonly in the kidneys, spleen, lungs, testes, and bones. No specific function for vanadium in humans has been found.

Diseases due to a lack of vanadium have been found in rats, chicks, and goats, but only under artificial conditions produced by researchers. A lack of vanadium has never been found to have any health effects on any kind of animals in natural settings.

Vanadium is a mild irritant to the skin, eyes, and respiratory system. If inhaled or ingested in more than small amounts, it may cause damage to the kidneys and the blood. No serious, long-term health effects have been identified with exposure to the element. Compounds of vanadium are much more harmful. For example, vanadium pentoxide is toxic if inhaled or swallowed.

Xenon



Key Facts

Symbol: Xe

Atomic Number: 54

Atomic Mass: 131.293

Family: Group 18 (VIIIA); noble gas

Pronunciation: ZEE-non

Overview

Xenon is a noble gas. The term noble gas is used to describe the elements in Group 18 (VIIIA) of the periodic table. The periodic table is a chart that shows how chemical elements are related to one another. "Noble gas" suggests a group of elements that is "too far above other elements" to react with them. The noble gases are also called the inert gases. That term has the same meaning. The noble gases react with other elements only under very unusual circumstances.

Xenon is very rare in the atmosphere. Its abundance is estimated to be about 0.1 parts per million. Xenon does not have many practical applications. One of its primary uses is to fill specialized lamps.

Discovery and Naming

It took chemists more than 100 years of careful research to understand the composition of air. In the early 1700s, they did not even understand the difference between the air around us and gases, like **oxygen**, carbon dioxide, and **nitrogen**. They used the word "air" to mean the same thing as "gas." Gases were very difficult to study. So it took a long time to figure out how various "airs" and "gases" differed from each other.

WORDS TO KNOW

Inactive: Does not react with any other element.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Liquid air: Air that has been cooled until all the gases in the air have condensed into a liquid.

Noble (inert) gas: An element in Group 18 (VIIIA) of the periodic table.

Periodic table: A chart that shows how chemical elements are related to one another.

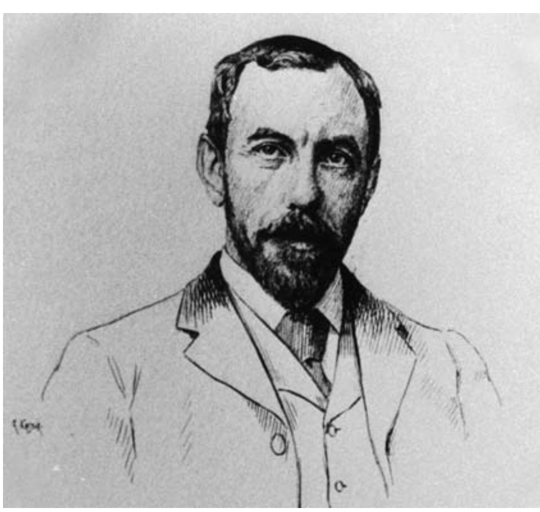
Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Slowly the differences became apparent. In 1774, English chemist Joseph Priestley (1733–1804) realized he could remove a separate gas—oxygen—from the air. Later, other gases in the air were identified. These included nitrogen, carbon dioxide, and other noble gases. One of the last gases to be isolated was xenon.

Xenon was discovered in 1898 by Scottish chemist and physicist Sir William Ramsay (1852–1916) and English chemist Morris William Travers (1872–1961). Ramsay and Travers used liquid air to make their discovery. Here's how they did the research:

If air is cooled to a very low temperature, it changes from a gas to a liquid. As it warms up, it changes back to a gas. But this change does not take place all at once. As liquid air warms, one gas (nitrogen) boils away first. As the temperature increases further, another gas (**argon**) boils off. Still later, a third gas (oxygen) boils off.

William Ramsay. LIBRARY OF CONGRESS



Great care must be used in doing this experiment. The first three gases to boil away (nitrogen, oxygen, and argon) make up 99.95 percent of air. It may look as if all the air is gone after the oxygen boils away, but it isn't.

After the oxygen is gone, a tiny bit of liquid air remains. That liquid air contains other atmospheric gases. One of those gases is xenon. Ramsay and Travers first recognized the presence of xenon in liquid air on July 12, 1898. They named the element xenon for the Greek word that means "stranger."

Physical Properties

Xenon is a colorless, odorless gas. It has a boiling point of –162.5°F (–108.13°C) and a melting point of –169.2°F (–111.80°C). It may seem strange to talk about the "melting point" and "boiling point" of a gas. So think about the opposite of those two terms. The opposite of melting is "turning from a liquid into a solid." The opposite of boiling is "turning from a gas into a liquid."

Thus, the boiling point of xenon is the temperature at which the gas turns into a liquid. The melting point of xenon is the temperature at which liquid xenon turns into a solid.

The density of xenon gas is 5.8971 grams per liter. That makes xenon about four times as dense as air.

Chemical Properties

For many years, xenon was thought to be completely inactive. Inactive means that it does not react with any other element. Then, in 1962, English chemist Neil Bartlett (1932–2008) made xenon platinofluoride ($XePtF_6$). Bartlett's success inspired other chemists to try making other xenon compounds. Chemists found ways to make such xenon compounds as xenon difluoride (XeF_2), xenon tetrafluoride (XeF_4), xenon hexafluoride (XeF_6), xenon trioxide (XeO_3), and xenon oxytetrafluoride ($XeOF_4$).

Occurrence in Nature

The Earth's atmosphere contains about 0.1 part per million of xenon. Studies indicate that the atmosphere of Mars may contain about the same amount of xenon, perhaps 0.08 parts per million. The element is not known to occur in Earth's crust.

Isotopes

Nine naturally occurring isotopes of xenon exist. They are xenon-124, xenon-126, xenon-128, xenon-129, xenon-130, xenon-131, xenon-132, xenon-134, and xenon-136. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Two of the naturally occurring isotopes of xenon are radioactive: xenon-124 and xenon-136. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive. Thirty-five radioactive isotopes of xenon made by artificial means are known also.

Two radioactive isotopes of xenon—xenon-127 and xenon-133—are used in medicine. These isotopes are used to study the flow of blood through the brain and the flow of air through the lungs. In most cases, the patient inhales the radioactive gas through a mask. The xenon gas moves through the body just like oxygen or any other gas. As it travels through the body, the xenon isotope gives off radiation. The radiation can be detected by measuring devices held over the body. Doctors can tell whether the patient's lungs are working properly.

Extraction

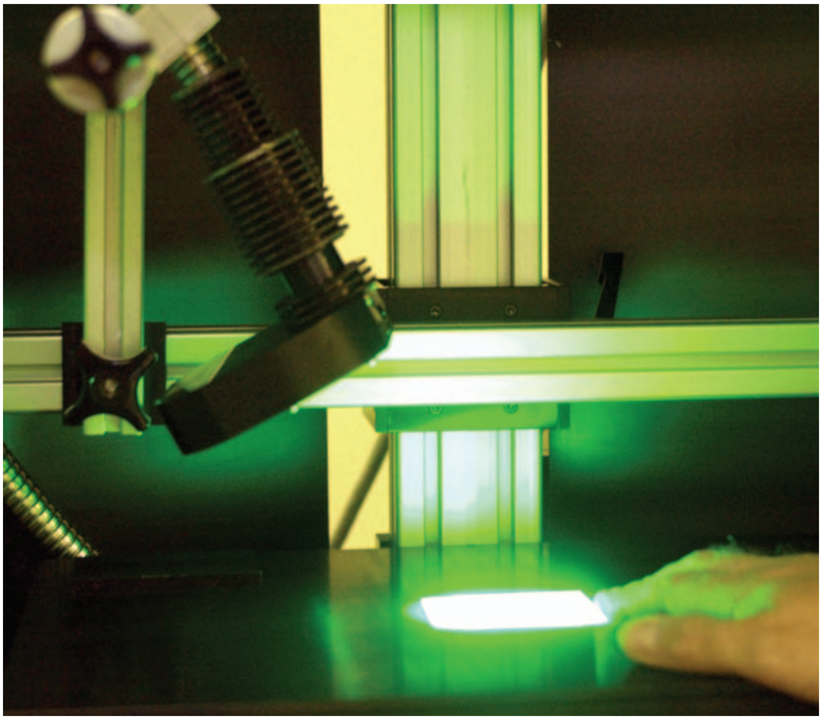
Xenon is produced in the same way it was discovered. Liquid air is allowed to evaporate. When most other gases have boiled off, xenon is left behind. The techniques used today are much better than those used by Ramsay and Travers, of course. It is now relatively easy to capture the xenon gas in air by this method.

Uses

The primary use of xenon is in lamps. When an electric current is passed through a gas, it can give off light. Fluorescent lamps and "neon" lights are examples of this process. The kind and color of light given off depend on the gas used in the lamp.

Xenon is used when a very bright, sun-like light is needed. For example, the flash units and bright lights used by photographers are often made with xenon gas.

Ultraviolet lights used to sterilize laboratory equipment may also contain xenon. The light produced is strong enough to kill bacteria. Xenon is also used in the manufacture of strobe lights. A strobe light produces a very bright, intense light in very short pulses. Strobe lights appear to "freeze" the movement of an object. Each time the light flashes on, it



A forensic scientist places a piece of paper, containing fingerprints, in front of a filtered green xenon light used to highlight chemical images captured on a digital camera. AP IMAGES.

shines on the moving object for a fraction of a second. The object's motion can be broken down into any number of very short intervals.

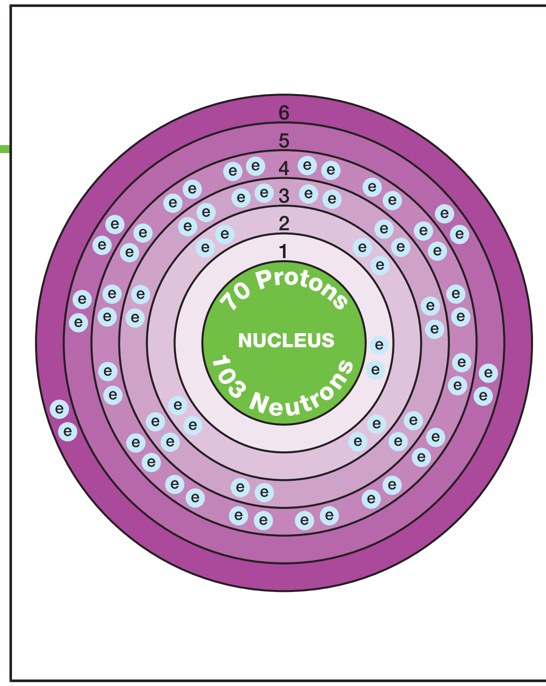
Compounds

So far, xenon compounds are only laboratory curiosities. They have no practical applications.

Health Effects

Xenon is a harmless gas. Some of its compounds, however, are toxic.

Ytterbium



Key Facts

Symbol: Yb

Atomic Number: 70

Atomic Mass: 173.054

Family: Lanthanoid (rare earth metal)

Pronunciation: i-TER-bee-um

Overview

Ytterbium belongs to the lanthanoid family. The lanthanoids are found in Row 6 of the periodic table. The periodic table is a chart that shows how the chemical elements are related to each other. The lanthanoids are also known as rare earth elements. The name suggests that the lanthanoids do not occur commonly in the earth. In fact, that is not correct. They are not all that uncommon. The name rare earth arose because the elements were once difficult to separate from each other. With modern techniques, this separation can be done much more easily.

Ytterbium was one of nine new elements discovered in the mineral yttria at the end of the 19th century. Analyzing this mineral posed great difficulties for chemists of the time. The elements in yttria have very similar properties. That makes it difficult to separate them from each other. Three chemists, Jean-Charles-Galissard de Marignac (1817–1894), Lars Fredrik Nilson (1840–1899), and Georges Urbain (1872–1938), all deserve partial credit for discovering ytterbium.

WORDS TO KNOW

Ductile: Capable of being drawn into thin wires.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Malleable: Capable of being hammered into thin sheets.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Discovery and Naming

In 1878, French chemist Jean-Charles-Galissard de Marignac reported his analysis of the mineral erbia. Erbia was one of the minerals found a century earlier in an interesting new rock called yttria. The rock had been discovered outside the town of Ytterby, Sweden, in 1787 by Swedish army officer Carl Axel Arrhenius (1757–1824). In the century that followed Arrhenius' discovery, chemists worked hard to find out what elements were in yttria. Earlier chemists thought erbia was a new element, but Marignac disagreed. He said that erbia consisted of two new elements, which he called **erbium** and ytterbium.

The very next year, a second Swedish chemist, Lars Fredrik Nilson, proved that Marignac was wrong. Ytterbium was not a new element, he said. Instead, it consisted of two other new elements. Nilson called these elements **scandium** and ytterbium.

Nilson's analysis still did not solve this confusion. In 1907, French chemist Georges Urbain announced that Nilson's ytterbium was also a mixture of two new elements. Urbain called these elements ytterbium and **lutetium**. Marignac, Nilson, and Urbain are all given part of the credit for the discovery of ytterbium.

In fact, the ytterbium studied by Marignac, Nilson, and Urbain was not pure ytterbium. Instead, it was combined with **oxygen** and other elements. Fairly pure ytterbium metal was not produced until 1937 and high purity ytterbium was not produced until 1953.

Physical Properties

Ytterbium is a typical metal. It has a bright, shiny surface and is malleable and ductile. Malleable means capable of being hammered into thin sheets. Ductile means capable of being drawn into thin wires. Its melting point is 1,515°F (824°C) and its boiling point is 2,600°F (1,427°C). It has a density of 7.01 grams per cubic centimeter, seven times the density of water.

Chemical Properties

Ytterbium tends to be more reactive than other lanthanoid elements. It is usually stored in sealed containers to keep it from reacting with oxygen in the air. It also reacts slowly with water and more rapidly with acids and liquid ammonia.

Occurrence in Nature

Ytterbium is one of the more common lanthanoids. It is thought to have an abundance of about 2.7 to 8 parts per million in Earth's crust. That makes it somewhat more common than **bromine**, **uranium**, **tin**, and **arsenic**. Its most common ore is monazite, which is found in beach sands in Brazil, India, and Florida, among other places. Monazite typically contains about 0.03 percent ytterbium.

Isotopes

Seven naturally occurring isotopes of ytterbium are known. These isotopes are ytterbium-168, ytterbium-170, ytterbium-171, ytterbium-172, ytterbium-173, ytterbium-174, and ytterbium-176. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Twenty-nine radioactive isotopes of ytterbium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

Studies have been done on one radioactive isotope of ytterbium—ytterbium-169—for possible use in a portable X-ray machine. This isotope gives off gamma radiation, which is similar to X rays. Gamma rays pass through soft tissues in the body, just like X rays. But they are blocked by bones and other thick material. A small amount of ytterbium-169 acts just like a tiny X-ray machine. It can be carried around more easily than can a big X-ray machine.

Extraction

Ytterbium is obtained from its ores by reaction with **lanthanum** metal:

$$2La + Yb_2O_3 \rightarrow 2Yb + La_2O_3$$

Uses

Ytterbium has no major commercial uses. A small amount is used to add strength to special types of steel. Some ytterbium is also used in making lasers. A laser is a device for producing very bright light of a single color. The kind of light produced by a laser depends on the elements used in making it. One use of yttrium lasers is in bar code readers used at grocery stores. The laser "reads" the series of lines on a grocery item and records the price for that item.

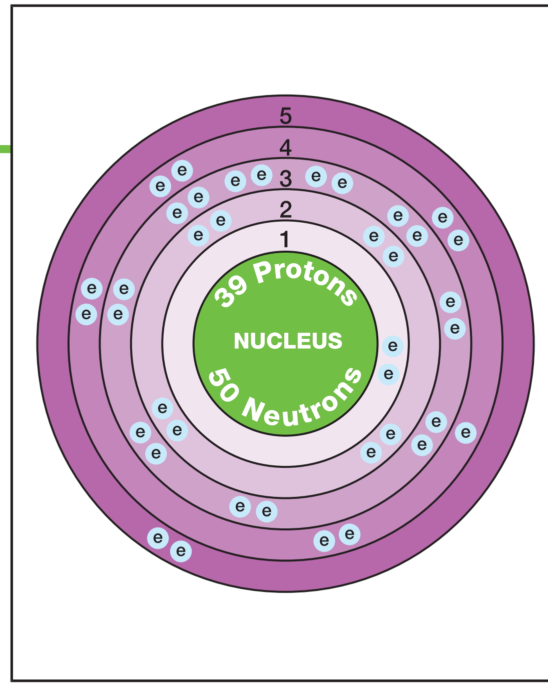
Compounds

The only ytterbium compound of commercial interest is ytterbium oxide (Yb_2O_3). This compound is used to make alloys and special types of ceramics and glass. In 2007, ytterbium oxide sold for about $450 per kilogram.

Health Effects

Ytterbium is not thought to be a very toxic element.

Yttrium



Overview

Yttrium is one of four elements named for the same small town of Ytterby, Sweden. The other three elements are **erbium**, **terbium**, and **ytterbium**. The element was discovered in 1794 by Finnish chemist Johan Gadolin (1760–1852). The discovery of yttrium marked the beginning of 100 years of complicated chemical research that resulted in the discovery of 10 new elements.

Yttrium is a transition metal. Transition metals are those elements in Groups 3 through 12 of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The element above yttrium in the periodic table is **scandium**. The space below yttrium is taken up by a group of elements known as the rare earth elements. Scandium, yttrium, and the rare earth elements are often found together in nature.

Yttrium is often used to make alloys with other metals. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Two of yttrium's most interesting applications are in lasers and superconducting materials.

A laser is a device for producing very bright light of a single color. One of the most popular lasers is made of yttrium, **aluminum**, and

Key Facts

Symbol: Y

Atomic Number: 39

Atomic Mass: 88.90585

Family: Group 3 (IIIB); transition metal

Pronunciation: I-tree-um

WORDS TO KNOW

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

"Doped": Containing a small amount of a material as an impurity.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Lanthanoids (rare earth elements): The elements in the periodic table with atomic numbers 57 through 71.

Laser: A device for making very intense light of one very specific color that is intensified many times over.

Periodic table: A chart that shows how chemical elements are related to each other.

Phosphor: A material that gives off light when struck by electrons.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Superconductor: A material that has no resistance to the flow of electricity; once an electrical current begins flowing in the material, it continues to flow forever.

Transition metal: An element in Groups 3 through 12 of the periodic table.

garnet. Garnet is a gem-like material with a sand-like composition. Superconducting materials are substances with no resistance to the flow of an electric current. An electric current that begins to flow through them never stops. Superconducting materials have many very important applications.

Discovery and Naming

In 1787, a lieutenant in the Swedish army named Carl Axel Arrhenius (1757–1824) found an interesting new stone near Ytterby. He gave the stone to Johan Gadolin for analysis. At the time, Gadolin was professor of chemistry at the University of Åbo in Finland. Gadolin decided that Arrhenius' rock contained a new element. That element was later given the name yttrium.

For about 50 years, nothing new was learned about yttrium. Then Swedish chemist Carl Gustav Mosander (1797–1858) discovered that yttrium was not a single pure substance. Instead, it was a mixture of three new substances. In addition to Gadolin's yttrium, Mosander found two more elements. He called these elements terbium and erbium.

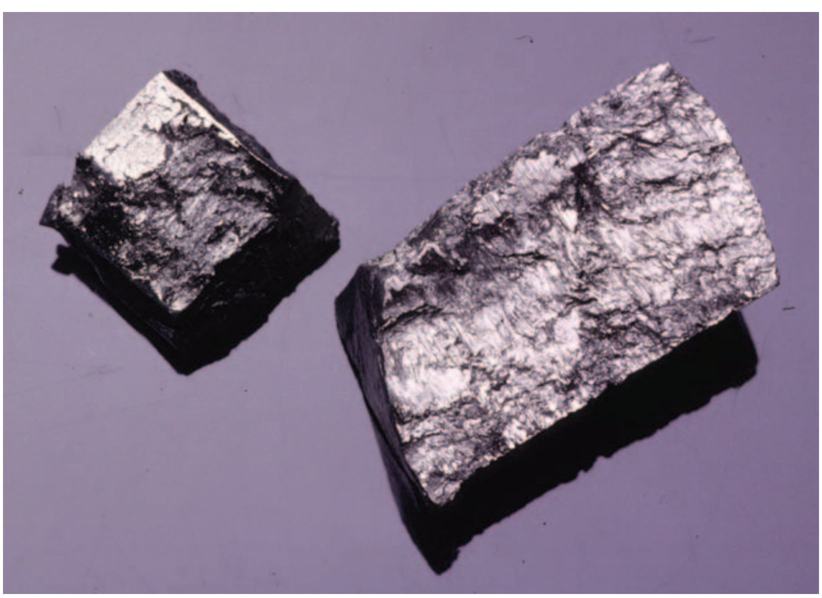
From that point on, the story of yttrium continued to get more and more complicated. As it turned out, neither terbium nor erbium was a pure element. Both new "elements" also contained other new elements. And these new "elements," in turn, contained other new elements. In the end, the heavy black mineral found by Arrhenius resulted in the discovery of 10 new elements! (See the individual entries for the nine other elements: **dysprosium**, **erbium**, **gadolinium**, **holmium**, **lutetium**, **scandium**, **terbium**, **thulium**, and **ytterbium**.)

Physical Properties

Yttrium has a bright, silvery surface, like most other metals. It also occurs as a dark gray to black powder with little shine. Yttrium has a melting point of 2,748°F (1,509°C) and a boiling point of about 5,400°F (3,000°C). Its density is 4.47 grams per cubic centimeter, more than five times the density of water.

Chemical Properties

The chemical properties of yttrium are similar to those of the rare earth elements. It reacts with cold water slowly, and with hot water very rapidly. It dissolves in both acids and alkalis. An alkali is the chemical opposite of an acid. Sodium hydroxide ("household lye") and limewater are common alkalis.



Yttrium samples. © CHARLES D. WINTERS/PHOTO RESEARCHERS, INC.

Solid yttrium metal does not react with **oxygen** in the air. However, it reacts very rapidly when in its powdered form. Yttrium powder may react explosively with oxygen at high temperatures.

Occurrence in Nature

Yttrium is a moderately abundant element in Earth's crust. Its abundance is estimated to be about 28 to 70 parts per million. That makes yttrium about as abundant as **cobalt**, **copper**, and **zinc**. As with other elements, the abundance of yttrium is quite different in other parts of the solar system. Rocks brought back from the Moon, for example, have a high yttrium content.

Yttrium occurs in most rare earth minerals. A rare earth mineral contains one or more—usually many—of the rare earth elements. The most important rare earth mineral is monazite. Monazite occurs in many places in the world, especially Brazil, Australia, Canada, China, India, and parts of the United States. Typically, monazite contains about 3 percent yttrium.

Isotopes

There is only one naturally occurring isotope of yttrium: yttrium-89. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

Forty radioactive isotopes of yttrium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of yttrium, yttrium-90, has some important practical applications. The isotope is combined with other substances to produce "smart drugs." Smart drugs are drugs that detect, attack, and destroy only certain, very specific kinds of cells, such as those found in cancerous tissue. One advantage of using yttrium-90 is that it is easy to obtain. It is produced when another radioactive isotope (strontium-90) breaks down. Strontium-90 is a by-product of nuclear reactions that occur in nuclear power plants.

Extraction

Yttrium is usually bought and sold in the form of yttrium oxide (Y_2O_3). In 2007, yttrium oxide sold for about $50 per kilogram. The pure metal can be obtained by combining another compound of yttrium, yttrium fluoride (YF_3), with calcium metal at high temperatures:

$$2YF_3 + 3Ca \rightarrow 3CaF_2 + 2Y$$

Uses

Traditionally, yttrium has had many of the same uses as the rare earth elements. For example, it has been used in phosphors. A phosphor is a material that gives off light when struck by electrons. The color of the light produced depends on the elements of which the phosphor is made. Yttrium phosphors have long been used in color television sets and in computer monitors. They have also been used in specialized fluorescent lights and newer plat-panel displays. In 2007, approximately 89 percent of all the yttrium consumed in the United States was used for the manufacture of lamp and cathode ray phosphors. Another 10 percent was used in ceramics.

Yttrium alloys have some special uses as well. These alloys tend to be hard, resistant to wear, and resistant to corrosion (rusting). They are used in cutting tools, seals, bearings, and jet engine coatings.

One of the areas in which yttrium is becoming more important is in the manufacture of lasers. Lasers are devices for producing very intense beams of light of a single color. These beams are used for precision metal cutting and surgery. There is some hope that lasers may someday replace the dental drill.

One of the most widely used lasers today is the yttrium-aluminum-garnet (YAG) laser. YAG lasers often contain other elements. These elements change the kind of light produced by the laser in one way or another. The laser is said to be doped with another element if it contains a small amount of that element. An example of this kind of laser is one doped with **neodymium**. The neodymium-doped YAG (Nd:YAG) laser has been used to make long distance measurements.

In this kind of laser, a beam is fired at a far-away object. The time it takes for the beam to be reflected is then measured. The time is used to calculate the distance to the distant object. One application of this principle is used by space probes.

The Scoop on Superconductors

One of the important uses for yttrium is in superconductors. Superconductors were first discovered by Dutch physicist Heike Kamerlingh-Onnes (1853–1926) in 1911. Kamerlingh-Onnes found that certain metals cooled to nearly absolute zero lose all resistance to an electric current. Absolute zero is the coldest temperature possible, about –459°F (–273°C). Once an electric current gets started in these very cold metals, it keeps going forever. These metals are called superconductors.

Research on superconductors did not advance very much for 70 years. It is very difficult to produce temperatures close to absolute zero, and it is difficult to work with materials at these temperatures.

Then, in 1986, a startling announcement was made. Two scientists at the IBM Research Laboratories in Zürich, Switzerland, had made a material that becomes superconducting at 35 degrees above absolute zero. That temperature, –396°F (–238°C), is still very cold, but it is much "warmer" than the temperature at which Kamerlingh-Onnes had worked.

An even bigger jump was announced only a year later. A team of researchers working under Ching-Wu "Paul" Chu (1941–) produced superconductors that work at 90 to 100 degrees above absolute zero. These temperatures are also still very cold, but they broke an important barrier. Those temperatures are close to the temperature of liquid nitrogen. Scientists have known how to make and work with liquid nitrogen for several hundred years. It had now become easy to work with superconducting materials.

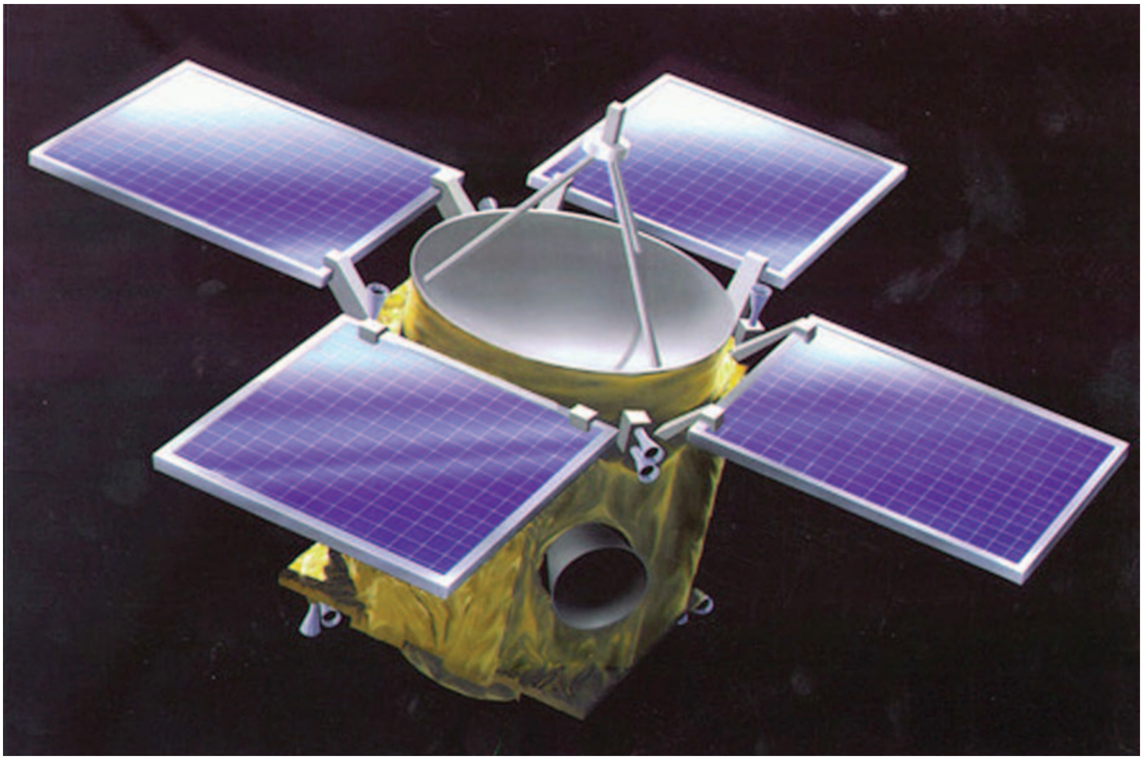
These "high-temperature" superconducting materials are very interesting. First, they are not metals. They are ceramics. A ceramic is a clay-like material. It often consists of sand, clay, brick, glass, or a stone-like material.

Second, the composition of these materials is difficult to determine. They usually contain barium, copper, lanthanum, yttrium, and oxygen. They often contain other elements. But they are not simple compounds, like copper oxide (CuO) or yttrium oxide (Y_2O_3). Instead, they are complex mixtures of the elements.

Superconductors may be very important materials in the future. Electrical machinery usually does not operate very efficiently. The electric current has to work hard to overcome resistance in wires and other parts of the machinery. A lot of the electrical energy is lost because of this resistance. The electrical energy turns into heat.

In a machine made of superconducting materials, the electrical current would meet no resistance at all. All of the electrical energy could be used productively. It could make the machine operate, rather than being lost as heat.

For example, an Nd:YAG laser was used by the Near Earth Asteroid Rendezvous (NEAR) spacecraft in 2000 to map the surface of the asteroid Eros. Light beams sent out by the laser measured with a high degree of accuracy the elevation of various parts of the asteroid, providing one of the best topographical maps of an asteroid surface ever obtained.



The Near Earth Asteroid Rendezvous (NEAR) spacecraft used an Nd:YAG laser. AP Images.

Compounds

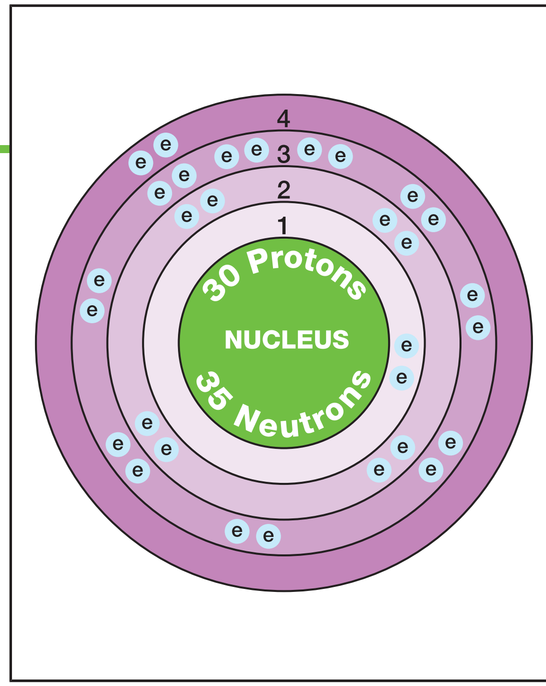
The only yttrium compound of commercial interest is yttrium oxide (Y_2O_3). Yttrium oxide is used to make phosphors for color television sets and in crystals used in microwave detection instruments.

Health Effects

Yttrium has been found to be toxic to laboratory rats in high doses. However, there is little information about its effects on humans. In such cases, an element is usually treated as if it were dangerous.

Some compounds of yttrium are mild irritants to the skin, eyes, and respiratory system.

Zinc



Key Facts

Symbol: Zn

Atomic Number: 30

Atomic Mass: 65.38

Family: Group 12 (IIB); transition metal

Pronunciation: ZINK

Overview

Zinc is a transition metal that occurs in the center of the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. The space between Groups 2 and 13 is occupied by the transition metals. These metals share many physical and chemical properties in common.

Alloys and compounds of zinc have been known since at least 500 BCE. But zinc metal was not known or used until much later. The reason is that zinc boils away or vaporizes easily when heated. Any effort to release zinc from its compounds also causes the metal to evaporate into the air.

Zinc was probably known in Asia before it was discovered in Europe. Ancient books from both India and China refer to zinc products. Such products were imported to Europe from Asia before they were made in Europe.

The most important use of zinc today is in galvanizing other metals. Galvanizing is the process of laying down a thin layer of zinc on the surface of a second metal. Zinc does not corrode (rust) as easily as **iron** and other metals. So the thin layer of zinc protects iron and other metals from corrosion.

WORDS TO KNOW

Alchemy: A kind of pre-science that existed from about 500 BCE to about the end of the 16th century.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Ductile: Capable of being drawn into thin wires.

Galvanizing: The process of laying down a thin layer of zinc on the surface of a second metal.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Malleable: Capable of being hammered into thin sheets.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Sublimation: The process by which a solid changes directly to a gas when heated, without first changing to a liquid.

Toxic: Poisonous.

Tracer: A radioactive isotope whose presence in a system can easily be detected.

Transition metal: An element in Groups 3 through 12 of the periodic table.

Discovery and Naming

Some metals can be obtained from their ores easily. In a few cases, all that is needed is to heat the ore. Heating an ore of zinc releases the free metal. But with zinc, there is an additional problem. Zinc metal sublimes very easily. Sublimation is the process by which a solid changes directly to a gas when heated, without first changing to a liquid. Anyone who wanted to make zinc from its ore would lose the zinc almost immediately by sublimation.

Of course, early people did not understand this process. They may very well have made zinc by heating its ores. But any zinc they made would have floated away immediately. Still, a process for extracting zinc from its ores was invented in India by the 13th century. The process involves heating the zinc ore in a closed container. When zinc vapor forms, it condenses inside the container. It can then be scraped off and used. That method seems to have been passed to China and then, later, to Europe.

In the meantime, ancient people were familiar with compounds and alloys of zinc. For example, there are brass objects from Palestine dating to 1300 BCE. Brass is an alloy of **copper** and zinc. The alloy may have been made by humans or formed naturally in the earth. No one knows the origin of the brass in these objects.

The first European to describe zinc was probably Swiss physician Paracelsus (1493–1541). Paracelsus' real name was Theophrastus Bombastus von Hohenheim. Early in life, he took the name Paracelsus, meaning "greater than Celsus." Celsus was one of the great Roman physicians. Paracelsus wanted the world to know that he believed that he was even "greater than Celsus."

Paracelsus was also an alchemist. Alchemy was a kind of pre-science that existed from about 500 BCE to near the end of the 16th century. People who studied alchemy were called alchemists. They wanted to find a way to change **lead**, **iron**, and other metals into **gold**. They were also looking for the "secret to eternal life."

Alchemy contained too much magic and mysticism to be a real science. But it developed a number of techniques and produced many new materials that were later found to be useful in modern chemistry.

Paracelsus first wrote about zinc in the early 1500s. He described some properties of the metal. But he said he did not know what was in the metal. Because of his report on the metal, Paracelsus is sometimes called the discoverer of zinc.

The name zinc was first used in 1651. It comes from the German name for the element, *Zink.* What meaning that word originally had is not known.

Physical Properties

Zinc is a bluish-white metal with a shiny surface. It is neither ductile nor malleable at room temperature. Ductile means capable of being drawn into thin wires. Malleable means capable of being hammered into thin sheets. At temperatures above 212°F (100°C), however, zinc becomes somewhat malleable.

Zinc's melting point is 787.1°F (419.5°C) and its boiling point is 1,665°F (907°C). Its density is 7.14 grams per cubic centimeter, more than seven times the density of water. Zinc is a fairly soft metal. Its hardness is 2.5 on the Mohs scale. The Mohs scale is a way of expressing the hardness of a material. It runs from 0 (for talc) to 10 (for diamond).

Chemical Properties

Zinc is a fairly active element. It dissolves in both acids and alkalis. An alkali is a chemical with properties opposite those of an acid. Sodium

Zinc alloys are used in many items, including the pipes of this church organ in Amorbach, Germany. Construction of the organ was completed in 1782. © AKG/PHOTO RESEARCHERS, INC.

hydroxide ("common lye") and limewater are examples of alkalis. Zinc does not react with oxygen in dry air. In moist air, however, it reacts to form zinc carbonate. The zinc carbonate forms a thin white crust on the surface, which prevents further reaction. Zinc burns in the air with a bluish flame.

Occurrence in Nature

The abundance of zinc in Earth's crust is estimated to be about 0.02 percent. That places the element about 23rd on the list of the elements in terms of their abundance.

Zinc never occurs as a free element in the earth. Some of its most important ores include smithsonite, or zinc spar or zinc carbonate ($ZnCO_3$); sphalerite, or zinc blende or zinc sulfide (ZnS); zincite, or zinc oxide (ZnO); willemite, or zinc silicate ($ZnSiO_3$); and franklinite [$(Zn,Mn,Fe)O \bullet (Fe,Mn_2)O_3$].

As of 2008, the largest producers of zinc ore were China, Australia, Peru, the United States, and Canada. In the United States, zinc was mined in seven states for a total of about $1.51 billion, according to the U.S. Geological Survey (USGS).

Isotopes

Five naturally occurring isotopes of zinc are known. They are zinc-64, zinc-66, zinc-67, zinc-68, and zinc-70. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

One naturally occurring isotope of zinc is radioactive: zinc-70. It has a half-life of 500 trillion (500,000,000,000,000) years. Twenty-four artificial radioactive isotopes of zinc are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

One radioactive isotope of zinc, zinc-65, has some practical importance. Zinc-65 is used as a tracer to study physical and biological events. A tracer is an isotope whose presence in a system can easily be detected. The isotope is injected into the system at some point. Inside the system, the isotope gives off radiation. That radiation can be followed by means of detectors placed around the system.

For example, zinc-65 is used to study how alloys wear out. An alloy can be made using zinc metal. But the zinc used is zinc-65 instead of ordinary zinc. Changes in radiation given off by the radioactive isotope can be followed to find patterns in the way the alloy wears out. Zinc-65 can also be used to study the role of zinc in the human body. A person can be fed food that contains a small amount of zinc-65. The movement of the isotope through the body can be followed with a detector. A researcher can see where the isotope goes and what roles it plays in the body.

Extraction

As with many metals, pure zinc can be prepared from an ore by one of two methods. First, the ore can be roasted (heated in air). Roasting converts the ore to a compound of zinc and oxygen, zinc oxide (ZnO). The compound can then be heated with charcoal (pure **carbon**). The carbon takes the oxygen away from the zinc, leaving the pure metal behind:

$$2ZnO + C \xrightarrow{\text{heated}} 2Zn + CO_2$$

The other method is to pass an electric current through a compound of zinc. The electric current causes the compound to break apart. Pure zinc metal is produced.

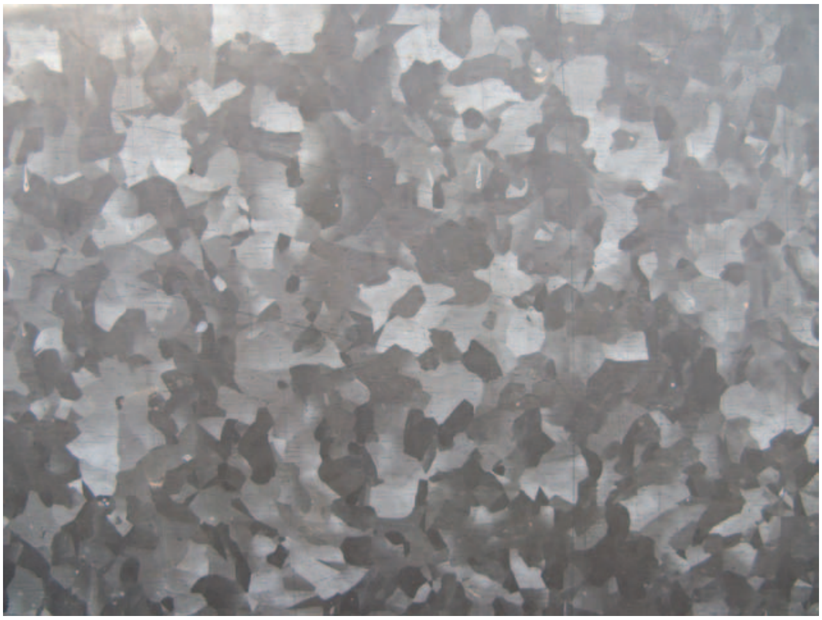
Uses

The annual cost of corrosion (rusting) in the United States is estimated to be about $267 billion. This is money lost when metals become corroded and break apart. Buildings and bridges are weakened, cars and trucks rust, farm equipment breaks down, and metal used in many other applications is destroyed. It is hardly surprising that protecting metal from corrosion is an important objective in American industry. One of the most effective ways of providing protection is through galvanizing. Today, about half of all the zinc produced in the United States is used to galvanize other metals. The largest consumers of galvanized metal are the construction and automotive industries.

The second largest use of zinc is in making alloys. An alloy is made by melting and mixing two or more metals. The mixture has properties different from those of the individual metals. Two of the most common alloys of zinc are brass and bronze. Brass is an alloy of zinc and copper. Bronze is an alloy of copper and **tin** that may also contain a small amount of zinc. Alloys of zinc are used in a great variety of products, including automobile parts, roofing, gutters, batteries, organ pipes, electrical fuses, type metal, household utensils, and building materials.

Compounds

A number of zinc compounds have important uses. Some examples follow:



Zinc is used to galvanize other metals, particularly iron and steel. A zinc-plated metal surface is shown here. IMAGE COPYRIGHT 2009, ZTS. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

- zinc acetate ($Zn(C_2H_3O_2)_2$): wood preservative; dye for textiles; additive for animal feed; glazing for ceramics
- zinc arsenate ($Zn_3(AsO_4)_2$): wood preservative; insecticide
- zinc borate (ZnB_4O_7): fireproofing of textiles; prevents the growth of fungus and mildew
- zinc chloride ($ZnCl_2$): solder (for welding metals); fireproofing; food preservative; additive in antiseptics and deodorants; treatment of textiles; adhesives; dental cement; petroleum refining; and embalming and taxidermy products
- zinc fluorosilicate ($ZnSiF_6$): mothproofing agent; hardener for concrete
- zinc hydrosulfite (ZnS_2O_4): bleaching agent for textiles, straw, vegetable oils, and other products; brightening agent for paper and beet and cane sugar juice
- zinc oxide (ZnO): used in rubber production; white pigment in paint; prevents growth of molds on paints; manufacturer of glass; photocopy machines; production of many kinds of glass, ceramics, tile, and plastics
- zinc phosphide (Zn_3P_2): rodenticide (rat killer)
- zinc sulfate ($ZnSO_4$): manufacture of rayon; supplement in animal feeds; dyeing of textiles; and wood preservative.

Zinc occurs naturally in some foods, such as cashews. One ounce of dry roasted cashews contains about 1.6 milligrams of zinc. IMAGE COPYRIGHT 2009, NORMAN CHAN. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Health Effects

Zinc is an essential micronutrient for plants, humans, and animals. Zinc deficiency has relatively little effect on the health of a plant, but it interferes with reproduction. Pea plants deprived of zinc, for example, will form flowers. But the flowers will not turn to seeds.

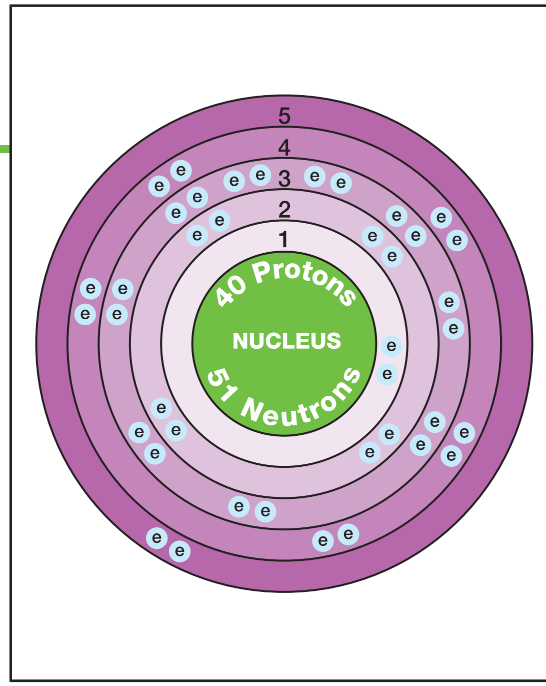
In humans, zinc deficiencies are more serious. Zinc is used to build molecules of DNA. DNA is the chemical in the body that tells cells what chemicals they should make. It directs the reproduction of humans also.

Fetuses (babies that have not yet been born) deprived of zinc may grow up to have mental or physical problems. Young children who do not get enough zinc in their diet may experience loss of hair and skin lesions. They may also experience retarded growth called dwarfism. Chemists have now found that zinc plays an essential role in the manufacture of many important chemicals in the human body.

On the other hand, an excess of zinc can cause health problems, too. Breathing zinc dust may cause dryness in the throat, coughing, general weakness and aching, chills, fever, nausea, and vomiting. One sign of zinc poisoning is a sweet taste in the mouth that cannot be associated with eating sweet foods. Certain compounds of zinc can be harmful to health also. Zinc chloride ($ZnCl_2$), for example, can cause skin rashes and sore throat.

Zinc occurs naturally in some foods. According to the Office of Dietary Supplements of the National Institutes of Health: "Oysters contain more zinc per serving [76.7 mg in 6 medium oysters] than any other food, but red meat and poultry provide the majority of zinc in the American diet. Other good food sources [of zinc] include beans, nuts, certain types of seafood (such as crab and lobster), whole grains, fortified breakfast cereals, and dairy products."

Zirconium



Key Facts

Symbol: Zr

Atomic Number: 40

Atomic Mass: 91.224

Family: Group 4 (IVB); transition metal

Pronunciation: zir-KO-nee-um

Overview

Compounds of zirconium have been known for centuries. Yet, the element itself was not recognized until 1789. In that year, German chemist Martin Heinrich Klaproth (1743–1817) discovered the element in a stone brought to him from the island of Ceylon (now Sri Lanka).

Zirconium is one of the transition metals. The transition metals are the elements found in Rows 4 through 7 and between Groups 2 and 13 in the periodic table. The periodic table is a chart that shows how chemical elements are related to each other. Zirconium is located below **titanium**, which it resembles, in the periodic table. Below zirconium is **hafnium**, a chemical twin of zirconium.

An important use of zirconium is in nuclear power plants. Its most important compound is zircon, which has a number of industrial applications. Zircon can also be obtained in gemstone quality. A gemstone is a mineral that can be cut and polished for use in jewelry or art.

Discovery and Naming

Naturally occurring compounds of zirconium have been used by humans since before the birth of Christ. For example, St. John talks about the

WORDS TO KNOW

Abrasive: A powdery material used to grind or polish other materials.

Alloy: A mixture of two or more metals with properties different from those of the individual metals.

Half life: The time it takes for half of a sample of a radioactive element to break down.

Isotopes: Two or more forms of an element that differ from each other according to their mass number.

Periodic table: A chart that shows how chemical elements are related to each other.

Radioactive isotope: An isotope that breaks apart and gives off some form of radiation.

Refractory: A material that does not conduct heat well.

Transition metal: An element in Groups 3 through 12 of the periodic table.

jacinth (or hyacinth) stone. He says it was one of the jewels found in the walls surrounding Jerusalem. The jacinth stone was the same mineral referred to by the Persians as *zargun,* meaning "gold-like" in Persian.

Early chemists did not study the jacinth stone very carefully. They thought it was another form of alumina (aluminum oxide). Alumina was a well-known mineral at the time. In fact, it was not until Klaproth undertook the study of the jacinth stone that he realized it contained a new element. Klaproth at first referred to the stone as Jargon of Ceylon. When he knew that he had found a new element, he suggested the name zirconium for it.

The material discovered by Klaproth was not a pure element. Instead, it was a compound of zirconium and **oxygen**, zirconium oxide (ZrO_2). The pure metal was not produced until 1824 when Swedish chemist Jöns Jakob Berzelius (1779–1848) made fairly pure zirconium. He made the metal by heating a mixture of **potassium** and potassium zirconium fluoride (ZrK_2F_6):

$$\mathbf{4K + ZrK_2F_6 \xrightarrow{\text{heated}} 6KF + Zr}$$

Physical Properties

Zirconium is a hard, grayish-white, shiny metal. Its surface often has a flaky-like appearance. It also occurs in the form of a black or bluish-black powder. It has a melting point of 3,375°F (1,857°C) and a boiling point of 6,471°F (3,577°C). Its density is 6.5 grams per cubic centimeter, more than six times the density of water.

Zirconium has one physical property of special importance: It is transparent to neutrons. Neutrons are tiny particles with no charge in the nucleus (center) of almost all atoms. Industrially, they are used to make nuclear fission reactions occur. Nuclear fission is the process in which large atoms break apart. Large amounts of energy and smaller atoms are produced during fission. Fission reactions are used to provide the power behind nuclear weapons (such as the atomic bomb). They are also used to produce energy in a nuclear power plant.

An important compound of zirconium is zircon. In addition to having various industrial applications, zircon can also be obtained in gemstone quality.

One of the problems in building a nuclear power plant is selecting the right materials. Many metals capture neutrons that pass through them. The neutrons become part of the metal atoms and are no longer available to make fission reactions occur. An engineer needs to use materials in a power plant that are transparent to neutrons—that allow neutrons to pass through them.

Zirconium is one of the best of these metals. If zirconium is used to make the parts in a nuclear power plant, it will not remove neutrons from the fission reaction going on inside the plant.

A special group of alloys of zirconium has been developed just for this purpose. They are called zircaloys. The manufacture of zircaloys is by far the most important use of zirconium metal in the world today.

Chemical Properties

Zirconium is a fairly inactive element. When exposed to air, it reacts with oxygen to form a thin film of zirconium oxide (ZrO_2). This film protects the metal from further corrosion (rusting). Zirconium does not react with most cold acids or with water. It does react with some acids that are very hot, however.

Occurrence in Nature

Zirconium is a fairly common element in Earth's crust. Its abundance is estimated to be 150 to 230 parts per million. That places it just below **carbon** and **sulfur** among elements occurring in Earth's crust. The two most common ores of zirconium are zircon, or zirconium silicate

($ZrSiO_4$); and baddeleyite, or zirconia or zirconium oxide (ZrO_2). The amount of zirconium produced in the United States is not reported. That information is regarded as a trade secret. As of 2008, the largest suppliers of zirconium minerals in the world are Australia and South Africa. These two countries produce about 72 percent of the world's zirconium.

Isotopes

There are five naturally occurring isotopes of zirconium: zirconium-90, zirconium-91, zirconium-92, zirconium-94, and zirconium-96. Isotopes are two or more forms of an element. Isotopes differ from each other according to their mass number. The number written to the right of the element's name is the mass number. The mass number represents the number of protons plus neutrons in the nucleus of an atom of the element. The number of protons determines the element, but the number of neutrons in the atom of any one element can vary. Each variation is an isotope.

One naturally occurring isotope of zirconium is radioactive: zirconium-96. It has a half life of 38 quintillion (38,000,000,000,000,000,000) years. Twenty-four artificial radioactive isotopes of zirconium are known also. A radioactive isotope is one that breaks apart and gives off some form of radiation. Radioactive isotopes are produced when very small particles are fired at atoms. These particles stick in the atoms and make them radioactive.

No radioactive isotope of zirconium has any important practical application.

Extraction

Zirconium ores are first converted to zirconium tetrachloride ($ZrCl_4$). This compound is then reacted with magnesium metal at high temperature:

$$2Mg + ZrCl_4 \rightarrow 2MgCl_2 + Zr$$

Uses

Many zirconium alloys are available. They are used to make flash bulbs, rayon spinnerets (the nozzles from which liquid rayon is released), lamp filaments, precision tools, and surgical instruments. These uses make up only a small amount of the metal produced, however, compared to its application in nuclear power plants.

Cubic zirconia (CZ) are much less expensive to buy than the real gems, but look just like the real thing.

Compounds

About 95 percent of all zirconium produced is converted into a compound before being used. The two most common compounds made are zircon (zirconium silicate) and zirconia (zirconium oxide).

Naturally occurring zircon is in demand as a gemstone. It is polished, cut, and used for jewelry and art. Natural zircon often includes **uranium**, **thorium**, and other radioactive elements. The presence of these elements often gives a zircon a special brilliance and fire-like quality, resembling fine diamonds. Synthetic diamonds and gemstones, known as cubic zirconia, are produced from zirconium oxide.

Zircon has other properties that make it desirable in industrial applications. For example, it is an excellent refractory material. A refractory is a material that does not conduct heat well. It is able to withstand very high temperatures without cracking or breaking down.

Zircon is used to create the foundry molds used to make metal pieces of all shapes. Molten metal is poured into the mold. When it cools, it is removed from the mold. The use of zircon in a refractory mold produces a smooth surface on the metal.

Zircon is also used to make bricks in high-temperature furnaces and ovens. These furnaces and ovens are used to work with molten metals. Zircon bricks are ideal for such ovens because they reflect heat and are not destroyed by high temperatures.

Zirconium is also being used in some dental products, particularly crowns, veneers, and bridges. IMAGE COPYRIGHT 2009, RCB SHOOTER. USED UNDER LICENSE FROM SHUTTERSTOCK.COM.

Both zircon and zirconia are used as abrasives. An abrasive is a powdery material used to grind or polish other materials. Another important use of zircon and zirconia is in making objects opaque. Opaque means that light is not able to pass through. Suppose a person wants to make a glaze for pottery that looks completely white. The glaze must reflect all light that strikes it and not let any light through. Adding zircon or zirconia to the glaze will achieve this result.

Health Effects

Zirconium is regarded as relatively safe. Some studies have shown that it can cause irritation of the skin, eyes, and respiratory system. Deodorant products containing zirconium have been found to produce skin rashes.

Where to Learn More

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American Chemistry Council, 1300 Wilson Blvd., Arlington, VA 22209. Phone: 703 741 5000. Internet: http://www.americanchemistry.com/.

American Hydrogen Association, 2350 W. Shangri La, Phoenix, AZ 85029. Phone: 602 328 4238. Internet: http://www.clean air.org/.

American Iron and Steel Institute, 1140 Connecticut Ave., NW, Suite 705, Washington, DC 20036. Phone: 202 452 7100. Internet: http://www.steel.org.

Australian Uranium Association, GPO Box 1649, Melbourne, VIC 3001, Australia. Phone: +61 3 8616 0440. Internet: http://aua.org.au/.

Copper Development Association, 260 Madison Ave., New York, NY 10016. Phone: 212 251 7200. Internet: http://www.copper.org/.

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