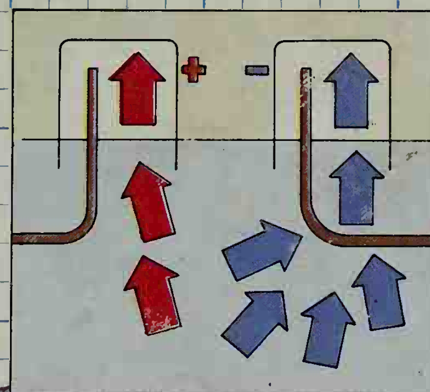
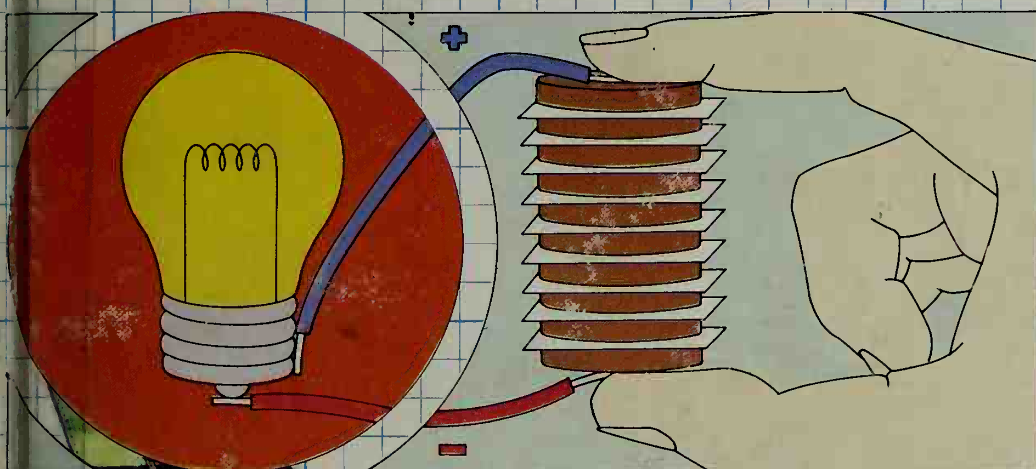
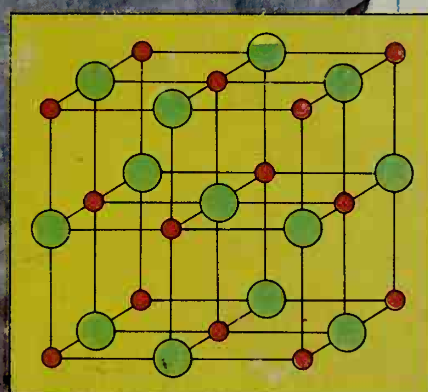
Franklin Watts Science World

Chemistry

Atoms, Molecules and Elements







Derek Walters

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Chemistry

Derek Walters

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Introduction

Chemistry is the science of substances – what they look like, what they do and why. It isn't just a subject for scientists in their laboratories, surrounded by bottles and beakers.

Chemistry can provide the answers to a wide variety of perplexing problems; what happens to paper when it burns; what is water made of; why are lemons sour? One aspect of chemistry deals with finding out what things are made of – this involves breaking down complex chemical substances into their basic constituents. The other side of chemistry is concerned with the invention of new materials, such as plastics, medicines, and even new foodstuffs.

This book introduces the subject through one of the most familiar processes of chemistry – burning – and shows how this is related to rusting, breathing and bleaching. Other types of chemical change – such as decomposition – are illustrated by examples from everyday life, from the homely matter of baking a cake to the splendid spectacle of a firework display. This leads us to the two great classes of chemical substances – acids and bases.

Since one of the products of mixing an acid with a base is water, this is an appropriate place to examine water's curious properties. Splitting water into its component parts by means of electricity introduces the subject of electrochemistry, including the chemical battery and chromium plating. The component parts are elements – the basic substances of which the world around us is composed, and the topic that is treated next. And finally, the elements can be further broken down into atoms – the building blocks of the universe!

Chemistry affects every aspect of our daily lives. Even something as simple as frying sausages involves chemical processes! And while it is well known that, say, car batteries contain acid, how often do we think of all the acids around us in the kitchen? Yet a few simple tests will prove their presence. Obviously, far more complicated chemical processes are involved in the industrial manufacture of synthetic materials. But however they occur, naturally or otherwise, all chemical substances are made up of the basic elements, whose atomic structure is the key to their behavior.

Burning

Testing for acids

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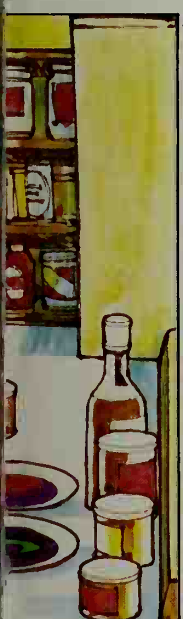
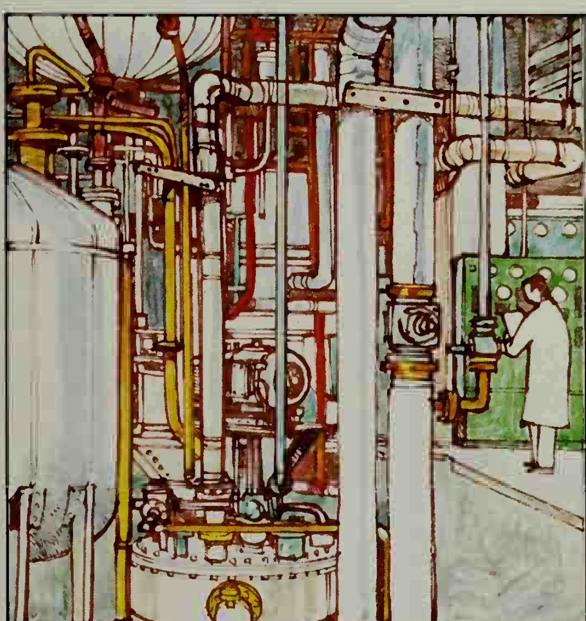
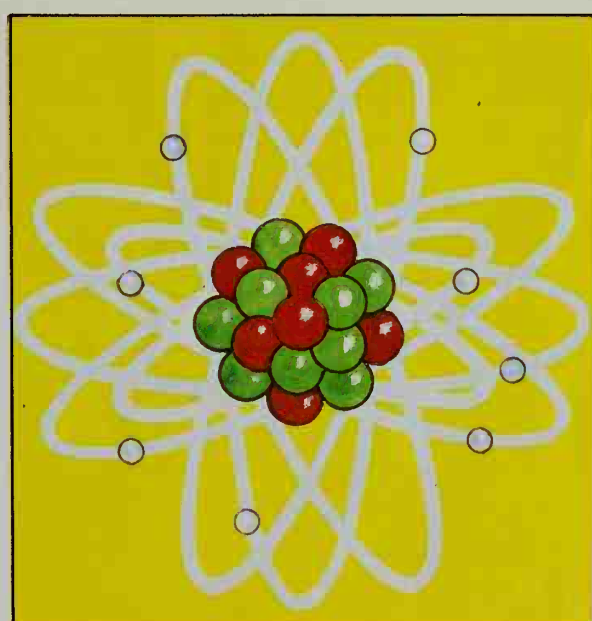




Inside a chemical plant



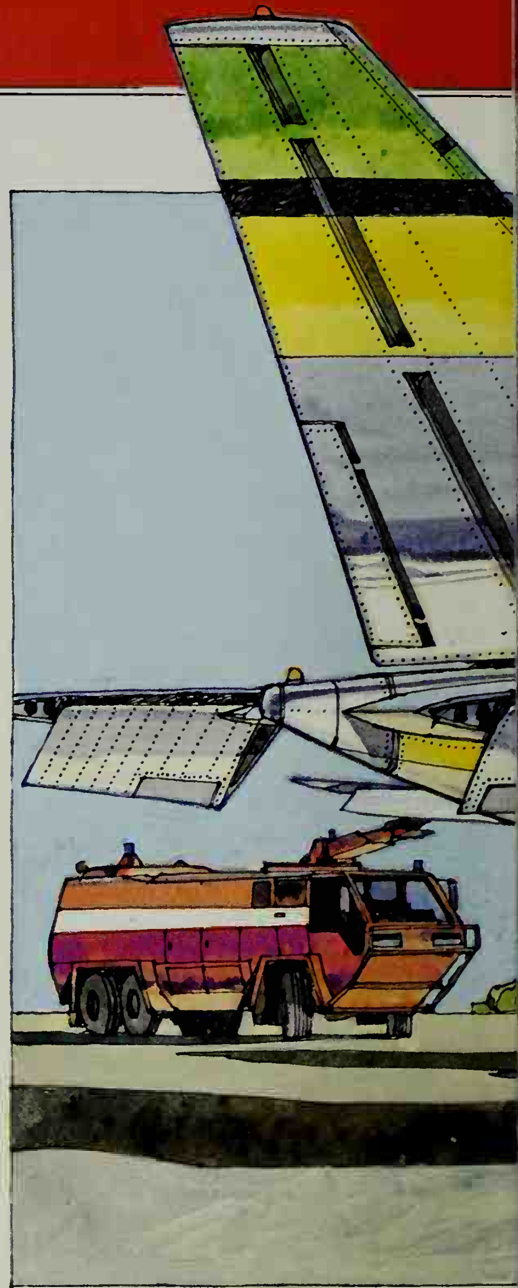
The structure of an atom

Burning

An airplane has to make an emergency landing. Fuel has started to leak from one of its tanks, and, as the plane touches down, heat from the friction of its tires hitting the ground is enough to set the kerosene fumes on fire. Fortunately, the airport's emergency services have been alerted, and they are on hand immediately to drench the plane with foam. What might have been a major disaster has been brought safely under control. All of which leads us to ask: why is kerosene so dangerous, and how can foam put the fire out?

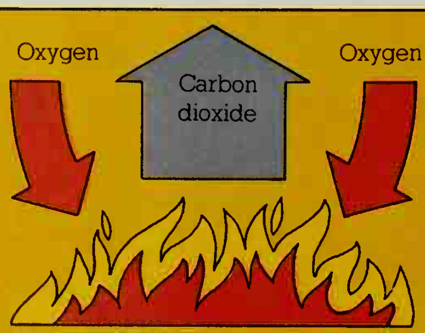
When fuels such as coal, wood, or oils are burned, most of the fuel seems to disappear into the air, while some heat is given out. Before something will burn, it needs to be "lit" by some other source of heat, such as a match. How much heat is needed to set fire to the fuel depends on the fuel's ignition point. Fuels such as coal, with a high ignition point, usually need another fire – perhaps from burning wood – to make them burn. Once lit, however, the heat from the burning process is enough to keep the fire going. On the other hand, fuels with low ignition points – such as kerosene or butane – have to be stored under special conditions, since the slightest spark is enough to ignite the fuel.

But nothing will burn without air. That is why, in the case of accidental fire, attempts are made to smother the flames with water, sand, blankets or, as with the burning plane, special foam. All these things act as barriers, keeping air away from the flames. Clearly, either the air, or something it contains, is needed for burning to take place. The vital ingredient is oxygen. Oxygen is so important that it is easy to forget that only a fraction of the air around us – just about one fifth – is made up of it. The rest consists mainly of nitrogen, which dilutes the oxygen in the air in much the same way as water is used to dilute concentrated fruit drinks.



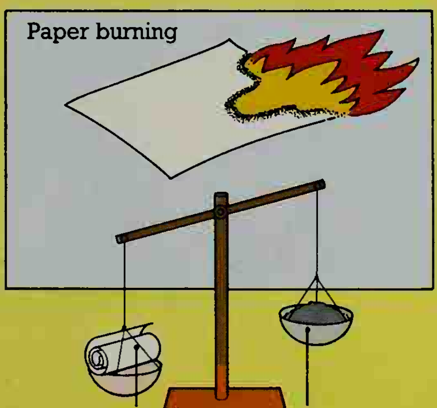
△ Firemen race against time to put out the fire before it reaches the aircraft's fuel tanks. The first priority is to keep the air away from the flames. This is done by smothering the flames with a special foam made up of bubbles containing carbon dioxide, in which things cannot burn. Foam has two advantages over water. It can be concentrated on its target more easily, and is easier to transport.

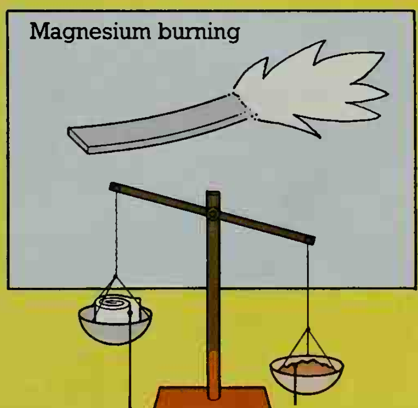
How things burn
Most fuels contain carbon. Charred wood, or charcoal, is almost pure carbon. When this burns in air, it combines with oxygen to make another gas, called carbon dioxide, and gives out heat energy.



Weighing the ash

When paper is burned, its ash weighs less than the original paper. This is because paper contains a lot of carbon, which is lost to the air as carbon dioxide. But burning magnesium (the metal used in a photo flash), captures oxygen from the air and deposits an ash, magnesium oxide, that will weigh more than the original metal.



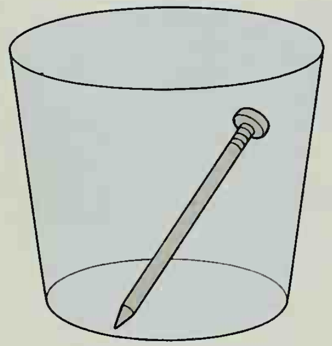


Rusting

Cars, bridges, and ships need to be painted regularly to prevent them rusting. Chemically, there is little difference between rusting and burning in air. In both, oxygen is taken from the air to make a new substance. The chemical name for rust is iron oxide. Normally, iron rusts more quickly if it is wet. However, iron can be kept underwater without rusting if the water is first boiled, to drive off its oxygen, and the container sealed with oil to prevent the oxygen from re-entering.

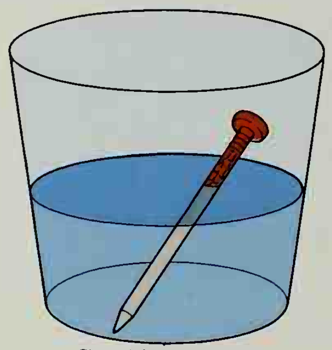
Rust takes its toll

In dry open air



Only slight rust

In water and air



Considerable rust

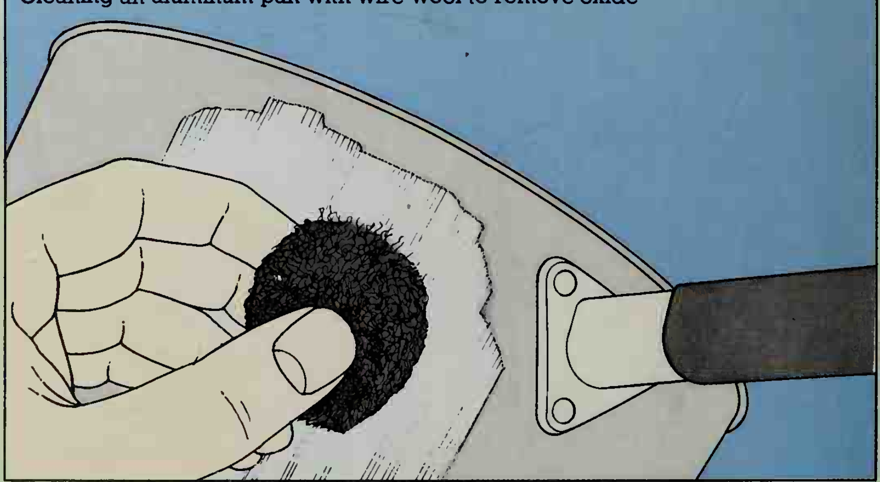
Under boiled water and sealed

Will not rust

Rusting can be a protection

The oxidation process affecting iron is harmful. As the rust (or iron oxide) falls off it exposes a fresh surface of iron to the air. But the oxygen captured from the air by aluminum helps to form a protective layer that sticks to the surface of the metal and actually prevents corrosion. However, it robs the metal of its shiny appearance.

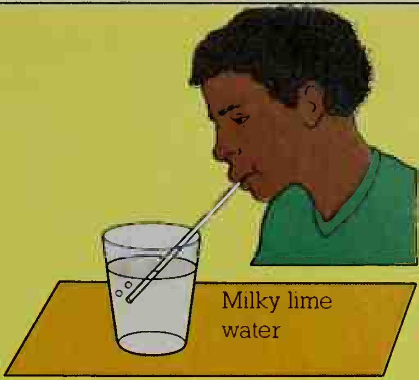
Cleaning an aluminum pan with wire wool to remove oxide



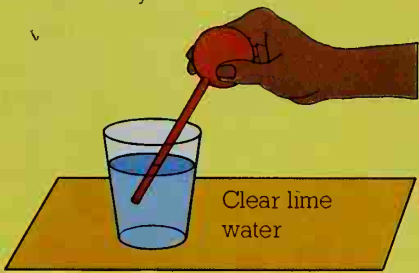
Divers giving off bubbles of carbon dioxide

Breathing

It can be shown that the oxygen we breathe combines with carbon (from our food) to make carbon dioxide by a natural process of oxidation. "Lime water" is normally clear, but turns cloudy when carbon dioxide is passed through it. The air around us contains only a trace of carbon dioxide, and so does not cause lime water to change color. But the air we breathe out, when bubbled through lime water, will turn it milky, because of the carbon dioxide present.



Breathing into lime water turns it milky



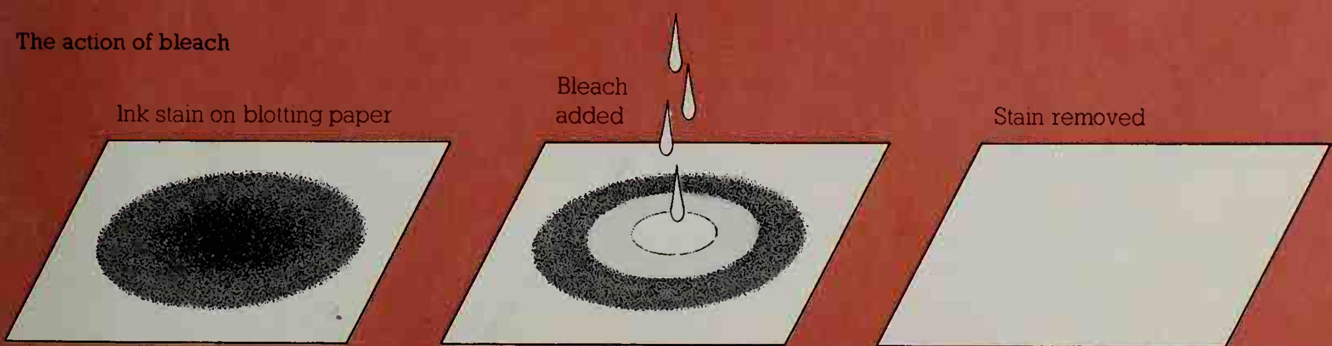
Ordinary air blown through lime water makes little change

Bleaching

Bleach may be used to make grimy or yellowed materials white again, to remove ink stains, or even to "dye" things white. The bleaching process is a form of oxidation, but a very odd one. Oxygen is not taken from the air, but is already contained in the bleach together with another substance, chlorine. Chlorine, however, has a stronger attraction for hydrogen than for oxygen and so, when it comes into contact with, for instance, grease or dyes, that contain hydrogen, it takes away hydrogen and leaves oxygen in its place. The oxides formed as a result are white, which is why the color disappears. Thus bleach does not actually remove grime, dyes or inks from materials. It merely oxidizes them.

Bleaching washing

The action of bleach



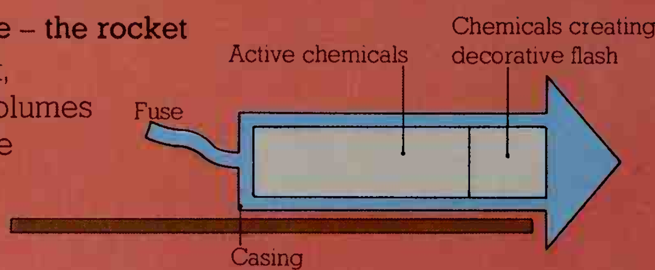
Active Substances

Sometimes, the celebration of a major event is accompanied by a spectacular firework display. In particular, firework displays are a traditional way of commemorating great victories in war; the loud explosions and brilliant flashes that light up the sky recapturing the thrill and excitement of battle while allowing the whole experience to be enjoyed in safety. But how are these gloriously noisy and colorful displays produced?

We saw earlier that in burning, oxygen in the air combines with something else to make a new substance. The opposite happens when a rocket is set off: a compound substance splits up into simpler ones, or decomposes. At least one of these substances is a gas, but produced in such vast quantities, and so suddenly, that it shoots out of the end of the firework, sending it into the air.

An explosive chemical mixture – the rocket

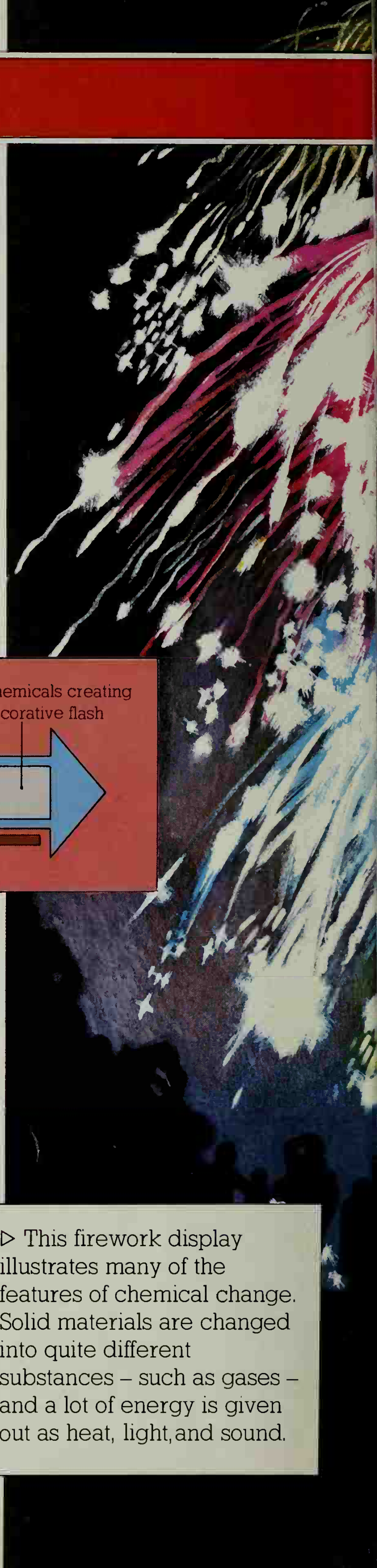
When the fuse to a rocket is lit, chemical reactions produce volumes of hot gas and propel it into the air. Further reactions in the nose produce decorative explosions in the sky.



Other fireworks involve more complicated chemical processes. Roman candles contain a mixture of combined, or compound, substances just waiting for the opportunity to change partners and rearrange themselves into new substances. When this happens, huge amounts of energy are released – the source of the dazzling displays of fire seen as the Roman candle burns. Some of the new substances are shot into the air as fiery sparks; others erupt like lava from miniature volcanoes.

Not all chemical processes are as energetic or spectacular as a firework display. But even striking a match involves a chemical reaction. Heat produced by friction when the match head is rubbed against the side of the box sets off a chemical process similar to that in a firework.

Many chemical processes, instead of giving out heat, need additional heat to make them work. But all chemical processes, great or small, spectacular or not, involve the making or breaking of partnerships between substances.

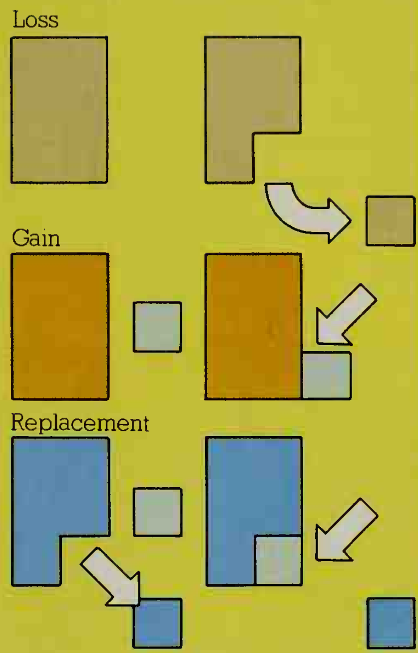


▷ This firework display illustrates many of the features of chemical change. Solid materials are changed into quite different substances – such as gases – and a lot of energy is given out as heat, light, and sound.

Chemical changes

Loss and Gain

When a chemical compound decomposes, it loses an ingredient and leaves a simpler substance behind. Combination is the opposite of decomposition. A simple substance gains a new ingredient in the course of a chemical reaction.

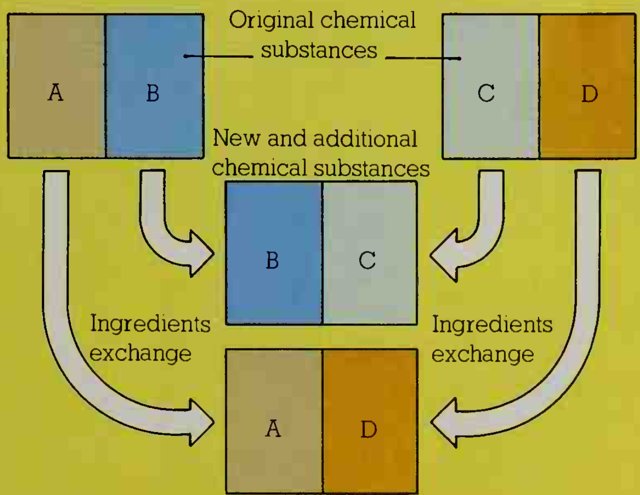


Replacement

Some chemical processes, including bleaching, involve the replacement of one ingredient of a compound by another.

Exchange

In other types of reactions, the ingredients of two substances may be exchanged to form two new substances. Sometimes this exchange is complete, sometimes only partial – the two new substances existing alongside the two original ones, as shown below.

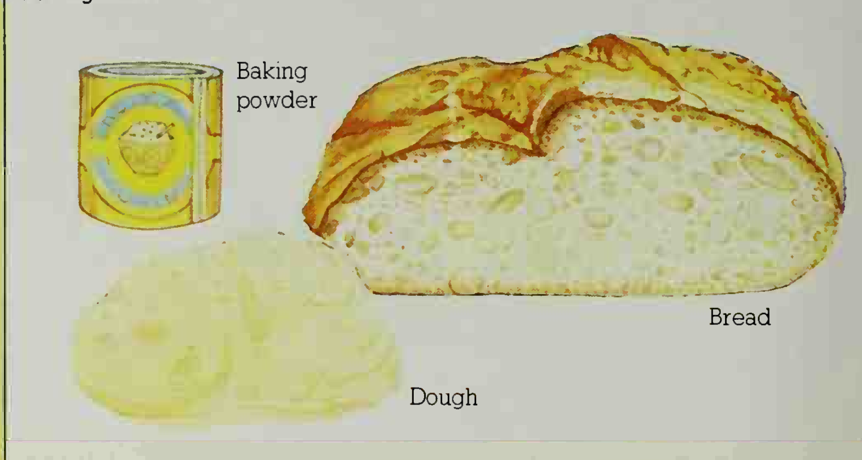


Loss

Baking soda

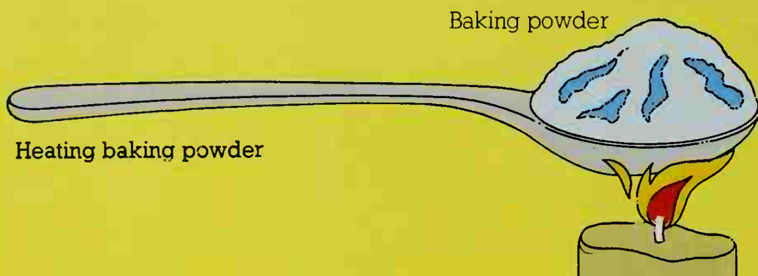
Making soda bread involves a chemical change – the decomposition of baking soda – which converts flat dough into something edible. Baking soda (sodium bicarbonate), when heated, breaks down into sodium carbonate ("washing soda") carbon dioxide and water. Bubbles of carbon dioxide are present throughout the dough, and lift it until the loaf has cooked all the way through.

Baking soda bread

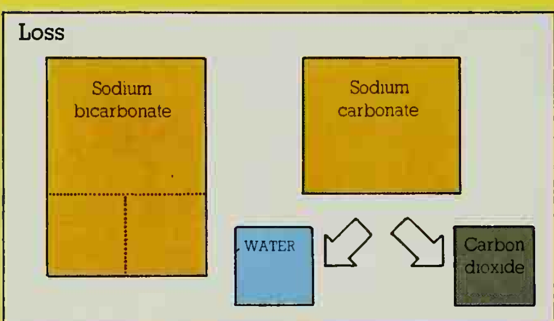


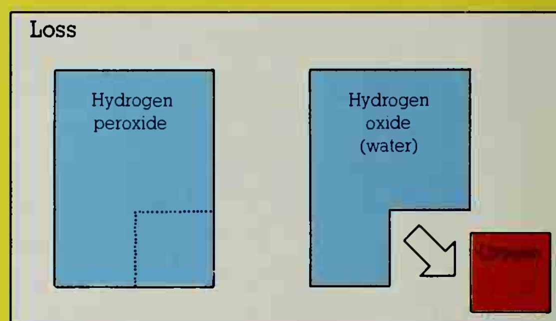
However, if too much baking soda is used, a lot of sodium carbonate will be left behind in the loaf, giving it a soapy taste.

Hydrogen peroxide solution is used as a mild bleach or antiseptic mouthwash. It has the same chemical ingredients as water, but contains extra oxygen. This is easily given up, leaving water behind. If you rinse your mouth with a weak hydrogen peroxide solution, you can feel oxygen bubbles being formed in your mouth.



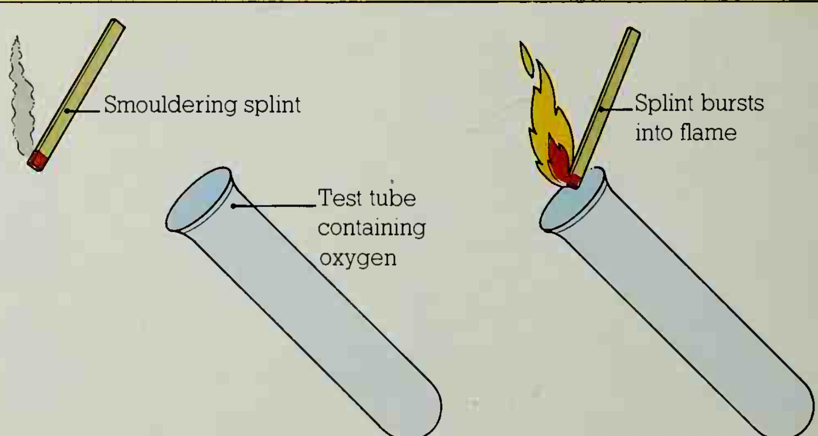
Heating baking powder





Testing for oxygen

Things burn much more readily in pure oxygen than they do in air. If a wooden splint is lit, and then blown out so that it is just glowing red, it will burst into flame again if put into a test tube containing pure oxygen. This is a way of testing for oxygen.

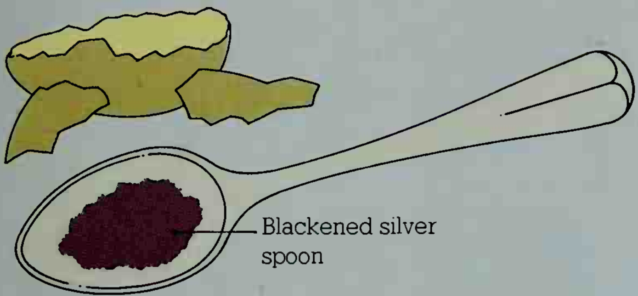


Gain

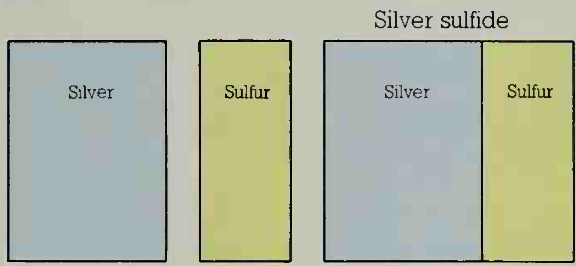
Silver combines with sulfur to form a black compound, silver sulfide. That is why silver cutlery turns black when it comes into contact with egg, or certain green vegetables, that contain traces of sulfur.

Eating an egg

Chemical names ending in "-ide" usually refer to compounds containing only the substances named. Thus silver sulfide consists of just silver and sulfur. The ending "-ate" as in copper sulfate, means that in addition to copper and sulfur, oxygen has to be one of the ingredients.



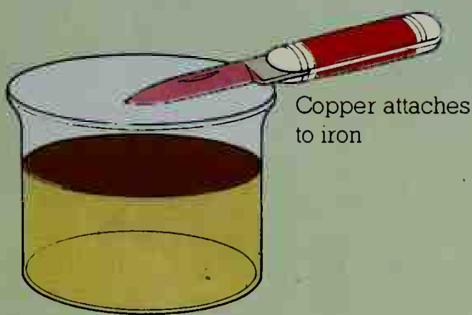
Gain



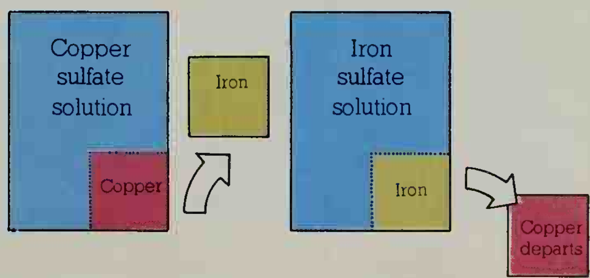
Replacement 1

Copper-plating iron

When an iron penknife blade is dipped into blue copper sulfate solution, it quickly becomes covered with a pink film, which is actually a thin coating of copper. This is an example of replacement. The "sulfate" part of copper sulfate has a very strong attraction for iron, so that, when it comes into contact with the iron blade of the penknife, it pushes the copper out of the way and binds with the iron instead. If the action is continued, all the copper will eventually be deposited on the blade, and a solution of iron sulfate left behind. The brown, rather than pink color that we usually associate with copper, is due to a film of copper oxide which forms when copper is exposed to the atmosphere.



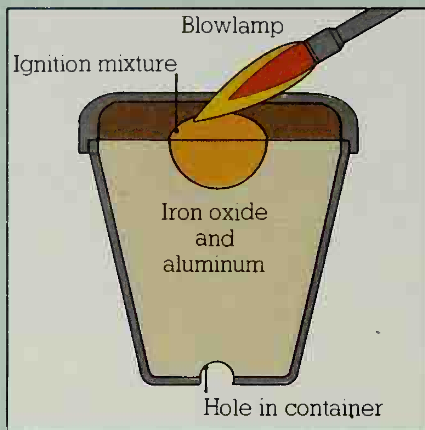
Replacement



Replacement 2

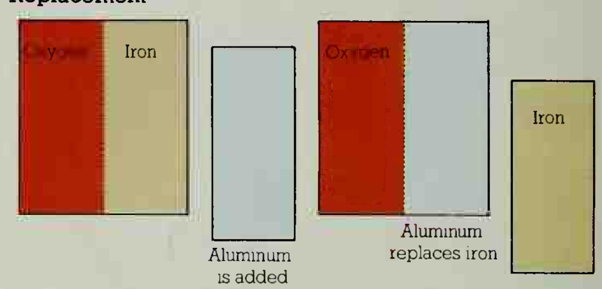
WARNING!
THIS IS A LABORATORY EXPERIMENT

One of the most energetic examples of chemical replacement is so powerful that it produces molten iron. This makes it very useful in remote places for on-the-spot repairs to iron structures. Called the Thermit process, it uses a mixture of powdered aluminum metal and iron oxide.



To start the reaction, a very high temperature is needed, for which an ignition mixture has to be used. As the aluminum replaces the iron in the iron oxide, the molten iron produced by the fierce heat pours through a hole in the special container and runs into the casting mold, or into the joint in need of repair.

Using the set-up on site



Exchange 1

Calcium sulfate sometimes hardens to form stalactites in damp caves

"Hard" water contains impurities dissolved in it, such as chalk, and when ordinary soap is put into hard water, a precipitate, or scum, forms. This is not only unattractive; it is also wasteful, since it prevents the soap from doing its job until all the chemicals causing the scum have been pushed out of the water. One of the main chemical ingredients of hard water is calcium sulfate. When soap (sodium stearate) is added to hard water, two new substances are formed.

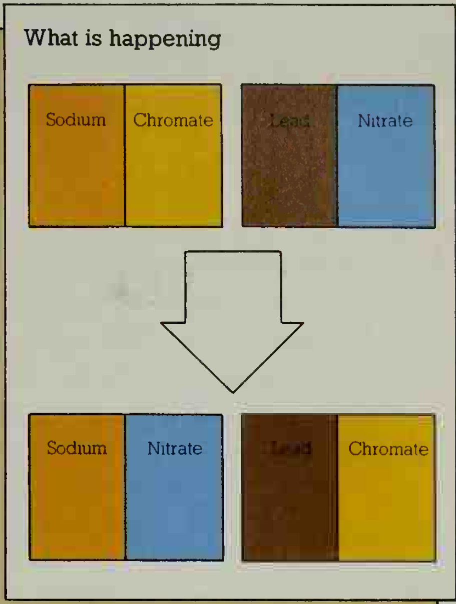
Scummy bath

These are sodium sulfate and calcium stearate. Calcium stearate does not dissolve in water, and instead floats to the surface as the familiar white scum. Sodium and calcium are

Exchange 2

Chrome yellow is the name given by artists to a bright yellow pigment. Surprisingly, this can be made in the laboratory by pouring one clear liquid into another, when – presto! – the bright yellow pigment suddenly appears! This is another example of the process known as exchange.

Very simply, the two chemical substances involved, sodium chromate and lead nitrate, have exchanged partners to make two new substances, sodium nitrate, which remains in the solution, and lead chromate. This settles at the bottom of the liquid as a very fine yellow powder, chrome yellow.



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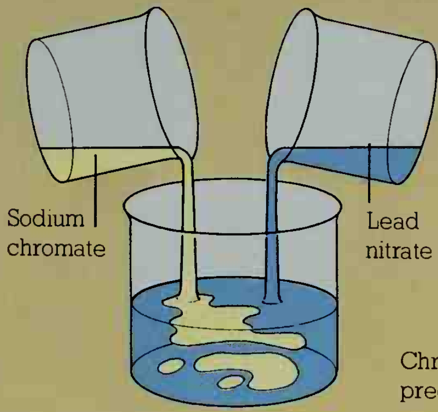
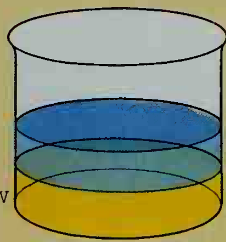
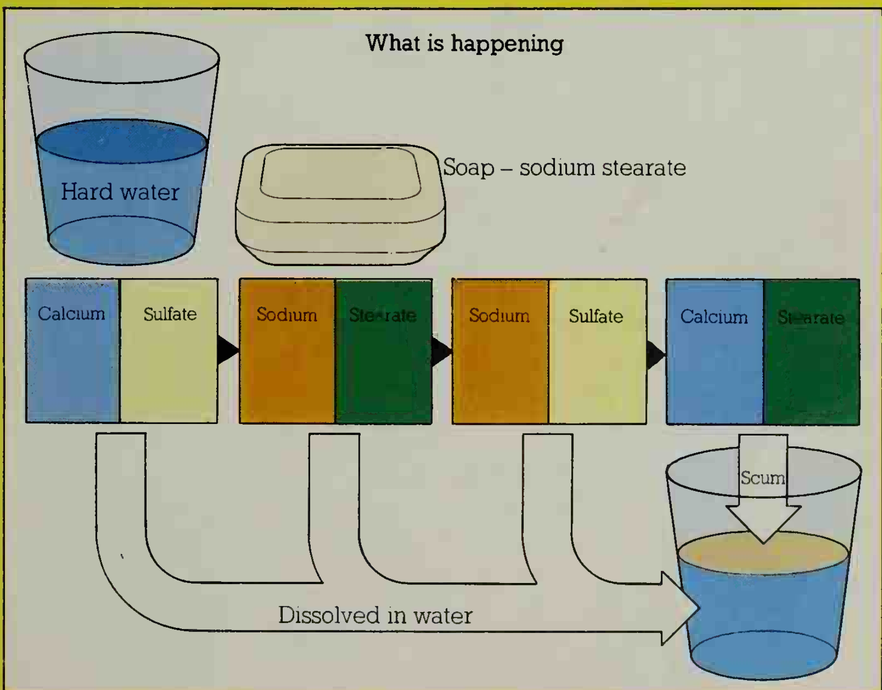
Chrome yellow paint





metals; stearate and sulfate are "radicals." The two metals have exchanged radicals to make two new substances. This type of chemical reaction is known as exchange.



Acids, Bases and Salts

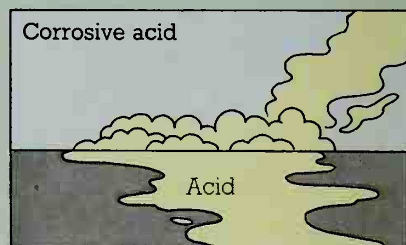
When people see a container labeled ACID, they like to keep well away. After all, it is rather an uncomfortable thought that something that looks as innocent as water can burn its way through leather, iron, steel and other materials that normally offer us protection. Corrosive acids spilled on the roads have been known to eat their way through car tires and the boots of rescue teams.

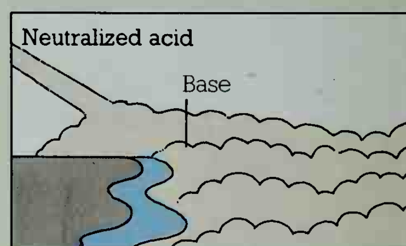
Fortunately, there are other substances – bases – which react with acids and make them safe. Bases are sometimes as powerfully corrosive as acids, but when an acid and a base are mixed together they neutralize each other, producing harmless "salts" and water. Containers carrying dangerous chemicals are marked with a placard identifying the chemical load, and must always carry instructions on the side as to which chemicals should be used as neutralizers in case of an accident.

In view of the reputation acid has, it might come as a surprise to know how many acids there are in the home – even in the kitchen and medicine cupboards. Yogurt, for instance, contains acid, and so does aspirin. Our own bodies, too, produce many complex acids to help build new tissue, carry messages around the body, and digest food.

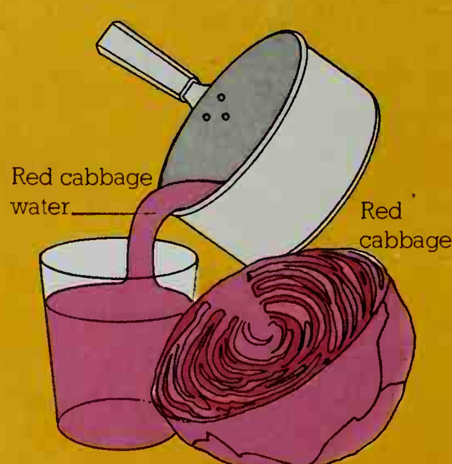
Bases also have their domestic uses. The various kinds of soda found in the home – baking soda, washing soda and caustic soda – are all bases. But the widest used base of all is lime. Besides its agricultural use, lime is a vital ingredient in cement, mortar, plaster and concrete. The lime reacts with carbon dioxide in the air and hardens the mixture as it dries out.

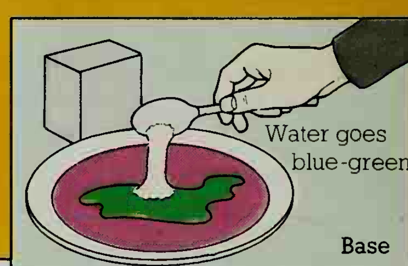
Bases neutralizing acids
How do an acid and a base neutralize each other? The two substances simply exchange partners by a chemical process with which we are already familiar: the exchange reaction.

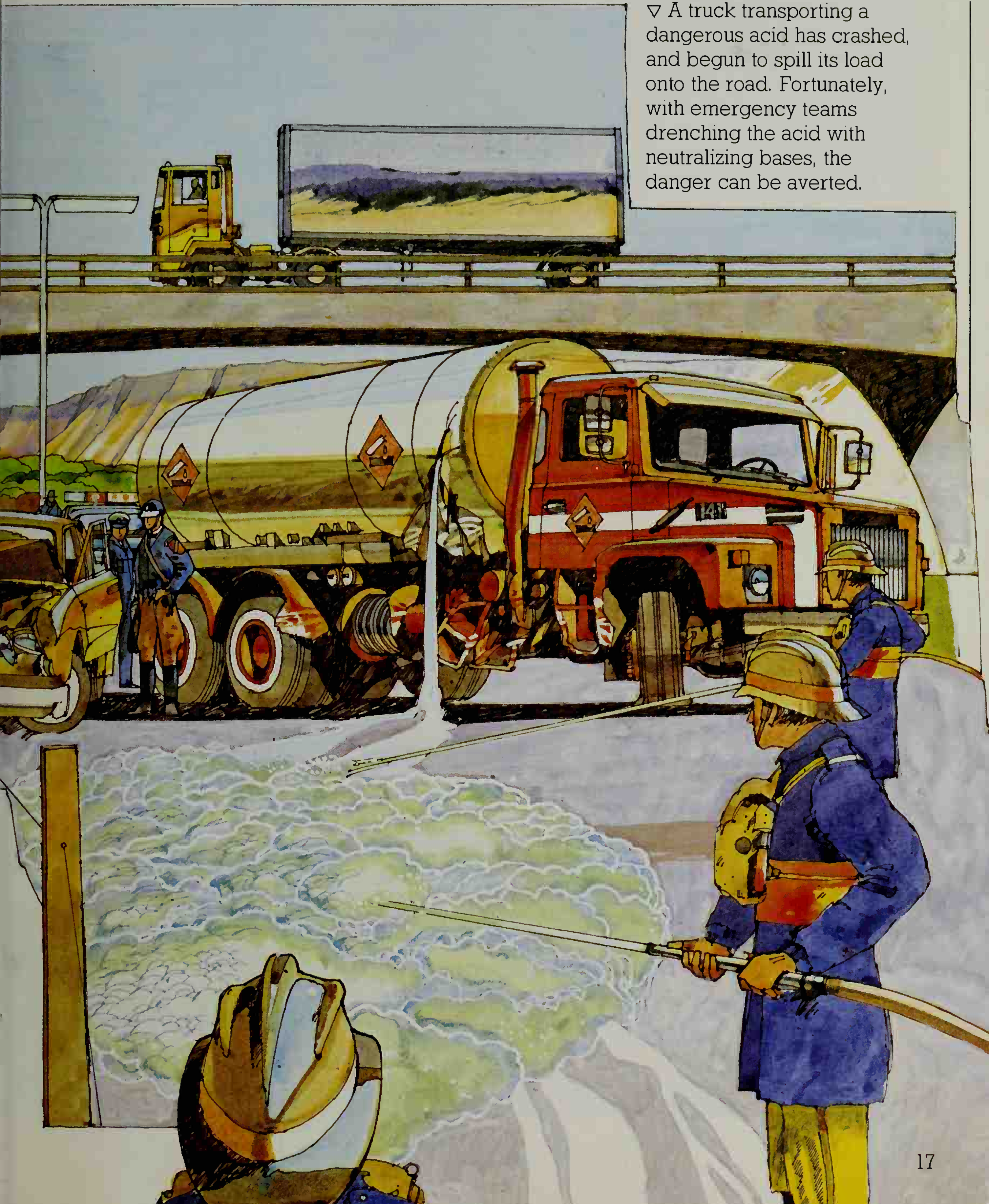




Testing for acids and bases
Many substances react differently to acids and bases, and so can be used as "indicators." An easily made indicator is the water in which red cabbage has been boiled. It turns red when an acid (e.g. vinegar or lemon juice) is added, but bluish-green when a base (such as washing soda) is added.







▽ A truck transporting a dangerous acid has crashed, and begun to spill its load onto the road. Fortunately, with emergency teams drenching the acid with neutralizing bases, the danger can be averted.

Weak Acids

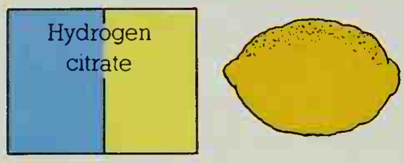
Not all acids are dangerous and corrosive. Many acids, such as Vitamin C (ascorbic acid), are essential to health. Even our own bodies produce acids, particularly to help break down food in our digestive systems.

A basket of "weak acids"

The sour taste of fruit is due to the fruit's own brand of acid. "Citrus" fruits, for example, contain citric acid. In other fruits the sour taste is often disguised by the sweetness of fruit sugars.

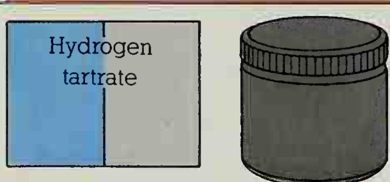
Acids can be thought of as hydrogen salts, with hydrogen taking the place of a metal. Acetic acid (in vinegar) can be thought of as "hydrogen acetate," lemon juice as "hydrogen citrate."

Some common weak acids



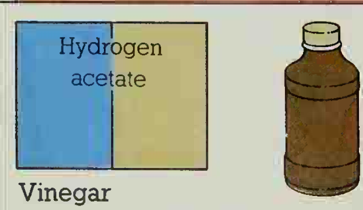
Lemon

Lemon juice, cream of tartar, and vinegar will all make bicarbonate of soda "fizz," so proving that they are acids.



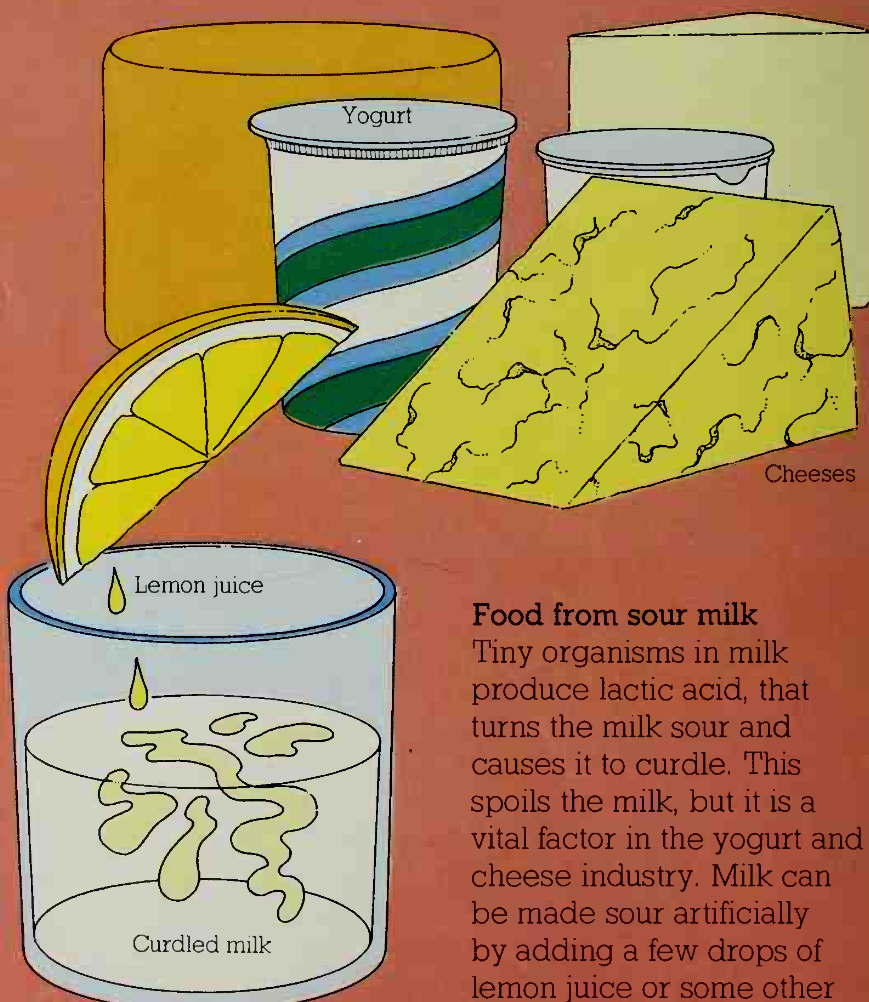
Cream of tartar

The acid "hydrogen tartrate" is better known as cream of tartar. It is obtained from fermenting wine.



Vinegar

Vinegar, probably the commonest acid in the home, is also made from wine or beer that has gone sour.

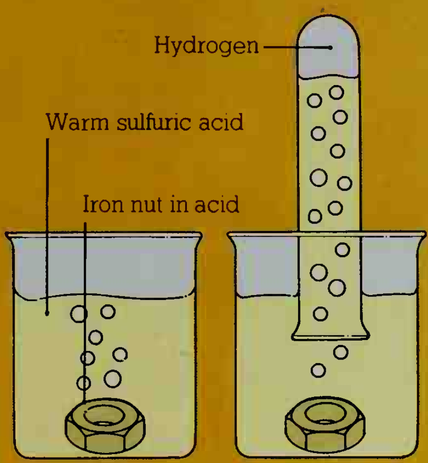


Food from sour milk

Tiny organisms in milk produce lactic acid, that turns the milk sour and causes it to curdle. This spoils the milk, but it is a vital factor in the yogurt and cheese industry. Milk can be made sour artificially by adding a few drops of lemon juice or some other mild acid.


Car battery

Strong Acids



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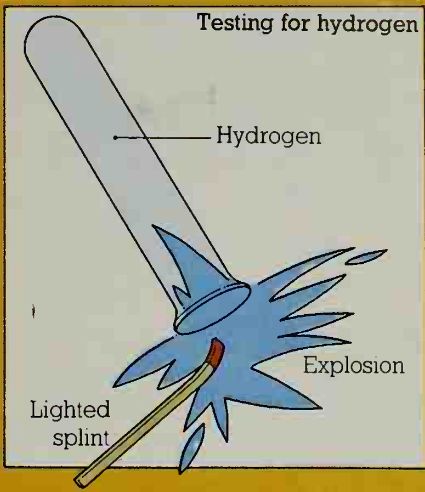


A car battery contains sulfuric acid, a powerful corrosive. Even when battery acid is diluted, it will still be strong enough to rot fabric and clothing. But strangely, cold concentrated sulfuric acid will not attack iron, and so can be carried safely in iron containers. Iron dissolves in warm sulfuric acid, giving off hydrogen. The iron replaces the hydrogen in the "hydrogen sulfate," and since hydrogen is highly inflammable, a lighted splint held at the mouth of a test tube containing this gas will cause it to explode with a loud "pop"

Electrochemical Series

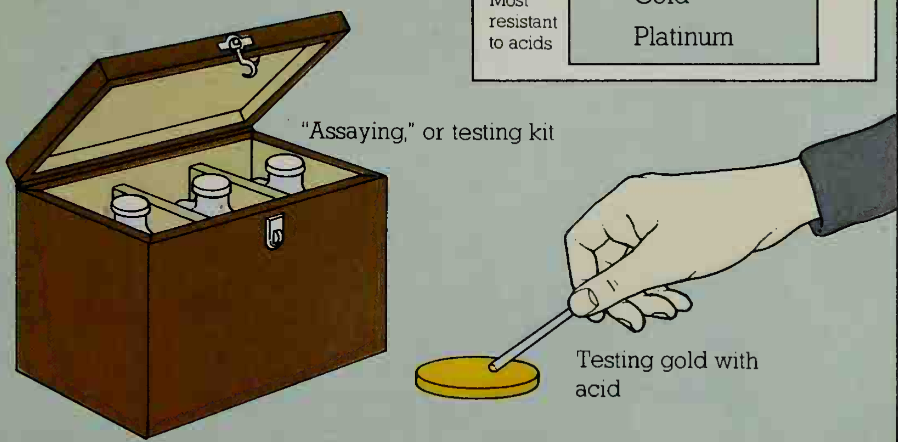
The electrochemical series gives a good idea of which metals are the most resistant to acids. Those at the top of the list are quickly attacked, those at the bottom, hardly at all.

Jewelers use this fact to test for the purity of gold by gradually increasing the strength of the testing acid. Pure gold remains unmarked, while cheaper metals stain or corrode.

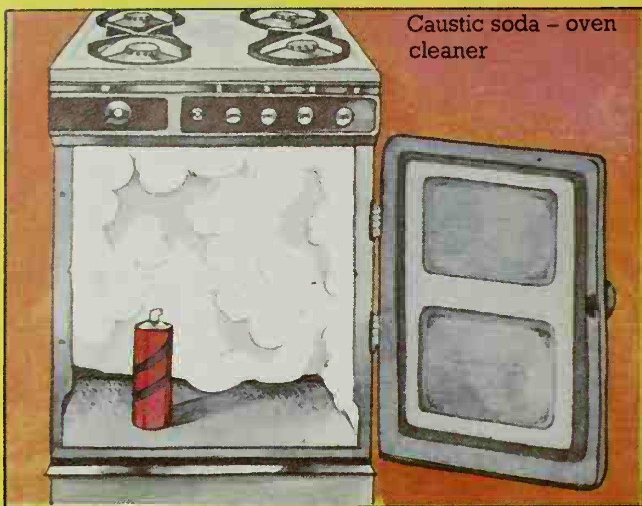
Electrochemical series

Least resistant to acids	Magnesium
	Aluminum
	Zinc
	Iron
	Lead
	Copper
	Mercury
	Silver
	Gold
Most resistant to acids	Platinum

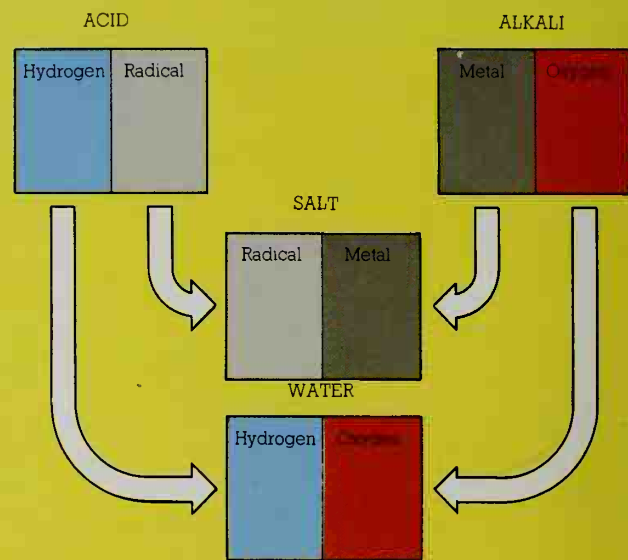

Gold jewelry and coins



Strong Bases



Caustic soda – oven cleaner

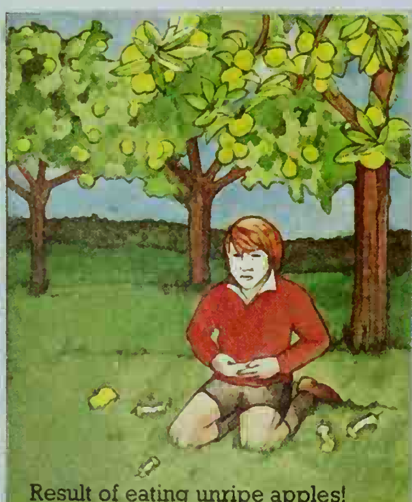


Just as there are strong and weak acids, so too there are strong and weak bases. One very common strong base is caustic soda – sodium hydroxide. This has a powerfully corrosive effect on grease and animal matter, and is often used in cleaning agents for ovens and drains.

An alternative term for a base is an "alkali," although strictly speaking, an alkali is a base that dissolves in water. Not all bases do. Bases are the opposite to acids, with oxygen forming part or all of the "radical" component of a metal compound – for instance, magnesium oxide.

When an acid and a base neutralize each other, the acid's hydrogen and the oxygen from the base join together to form water. The remaining components combine to form a "salt." In the case of hydrochloric acid and caustic soda, the salt produced is actually common salt.

Weak Bases



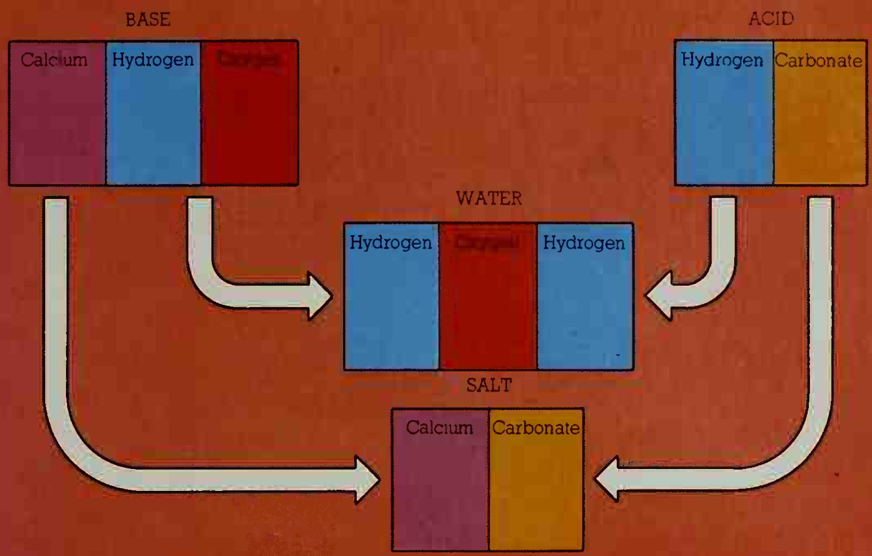
Result of eating unripe apples!

A stomach upset is often brought on by eating too much acidic food. When this happens, a weak base is needed to combat the stomach's excess acidity. "Milk of magnesia" (magnesium hydroxide) is one of the most common mild bases used for this purpose. It is able to neutralize acids in the stomach without producing any harmful side effects.

Unripe apples contain a lot of acid

Lime

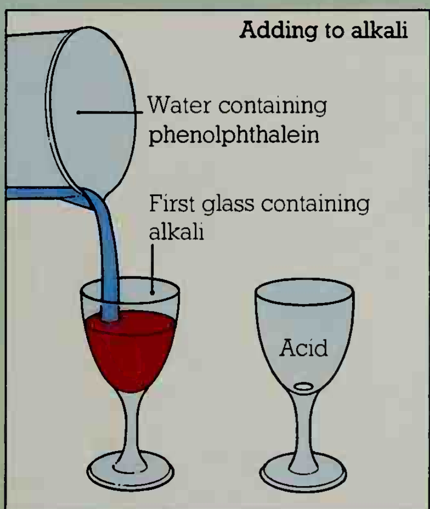
Farmers use lime (calcium hydroxide) to "sweeten" an acid soil, and make heavy, clay-laden soils more workable. Carbon dioxide in the air dissolves in water to form the very weak carbonic acid (hydrogen carbonate). The alkaline lime neutralizes any traces of carbonic acid in the earth, producing calcium carbonate (or chalk) – and some more water.

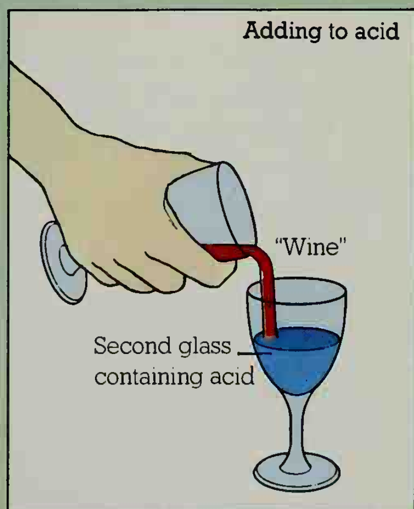


Liming fields

A Chemical Indicator

As water is poured into one glass, it appears to change into wine. When this "wine" is poured into another glass, it turns back to water! The reason is that the water jug contained a spot of phenolphthalein, which turns water bright red in the presence of an alkali. A drop of alkali in the first glass, and a drop of acid in the second is all you need.





Water

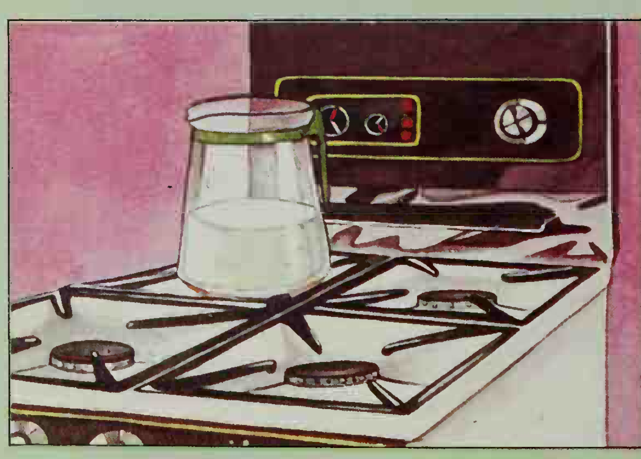
Water is the most important substance on our planet. For life on Earth to exist, this water must be in liquid form. Considering the vast range of temperatures in the universe, from the absolute cold of the deepest regions of outer space to the incredible heat of the Sun's furnace, it is remarkable that our planet should be at exactly the right temperature for this to happen.

Water is so important to chemistry – and hence to life – because it acts as a chemical vehicle for substances taking part in reactions. We have already seen that iron will not normally rust so quickly when there is no water present; neither will it be corroded by sulfuric acid provided that it is kept dry. When substances dissolve in water, they are brought into contact with each other and can react in a way that was not possible under dry conditions.

Water, as we have discovered, is a compound of two substances – hydrogen and oxygen. (The chemical formula for water, H_2O, shows that it contains twice as much hydrogen as oxygen.) Many chemical reactions produce water. Copper oxide, for instance, reacts with hydrogen to form pure copper and water. More familiarly, bases and acids react together to form water as one of the products of chemical exchange.

Water's main ingredient, hydrogen, is the commonest substance in the universe, yet there is very little free hydrogen in the Earth's atmosphere. The reason why is not difficult to guess. During the formation of the Earth most of the available hydrogen would have been burned up in producing the water to make up the vast oceans now covering the Earth's surface.

Chemical formation of water
A glass jug of milk on a gas ring appears to "sweat." The jug is not leaking! What is happening is that hydrogen from the gas supply and oxygen in the air burn together, to form steam. This condenses as tiny droplets of water on the cold surface of the jug – a microcosm of how the oceans were formed.



◁ Liquid water is the Earth's unique feature. Millions of years ago, our planet was formed amid vast clouds of steam. In time, the Earth cooled, and the steam condensed to make the oceans. It was only then – when water was not vaporized into steam or frozen into ice – that life on Earth became possible.

Hydrogen and Water

Hydrogen-filled airship burning

Because it is the lightest known gas, hydrogen was once used to float airships and aeronautical balloons. But it happens to be also extremely dangerous, and will burn readily (sometimes explosively) in oxygen. After a couple of spectacular disasters, the idea of passenger airships was abandoned in favor of airliners. Today, gas-filled balloons (often used for weather surveys) contain helium, which is also light, and safer than hydrogen.

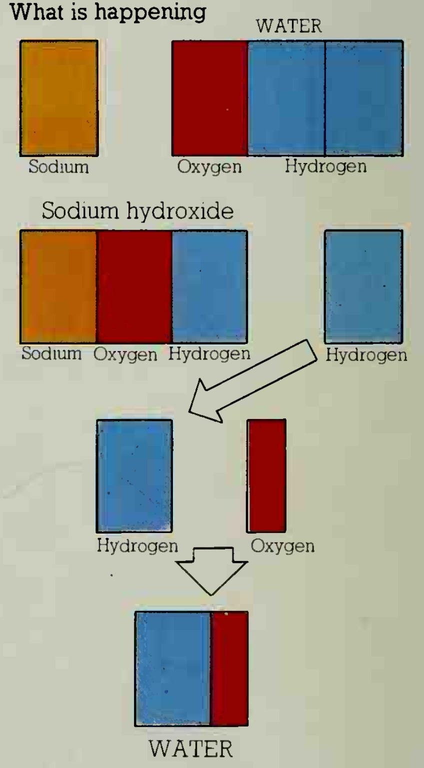
Burning Water

Sodium "burning" in water

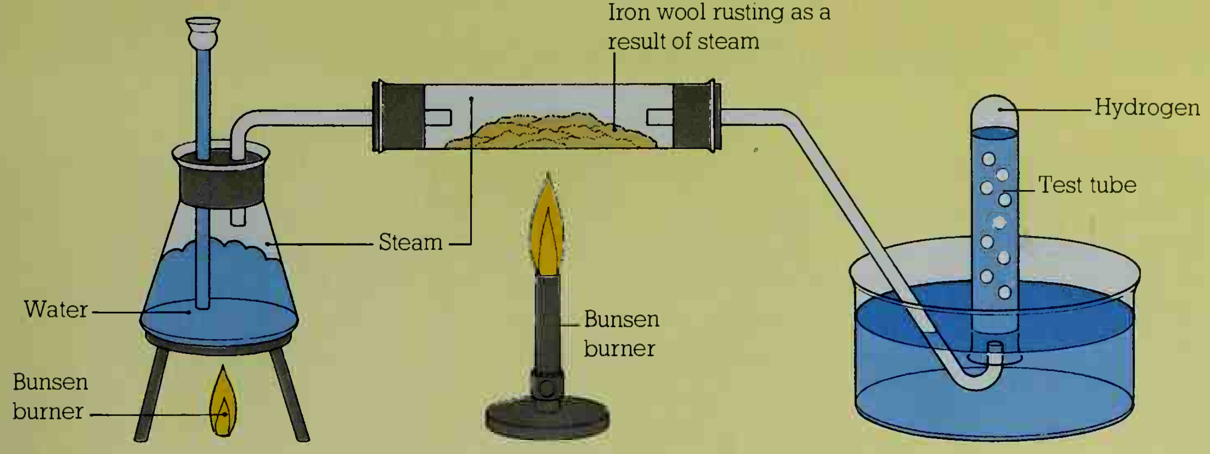
WARNING!
THIS IS A LABORATORY EXPERIMENT

Is it really possible to set water on fire? Yes. If you drop sodium into the water it will burst into flame! Sodium is a very reactive metal. It pushes half of the water's own hydrogen out of the way and takes its place (in much the same way that iron pushes copper out of copper sulfate solution). The sodium combines with the remaining hydrogen and oxygen to form sodium hydroxide. The hydrogen that is pushed out escapes as bubbles of gas, that propel the sodium round the surface of the water. Heat from the reaction sets the hydrogen alight, when it combines with oxygen in the air to form water again.

What is happening



Separating hydrogen from water

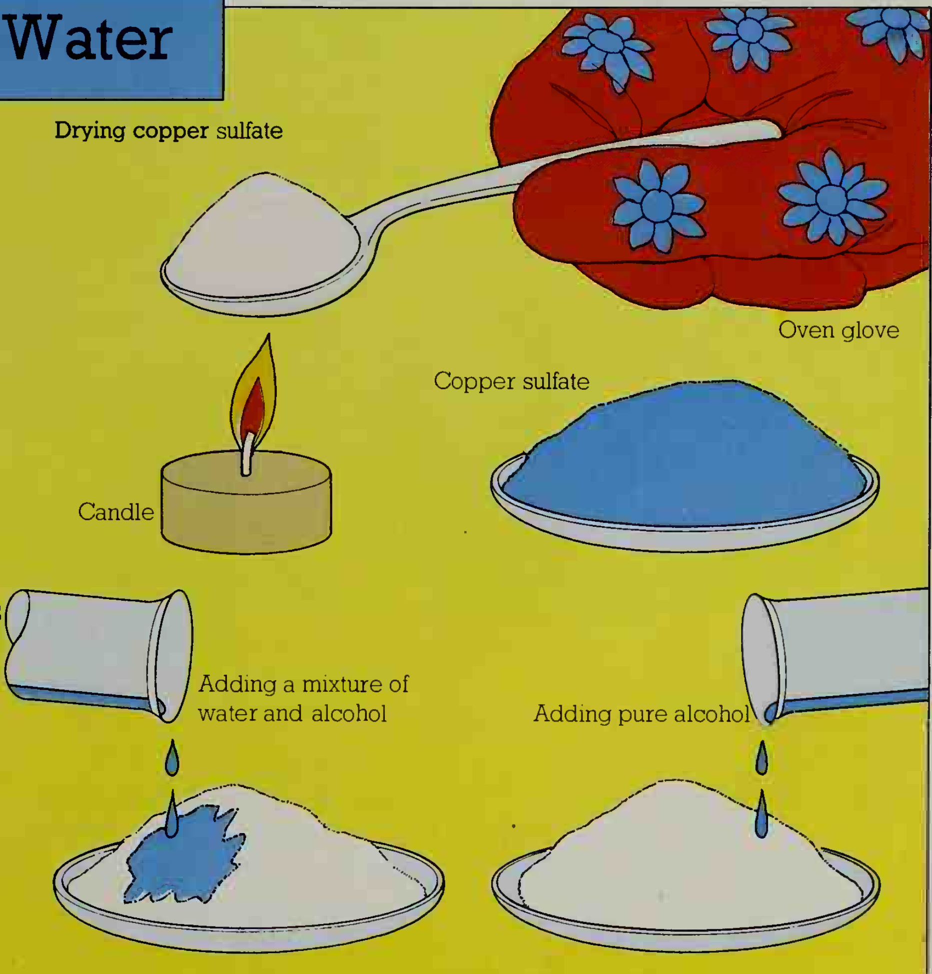


Like sodium, red-hot iron can also be used to make hydrogen from water. The water must be in the form of steam, which causes the iron to oxidize, so producing iron oxide (rust). With oxygen removed from the water, hydrogen is left behind. Hydrogen does not easily dissolve in water, and so it can be collected by bubbling it into an upturned jar of water. Effectively, the same type of replacement has occurred to produce hydrogen as in the reaction of sodium with water.

Absorption of Water

Some crystal substances, such as copper sulfate, have water locked into them. This is known as "water of crystallization," and may affect their color. If blue copper sulfate is heated to drive the water away, a whitish powder is formed – "anhydrous" (waterless) copper sulfate. This can be used to test for water. When a liquid such as pure alcohol is poured onto the powder, there is no color change. But if any water has been added to the alcohol, the copper sulfate powder will turn blue again. This is because it has taken some water from the alcohol-water mixture to re-form the blue crystals.

Drying copper sulfate



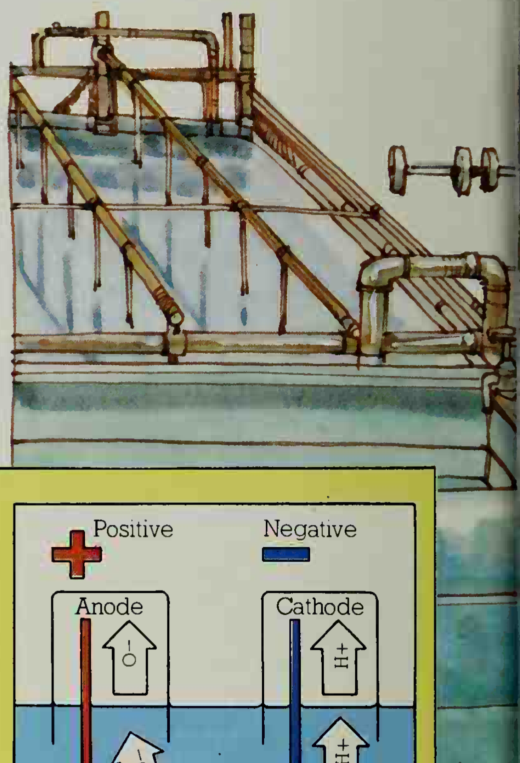
Electrolysis

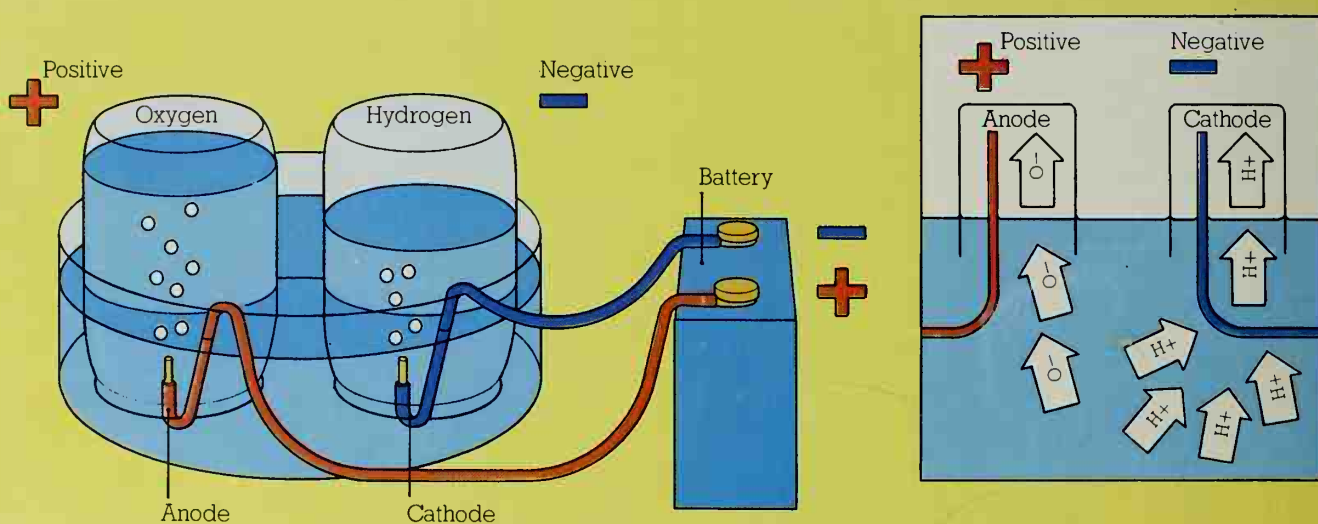
When hydrogen burns in oxygen, to form water, a great deal of energy is given out in the form of heat. If we wanted to separate the hydrogen from the oxygen again, this energy would have to be put back in some way. One method of doing this is to use electrical energy. Causing a chemical change by means of electricity is known as electrolysis.

Electrolysis is a very important industrial process. It can be used for metal-plating – putting very thin coatings of expensive metals, such as silver or chromium, onto articles made of cheaper materials. This both improves their appearance and protects them from corrosion.

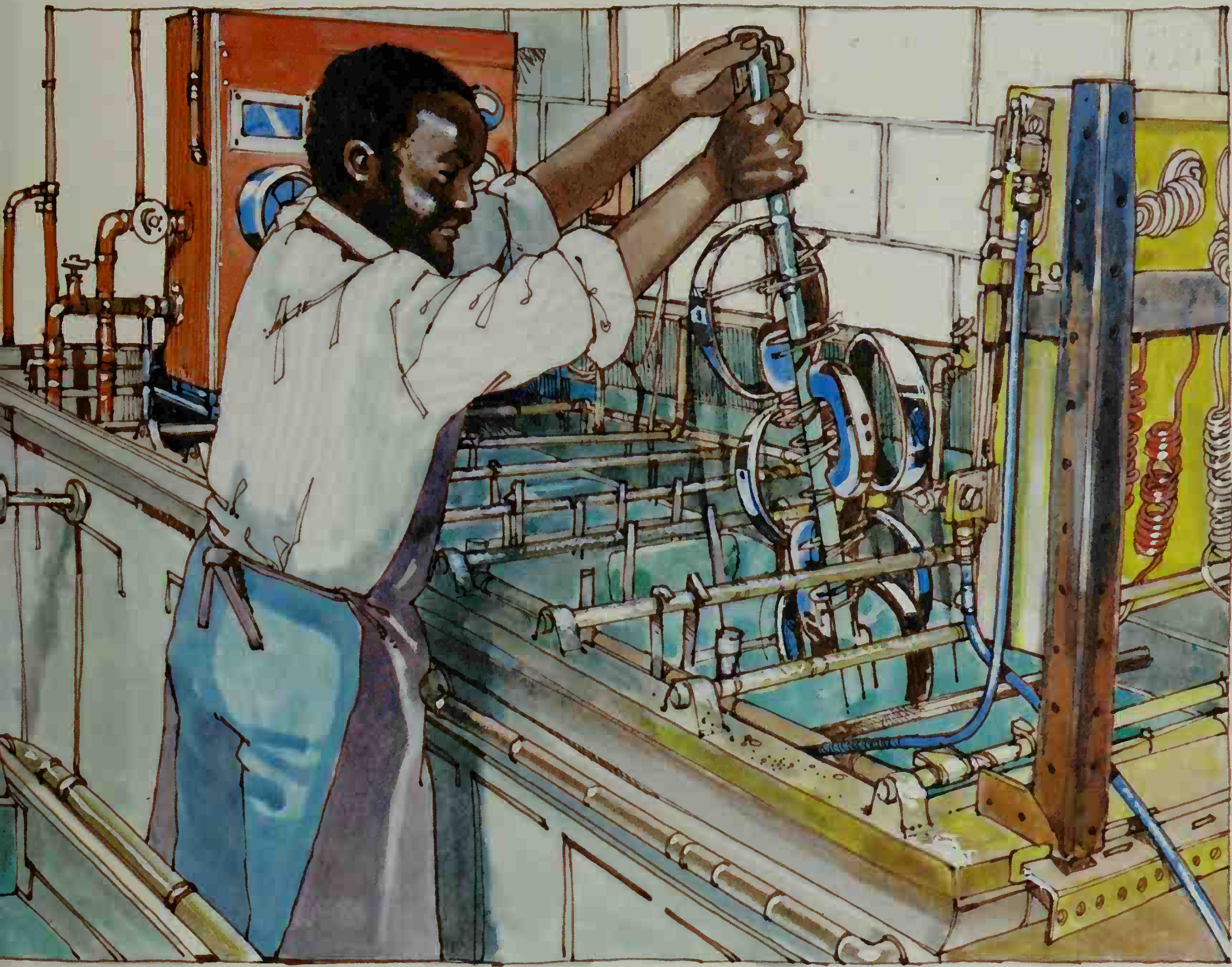
Another important use of electrolysis is the extraction of metals from their ores. Aluminum, one of the Earth's most common substances, is always found combined with other materials in the form of rock or clay. A hundred years ago the cost of extraction made aluminum metal more expensive than gold. Today, aluminum can be extracted by the electrolytic process and is one of our cheapest – and most useful – metals.

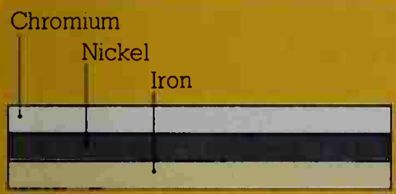
▷ In this workshop, articles made of thin sheet iron are being given a protective coating of nickel, a much more expensive metal. By using electrolysis a number of objects can be plated at the same time.





Electrolysis of water
Water can be split into its components by means of electricity. Pure water is almost totally resistant to an electric current. But if there is the slightest trace of an electrolyte present, such as sulfuric acid or salt, (which are good conductors), a current can flow through. Once the gases have begun to evolve, it is easy to see that there is twice as much hydrogen as oxygen in water. Oxygen bubbles appear at the anode (+), and hydrogen at the cathode (−). Because unlike signs attract, the oxygen ions must be negative, and the hydrogen ions positive.





Electroplating layers
Chromium cannot easily be plated onto iron direct. Instead, layers of other metals such as nickel and copper are plated onto the iron first.

When a salt dissolves in water it splits up into ions. Only substances that "ionize" can carry an electric current; they are known as electrolytes. For example, ordinary salt dissolves in water, ionizes into sodium and chloride ions, and so can carry an electric current. But sugar, does not ionize and so is not an electrolyte.

Ions carry electrical charges, and are either positive (+) or negative (−). As with magnetism, opposite signs attract and similar signs repel. In electrolysis, two metal plates, called electrodes, are dipped into the salt solution and connected to a battery. The electrode connected to the positive terminal of the battery is the "anode," and the other, attached to the negative terminal, the "cathode." Thus the positive ions are attracted to the cathode, and the negative ions to the anode.

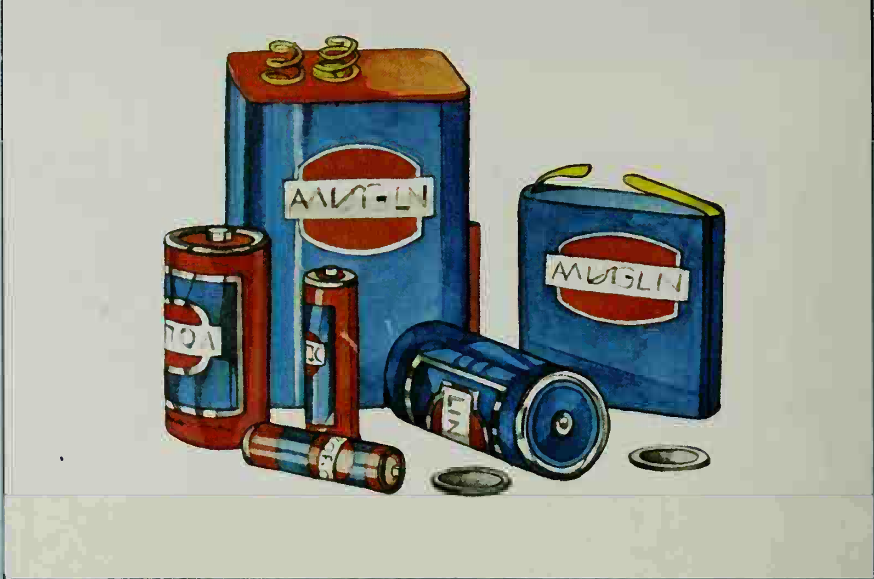
Batteries

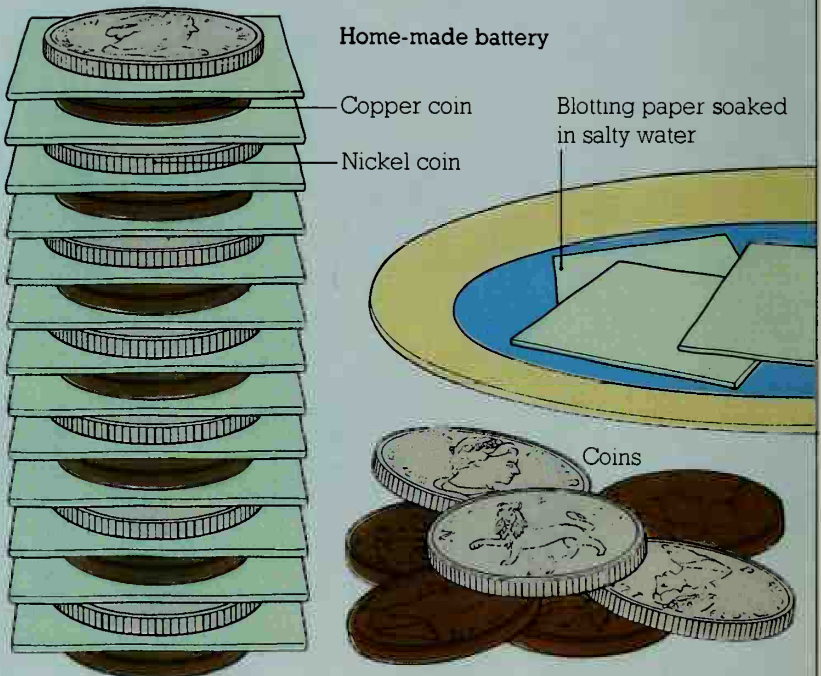
Electrolysis uses electricity to produce a chemical change. A battery, or cell, does the opposite: it uses a chemical change to produce electricity. Car batteries ("storage batteries") use both processes; electrolysis reverses the chemical changes that occur when the battery is used, and is able to "store" electrical energy.

The first batteries date from the early 1800s. They consisted of a stack of disks made of two different metals, arranged alternately, with pads of cloth soaked in salt solution in-between each layer. A pile of nickel and copper coins separated by blotting paper that has been dipped in salty water will do just as well. Electrons will flow through the pile, from nickel to copper, but cannot escape until the top and bottom are connected by a wire.

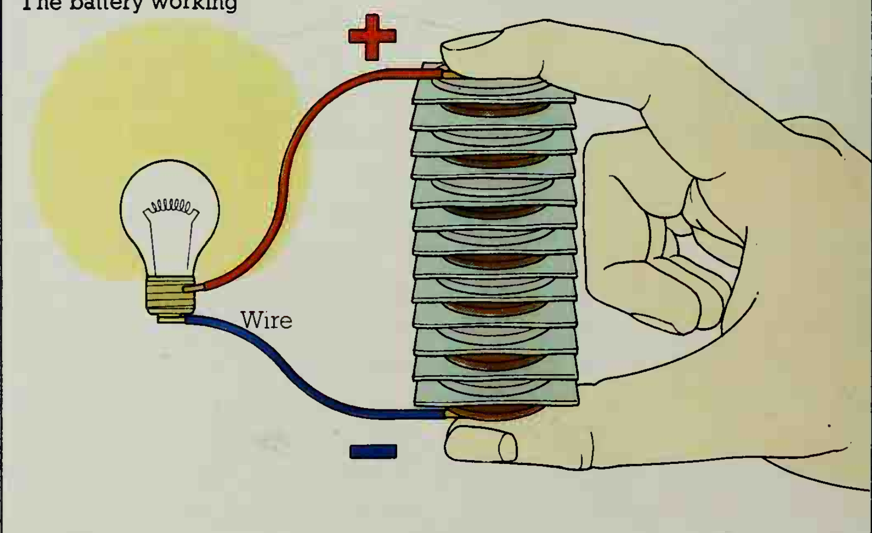
The electric current produced, once the connection is made, may be enough to light a small torch bulb rather dimly. The voltage will depend on which metals are used for the disks. The further apart the metals are in the electrochemical series (page 19), the greater the voltage. Nickel and copper produce about half a volt; aluminum and silver about two volts.

Various commercial batteries



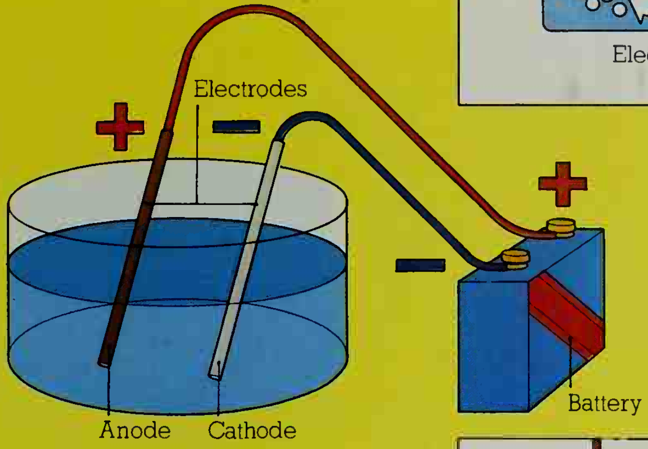


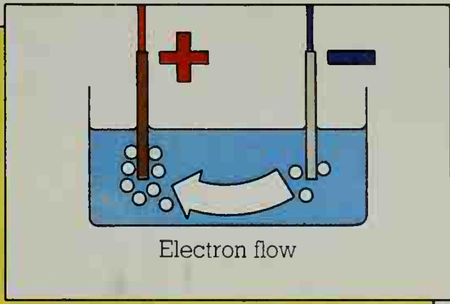
The battery working



Electroplating

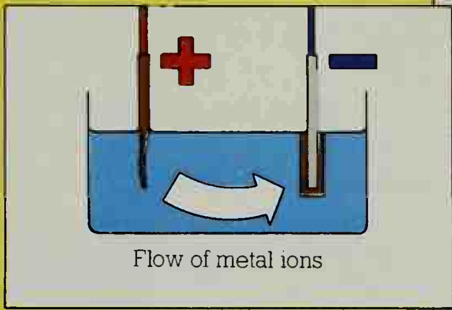
Electroplated articles





Articles to be plated are dipped in a silver salt solution, and connected to the cathode of a battery. The anode is made of silver, and replenishes the ions being used up from the solution.

During electrolysis, metal appears to be transferred from the anode to the cathode. But the electric current (the electron flow) is actually in the opposite direction.

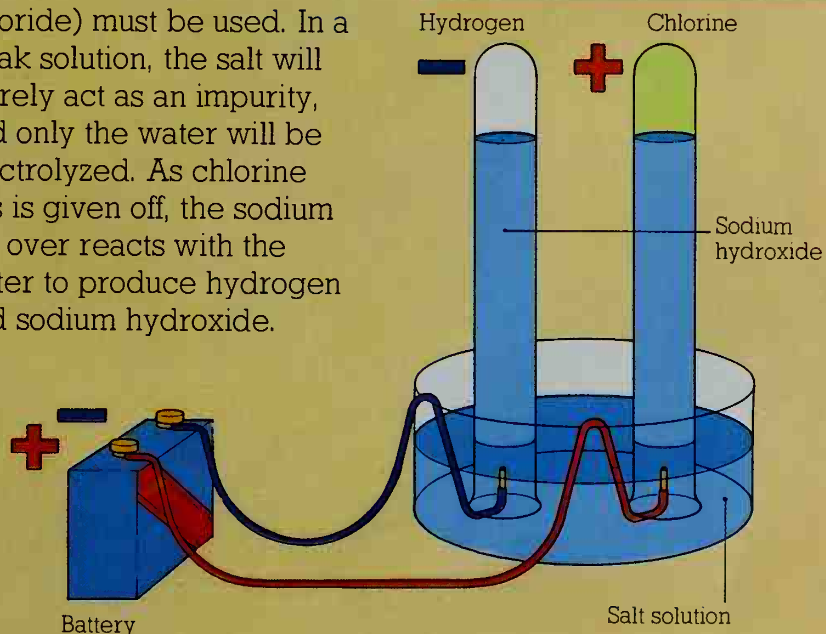


Making Chlorine by Electrolysis

Chlorine, used in bleach, is made commercially by electrolysis of common salt solution. For this, a concentrated solution of common salt (sodium chloride) must be used. In a weak solution, the salt will merely act as an impurity, and only the water will be electrolyzed. As chlorine gas is given off, the sodium left over reacts with the water to produce hydrogen and sodium hydroxide.

Bleach

WARNING!
THIS IS A LABORATORY EXPERIMENT



Elements

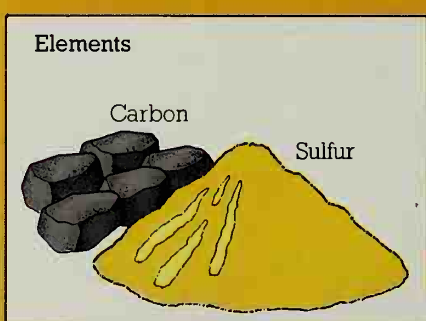
The countless objects of all kinds that surround us in our daily lives are made of materials chosen because they best serve the purpose for which the object was designed. A car's tires are made of rubber; its headlights are glass, the bodywork steel. Yet all these materials – and indeed the whole universe – are composed of the same basic substances – the elements. An element, by definition, contains only one substance, and has no other ingredients. There are 90 elements occurring naturally, although many are extremely rare. Almost everything we are likely to encounter under normal circumstances will be made from just a few dozen elements. Of these, a mere eight, including aluminum, silicon, iron and oxygen, comprise 98 percent of the Earth's crust.

Most of the materials we use are compounds – that is, they contain two or more elements combined chemically; but some, particularly metals, are elements in their own right. Aluminum, for instance, because it is light in weight and strong, is used in ship and aircraft construction. But for building engines iron is sometimes preferred; it can withstand high temperatures that would melt aluminum.

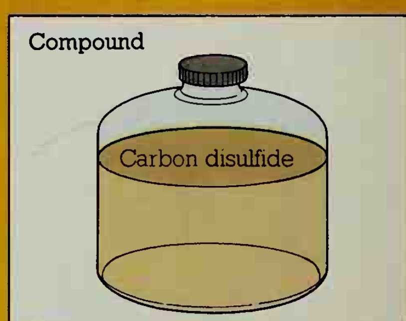
Although the majority of the elements are metals, not all the metals we meet are elements. Steel is basically iron to which other elements, including carbon, have been added. Brass and bronze are mixtures of copper with other metals, such as zinc and tin. Before the elements were known about, it was thought to be possible to make gold by mixing other metals together. Many a lifetime's work was wasted looking for the secret recipe.

Combining elements

A few elements, such as oxygen, carbon and gold, occur in nature on their own. Most, however, are found in combination with other elements. There is an almost infinite number of ways in which elements can combine, and the resulting compounds seldom have any of the properties of the original elements.



For instance, when the elements carbon – a black solid – and sulfur – a yellow



solid – are combined chemically, they create between them a clear, greasy liquid!

◁ In this busy garage scene, several elements can be seen in their simple state.

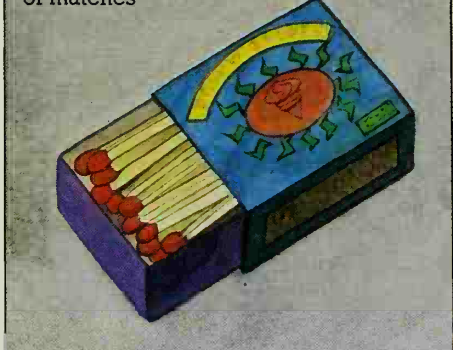
Metallic Elements


Metal worker

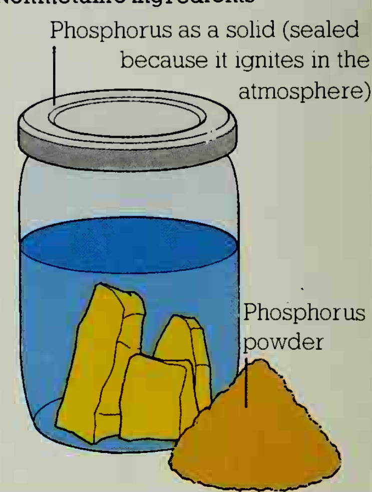
Metals are easy to recognize, but less easy to describe. The properties often vary between metals. Aluminum is light, lead heavy. Iron is hard; mercury is a liquid. Most metals are silver-gray, but not so copper or gold. One property that all metals share, however, is that they are good conductors of electricity.

Metal-bearing rocks

Nonmetallic Elements

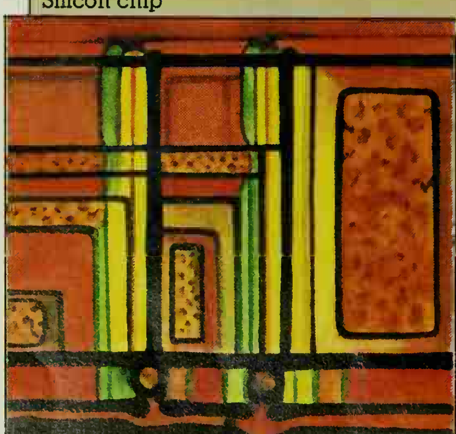

Phosphorus is the basic ingredient of matches

The nonmetals are harder to recognize than the metals. Some, like boron, are "earthy" solids; others are colorless gases; bromine is a liquid. Some are even able to assume different disguises! Phosphorus can be either a luminous, yellow, waxy solid or a red powder. But nonmetals are all poor electrical conductors.

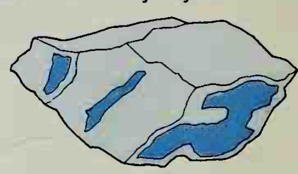


Nonmetallic ingredients

Half-way Elements

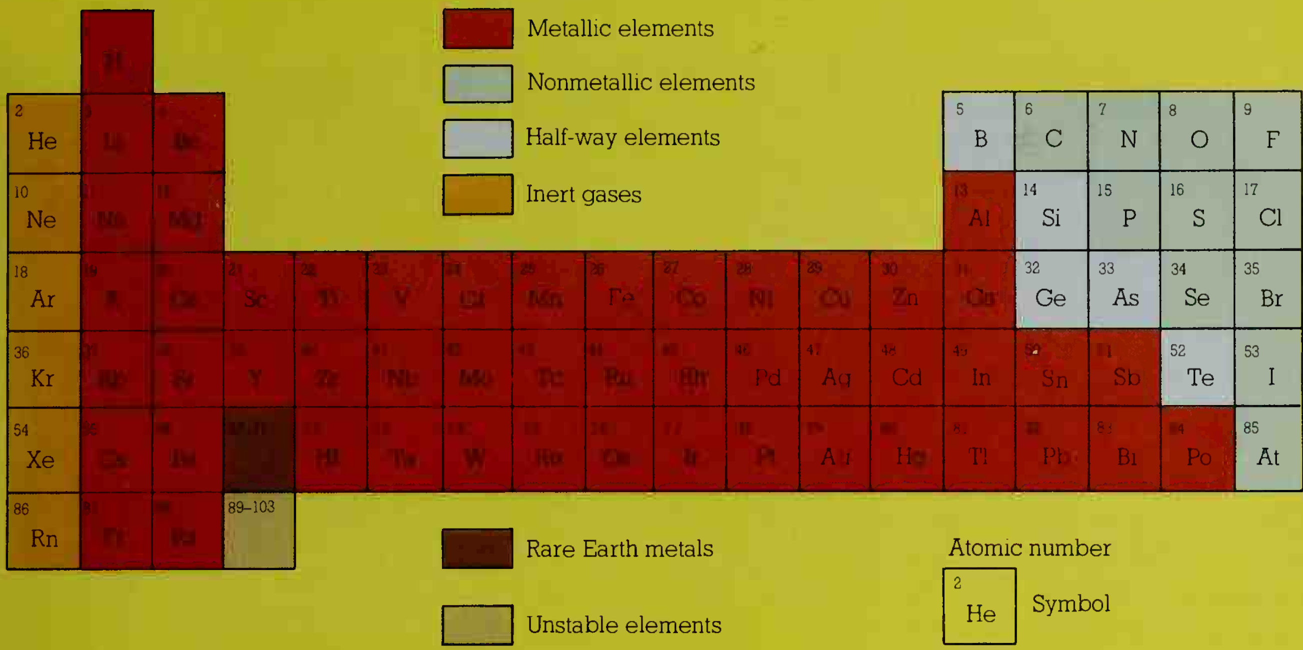

Silicon chip

Half-way elements share properties of both metals and nonmetals. Antimony, for example, has "metallic" and "nonmetallic" forms. At higher temperatures they are better conductors than metals – a property that makes them important for the electronics industry. Silicon, the basis of the microchip, is the best known half-way element.


Metallic antimony crystal


Nonmetallic antimony powder

The Periodic Table



If all the elements are arranged by order of the weight of their individual atoms, a fascinating fact emerges. The properties of the elements – physical and chemical – follow a definite pattern that recurs like the notes on a piano keyboard. The Periodic Table (above) shows the elements arranged in this way. The left-hand column contains those gases such as helium and neon that never combine with any other element. Next to them are the reactive metals, such as sodium and potassium, which dissolve in water to form hydroxides. On the far right, the column includes the very important reactive nonmetals – chlorine, iodine and fluorine. In the center are the durable metals, such as copper, silver and gold, used since ancient times for coinage and jewelry.

The periodic table

ELEMENT	SYMBOL	ATOMIC NO.
Actinium	Ac	89
Aluminum	Al	13
Americium	Am	95
Antimony	Sb	51
Argon	Ar	18
Arsenic	As	33
Astatine	At	85
Barium	Ba	56
Berkelium	Bk	97
Beryllium	Be	4
Bismuth	Bi	83
Boron	B	5
Bromine	Br	35
Cadmium	Cd	48
Calcium	Ca	20
Californium	Cf	98
Carbon	C	6
Cerium	Ce	58
Cesium	Cs	55
Chlorine	Cl	17
Chromium	Cr	24
Cobalt	Co	27
Copper	Cu	29
Curium	Cm	96
Dysprosium	Dy	66
Einsteinium	Es	99
Erbium	Er	68
Europium	Eu	63
Fermium	Fm	100
Fluorine	F	9
Francium	Fr	87
Gadolinium	Gd	64
Gallium	Ga	31
Germanium	Ge	32
Gold	Au	79
Hafnium	Hf	72
Helium	He	2
Holmium	Ho	67
Hydrogen	H	1
Indium	In	49
Iodine	I	53
Iridium	Ir	77
Iron	Fe	26
Krypton	Kr	36
Lanthanum	La	57
Lawrencium	Lr	103
Lead	Pb	82
Lithium	Li	3
Lutetium	Lu	71
Magnesium	Mg	12
Manganese	Mn	25
Mendelevium	Md	101

ELEMENT	SYMBOL	ATOMIC NO
Mercury	Hg	80
Molybdenum	Mo	42
Neodymium	Nd	60
Neon	Ne	10
Neptunium	Np	93
Nickel	Ni	28
Niobium	Nb	41
Nitrogen	N	7
Nobelium	No	102
Osmium	Os	76
Oxygen	O	8
Palladium	Pd	46
Phosphorus	P	15
Platinum	Pt	78
Plutonium	Pu	94
Polonium	Po	84
Potassium	K	19
Praseodymium	Pr	59
Promethium	Pm	61
Protactinium	Pa	91
Radium	Ra	88
Radon	Rn	86
Rhenium	Re	75
Rhodium	Rh	45
Rubidium	Rb	37
Ruthenium	Ru	44
Samarium	Sm	62
Scandium	Sc	21
Selenium	Se	34
Silicon	Si	14
Silver	Ag	47
Sodium	Na	11
Strontium	Sr	38
Sulfur	S	16
Tantalum	Ta	73
Technetium	Tc	43
Tellurium	Te	52
Terbium	Tb	65
Thallium	Tl	81
Thorium	Th	90
Thulium	Tm	69
Tin	Sn	50
Titanium	Ti	22
Tungsten	W	74
Uranium	U	92
Vanadium	V	23
Xenon	Xe	54
Ytterbium	Yb	70
Yttrium	Y	39
Zinc	Zn	30
Zirconium	Zr	40

Atoms and Molecules

An atom is the tiniest part of an element that can exist and still have the properties of that element. Every element has its own kind of atom. The simplest atom is that of hydrogen – of which most of the universe is composed. During the evolution of a star, under tremendous pressure and intense heat, hydrogen atoms become welded together in a way that is not possible in chemistry. First of all, helium atoms are formed; and then, as the star begins to explode, these helium atoms "fuse" together, creating even more elements, before being hurled out into space to become planets like our own.

Besides being the building bricks of the universe, atoms are tiny solar systems in themselves, having a central nucleus surrounded by a cloud of electrons, rather like planets orbiting the Sun. But atoms are so small that there are as many of them in a full stop as there are people in the world! Even more surprising, perhaps, is the fact that atoms consist almost entirely of empty space. If our diagram of the hydrogen atom were drawn to scale it would have to be the size of a football pitch, with a minute speck, no bigger than a pinhead, on the center spot, representing the nucleus. Somewhere on the touch line would be an even tinier speck representing the electron. Everything in-between would be empty space.

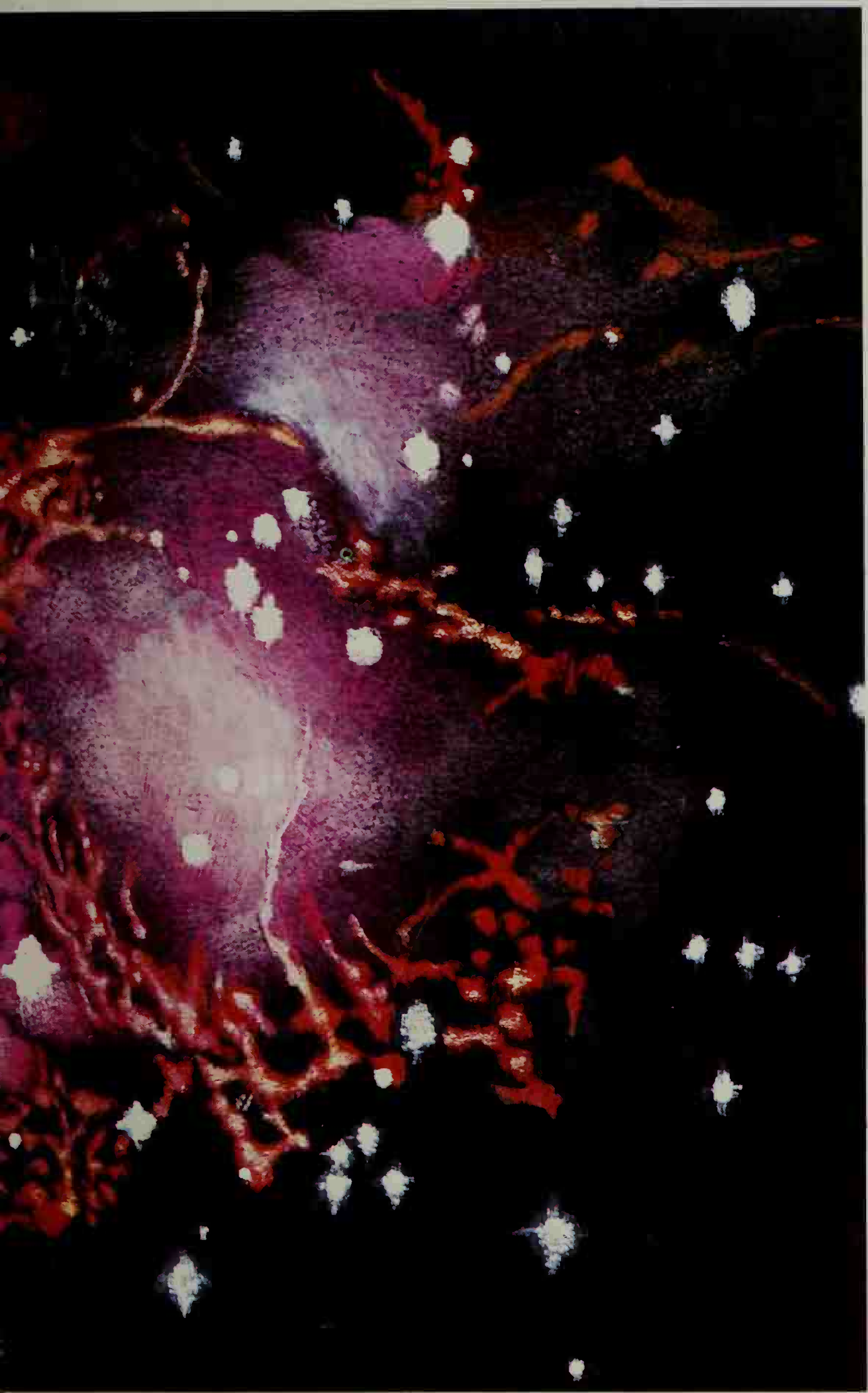
Chemistry is, essentially, the study of the behavior of the electrons of an atom, and chemical energy the result of electron activity on the outside of the atom. Our look at chemistry began with the human race's first experience of chemical change – fire – and ends with the power of the future – nuclear energy. Nuclear energy is the result of changes within the atomic nucleus itself. Whereas in a chemical reaction atoms of different elements combine, a nuclear reaction actually changes one element into another, releasing enormous energy in the process.

▷ In AD 1054 a new star appeared, so bright that it could be seen even by day. Two years later, it had vanished altogether, leaving only a faint wisp, the celebrated Crab Nebula, and hurling millions of atoms into space.

Atomic charges

The mass of an atom is in the nucleus, and made up of protons (positively charged particles) and neutrons (carrying no charge). The orbiting electrons have a negative charge, but almost no mass.

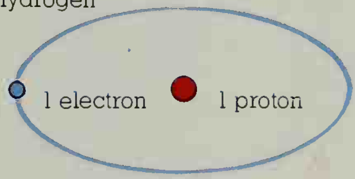
	Proton	Neutron	Electron
Charge	+1	Zero	−1
Mass	1	1	Zero



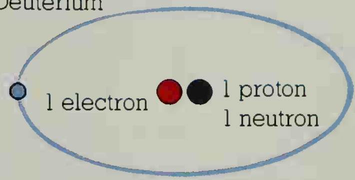
Atoms

A simple hydrogen atom consists of a single proton (+) orbited by an electron (−). Rarer forms of hydrogen, such as deuterium and tritium, also have neutrons in their nuclei.

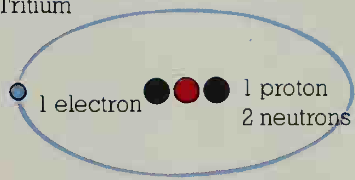
Hydrogen



Deuterium



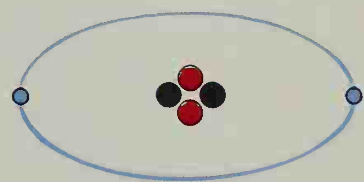
Tritium



Helium

Helium has two protons in the nucleus, and two electrons in orbit. Most helium atoms also contain two neutrons.

2 electrons
2 protons
2 neutrons



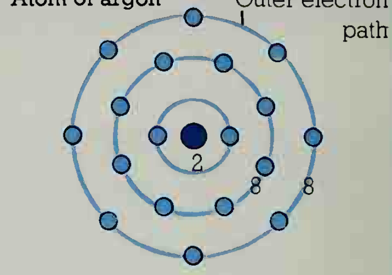
Sharing Electrons

Unlike other sub-atomic particles, electrons are easily detached from the atom. The picture on your TV set is produced by firing electrons at the screen, which has been coated with zinc sulfide.

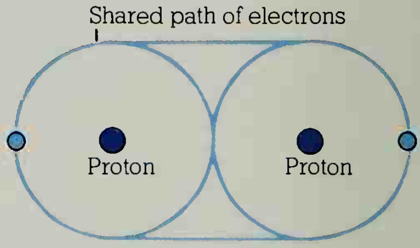
Television tube

How many electrons an element has is important. The electrons in an atom try to arrange themselves into orbits of eight, but with just two electrons in the inner orbit. Argon has 18 electrons, two in its inner orbit, and eight in each outer – the ideal arrangement. Argon is thus perfectly balanced and refuses to combine with any other element. Hydrogen has only one electron, and so two hydrogen atoms readily combine to allow a single orbit of two electrons. This is called covalent, or shared, bonding.

Atom of argon

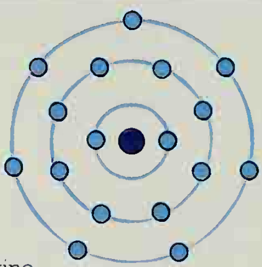


Covalent bonding

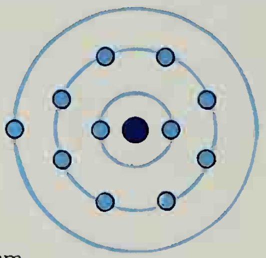


Atoms of hydrogen sharing electrons

Donating Electrons

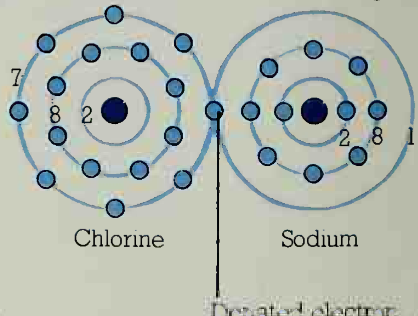


Chlorine



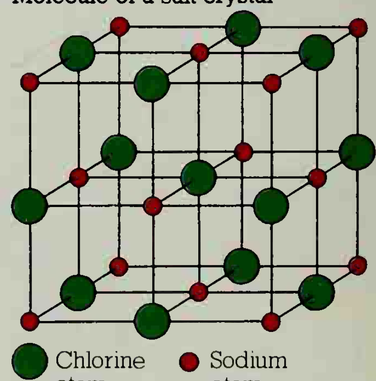
Sodium

Ionic bonding

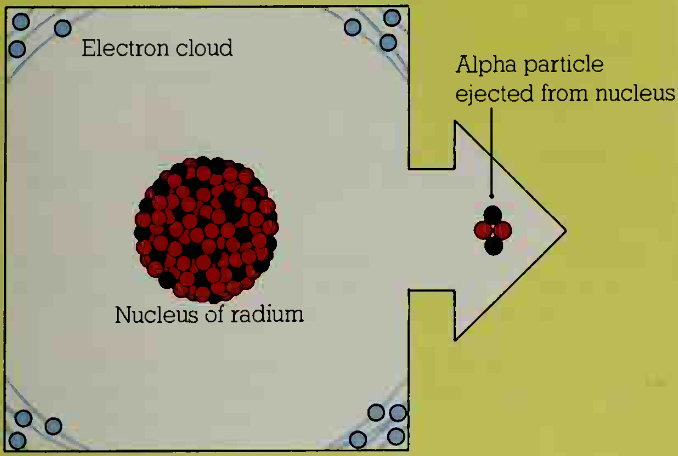


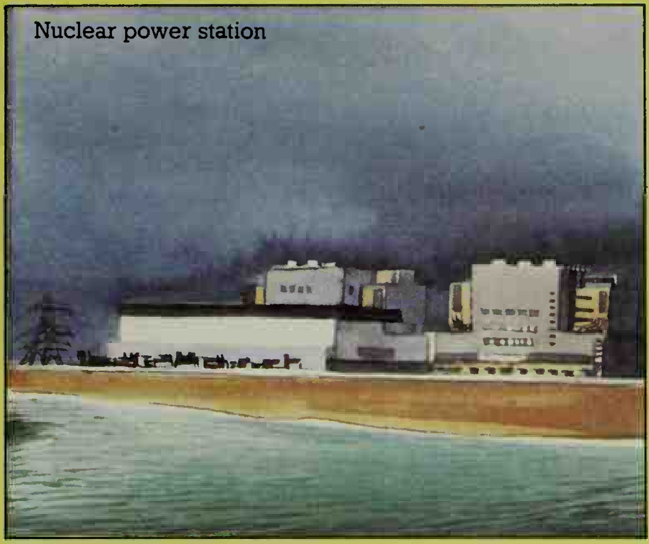
If the outer electrons of two elements add up to eight, the elements should react together easily. Chlorine has 17 electrons: two in its inner orbit, eight in the next, and seven in the outer orbit. Sodium has 11 electrons: two, then eight, but only one in its outer orbit. Atoms of chlorine and sodium combine to form molecules of sodium chloride. Now the atoms of both elements have eight electrons in their outer orbits, sodium having lost one electron and chlorine having gained one. This is called ionic bonding. The cubic structure of a salt crystal is due to the regular arrangements of its sodium and chlorine atoms.

Molecule of a salt crystal



Splitting the Atom

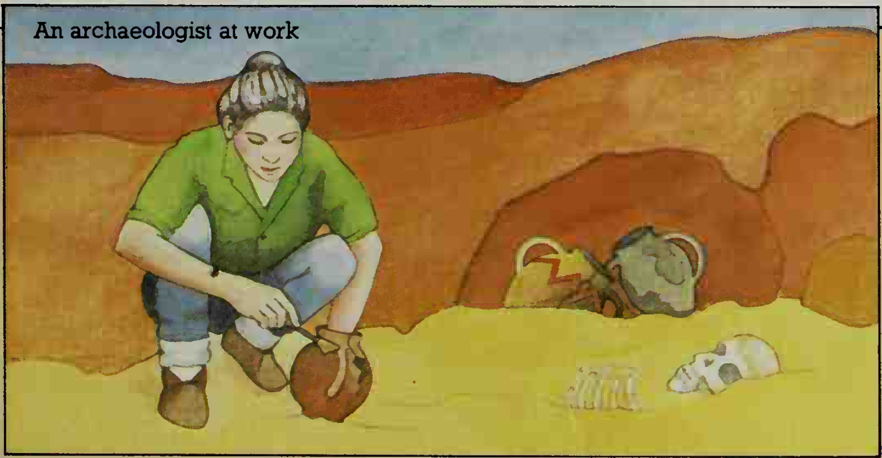


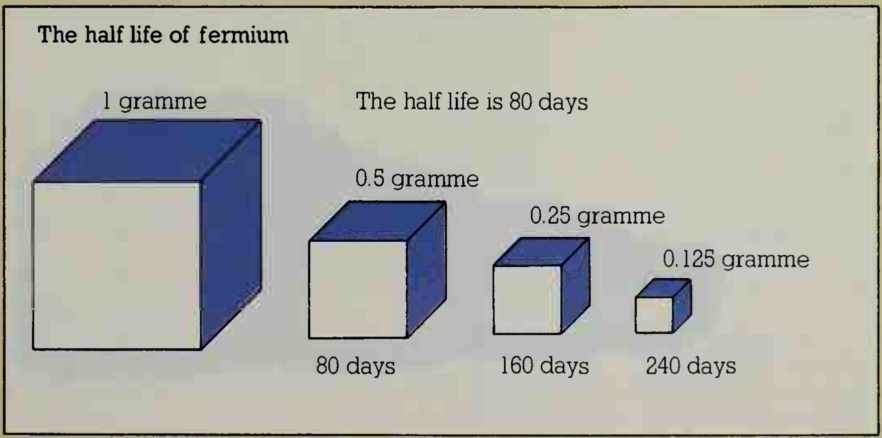


"Radioactive elements" are those which have a naturally unstable atomic nucleus. In the case of radium, two protons and two neutrons bonded together – an "alpha particle" – break away from the nucleus. The radium atom, having lost the alpha particle, now has the atomic structure of another element – radon. Other elements – uranium, for example – break up in a similar way, but also release huge amounts of energy as they do so. This energy is harnessed in nuclear power plants.

Half-life

Radioactive elements are ones in which the atoms break up, changing into atoms of other elements. The time taken for half the original element to disappear is called the half-life. The man-made element fermium has a half-life of 80 days. Thus, if a gramme of fermium were made today, less than one-sixteenth of a gramme would be left at the end of a year. The half-life can be very useful. By measuring the amount of radioactive carbon left in fossil remains, or other matter that was once alive, scientists can determine their age.





Glossary

Acid A substance containing hydrogen that can be replaced by a metal to form a salt. The opposite kind of substance to a base.

Atom The smallest part of an element that can exist and still have the properties of that element. Strictly speaking, the smallest part of an element that can take place in a chemical process.

Base A substance which reacts with an acid to produce a salt and water only. Bases which dissolve in water are called alkalis.

Compound A substance which is a chemical combination of more than one element.

Electrolysis Causing a chemical change by passing an electric current through a liquid.

Electron A negatively charged atomic particle, normally orbiting the nucleus of an atom.

Element A substance which contains only one kind of atom. All the elements are listed on page 33.

Indicator A substance which can detect certain chemical changes by turning a particular color, e.g. phenolphthalein turns red in the presence of an alkali.

Molecule The smallest particle of a substance that still has the chemical properties of that substance.

Neutron A particle at the nucleus of an atom, with a mass of 1, but no electrical charge.

Nucleus The central core of an atom, containing all the atom's neutrons and protons; almost all the atom's mass is concentrated in the nucleus.

Oxidation The chemical process of combining a substance with oxygen. Rusting, bleaching, and even breathing are all forms of oxidation.

Proton A particle at the nucleus of an atom, with a mass of 1 and a positive electrical charge. The number of protons in an atom is the element's atomic number.

Radical A group of atoms with distinct features when combined with other elements, but which do not exist on their own, e.g. "sulfate," a combination of oxygen and sulfur atoms.

Reactive Readily undergoing a chemical change, e.g. sodium and chlorine are both very reactive, lead and nitrogen are not. Helium and similar gases are totally unreactive.

Salt A chemical compound formed when the hydrogen of an acid has been replaced by a metal. Salts take their names from the metal and acid which form them, e.g. lead nitrate, from lead (metal) and nitric acid.

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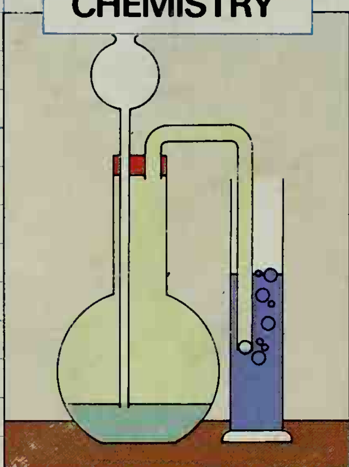

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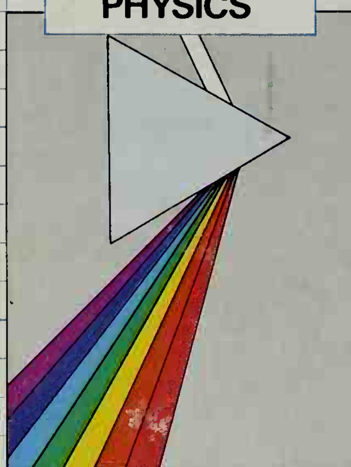

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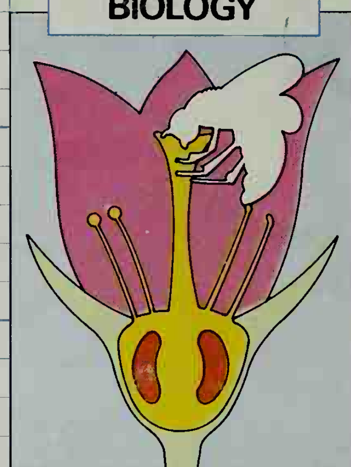

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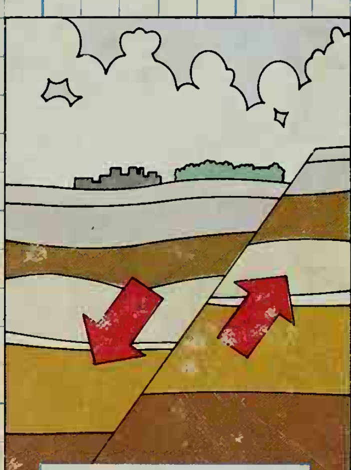

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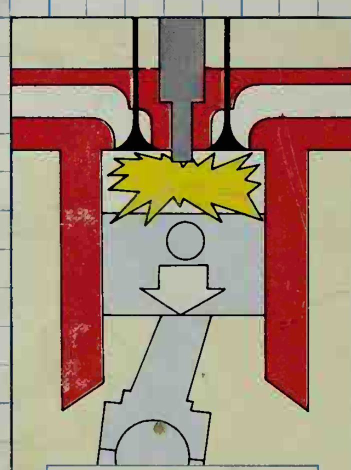

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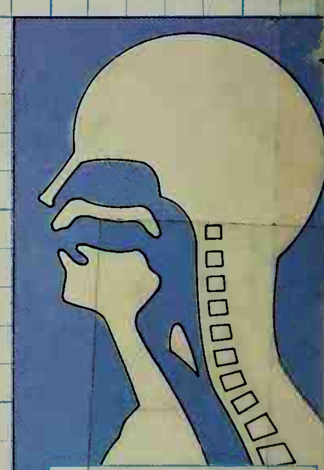

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