22) GENERAL PRINCIPLES OF FOOD PACKAGING: PACKAGING MATERIALS

1. Glass

Pliny the Elder recorded that Phoenician sailors came ashore and, not finding any local materials suitable for supporting their cooking pots above the sandy shore, used lumps of trona (natural soda or sodium carbonate) that formed part of their ship's cargo. As the trona was heated in the fire it combined with the sand to give a material that flowed. This story may not be entirely accurate but points to the fact that glass as a man-made material has a long history and some of the oldest dated Middle Eastern pieces are over 4000 years old; a deep blue charm is estimated to date from 7000 BC. Egyptians and Romans fashioned a wide range of intricate and colored glass objects. A highly developed industry existed in Syria in 1500 BC. In medieval times the centre of the glass blowing expertise was Venice (1200-1600 AD).

The serendipitous preparation of glass by the Phoenician sailors is basically the same as that used today. A mixture of purified sand is heated with sodium and calcium carbonate together with some sodium sulphate. The gases evolved help to stir the mixture. The addition of calcium is necessary to make the glass insoluble in water - simple sodium glass is water soluble to give a very viscous liquid known as water-glass (used as an egg preservative in WW2). For those who like the chemistry:

$Na_2CO_3 + SiO_2 \rightarrow Na_2SiO_3 + CO_2$
$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$
$Na_2SO_4 + SiO_2 \rightarrow Na_2SiO_3 + SO_3$

Glass made as above is known as soda-glass. Replacement of sodium with some potassium gives a harder glass that is familiar as window and bottle glass. The molten glass is made by a continuous process and is floated on a bath of pure molten tin, with which it does not mix, and cooled to give flat smooth sheets. The scale of production is enormous - in 1939/40 a glass melting plant poured out a 51" wide sheet of glass without interruption for 600 days - each day 3.25 miles of glass poured from the plant, which is 46,000 tons or 42,100,000 square feet!!!

Common glass is sodium (+ potassium) calcium metasilicate but by replacing the metal ions (Na,K,Ca) by other metal ions (Pb,Ba,Fe,Co) and by replacing the silicate (SiO_3) with borate (BO_3) or phosphate (PO_3) a wide variety of different glasses can be made.

1.1. Most Important Advantages and Disadvantages of Glass

1.1.1. Transparency - the ability to transmit (conduct) visible light without distortion. What other common materials are transparent? Most liquids and some plastics (perspex, polycarbonate) are. Note that colored glass is transparent but only to selective wavelengths of light. What have many of these materials in common? They have non-ordered structures - they all have the "liquid" structure, i.e., molecules in close contact but free to move. Glass can be considered as a very viscous liquid. Does glass flow like a liquid? Yes it does! When stained glass windows at Chartres Cathedral were restored it was found that many pieces of glass were much thicker at the bottom than at the top because the 500 or 600-year-old glass has flowed under the influence of gravity. Glass, like many polymers, does not melt - it softens into a treacly liquid above the glass transition temperature.

Any of you who use a dishwasher may have noticed that glass items that are regularly washed in a dishwasher become cloudy or, in extremes case, opaque. This devitrification occurs because certain components of dishwasher detergents chemically scour the glass surface and induce the growth of tiny crystals, which continue to grow (much like clear honey eventually crystallizes) and render the glass opaque. The devitrification extends into the glass and cannot be removed by polishing.

1.1.2. Structure and Bonding

The structure of glass can be regarded as a mixture of an ionic compound (containing cations and anions) and a covalent polymer (containing long branched chain molecules). The basic structure comprises long branched polysilicate chains that are sometimes known as network formers. The chains are tangled and branched and even when molten the chains are not free to move and molten glass is viscous. The silicon atoms can be, partly or wholly replaced by, e.g., boron in borosilicate glass or Pyrex^{TM} or phosphorus in crown glass (optical glass). The lecture diagram showed a tiny fragment of a polysilicate chain. Each silicon is covalently bonded to four oxygen atoms and each oxygen can either form two covalent bonds to silicon or forms one covalent bond and carries a negative charge.

In order to balance the accumulated negative charge on the silicate chains there are metal cations that randomly occupy suitably sized cavities in the silicate network. The bonding between the cations and the chain anions is ionic.

When simple glass is subject to stress - dropped on to a hard surface or hit with a hammer - it shatters readily because it is brittle. This brittle nature arises, in part, from the ionic nature of glass - ionic compounds are usually brittle, e.g., a large crystal of rock salt will shatter is struck with a hammer. However the way in which glass breaks is different to that of ionic compounds. Ionic compounds contain highly regular arrays of ions and split or cleave cleanly between layers or rows of ions - ionic compounds display good cleavage. Glass does not cleave - it fractures - or breaks randomly to give curved (conchoidal) surfaces with sharp edges. The random fracture arises, in part, because of the lack of order on the molecular scale.

Why does glass sometimes shatter when heated suddenly? There are three properties of soda-glass that lead it to shatter:

1. Expands significantly when heated,
2. Is a poor conductor of heat,
3. The structure contains voids.

When hot water is poured into a cold glass vessel the inner wall of the glass in contact with the hot water expands. However because glass is a poor conductor of heat the outer walls remain cool and do not expand but remain in contact with the expanded inner surface. The temperature difference thus sets up strain in the glass, which may lead to cracking or shattering. Thin walled tumblers are much less likely to crack as a result of thermal stress than are thick walled tumblers. The expansion of glass is concentrated around voids in the structure of glass. An article manufactured out of thick glass needs careful annealing (heat treatment) and slow cooling to remove strain - the 20-ton glass mirror used to manufacture the 200" reflecting mirror of the Mount Palomar telescope required one year’s cooling!

Pyrex™ or borosilicate glass contains about 12% boric oxide replacing some silicate and contains much less sodium and more aluminum. The resultant glass contains more branching and cross-links and fewer voids, expands very little when heated, is not subject to the thermal stresses of common glass and is widely used for oven-to-table ware. More sophisticated glasses can be used to manufacture pans that can be placed directly onto a gas flame or red-hot electric cooker ring.

Ultra low expansion glass Vycor™ is made by moulding a vessel from glass and then leaching out the metal oxide with strong acid to leave only the silica network. The vessel is then baked at high temperature whereupon it fuses and shrinks to give a translucent glass resembling quartz that can be plunged from red-heat into ice-cold water without shattering.

Glass can also easily shatter as a result of impact and in many situations this is highly undesirable. Car windscreens are regularly hit by flying grit and insects - a cockchafer beetle hitting a windscreen at 40 mph packs quite a punch! It is essential that a windscreen is able to withstand such impacts and, if it does fail, that it does so safely. The glass windscreen is carefully annealed or tempered during manufacture to strengthen it and also incorporates a polymer interleaving which prevents the glass shards from dispersing if the windscreen shatters. The downside is that if the windscreen shatters whilst the car is in motion the driver cannot see a thing through the crazed glass until he/she is able to break a hole in the windscreen.

Specially toughened glass Amourplate™ and Herculite™ are used in the construction industry (glass doors etc.) and are manufacture to shape, then heated to softening point and chilled suddenly to leave the surface of the glass under a good deal of compressive tension - such glass is four or more times stronger than ordinary glass but cannot be machined further. Glass can also be reinforced with steel mesh to give security glass (burglar proof).

What color is ordinary glass? Look through a section of the base of a milk bottle and you'll see that it is perceptibly green. The old ink-bottle, shown to you in the lecture, is more distinctly green. The green color is due to ferrous Fe^{2+} ions in the glass, which come from impurities in the sand - mainly iron oxide $(Fe^{3+})(O^{2-})_3$ (rust). The Fe^{3+} ions are reduced to Fe^{2+} during the manufacture of the glass. However by using purified sand the green color is usually not a problem. An alternative is to add oxidizing manganic ions Mn^{4+} (MnO_2 or pyrolusite) during manufacture, which oxidizes green Fe^{2+} to almost colorless Fe^{3+} (the black MnO_2 is reduced to almost colorless Mn^{2+}).

However for certain applications, e.g., optical fibres, the glass must be absolutely transparent (100% transmittance or light or zero absorbance). Fibre optic cables transmit information as light pulses rather than electric pulses. Optical fibres are usually double glass with an outer sheath of lower refractive index, which prevents light escaping out of the fibre. The high purity optical glass is drawn out into fine fibres (5-100 µm diameter), which are then packed into bundles of several thousand. The bundles are strong but retain the flexibility of individual fibres. Such a bundle of fibres can transmit 30 000 times more information than an equivalent diameter copper communications cable as well as being cheaper and lighter. Fibre optic technology has contributed to the communications revolution and a fibre optic cable link Europe with the States and three cables link Japan with the States. An undersea fibre optic cable will (or may already) connect the U.K. with Japan. Fibre optics are also used in endoscopes for internal bodily examination and, in conjunction with lasers, in controversial keyhole surgery.

For other purposes many other different sorts of glass may be required. These are just a few other types of glass:

- **Lead crystal** (or flint glass) - by the addition of lead oxide gives a brilliant glass of high refractive index that can be easily cut and polished is obtained,
- **Crown glass** - 0% silicon 5% boron 57% phosphorus used in lenses and other optical applications, barium flint glass is used in bifocal lenses,
- **Amber glass** - for protection of light sensitive liquids (drugs, chemicals) contains Fe^{3+} and S^{2-} which make the glass dark brown, also green glass for wine (Fe^{2+} rich glass),
- **Cobalt blue glass** - contains Co^{2+} and was formerly used for poisons and by chemists in flame tests to mask the yellow color of sodium ion which is a common contaminant,
- **White opaque glass** - is made by the addition of calcium fluoride (CaF_2 fluorspar) or stannic oxide (SnO_2) to the glass and is used in the food and drink packaging industry,
- **Nuclear storage glass** - molten glass is an excellent solvent for metal oxides which are accommodated in the voids in the structure; metallic nuclear waste (caesium, cobalt, strontium etc.) is converted into oxides and dissolved in molten glass (vitrification) to give a relatively inert shiny black glass which is stored in sealed steel containers underground in geologically sound areas (nimbly!),
- **One-way glass**, **heat/light reflecting glasses**, **low transmission**, and **insulating glasses** are designer glasses manufactured to meet a wide range of security and construction purposes,
- **Optically variable** or **photochromic glass** is used in spectacles and car windows in sunny climates and is borosilicate glass containing silver and copper compounds - the silver ions are photochemically reduced by copper ions to silver metal in strong sunlight causing the glass to darken, when the light fades the reverse reaction occurs and the glasses becomes light again.
  Low light $Cu^+ + Ag^+ \text{->} Cu^{2+} + Ag$ strong light
- **fibre glass** is coarsely spun conventional glass and is widely used in insulation and the manufacture of fireproof cloth (replacing dangerous asbestos) in safety curtains and fire blankets. Mixed with resins, glass fibre forms light rigid materials for construction of boats, skis, canoes etc. Glass fibre filter papers are used by chemists to filter corrosive solutions

2.Paper

2.1. History of Paper

The papermaking process has come a long way since 105 A.D. when Ts'ai Lun, a Chinese court official, invented paper, as we know it today. In all likelihood, Ts'ai mixed mulberry bark, hemp and rags with water, mashed it into pulp, pressed out the liquid, and hung the thin mat to dry in the sun. Thus began mankind's greatest revolution in communications.

William Rittenhouse and William Bradford founded the first North American paper mill in 1690 at Wissahickon Creek, near Philadelphia. Thanks to a great deal of imagination and hard work, they successfully collected, separated, cleaned, and recycled old cloth rags to make America's first writing papers.

In the early 1800s, Nicholas-Louis Robert of France invented and the Fourdrinier brothers in England patented, a machine that would produce paper on an endless wire screen. Fifty years later, papermakers began successfully using wood fiber to make paper, a process that was introduced in the United States in the early 1900s.

In 1866 an American, Benjamin Tilghman, developed the sulfite pulping process. The first mill using this process was built in Sweden in 1874. This was the dominant pulping process until 1937. At that time, the Kraft pulping process became the dominant chemical pulping process and still is today. A German chemist, C. F. Dahl, developed the Kraft (from the German word meaning "strong") pulping process in 1879. The first Kraft mill in the United States was built in 1911 in Pensacola, Florida. The Kraft process had several distinct advantages: the chemicals used to dissolve the lignin were recoverable and tremendous amounts of energy were produced during the recovery process, and the process could pulp pine trees, a predominant forest species in the United States The Kraft process allowed the United States to become a major producer of paper products.

Today, cotton fibers are still used to make a variety of high-quality, durable papers from financial documents to stationery to paper money. But a shortage of rags and the enormous demand for more and more paper has long given lead to new technologies that further transformed the manufacturing process.

Since that time, the principle of papermaking has remained essentially the same. But the technology has become increasingly more efficient, leading to greatly expanded production of a wide variety of quality products not imagined in those early days.

2.2. Paper Making Process

Typically, trees used for papermaking are specifically grown and harvested like a crop for that purpose. To meet tomorrow's demand, forest products companies and private landowners plant millions of new seedlings every day. Trees harvested for papermaking are cut into prescribed lengths, measured in cords and transported from the forests to the paper mill's wood yard.

To begin the process, logs are passed through a debarker, where the bark is removed, and through chippers, where spinning blades cut the wood into 1" pieces. Those wood chips are then pressure-cooked with a mixture of water and chemicals in a digester.

Today's paper fiber comes principally from two sources, wood and recovered paper. Wood or pulpwood as paper manufacturers call it, comes from harvested hardwood and softwood trees. Approximately 40 percent of today's paper fiber comes from pulpwood logs. The efficient recovery of waste wood from manufacturing processes and forest residues currently provides another 24 percent of the industry's raw material. Recovered paper is another important source of paper fiber. Thanks to curbside recycling programs in many communities, we recover over 40% of all paper used in America for recycling and reuse. The paper is shredded and mixed with water.

Paper is actually made from a pulp mixture of 1 percent fiber and 99 percent water. In addition to the fiber, the mixture also includes other additives such as dyes, resins, sizing or fillers that provide paper and paperboard with the different characteristics necessary for its final use. There are three forms of pulping: mechanical pulping, chemical pulping and recycled pulping.

2.3. Mechanical Pulping

There are two major processes for manufacturing mechanical pulp. The stone groundwood process involves grinding wood and mixing the fibers with water. Another common process is thermomechanical pulping (TMP), which is similar except that the wood chips are ground under pressure, producing heat. The heat weakens the lignin in the wood chips, making the separation of the fibers easier. The pulp produced by mechanical pulping uses much more of the wood (85 to 95 percent) than chemical pulping. The third type of mechanical pulping, chemithermomechical pulping CTMP), builds on TMP by adding chemicals to the process to help soften the lignin, reducing the energy required to produce pulp. The most common use for mechanical pulps is for newsprint and groundwood printing-writing papers. Mechanical pulping produces mechanical pulp and fluff pulp.

2.4. Chemical Pulping

The most common process for chemical pulping by far is the sulfate, or Kraft, process. The wood chips are cooked along with various chemicals in a high-pressure vat. The combination of heat and pressure allow the chemicals to penetrate the wood and dissolve the lignin and other nonfiber materials. This method only uses about 45 to 47% percent of the wood, but the characteristics of the resulting pulp are generally much more favorable in terms of overall strength, color, and durability. Chemical pulping produces six types of pulp: chemical pulp, dissolving pulp/special alpha, fluff pulp, Kraft pulp, sulfite pulp, and unbleached pulp.

2.5. Recycled Pulping

Recovered paper is placed in water forming pulp slurry. The slurry is screened, cleaned, and sometimes whitened (or de-inked) to produce pulp. After each of these pulping processes, the pulp may be bleached depending upon its end use. In most cases a mixture of several kinds of pulp will be used to make paper with very specific characteristics.

The pulp is sent either to a paper machine immediately or it is dried and is shipped to an affiliated mill or sold to another company. The water, spent chemicals, and other waste are treated both biologically and mechanically. This treatment can last up to 30 days so that it can meet stringent federal or state standards.

The pulp is washed, refined, cleaned, and sometimes bleached, then turned to slush in the beater. Color dyes, coatings, and other additives are mixed in, and the pulp slush is pumped onto a moving screen. As the pulp travels down the screen, water is drained away and recycled. The resulting crude paper sheet, or web, is squeezed between large rollers to remove most of the remaining water and ensure smoothness and uniform thickness. The semidry web is then run through heated dryer rollers to remove the remaining water.

The finished paper is then wound into parent rolls, which can be 30 feet wide and weigh close to 25 tons. A slitter cuts the paper into more manageable rolls, and the paper is ready for use.

Computerized sensors and state-of-the-art control equipment monitor each stage of the process. Paper-makers carefully test for such things as uniformity of color and surface, water resistance, and ink ability.

Modern paper-makers are one of the most capital-intensive industries in the nation, investing over $100,000 in equipment support for each employee. The largest papermaking machines are over 32 feet wide, 550 feet long, and weigh thousands of tons. Some can produce over 1,000 miles of paper a day.

2.6. Paper Products

Paper Products	**Examples**
Containerboard	Corrugated (cardboard) boxes, box dividers, reusable shipping pallets, cushioning material
Cotton Fiber Papers	Fine stationery, paper money, maps, onionskin
Kraft Packaging Papers	Grocery bags, yard waster bags, shopping bags, pet food bags, brown wrapping paper
Newsprint	Newspapers, advertising flyers
Paperboard	Drink cartons, milk cartons, cereal boxes, beer and soft drink cartons, paper plates and cups, shoeboxes, board for binder covers
Printing-Writing Papers	Books, magazines, copy paper, fine stationery, catalogs, direct mail pieces, envelopes, business forms, school filler paper
Pulp-Dissolving	A special wood or cotton fiber pulp used to make rayon, cellophane, and chemicals
Pulp-Paper Grade	An intermediate product made from fibrous material such as wood, cotton, straw, or grasses and recovered paper by mechanical or chemical processes for use in making paper and cellulose products
Specialty Papers	Coffee filters, automotive filters, sandpaper, greaseproof paper, parchment paper
Text & Cover	Annual reports, menus, social announcements
Tissue	Bathroom tissues, facial tissue, towels, napkins
Alternative Fiber Sources	Kenaf, hemp, and bagasse

2.6.1. Containerboard or Corrugated Containers

Containerboard is solid fiber or corrugated and combined board used in the manufacture of shipping containers and related products. Corrugated Boxes ship over 95 percent of all products in the United States because of its strength and convenience. It is also the component materials used in fabrication of corrugated board and solid fiber combined board. The primary containerboard products are linerboard and corrugated medium, which are used to make corrugated boxes. Linerboard makes up the outer shell, which contains the ruffled corrugated medium.

Corrugated containers in their most common form are boxes manufactured from containerboard—two layers of linerboard and one layer of medium. The layers are combined on a corrugator, a machine that presses corrugations into the medium and laminates a layer of linerboard to each side. The sheets are folded, printed, and glued or stapled to make a finished box.

Corrugating medium is a paperboard used by corrugating plants to form the corrugated or fluted member in making corrugated combined board, corrugated wrapping, and the like. It is usually made from chemical or semichemical wood pulps, straw, or reclaimed paper stock on cylinder or fourdrinier machines.

Linerboard is paperboard made on a fourdrinier or cylinder machine and used as the facing material in the production of corrugated and solid fiber shipping containers. Linerboard is usually classified according to furnish and method of web formation, as for example fourdrinier Kraft linerboard, cylinder Kraft linerboard, and jute linerboard. It can be made from wood fiber derived by the Kraft process, containing a limited amount of recycled material, or be made of 100 percent recycled material.

Image courtesy of Smurfit-Stone

2.6.2. Corrugated Paperboard

The use of corrugated paperboard apparently comes from clothing fashions. In 1856, two Englishmen, Healey and Allen, received a patent for the first known use of corrugated paper. Using a hand-cranked adaptation of a collar press (originally intended for pressing pleats and ruffles on clothing) they started producing "pleated" paper to line tall, stiff men's hats that were so popular in Victorian England. Corrugated paper was stronger than the cylinder of plane paper previously used to line hats and its flutes provided cushioning in the sweatband.

The first use of corrugated paper for packaging came in 1871, when an American, Albert Jones, introduced an idea of wrapping bottles and glass chimneys in it. But it was the addition of a liner to one and then to the other side of corrugated paper that signaled the birth of cardboard, as we know it.

Walls of cardboard boxes consist of two main parts: linerboard (or facing) and corrugating medium (fluted paper). The flutes in the corrugating medium form a series of connecting arches. An arch with a certain curve is can support many times its own weight, especially when the ends of the arch are anchored. In corrugated containers, they are anchored to a facing. A vertical sheet of linerboard used as the skin or facing, can support a weight greater than itself if it is held in place. Most linerboard is produced using softwoods. They have the longest fibers, and produce the strongest paperboard. The fluted corrugating material helps it stay in place, while the facing, in turn, protects the flutes from damage.

Containers made from these materials protect products both from external forces and sudden temperature changes. Arches of the flute act like springs when affected by pressure, and the air trapped between the flutes acts as a cushion. This trapped air also serves as a thermal insulator.

Benefits of Corrugated Boxes

Strength: Corrugated is designed to be stacked. It withstands top and side pressure; is crush resistant and passes burst strength test. It is impact, drop and vibration damage-resistant. In addition, it can be customized for added protection.

Convenience: Despite its strength, corrugated containers are also relatively lightweight and they can be broken down for easy transport. Moreover it is highly "designable," it can be cut and folded into an infinite variety of shapes, and printing can be directly applied to its surface.

Photo courtesy of Smurfit-Stone

Environmental impact: Corrugated containers are made from a renewable resource. Along with Kraft paper, corrugated containers consistently lead the pack when it comes to recovery: in 1995 over 60% of corrugated containers were recycled. In 1998, over 75% of corrugated containers were recycled.

2.6.3. Kraft Paper

Kraft Paper is made essentially from wood pulp produced by a modified sulfate pulping process. The word Kraft is from the German word for "strong." It is a comparatively coarse paper particularly noted for its strength, and in unbleached grades is primarily used as a wrapper or packaging material.

Kraft paper can be watermarked, striped, or calendared, and it has an acceptable surface for printing. Its natural unbleached color is brown but by the use of semi bleached or fully bleached sulfate pulps it can be produced in lighter shades of brown, cream tints, and white.

The most recognizable use of Kraft paper to consumers is the paper grocery sack. Paper grocery sacks come in a variety of paperweights, from light (30 lb.) to heavy duty (70 lb.) and 14 stock sizes, capable of holding 2 to 25 pounds. The standard paper grocery sack measures about 12 inches wide, 7 inches deep and 17 inches tall. A shorter sack, measuring 14 inches tall, is popular in many areas. It uses less paper and holds almost as much as the standard sack. Today's paper grocery sacks may also have a paper handle making them easy to carry and reuse.

The self-opening sack (SOS), which stands on its own is an American innovation that has been around since 1883. Paper sacks are made from a renewable resource and they can be reused several times for shopping and then be recycled at curbside or drop-off sites. Paper grocery sacks make excellent recycling containers at curbside for old newspapers, magazines, mixed paper and other recyclables.

Kraft paper—unbleached and bleached—is used for paper grocery bags, multiwall sacks (e.g. pet foods, lawn and garden seed, fertilizer, yard/leaf compost, cement, agricultural seed and chemicals), and other consumer and industrial packaging. This versatile material is used to haul everything from lunch to cement.

2.6.4. Newsprint

Newsprint describes paper of the type generally used in the printing of newspapers. It is uncoated paper made largely from fiber derived by a mechanical wood pulping process. Some fiber is derived from the chemical wood pulping process and recycled fiber derived from the recycled pulping process is also utilized.

Newsprint is engineered to be bright and opaque for the good print contrast needed by newspapers. It contains special tensile strength for folding. Although newsprint is made specifically for use in newspapers, it is used occasionally for other types of printing or to make products such as art or school tablets or packing paper.

Newsprint is a major end-use for recovered paper. In 1998, for instance, recovered paper accounted for just over half the fiber used by U.S. newsprint mills, up from 29 percent in 1990

2.6.5. Paperboard

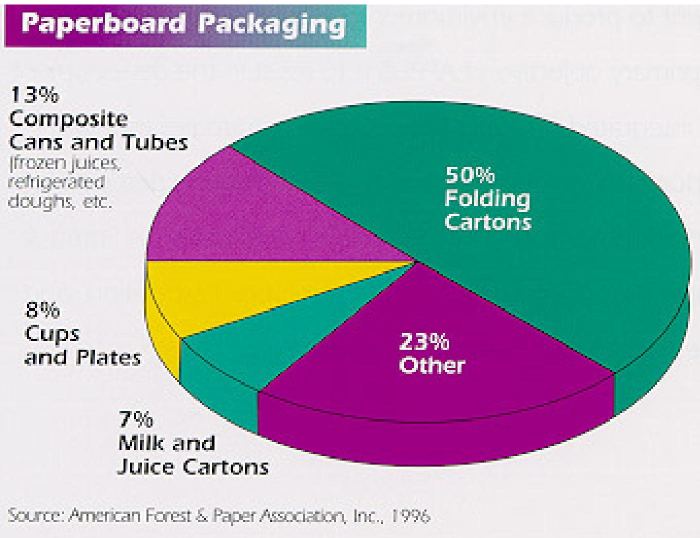
Paperboard is distinct from what is simply called paper. Paperboard is heavier in weight, thicker, and more rigid than paper. Because of these properties, it is better suited to a variety of packaging products. About 70 percent of paperboard packaging is used to protect food and other consumer goods.

Paperboard is made by pressing layers of paper or paper pulp together to make a stiff board. This board is then coated if needed and printed for product identification and marketing. From there the paperboard goes to a converting machine to be made into a variety of containers. Paperboard may be made from bleached, recycled, or unbleached fiber:

Bleached paperboard is made from virgin solid bleached sulfate pulp (SBS), or a combination of virgin and recovered fiber. Examples of this type of paperboard are milk and juice cartons, drink boxes, cosmetic boxes, and many frozen food boxes.

Recycled paperboard is made from a combination of recovered fibers, which may include newspaper, magazines, corrugated cardboard, paperboard folding cartons, and telephone books. One side of the paperboard may be gray in color. Examples of this type of paperboard are cereal, cracker, pasta and other food packages, detergent boxes, many toy and hardware boxes as well as shoe and shirt boxes.

Unbleached paperboard is made from predominantly unbleached Kraft fiber, and may contain some recycled content. Examples of this type of paperboard are 6- and 12- pack beverage carrying cases and folding cartons.



2.6.6. Printing and Writing Papers

Printing and Writing paper refers to a variety of papers used in offices, communications, books, magazines, catalogs, annual reports, brochures, direct mail, and other printed papers. The United States has more than 25 percent of the world's capacity in Printing and Writing Papers, more than any other country in the world. The 26.5 million short tons manufactures in 1998 by U.S. companies are identified under major categories: Uncoated Free Sheet, Coated Printing Paper Groundwood Paper, and Cotton Fiber Paper.

Uncoated Freesheet Papers contain not more than 10 percent mechanical fiber with the remainder of the fiber being chemical wood pulps, either wood pulp or secondary fiber.

Specific grades falling into this major printing and writing paper category include: **Bond** and Writing paper is used for letterheads, business and social correspondence and checks.

Form Bond paper is bond-type paper used for business forms end uses and sold in roll form only.

Offset Paper is designed for use in offset lithography. Important properties include good internal bonding, high strength, dimensional stability, lack of curl, and freedom from fuzz and foreign surface material. Used on both sheet-fed and web presses. This is commodity offset.

Premium/Opaque Offset is high quality offset markedly brighter and more opaque than Offset Paper as defined above. It is usually produced in smooth and vellum finishes and may have a companion cover paper. This is a mid-range product between Offset Paper and higher quality papers in the Text and Cover category.

Envelope Paper is any uncoated printing-writing paper used in the manufacture of envelopes. Desirable properties include smooth fold, strength at crease, good printability, and lack of tendency to curl. There are three types of Envelope Paper.

Wove Envelope is general-purpose paper, either white or colors, used primarily for commercial purposes. Also refers to commodity envelope base stock. Bond, cotton fiber, text grades, and similar distinctive grades used for envelope end use are not included in this category; rather they are included with their unique grades.

Brown Kraft Envelopes are machine-glazed paper, usually made from unbleached sulfate pulp or dyed bleached sulfate pulp, used in the manufacture of envelopes when strength is a primary requirement.

White Kraft Envelopes are machine-glazed paper usually made from bleached sulfate pulp, in white and colors; used in manufacture of envelopes when strength is a primary requirement.

Text and Cover Papers are papers of fine quality and texture for printing. Text papers are manufactured in white and colors, from bleached chemical wood pulp or cotton fiber content furnishes with a decked or plain edge, and are sometimes watermarked. They are made in a wide variety of finishes, including antique, vellum, smooth, felt-marked, and patterned surfaces-some with laid formations. Designed for advertising printing, the principal use of text papers is for booklets, brochures, fine books, announcements, annual reports, menus, folders, etc.

Coated Printing Paper has surface coatings added for the purpose of improving the appearance and printing surface. It includes coated free sheet and coated groundwood papers.

Coated Freesheet Papers are coated papers not containing more than 10 percent mechanical fiber with the remained of the fiber being chemical wood pulps, wither wood pulp or secondary fiber.

Groundwood Papers are papers other than newsprint, made with substantial proportions of mechanical pulp, and used for printing or converting.

Coated Groundwood Paper: Coated printing paper containing more than 10 percent mechanical fiber in its finish, excluding newsprint. It is used for magazines, catalogs, and advertising.

Uncoated Groundwood Paper: Uncoated printing paper containing more than 10 percent mechanical (groundwood) fiber in its furnish. This is used for directories and freestanding inserts. Includes converting grades, carbonless copy paper, form bond and colored school construction paper.

Cotton Fiber contains 25 percent or more of cotton, cotton rags, cotton waste, linters, linter pulp, flax or similar fibers in its furnish. A key subgrade is the bond and writing category of papers used for letterheads, business and social correspondence, and other documents. Cotton fiber paper is one of the oldest types of paper. These durable papers have excellent printing surfaces required for financial documents, paper money, business letterhead, personal stationery and art papers.

Solid Bleached Bristols are heavyweight papers used primarily for printing and for conversion into office products and school supplies. End uses include such items as advertising pieces, softbound book covers, greeting cards, boarding passes, postcards, file folders, business reply cards and business cards.

Specialty Packaging and Industrial Papers

Photo courtesy of Hazen Papers

Specialty Packaging and Industrial Papers are grades of paper and/or paperboard made with specific characteristics and properties to adapt them to particular uses. Specialty papers are made-to-order to customer specifications and, in most cases, are integral parts of finished industrial and consumer products. In addition to manufacturing papers and paperboards for very specific purposes, this category sometimes applies to companies that apply a coat to paper or those that put a layer of plastic on a piece of paper or paperboard.

Some examples of Specialty Packaging include greaseproof and vegetable parchment paper, and fast food and frozen food wrapping. Specialty Industrial Papers include electrical insulation, paper-based tape, sandpaper, and filter paper.

Specialty Extrusion Coating is a coating, which is applied by means of extrusion and lamination onto the surface of the material to be coated. Coatings of the extrusion type are normally hot melt polymers applied at elevated temperature, usually associated with plastics.

Specialty Industrial Papers are intended for industrial uses and include paper and board of all thickness and fiber types designed for special uses and manufactured to exact customer specifications. Some examples are abrasive paper, electrical insulation, filter paper, and similar grades.

Tissue Paper

Tissue is a general term indicating a class of papers of characteristic gauzy texture, in some cases, fairly transparent. Tissue papers are made on any type of paper machine, from any type of pulp, including reclaimed paper stock. They may be glazed, unglazed, or creped, and are used for a variety of purposes. Examples are primarily sanitary grades such as toilet, facial, napkin, toweling, wipes, and special sanitary papers. Desirable characteristics are softness, strength, and freedom from lint. There are also waxing, wrapping, and miscellaneous non-sanitary grades.

Tissue Papers can be classified in one of two major categories: At-Home and Away-from-

Home.

At-home products are tissue products you purchase in the grocery store and convenience stores for use at your personal home.

Away-from-Home products, or Commercial Products serve markets such as hospitals, restaurants, businesses, institutions, and janitorial supply firms.

Recycled Content of Tissue Paper

Tissue manufacturers have one of the highest recycled paper utilization rates in the paper and paperboard industry: over 60 percent in recent years. That means that tissue manufacturers require 60 tons of recovered paper for every 100 tons of tissue paper produced.

How You Can Make Paper at Home:

Here are easy to follow step-by-step directions on how to make paper using only facial tissue, starch and water. You will be following the same process used by professional papermakers on paper machines.

You will now make paper in the same way a paper machine does.

MATERIALS

1. A tub will replace the mixing box
2. An eggbeater will replace the beater
3. A screen will replace the wire screen belt
4. A blotting paper will replace the felt blankets
5. A rolling pin will replace the presses
6. An iron will replace the dryers

EQUIPMENT

1. 30 Sheets of facial tissue (not wet strength)
2. A tub or basin that will hold at least 10 quarts of water
3. One tablespoon of liquid laundry starch in two cups of water
4. An eggbeater or blender
5. A fine-mesh wire screen, screwed or stapled onto the back of a frame
6. Blotting paper cut to the size of the screen
7. A rolling pin
8. Household electric iron

STEPS

1. Tear sheets of tissue and place in tub. Pour in starch and additional water to make about 10 quarts.
2. Beat until thoroughly mixed. Tissue should be completely dissolved.
3. Holding screen firmly, dip sideways into the mixture.
4. Slowly lift screen out of water and let excess water drip while sheet is forming. Dry screen between two pieces of blotting paper.
5. Remove sheet from screen, place between blotting paper, and press out water with rolling pin.
6. Iron-dry (not too hot) the sheet still between the blotting paper.
7. You now have a sheet of hand-made paper. You can trim the edges with scissors.

Paper Products Glossary

Base Paper (Body Stock)-The base stock for plain or decorated coated papers and boards. It may be uncoated or precoated on the paper machine. It is also used in connection with industrial papers before they are treated. Because it can usually be custom made and has a variety of uses, it cannot be described as containing certain amounts of any particular kind of pulp nor is there any way to refer to weights and colors.

Bond Paper-Originally a cotton-content writing or printing paper designed for the printing of bonds, legal documents, etc., and distinguished by superior strength, performance and durability. The term is now also applied to papers such as letterhead, business forms, social correspondence papers, etc. Properties include printability, erasability, whiteness, cleanliness, freedom from fuzz, uniform finish, and good formation.

Coated Paper-Any paper, which has been coated. This term covers a wide range of qualities, basis weights, and uses.

Construction Paper -Sheathing paper, roofing, floor covering, automotive, soundproofing, industrial, pipe covering, refrigerator, and similar felts.

Containerboard-Solid fibre or corrugated and combined board used in the manufacture of shipping containers and related products. Also the component materials used in fabrication of corrugated board and solid fibre combined board.

Chipboard-A paperboard used for many purposes that may or may not have specifications of strength, color, or other characteristics. It is normally made from a paper stock with a relatively low density in thickness of .006 of an inch and up.

Corrugated Container-A box, its most common form, is manufactured from containerboard - layers of linerboard and one layer of medium. The layers are combined on a corrugator, a machine that presses corrugations into the medium and laminates a layer of linerboard to each side. The sheets are folded, printed, and glued or stapled to make a finished box.

Corrugating Medium-A paperboard used by corrugating plants to form the corrugated or fluted component in making corrugated combined board, corrugated wrapping, and the like. It is usually made from chemical or semichemical wood pulps, straw, or reclaimed paper stock on cylinder or fourdrinier machines.

Cotton Fiber-Paper that contains 25% or more cellulose fibers derived from lint cotton, cotton linters and cotton or linen cloth cuttings. Sometimes flax is used in place of linen cuttings. The term is used interchangeably with rag content and cotton content papers.

Cover Paper-Any wide variety of fairly heavy plain or embellished papers, which are converted into, covers for books, catalogs, brochures, pamphlets, etc. It is a specific coated or uncoated grade made from chemical wood pulps, and/or cotton pulps. Good folding qualities, printability, and durability characterize it.

Cylinder Paper Machine-One of the principal types of papermaking machines, characterized by the use of wire-covered cylinders or molds, on which a web is formed. These cylinders may be partially immersed and rotated in vats containing a dilute stock suspension or may be equipped with a headbox or other apparatus for distributing the fibers. The pulp fibers are formed into a sheet on the mold as the water drains through, leaving the fibers on the cylinder face. The wet sheet is couched off the cylinder onto a felt, which is held against the cylinder by a couch roll. A cylinder machine may consist of one or several cylinders, each supplied with the same or with different kinds of stock. In the case of a multi-cylinder machine, the webs are successively couched one upon the other before entering the press section. This permits wide latitude in thickness or weight of the finished sheet, as well as in the kind of stock used for the different layers of the sheet. The press section and the dry end of the machine are essentially the same as those of other types of machines.

Deinking-A process in which most of the ink, filler and other extraneous material is removed from printed and/or unprinted recovered paper. The result is a pulp, which can be used, along with varying percentages of wood pulp, in the manufacture of new paper, including printing, writing and office papers as well as tissue.

Digester-A cylindrical or spherical vessel used to treat cellulose materials with chemicals under elevated pressure and temperature, so as to produce pulp for papermaking.

Envelope Paper-Any uncoated printing-writing paper used in the manufacture of envelopes. Desirable properties include smooth fold, strength at crease, good printability, and lack of tendency to curl or cockle. Basis weights normally range from 16# to 44# (17" x 22" - 500).

Brown Kraft Envelope-Fourdrinier machine finished or machine glazed paper, usually made from unbleached sulfate pulp or dyed bleached sulfate pulp, used in the manufacture of envelopes when strength is a primary requirement.

White Kraft Envelope-Fourdrinier machine finished or machine glazed paper usually made from bleached sulfate pulp, in white and colors. It is used in the manufacture of envelopes when strength is a primary requirement.

Wove Envelopes-General purpose paper, either white or colors, used primarily for commercial purposes. Also refers to commodity envelope base stock. Bond, cotton fiber, text grades, and similar distinctive grades used for envelope end use are not included in this category; rather they are included with their unique grades.

Form Bond-A lightweight commodity paper designed primarily for printed business forms. It is usually made from chemical wood and/or mechanical pulps. Important product qualities include good perforating, folding, punching, and manifolding properties. The most common end use for this grade is carbon-interleaved multi-part computer printout paper, which is marginally punched, cross-perforated, and fanfolded.

Fourdrinier Paper Machine-Named after its sponsor, with its modifications and the Cylinder machine, comprise the machines normally employed in the manufacture of all grades of paper and board. The fourdrinier machine, for descriptive purposes, may be divided into four sections: the wet end, the press section, the drier section, and the calendar section. In the wet end, the pulp or stock flows from a headbox through a slice onto a moving endless belt of wire cloth, called the fourdrinier wire or wire, of brass, bronze, stainless steel, or plastic. The wire runs over a breast roll under or adjacent to the headbox, over a series of tube or table rolls or more recently drainage blades, which maintain the working surface of the wire in a plane and aid water removal. The tubes or rolls create a vacuum on the downstream side of the nip. Similarly, the drainage blades create a vacuum on the downstream side where the wire leaves the blade surface, but also performs the function of a doctor blade on the upstream side. The wire then passes over a series of suction boxes, over the bottom couch roll (or suction couch roll), which drives the wire and then down and back over various guide rolls and a stretch roll to the breast roll. The second section, the press section, usually consists of two or more presses, the function of which is to mechanically remove further excess of water from the sheet and to equalize the surface characteristics of the felt and wire sides of the sheet. The wet web of paper, which is transferred from the wire to the felt at the couch roll, is carried through the presses on the felts; the texture and character of the felts vary according to the grade of paper being made. The third section, the drier section, consists of two or more tiers of driers. These driers are steam-heated cylinders, and the paper is held close to the driers by means of fabric drier felts. As the paper passes from one drier to the next, first the felt side and then the wire side comes in contact with the heated surface of the drier. As the paper enters the drier train approximately one-third dry, the bulk of the water is evaporated in this section. Moisture removal may be facilitated by blowing hot air onto the sheet and in between the driers in order to carry away the water vapor. Within the drier section and at a point at least 50% along the drying curve, a breaker stack is sometimes used for imparting finish and to facilitate drying. This equipment is usually comprised of a pair of chilled iron and/or rubber surfaced rolls. There may also be a size press located within the drier section, or more properly, at a point where the paper moisture content is approximately 5 percent. The fourth section of the machine, the calendar section, consists of from one to three calendar stacks with a reel device for winding the paper into a roll as it leaves the paper machine. The purpose of the calendar stacks is to finish the paper, i.e., the paper is smoothed and the desired finish, thickness or gloss is imparted to the sheet. The reel winds the finished paper into a roll, which for further finishing either can be taken to a rewinder or, as in the case of some machines; the rewinder on the machine produces finished rolls directly from the machine reel. The wire, the press section, the several drier sections, the calendar stacks, and the reel are so driven that proper tension is maintained in the web of paper despite its elongation or shrinkage during its passage through the machine. There are two modifications of the fourdrinier in use, known as the Harper and the Yankee or M.G. machine, which in principle are similar to the fourdrinier machine.

Freesheet-Paper free of mechanical wood pulp or paper made from pulps having a high freeness (the rate at which water drains from a stock suspension through a wire mesh screen or a perforated plate).

Grade-(1) A class or level of quality of a paper or pulp which is ranked, or distinguished from other papers or pulps, on the basis of its use, appearance, quality, manufacturing history, raw materials, or a combination of these factors. Some grades have been officially identified and described; others are commonly recognized but lack official definition. (2) With reference to one particular quality, one item (q.v.) differing from another only in size, weight, or grain; e.g., an offset book paper cut grain long is not the same grade as the same paper cut grain short.

Groundwood Paper--Papers other than newsprint, made with substantial proportions of mechanical pulp, and used for printing or converting.

Insulating Board-A type of board composed of some fibrous material, such as wood or other vegetable fiber, sized throughout, and felted or pressed together in such a way as to contain a large quantity of entrapped or "dead" air. It is made either by cementing together several thin layers or forming a non-laminated layer of the required thickness. It is used in plain or decorative finishes for interior walls and ceilings in thickness of 0.5 and 1 inch (in some cases up to 3 inches) and also as a water-repellent finish for house sheathing. Desirable properties are low thermal conductivity, moisture resistance, fire resistance, permanency, vermin and insect resistance, and structural strength. No single material combines all these properties but all should be permanent and should be treated to resist moisture absorption.

Kraft Bag Paper-A paper made of sulfate pulp and used in the manufacture of paper bags. It normally has a greater bulk and a rougher surface than the usual Kraft wrapping paper.

Kraft Paper-A paper made essentially from wood pulp produced by a modified sulfate pulping process. It is a comparatively coarse paper particularly noted for its strength, and in unbleached grades is primarily used as a wrapper or packaging material. It can be watermarked, striped, or calendared, and it has an acceptable surface for printing. Its natural unbleached color is brown but by the use of semi bleached or fully bleached sulfate pulps it can be produced in lighter shades of brown, cream tints, and white. In addition to its use as a wrapping paper, it is converted into such products as: grocery bags, envelopes, gummed sealing tape, asphalted papers, multiwall sacks, tire wraps, butcher wraps, waxed paper, coated paper, as well as specialty bags and sacks.

Newsprint-A lightweight paper, made mainly from mechanical wood pulp, engineered to be bright and opaque for the good print contrast needed by newspapers. Newsprint also contains special tensile strength for repeated folding. It does not includes printing papers of types generally used for purposes other than newspapers such as groundwood printing papers for catalogs, directories, etc.

Offset Paper-Paper designed for use in offset lithography. Important properties include good internal bonding, high strength, dimensional stability, lack of curl, and freedom from fuzz and foreign surface material. Used on both sheet-fed and web presses. This is commodity offset.

Premium/Opaque Offset-High quality offset markedly brighter and more opaque than Offset

Paper as it is defined above. It is usually produced in smooth and vellum finishes and may have a companion cover paper. This is a mid-range product between Offset Paper and higher quality papers in the Text and Cover category.

Packaging Papers-These papers are used to wrap or package consumer and industrial products such as grocer's bags and sacks, shopping and merchandise bags, and multiwall shipping sacks used for shipping such products as cement, flour, sugar, chemicals and animal food. "Specialty" packaging papers are used for cookies, potato chips, ice cream, and similar products.

Paper-The name for all kinds of matted or felted sheets of fiber (usually vegetable, but sometimes mineral, animal or synthetic) formed on a fine screen from a water suspension. Paper derives its name from papyrus, a sheet made by pasting together thin sections of an Egyptian reed (Cyprus papyrus) and used in ancient times as a writing material. Paper and paperboard are the two broad categories of paper. Paper is usually lighter in basis weight, thinner, and more flexible than paperboard. Its largest uses are for printing, writing, wrapping, and sanitary purposes, although it is employed for a wide variety of other uses.

Paperboard-One of the two subdivisions of paper. The distinction is not great, but paperboard is heavier in basis weight, thicker, and more rigid than paper. All sheets 12 points (0.012 inch) or more in thickness are classified as paperboard. There are exceptions. Blotting paper, felts, and drawing paper in excess of 12 points are classified as paper while corrugating medium, chipboard, and linerboard less than 12 points are classified as paperboard. The broad classes within paperboard include containerboard, boxboard, and all other paperboard.

Bleached Board-A general term covering any board composed of 100% bleached fiber.

Bleached Packaging Paperboard-A paperboard made from approximately 85% virgin bleached chemical pulp.

Bleached Paperboard-A general term covering any board composed of 100% bleached fiber.

Boxboard-The general term designating the paperboard used for fabricating boxes. It may be made of wood pulp or paper stocks or any combinations of these and may be plain, lined, or clay coated.

Clay-coated boxboard-A grade of paperboard that has been clay coated on one or both sides to obtain whiteness and smoothness. It is characterized by brightness, resistance to fading, and excellence of printing surface. Colored coatings may also be used and the body stock for coating may be any variety of paperboard.

Folding Boxboard-A paperboard suitable for the manufacture of folding cartons, which can be made from a variety of raw materials on either a cylinder machine or a fourdrinier machine. It possesses qualities that permit scoring and folding, and has variable surface properties depending upon the printing requirements. This classification includes such products as clay-coated boxboard, white patent coated news, manila lined news, and fourdrinier bleached Kraft board.

Linerboard-A paperboard that is used as the facing material in the production of corrugated and solid fibre shipping containers.

Medium-The paperboard grade used to form the inner layer of corrugated board. It can be made of recycled material or wood pulp.

Recycled Paperboard-Paperboard manufactured using 100 percent recovered paper, such as old newspapers, old corrugated containers, and mixed papers. Products include linerboard and corrugating medium; folding boxboard (both clay coated and uncoated) used for packaging cereal and other food products, soap powders, and other dry products; set-up boxboard, used for candy boxes, shoe boxes, perfume boxes and similar products. Recycled paperboard is also used for many non-packaging products, such as gypsum wallboard facing, tubes, cans and drums, matches, tags, tickets, game boards, and puzzles.

Solid Bleached Kraft-The major uses are in clay-coated folding boxes for such products as frozen foods, butter, ice cream, and cosmetics, and cartons for milk, juices and other moist, liquid and oily foods, as well as for plates, dishes, trays, and cups.

Unbleached Kraft-The primary grade is linerboard, used as the facing material for corrugated boxes. Kraft folding boxboard is usually clay coated. Its largest market is beverage carriers. Other products include drums, cans, and tubes.

Printing-Writing-Any paper suitable for printing, such as book paper, bristols, newsprint, writing paper, etc.

Fine Paper-A broad term including printing, writing, and cover papers, as distinguished from wrapping papers and paper not generally used for printing purposes, which are generally referred to as coarse papers.

Pulp-Fibrous material prepared from wood, cotton, grasses, etc., by chemical or mechanical processes for use in making paper or cellulose products.

Chemical Pulp-Pulp obtained by digestion of wood with solutions of various chemicals. The paper produced is strong and less prone to discoloration. The pulp yield is lower in this process. The principal chemical processes are the sulfate (kraft), sulfite, and soda processes. Chemical pulps are used to make shipping containers, paper bags, printing and writing papers, and other products requiring strength.

Brown Pulp-A groundwood pulp made from wood, which is steamed before grinding. The color-bearing, non-cellulose components of the wood remain with the pulp. The pulp is generally used for wrapping and bag paper.

Dissolving Pulp/Special Alpha- A special grade of chemical pulp usually made from wood or cotton linters for use in the manufacture of regenerated or cellulose derivatives such as acetate, nitrate, etc.

Fluff Pulp-A chemical, mechanical or combination chemical/mechanical pulp, usually bleached, used as an absorbent medium in disposable diapers, bedpads and hygienic personal products. Also known as "fluffing" or "comminution" pulp.

Kraft (Sulfate) Pulp-Term refers to a strong papermaking fiber produced by the Kraft process where the active cooking agent is a mixture of sodium hydroxide and sodium sulfide. The term "Kraft" is commonly used interchangeable with "sulfate" and is derived from a German word, which means "strong."

Market Pulp-Wood, cotton, or other pulp produced for, and sold on, the open market, as opposed to that which is produced for internal consumption by an integrated paper mill or affiliated mill.

Mechanical Pulp-Any wood pulp manufactured wholly or in part by a mechanical process, including stone-ground wood, chemigroundwood and chip mechanical pulp. Paper made by this process is opaque and has good printing properties, but it is weak and discolors easily when exposed to light due to residual lignin in the pulp. Uses include newsprint printing papers, specialty papers, tissue, toweling, paperboard and wallboard.

Sulfite Pulp-A papermaking fiber produced by an acid chemical process in which the cooking liquor contains an excess of SO2. The sulfite liquor is a combination of a soluble (such as ammonium, calcium, sodium, or magnesium) and sulfurous acid. Calcium was commonly used in the past but is not as widely used now because of chemical recovery and pollution abatement problems.

Unbleached Pulp-Pulp not treated with any bleaching agents.

Recovery Boiler-In wood pulping, a unit for concentrating black liquor to a stage where the residual carbon is then burned out and the inorganic sodium salts melted and recovered.

Recycled Fiber-Cellulose fiber reclaimed from waste material and reused, sometimes with a minor portion of virgin material, to produce new paper.

Recycled Paper-Usually old newspaper or waste paper used with very little refining, often with groundwood or semi-bleached Kraft.

Solid Bleached Bristols-A heavier printing paper produced on cylinder or fourdrinier paper machines in whites and colors. It is also used for conversion into office products and school supplies. Examples of bristols include index cards, tags, file folders, boarding passes, business cards, and postcards. Coated bristols are generally used for menus and as covers for booklets or pamphlets.

Specialty-Grades of paper and/or paperboard made with specific characteristics and properties to adapt them to particular uses. Also refers to grades made in a given mill that are not the primary products of that mill.

Specialty Extrusion Coating-A coating, which is applied by means of extrusion, either simultaneous with or separate from the actual extrusion itself. Coatings of the extrusion type are normally quite quick, solvent based and applied at elevated temperatures, usually associated with plastics.

Specialty Industrial Paper-Papers intended for industrial uses, as opposed to those for cultural or sanitary purposes. Paper and board of all thickness and fiber types designed for special uses and manufactured to exact customer specifications. Includes abrasive paper, electrical insulation, filter paper, and similar grades.

Text Paper-A paper of fine quality and texture for printing. Text papers are manufactured in white and colors, from bleached chemical wood pulp or cotton fiber content furnishes with a decked or plain edge, and are sometimes watermarked. They are made in a wide variety of finishes, including antique, vellum, smooth, felt-marked, and patterned surfaces-some with laid formations. Designed for advertising printing, the principal use of text papers is for booklets, brochures, fine books, announcements, annual reports, menus, folders, etc.

Thin Papers-Includes carbonizing, cigarette, bible and similar papers.

Tissue-A general term indicating a class of papers of characteristic gauzy texture, in some cases fairly transparent. Includes sanitary tissues, wrapping tissue, waxing tissue stock, twisting tissue stock, fruit and vegetable wrapping tissue stock, pattern tissue stock, sales-book tissue stock, and creped wadding. Tissue papers are made on any type of paper machine, from any type of pulp including reclaimed paper stock. They may be glazed, unglazed, or creped, and are used for a variety of purposes. Examples are primarily sanitary grades such as toilet, facial, napkin, toweling, wipes, and special sanitary papers. There are also waxing, wrapping, and miscellaneous non-sanitary grades.

At-home products-Tissue products you purchase in the grocery store for use at your personal home.

Away-from-Home products-Tissue products seen servicing washrooms in airports, hotels, industry, office buildings, etc.

Facial Tissue-The name given the class of soft absorbent papers in the sanitary tissue group. Originally used for removal of creams, oil, etc., from the skin, it is now used in large volume for packaged facial tissue, toilet paper, paper napkins, professional towels, industrial wipes, and for hospital items. It is made of bleached sulfite or sulfate pulp, sometimes mixed with bleached and mechanical pulp, on a single-cylinder or fourdrinier Yankee machine. Desirable characteristics are softness, strength, and freedom from lint.

Wallboard (1) A type of fibreboard composed of a number of layers of chip, binders, or pulpboard, molded or pasted together and generally sized, either throughout or on the surface. It may also be non-laminated and homogenous in nature. Wallboard is generally 3/16 to ¼ of an inch in thickness. (2) A general term used to indicate a composition material used in the construction of partitions, sidewalls, and ceilings in interior construction; it is made generally of waste papers, wood pulp, or wood or other materials.

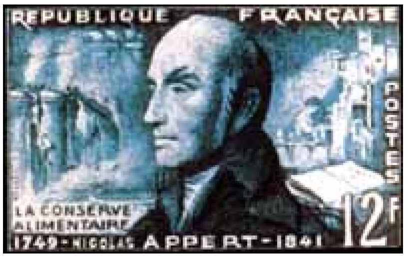
Wet Machine Board-A very thick paperboard, used for bookbinders, shoeboard, automotive board, chair seat backing, coaster board, and the like.

3. Metal

3.1. History of Canning

The process of canning was pioneered in the 1790's when a French confectioner, Nicolas Appert, discovered that the application of heat to food in sealed glass bottles preserved the food from deterioration.

In about 1806 Appert's principles were successfully tried by the French Navy on a wide range of foods including meat, vegetables, fruit and even milk.

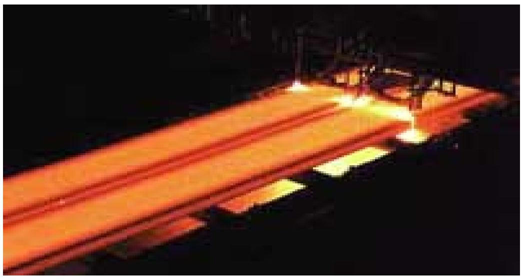


Based on Appert's methods of food preservation the packaging of food in sealed airtight tin-plated wrought-iron cans was first patented by an Englishman, Peter Durand, in 1810.

Can of roast veal taken on Parry's voyage to the Arctic in 1824.

Parry's tin of roasted veal contained instructions to open the can - "Cut round on the top near to the outer edge with a chisel and hammer". It was said a good worker could produce four cans in one day. Cans are now manufactured at around 400 per minute.

3.2. Steel Can Manufacture



Steel is produced at the Basic Oxygen Steelmaking Plant (BOS) using molten iron, made in the blast furnace, scrap steel and various alloy additions to yield the required steel chemistry and metallurgy.

The molten steel is continuous cast into slab form and the slabs are hot rolled in the Hot Strip Mill into coils of steel strip with a thickness of 2 mm.

In the Tin Mill, these 20 tonne feed coils are cold rolled to final thickness, usually in the range of 0.16 to 0.30 mm for food cans.

The three piece steel can

The tin coating is applied by continuous electro-deposition of tin on to thin steel strip, after which the tinplate is either sold in coil form or cut into sheets for the can manufacturer.

At the can manufacturers, the tinplate is slit into rectangular "body blanks" which are then rolled into a cylindrical shape and the contacting edges welded together at very high speeds. The ends of this cylinder are flanged, ready to receive the can ends. Corrugations known as "beads" are often rolled into the cylinder walls for added strength.

The can end is applied forming the "open top can" which is then supplied to the food canning company.

The draw-redraw (DRD) steel can

Two-piece Draw-Redraw cans, usually with a ring pull opener, are commonly used to can food. In this method, a cup is stamped or drawn out of a disc of tinplate.

This cup is then redrawn, trimmed and flanged to form the finished can. The cup has no separate bottom end, no side seam and, after lacquering, is ready for the canner to seal with an end.

The necked-in can

The development of the 'necked-in' can has been a recent innovation that has been strongly welcomed by both households and retailers. This can features a slightly wider top end in comparison to the necked in bottom end, making it easier to stack in the pantry at home and easier to stack on supermarket shelves.

The peelable foil end steel can

An innovation in food can manufacture is a can with a foil end that is easy to peel open.

The peelable foil end leaves non-sharp edges after opening, which makes the end particularly, safe after opening and has excellent product-resistance qualities. So far this can has been used only for packing 140g fruit snacks but the specially formulated internal coating on the foil makes the end suitable for packing a wide range of food products.The foil end can be printed externally with brand or product information.

3.3. Manufacture of aluminum cans

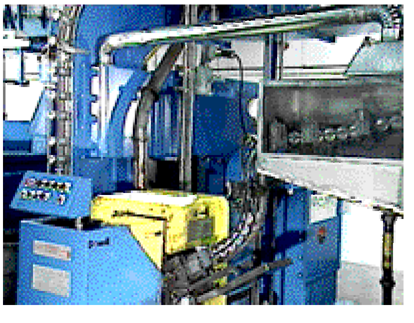
The process of making a beverage can from flat aluminum sheet is one of amazing technical achievement. The can body is formed from a combination of processes -- blanking, drawing & ironing and forming. The can end, the flat top with the opening tab, is formed by punching and scoring the flat aluminum. The open-ended can is filled and then closed by seating and sealing the can end on top.

Copper

Aluminum coil sheet is fed through a press that punches out shallow cups.

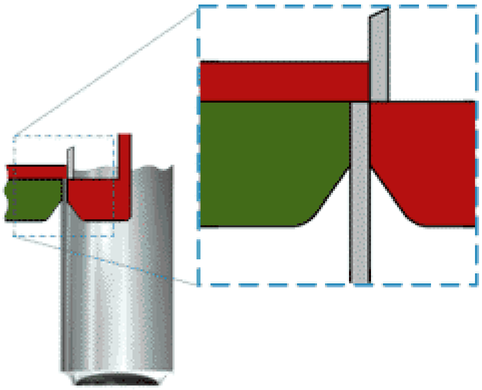
Bodymaker

Cups are fed into an ironing press where successive rings redraw and iron the cup. This reduces the sidewall thickness, making a full length can. The bottom is domed for strength.



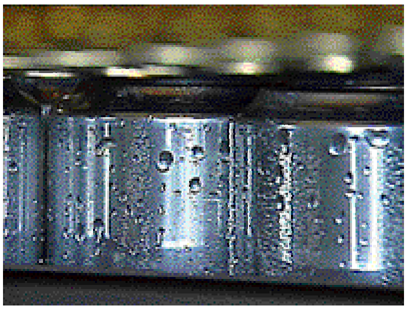
Trimmer

Cans are spun as a cutting tool punctures the aluminum near the top and trims the uneven edge formed in the redraw and iron process.



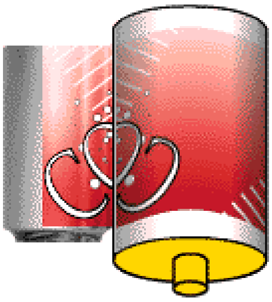
Washer

The cans are cleaned and pretreated for decoration and inside coating.



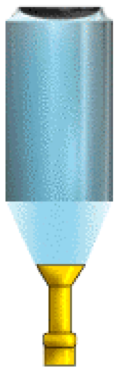
Decorating & Varnishing

Cans are rolled against a rubber cylinder, printing multiple colors simultaneously. A clear protective overvarnish is then applied.



Internal Coater

A specially selected coating is sprayed on the inside of the cans.

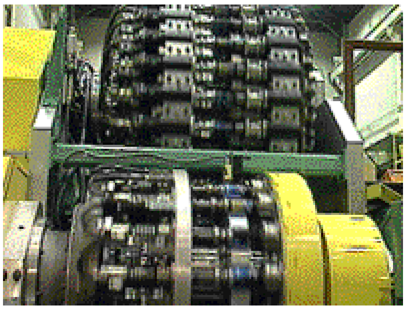


Oven

Cans are conveyed through ovens that cure the inside and outside coating materials.

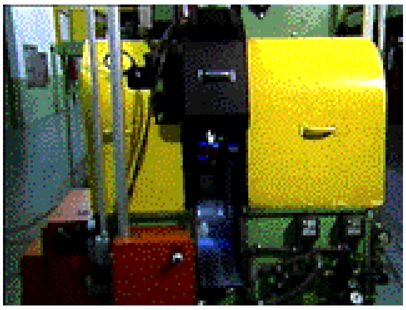
Necking & Flanging

Cans are necked-in at the top to reduce can diameter and flanged to accept the end.



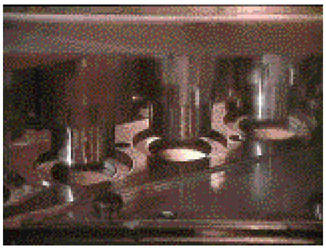
Light Tester

Cans are cycled through a light tester that detects pinholes and rejects defective cans.



Bodymaker

Ends are stamped out of precoated aluminum coil. Compound is added to assure a perfect seal between can and end.



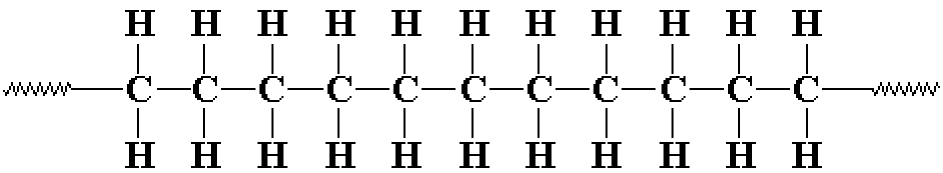
Decorating & Varnishing

Ends are fed through a high-precision press where rivet making, scoring and tabbing occur in progressive operations.

4. Polymers

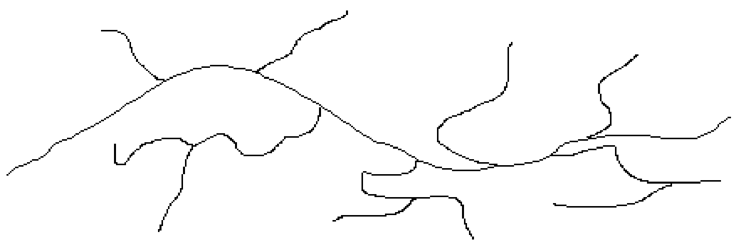
4.1. Polyethylene

Polyethylene is probably the polymer you see most in daily life. Polyethylene is the most popular plastic in the world. This is the polymer that makes grocery bags, shampoo bottles, children's toys, and even bullet proof vests. For such a versatile material, it has a very simple structure, the simplest of all commercial polymers. A molecule of polyethylene is nothing more than a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom. That's what the picture at the top of the page shows, but it might be easier to draw it like the picture below, only with the chain of carbon atoms being many thousands of atoms long:



Sometimes it's a little more complicated. Sometimes some of the carbons, instead of having hydrogens attached to them, will have long chains of polyethylene attached to them. This is called branched, or low-density polyethylene, or LDPE. When there is no branching, it is called linear polyethylene, or HDPE. Linear polyethylene is much stronger than branched polyethylene, but branched polyethylene is cheaper and easier to make.

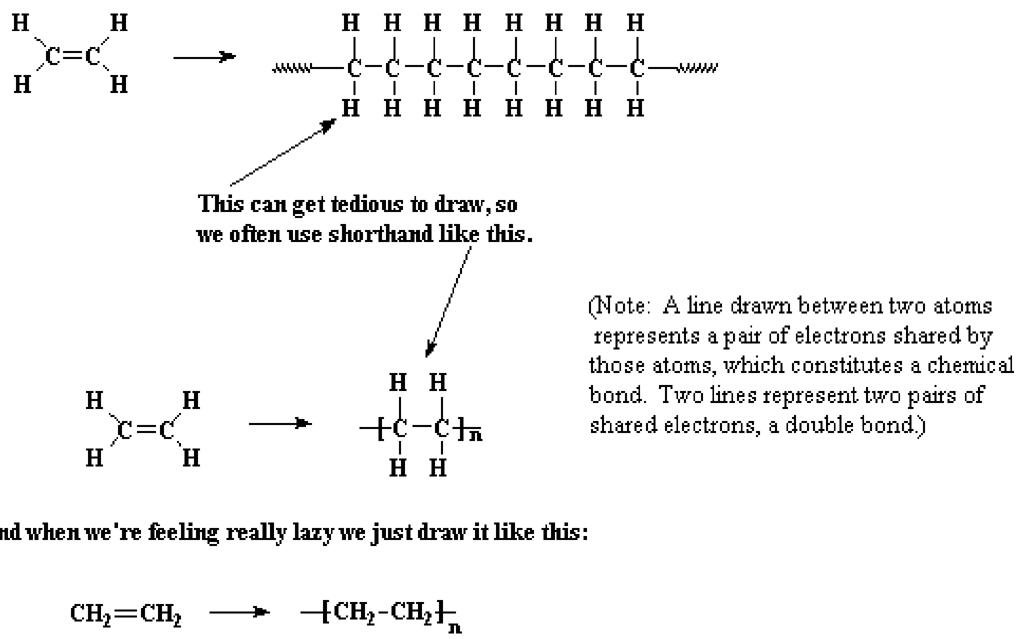
A molecule of linear polyethylene, or HDPE



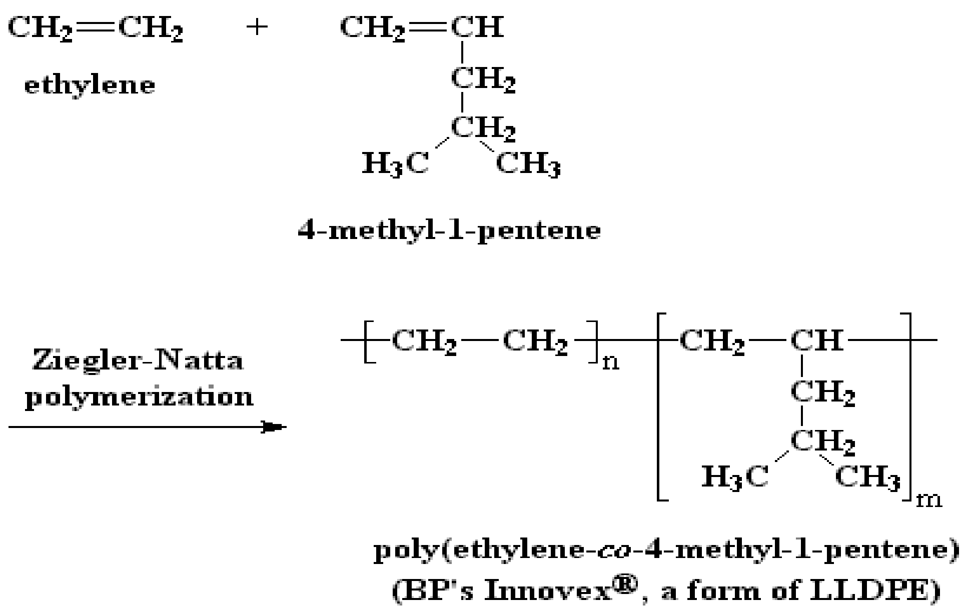
A molecule of branched polyethylene, or LDPE

Linear polyethylene is normally produced with molecular weights in the range of 200,000 to 500,000, but it can be made even higher. Polyethylene with molecular weights of three to six million is referred to as ultra-high molecular weight polyethylene, or UHMWPE. UHMWPE can be used to make fibers, which are so strong they replaced Kevlar for use in bulletproof vests. Large sheets of it can be used instead of ice for skating rinks.

Polyethylene is vinyl polymer, made from the monomer ethylene. Here's a model of the ethylene monomer. Branched polyethylene is often made by free radical vinyl polymerization. Linear polyethylene is made by a more complicated procedure called Ziegler-Natta polymerization. UHMWPE is made using metallocene catalysis polymerization.



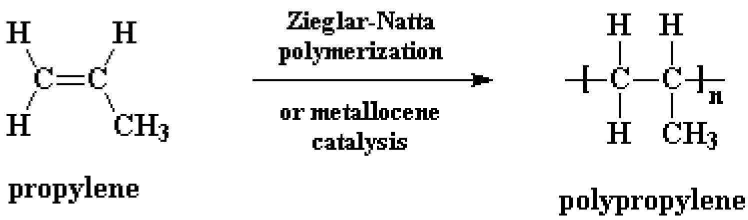
But Ziegler-Natta polymerization can be used to make LDPE, too. By copolymerizing ethylene monomer with an alkyl-branched comonomer such as one gets a copolymer, which has short hydrocarbon branches. Copolymers like this are called linear low-density polyethylene, or LLDPE. BP produces LLDPE using a comonomer with the catchy name 4-methyl-1-pentene, and sells it under the trade name Innovex®. LLDPE is often used to make things like plastic films.



4.2. Polypropylene

Polypropylene is one of those rather versatile polymers out there. It serves double duty, both as a plastic and as a fiber. As a plastic it is used to make things like dishwasher-safe food containers. It can do this because it doesn't melt below 160 ^oC, or 320 ^oF. Polyethylene, a more common plastic, will anneal at around 100 ^oC, which means that polyethylene dishes will warp in the dishwasher. As a fiber, polypropylene is used to make indoor-outdoor carpeting, the kind that you always find around swimming pools and miniature golf courses. It works well for outdoor carpet because it is easy to make colored polypropylene, and because polypropylene doesn't absorb water, like nylon does.

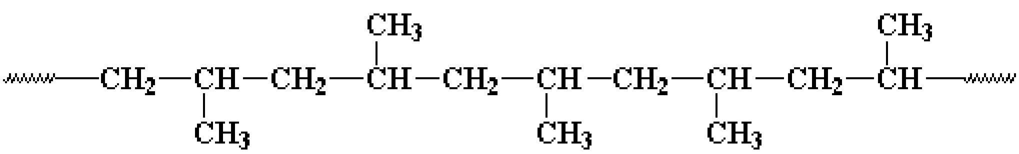
Structurally, it is a vinyl polymer, and is similar to polyethylene, only that on every other carbon atom in the backbone chain has a methyl group attached to it. Polypropylene can be made from the monomer propylene by Ziegler-Natta polymerization and by metallocene catalysis polymerization. This is what the monomer propylene really looks like:



Research is being conducted on using metallocene catalysis polymerization to synthesize polypropylene. Metallocene catalysis polymerization can do some pretty amazing things for polypropylene. Polypropylene can be made with different tacticities. Most polypropylene we use is isotactic. This means that all the methyl groups are on the same side of the chain, like this:

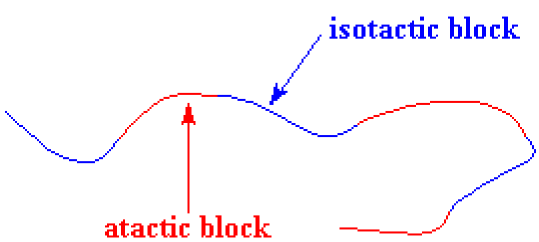
But sometimes we use atactic polypropylene. Atactic means that the methyl groups are placed randomly on both sides of the chain like this:

However, using special metallocene catalysts it is believed that we can make polymers

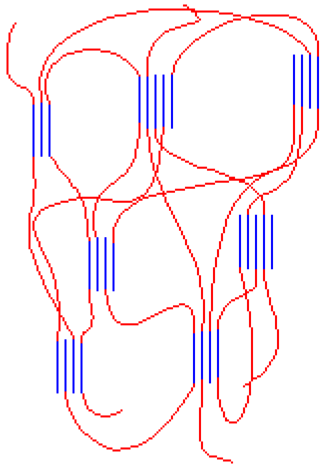


atactic polypropylene

which contain blocks of isotactic polypropylene and blocks of atactic polypropylene in the same polymer chain, as is shown in the picture:



This polymer is rubbery, and makes a good elastomer. This is because the isotactic blocks will form crystals by themselves. But because the isotactic blocks are joined to the atactic blocks, each little hard clump of crystalline isotactic polypropylene will be tied together by soft rubbery tethers of atactic polypropylene, as you can see in the picture below.



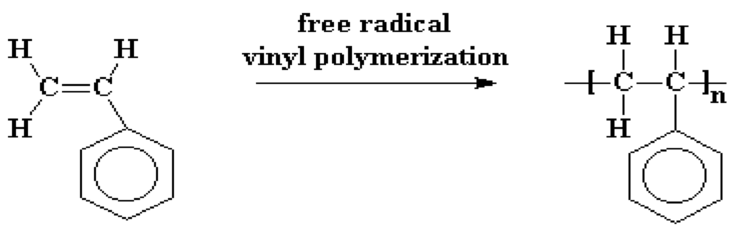
To be honest, atactic polypropylene would be rubbery without help from the isotactic blocks, but it wouldn't be very strong. The hard isotactic blocks hold the rubbery isotactic material together, to give the material more strength. Most kinds of rubber have to be crosslinked to give them strength, but not polypropylene elastomers.

Elastomeric polypropylene, as this copolymer is called, is a kind of thermoplastic elastomer. However, until the research is completed, this type of polypropylene will not be commercially available. The polypropylene which you can buy off the shelf at the store today has about 50-60% crystallinity, but this is too much for it to behave as an elastomer.

4.3. Polystyrene

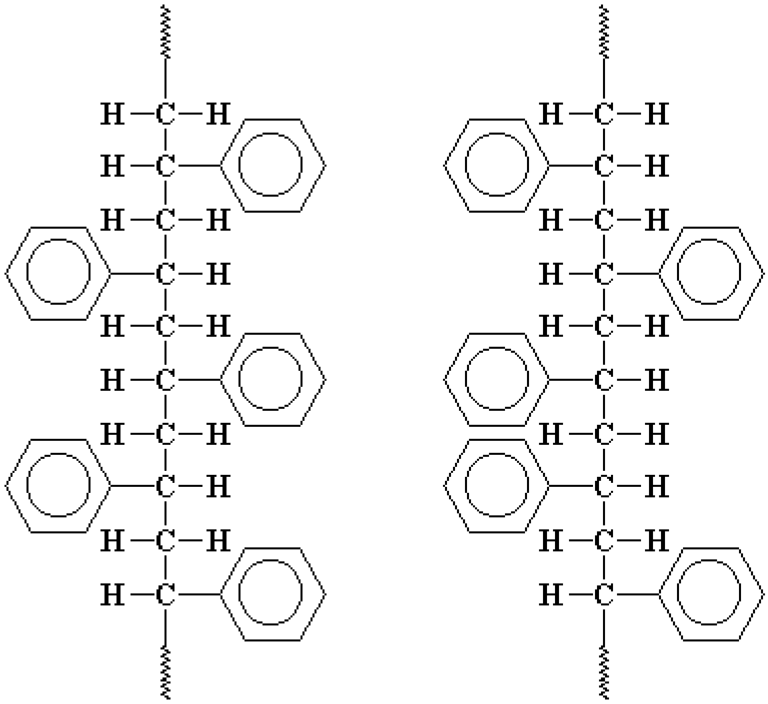
Polystyrene is an inexpensive and hard plastic, and probably only polyethylene is more common in your everyday life. The outside housing of the computer you are using now is probably made of polystyrene. Model cars and airplanes are made from polystyrene, and it also is made in the form of foam packaging and insulation (Styrofoam™ is one brand of polystyrene foam). Clear plastic drinking cups are made of polystyrene. So are a lot of the molded parts on the inside of your car, like the radio knobs. Polystyrene is also used in toys, and the housings of things like hairdryers, computers, and kitchen appliances.

Polystyrene is a vinyl polymer. Structurally, it is a long hydrocarbon chain, with a phenyl group attached to every other carbon atom. Polystyrene is produced by free radical vinyl polymerization, from the monomer styrene.



Polystyrene is also a component of a type of hard rubber called poly(styrene-butadiene-styrene), or SBS rubber. SBS rubber is a thermoplastic elastomer.

There's a new kind of polystyrene, called syndiotactic polystyrene. It's different because the phenyl groups on the polymer chain are attached to alternating sides of the polymer backbone chain. "Normal" or atactic polystyrene has no order with regard to the side of the chain on which the phenyl groups are attached. The new syndiotactic polystyrene is crystalline, and melts at 270 ^{o}C. But it's a lot more expensive! Syndiotactic polystyrene is made by metallocene catalysis polymerization.

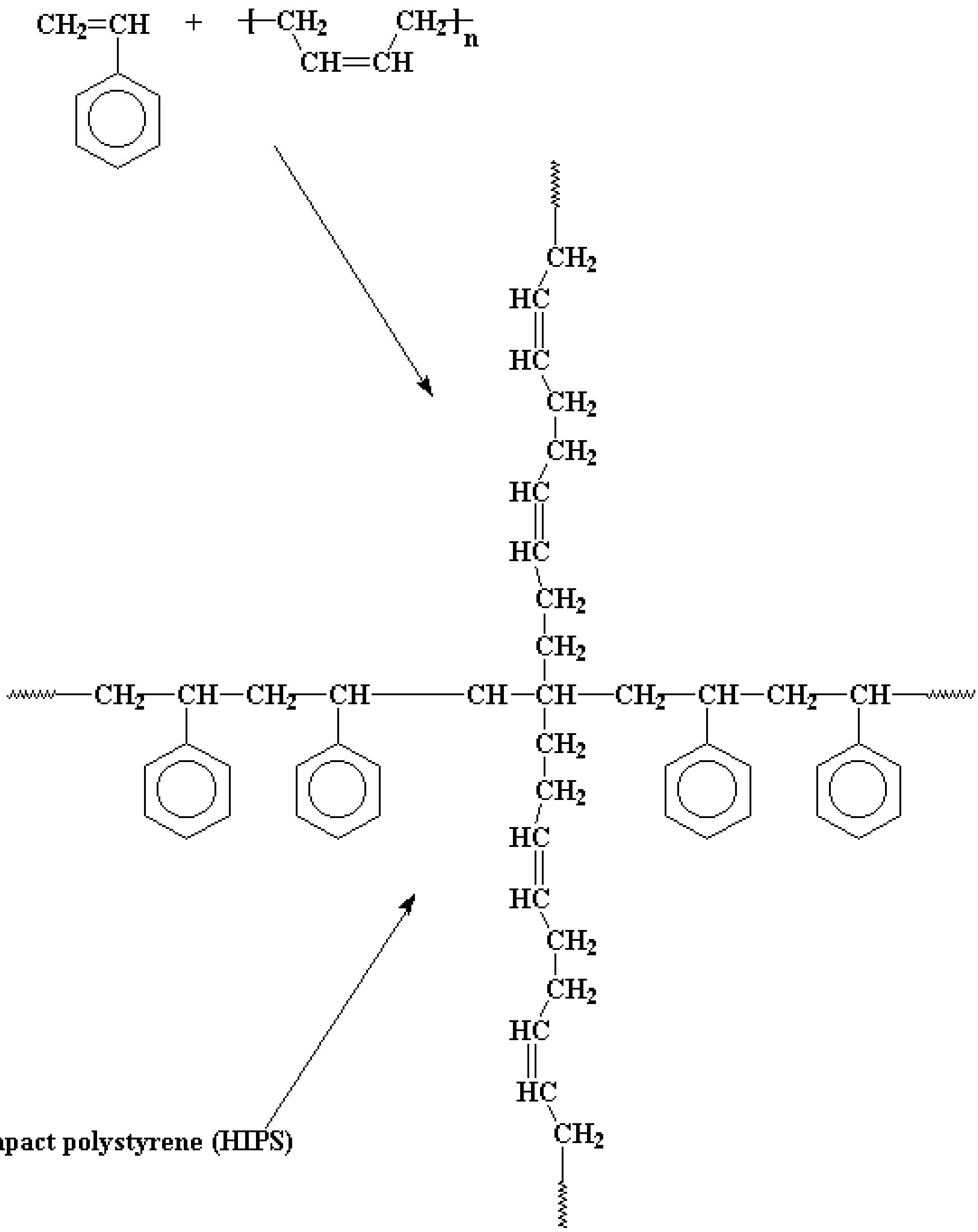


syndiotactic polystyrene | **atactic polystyrene**

Syndiotactic polystyrene has a regular structure, so it can pack into crystal structures. The irregular atactic polystyrene can't.

What would happen if we were to take some styrene monomer, and polymerize it free radically, but let's say we put some polybutadiene rubber in the mix? Take a look at polybutadiene, and you'll see that it has double bonds in it that can polymerize. We end up with the polybutadiene copolymerizing with the styrene monomer, to get a type of copolymer called a graft copolymer. This is a polymer with polymer chains growing out of it, and which are a different kind of polymer than the backbone chain. In this case, it's a polystyrene chain with chains of polybutadiene growing out of it.

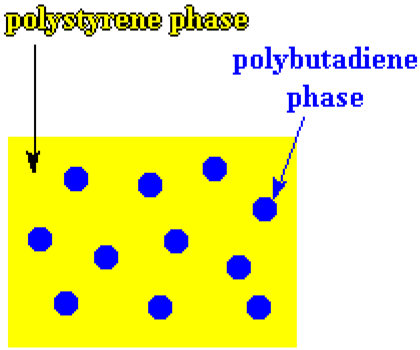
These rubbery chains hanging off of the backbone chain do some good things for polystyrene. Polybutadiene and polystyrene homopolymers don't mix, mind you. So the polybutadiene branches try as best they can to phase separate, and form little globs, like you see in the picture below. But these little globs are always going to be tied to the polystyrene phase. So they have an effect on that polystyrene. They act to absorb energy when the polymer gets hit with something. They give the polymer a resilience that normal polystyrene doesn't have. This makes it stronger, not as brittle, and capable of taking harder impacts without breaking than regular polystyrene. This material is called high-impact polystyrene, or HIPS for short.



High-impact polystyrene (HIPS)

Not all the chains in HIPS are branched like this. There are many chains of plain polystyrene and plain polybutadiene mixed in there, too. This makes HIPS something we call and immiscible blend of polystyrene and polybutadiene. But it is the grafted polystyrene-polybutadiene molecules that make the whole system work by binding the two phases (the polystyrene phase and the polybutadiene phase) together.

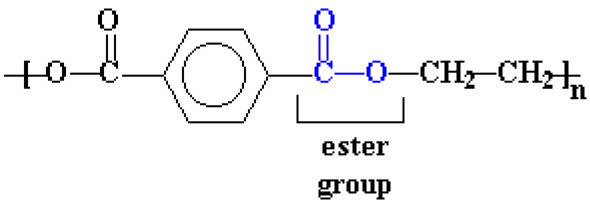
HIPS can be blended with a polymer called poly(phenylene oxide), or PPO. This blend of HIPS and PPO is made by GE and sold as Noryl™.



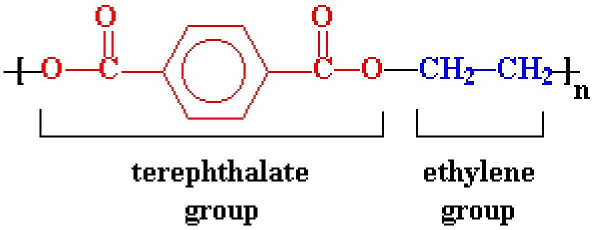
4.4. Polyester

Polyesters are the polymers, in the form of fibers that were used back in the seventies to make all that wonderful disco clothing, the kind you see being modeled on the right. But since then, the nations of the world have striven to develop more tasteful uses for polyesters, like those nifty shatterproof plastic bottles that hold your favorite refreshing beverages, like the blue bottle in the picture below. So you see, polyesters can be both plastics and fibers. Another place you find polyester is in balloons. Not the cheap ones that you use for water balloons, those are made of natural rubber. I'm talking about the fancy ones you get when you're in the hospital. These are made of a polyester film made by DuPont called Mylar. The balloons are made of a sandwich, composed of Mylar and aluminum foil. Materials like this, made of two kinds of material, are called composites.

Polyesters have hydrocarbon backbones that contain ester linkages, hence the name.



The structure in the picture is called poly(ethylene terephthalate), or PET for short, because it is made up of ethylene groups and terephthalate groups (duh!). I realize that terephthalate is not the kind of word most English-speaking mouths are used to saying, but with practice you should be able to say it with only a slight feeling of awkwardness when it rolls off your tongue.



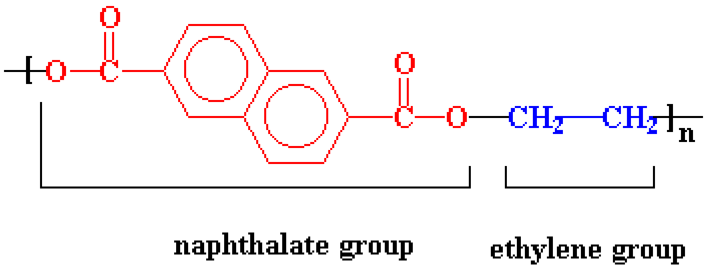
The ester groups in the polyester chain are polar, with the carbonyl oxygen atom having a somewhat negative charge and the carbonyl carbon atom having a somewhat positive charge. The positive and negative charges of different ester groups are attracted to each other. This allows the ester groups of nearby chains to line up with each other in crystal form, which is why they can form strong fibers.

The inventor who first discovered how to make bottles from PET was Nathaniel Wyeth. He's the brother of Andrew Wyeth the famous painter. But others had tried before. Go read this story of someone who may have been the first person to try to make a shatterproof bottle.

Why can't you return plastic soft drink bottles to get a cool nickel per bottle like you could with the old glass bottles? And the second one, which I'm positive everyone is wondering about, is: How come peanut butter comes in neato shatterproof jars but jelly doesn't? These two riveting questions, as it turns out, have the same answer. The answer is that PET has too low a glass transition temperature, which is the temperature at which the PET becomes soft. Now reusing a soft drink bottle requires that the bottle be sterilized before it is used again. This means washing it at really high temperatures, temperatures too high for PET. Filling a jar with jelly is also carried out at high temperatures. Down at your local jelly factory, the stuff is shot into the jars hot, at temperatures, which would cause PET to become soft. So PET is no good for jelly jars.

PEN Saves the Day!

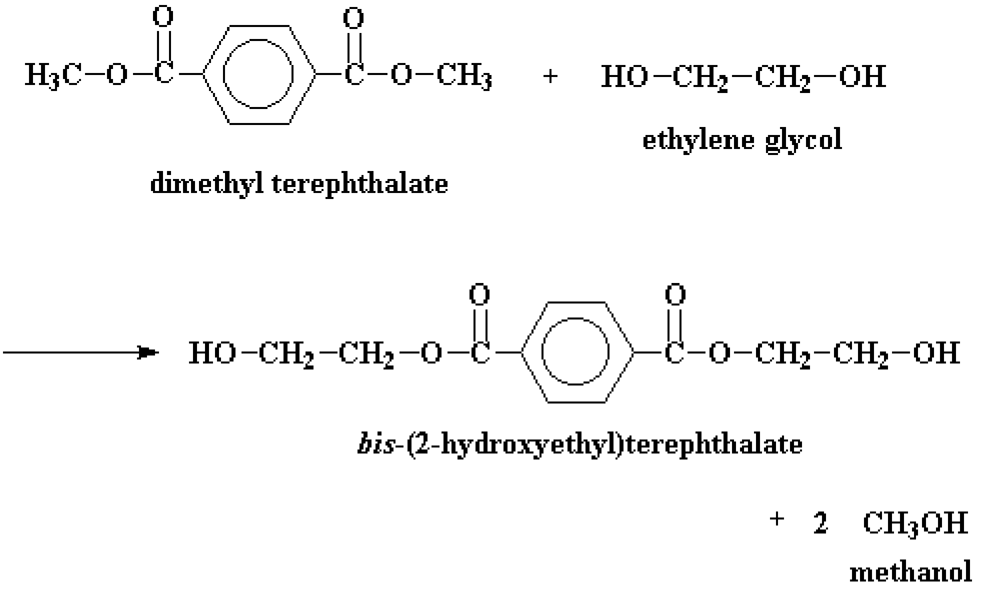
There is a new kind of polyester that is just the thing needed for jelly jars and returnable bottles. It is poly(ethylene naphthalate), or PEN.



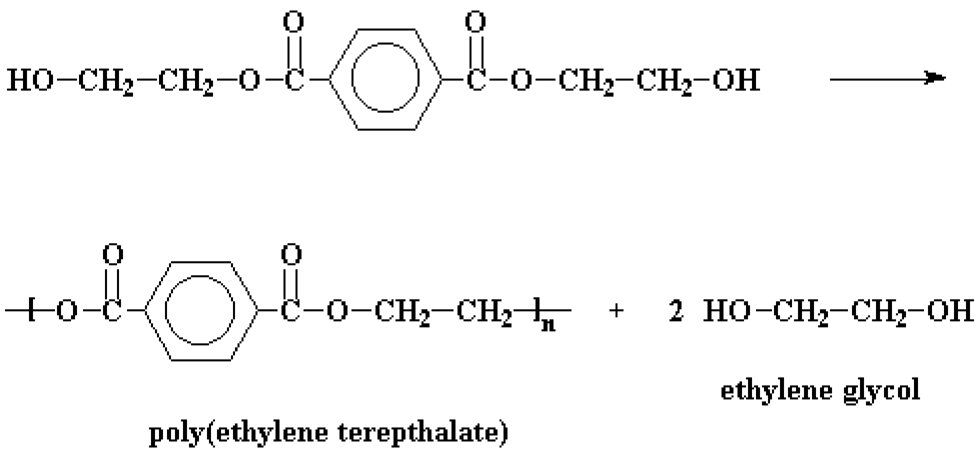
Poly(ethylene naphthalate), the polymer that bestows upon us the plastic jelly jar.

PEN has a higher glass transition temperature than PET. That's the temperature at which a polymer gets soft. The glass transition temperature of PEN is high enough so that it can withstand the heat of both sterilizing bottle washing and hot strawberry jelly. PEN is so good at standing the heat that you don't even have to make the bottle entirely out of it. Just mixing some PEN in with the old PET gives a bottle that can take the heat a lot better than plain old PET.

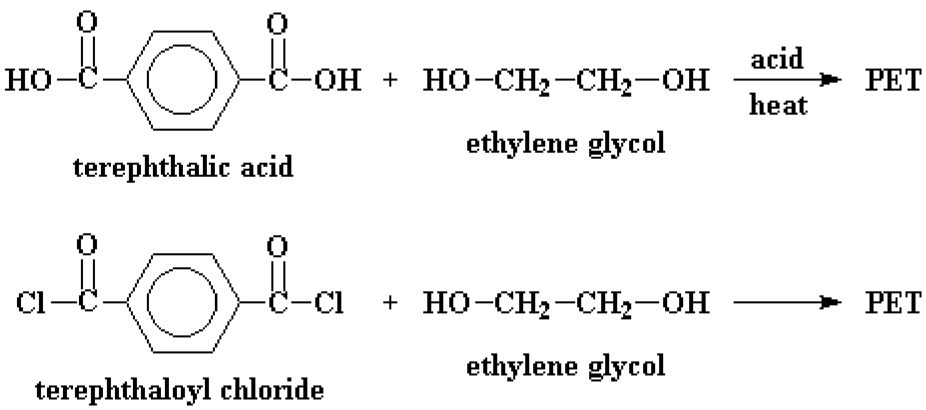
In the big plants where they make polyester, its normal to start off with a compound called dimethyl terephthalate. This is reacted with ethylene glycol is a reaction called transesterification. The result is bis-(2-hydroxyethyl) terephthalate and methanol. But if we heat the reaction to around 210 ^{o}C the methanol will boil away and we don't have to worry about it anymore.



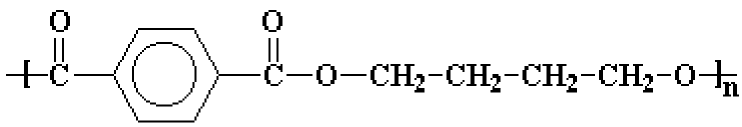
Then the bis-(2-hydroxyethyl) terephthalate is heated up to a balmy 270 ^{o}C, and it reacts to give the poly(ethylene terephtalate) and, oddly, ethylene glycol as a by-product. Funny, we started off with ethylene glycol.



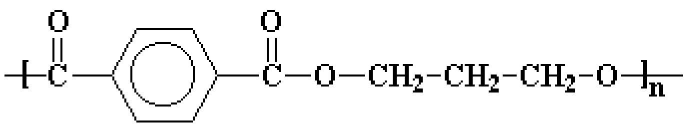
But in the laboratory, PET is made by other reactions. Terephthalic acid and ethylene glycol can polymerize to make PET when you heat them with an acid catalyst. It's possible to make PET from terephthoyl chloride and ethylene glycol. This reaction is easier, but terephthoyl chloride is more expensive than terephthalic acid, and it's a lot more dangerous.



There are two more polyesters on the market that are related to PET. There is poly(butylene terephthalate) (PBT) and poly(trimethylene terephthalate). They are usually used for the same type of things as PET, but in some cases these perform better.



poly(butylene terephthalate)

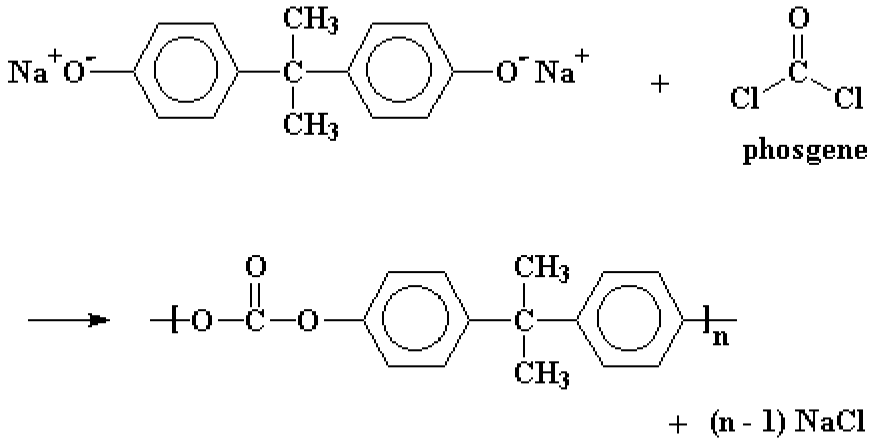


poly(trimethylene terephthalate)

4.5. Polycarbonate

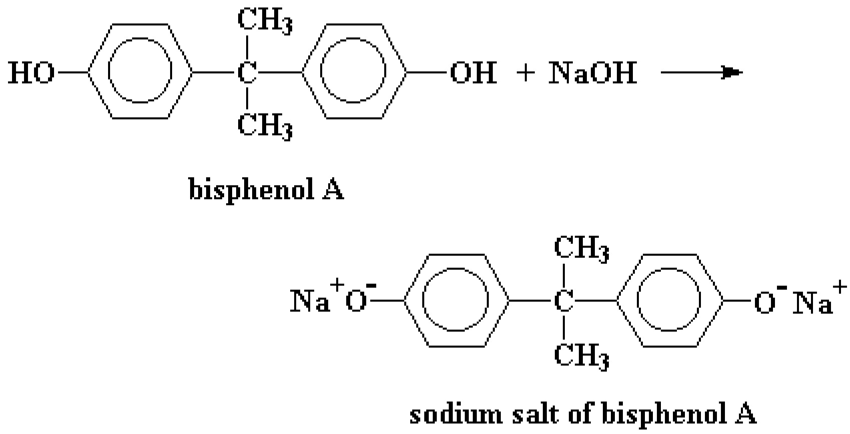
Polycarbonate, or specifically polycarbonate of bisphenol A, is a clear plastic used to make shatterproof windows, lightweight eyeglass lenses, and such. General Electric makes this stuff and sells it as Lexan.

Polycarbonate gets its name from the carbonate groups in its backbone chain. We call it polycarbonate of bisphenol A because it is made from bisphenol A and phosgene. This starts out with the reaction of bisphenol A with sodium hydroxide to get the sodium salt of bisphenol A.

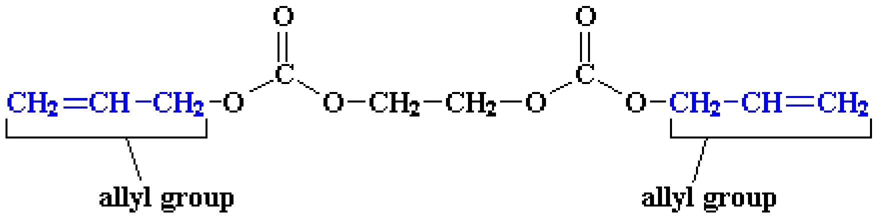


The sodium salt of bisphenol A is then reacted with phosgene, a right nasty compound which was a favorite chemical weapon in World War I, to produce the polycarbonate.

Up until now, we've been talking about only one polycarbonate, polycarbonate of bisphenol A. But there's another polycarbonate out there, that some of us look at all the time. This is the polycarbonate that is used to make ultra-light eyeglass lenses. For people with really bad eyesight, if the lenses were made out of glass, they would be so thick that they'd be too heavy to wear. But this new polycarbonate changed all that. Not only is it a lot lighter than glass, but also it has a much higher refractive index. That means it bends light more than glass, but doesn't need to be nearly so thick.

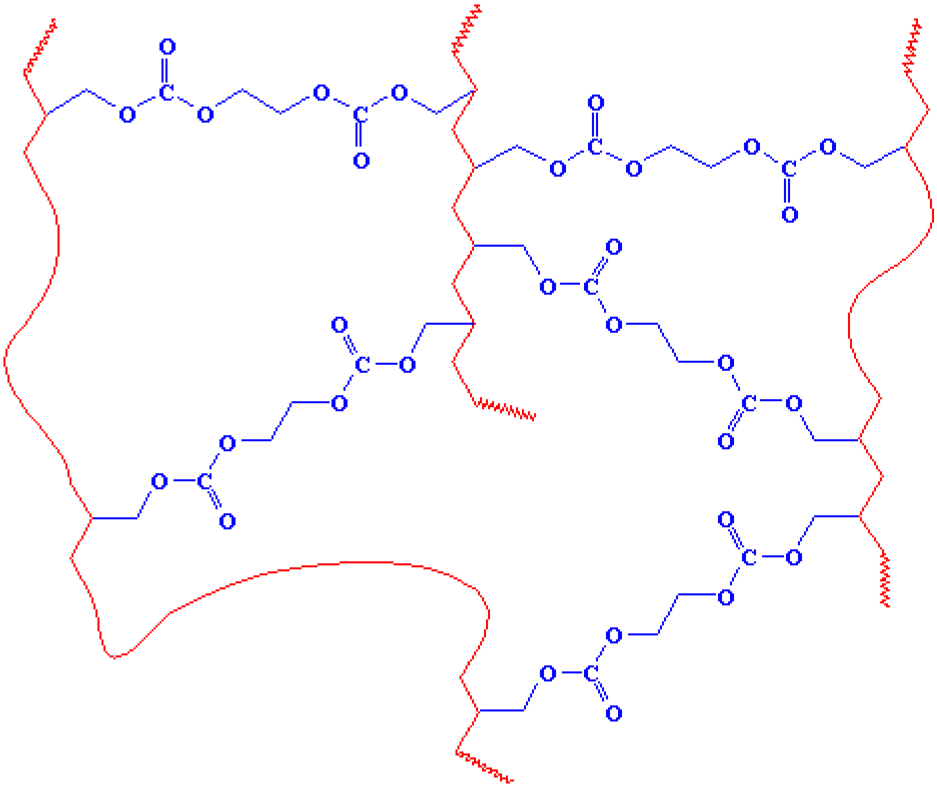


So what is this wonderful new polycarbonate? It's very different from polycarbonate of bisphenol A. We make it by starting with this monomer:



You can see that it has two allyl groups on the ends. These allyl groups have carbon-carbon double bonds in them. This means they can polymerize by free radical vinyl polymerization. Of course, there are two allyl groups on each monomer. The two allyl groups will become parts of different polymer chains. In this way, all the chains will become tied together to form a crosslinked material that looks like this:

As you can see, the carbonate containing groups (shown in blue) for the crosslinks between the polymer chains (shown in red). This crosslinking is makes the material very strong, so it won't break nearly as easily as glass will. This is really important for kids' glasses!



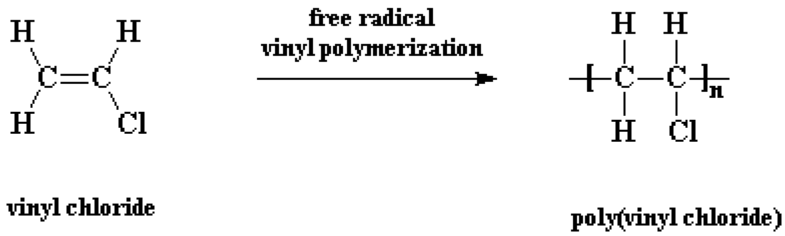
There is a fundamental difference in the two types of polycarbonate described here. Polycarbonate of bisphenol A is a thermoplastic. This means it can be molded when it is hot. But the polycarbonate used in eyeglasses is a thermoset. Thermosets do not melt, and they can't be remolded. They are used to make things that need to be really strong and heat resistant.

4.6. Poly(vinyl chloride)

Poly(vinyl chloride) is the plastic known at the hardware store as PVC. This is the PVC from which pipes are made, and PVC pipe is everywhere. The plumbing in your house is probably PVC pipe, unless it's an older house. PVC pipe is what rural high schools with small budgets use to make goal posts for their football fields. But there's more to PVC than just pipe. The "vinyl" siding used on houses is made of poly(vinyl chloride). Inside the house, PVC is used to make linoleum for the floor. In the seventies, PVC was often used to make vinyl car tops.

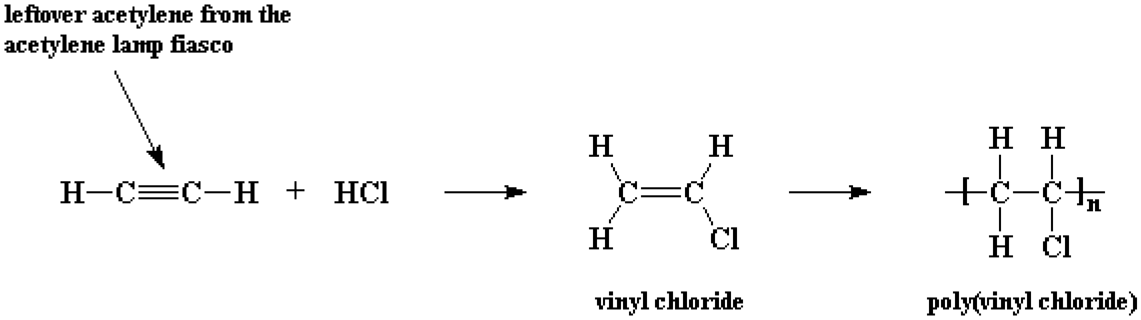
PVC is useful because it resists two things that hate each other: fire and water. Because of its water resistance it is used to make raincoats and shower curtains, and of course, water pipes. It has flame resistance, too, because it contains chlorine. When you try to burn PVC, chlorine atoms are released, and chlorine atoms inhibit combustion.

Structurally, PVC is a vinyl polymer. It is similar to polyethylene, but on every other carbon in the backbone chain, one of the hydrogen atoms is replaced with a chlorine atom. It is produced by the free radical polymerization of vinyl chloride.



PVC was one of those odd discoveries that actually had to be made twice. It seems around a hundred years ago, a few German entrepreneurs decided they were going to make loads of cash lighting people's homes with lamps fueled by acetylene gas. Wouldn't you know it, right about the time they had produced tons of acetylene to sell to everyone who was going to buy their lamps, new efficient electric generators were developed which made the price of electric lighting drop so low that the acetylene lamp business was finished. That left a lot of acetylene lying around.

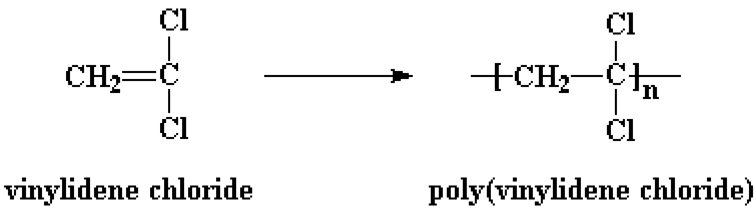
So in 1912 one German chemist, Fritz Klatte decided to try to do something with it, and reacted some acetylene with hydrochloric acid (HCl). Now this reaction will produce vinyl chloride, but at that time no one knew what to do with it, so he put it on the shelf, where it polymerized over time. Not knowing what to do with the PVC he had just invented, he told his bosses at his company, Greisheim Electron, who had the material patented in Germany. They never figured out a use for PVC, and in 1925 their patent expired.



Wouldn't you know it, in 1926 the very next year, and American chemist, Waldo Semon was working at B.F. Goodrich when he independently invented PVC. But unlike the earlier chemists, it dawned on him that this new material would make a perfect shower curtain. He and his bosses at B.F. Goodrich patented PVC in the United States (Klatte's bosses apparently never filed for a patent outside Germany). Tons of new uses for this wonderful waterproof material followed, and PVC was a smash hit the second time around.

4.7. Poly(vinylidene chloride)

Poly(vinylidene chloride) is polymer that's only used for one thing, but it's an important thing. PVDC, as we call it for short, is the plastic wrap that food comes in at the grocery store, and that you put over your dish of casserole that you're taking to the potluck supper. Dow Chemical makes this stuff, and calls it Saran.



Poly(vinylidene chloride) is a vinyl polymer. It is made from the monomer vinylidene chloride, using free radical vinyl polymerization like this:

4.8. Nylons

Nylons are one of the most common polymers used as a fiber. Nylon is found in clothing all the time, but also in other places, in the form of a thermoplastic. Nylon's first real success came with its use in women's stockings, in about 1940. They were a big hit, but they became hard to get, because the next year the United States entered World War II, and nylon was needed to make war materials, like parachutes and ropes. But before stockings or parachutes, the very first nylon product was a toothbrush with nylon bristles.

Nylons are also called polyamides, because of the characteristic amide groups in the backbone chain. Proteins, such as the silk nylon was made to replace, are also polyamides. These amide groups are very polar, and can hydrogen bond with each other. Because of this, and because the nylon backbone is so regular and symmetrical, nylons are often crystalline, and make very good fibers.

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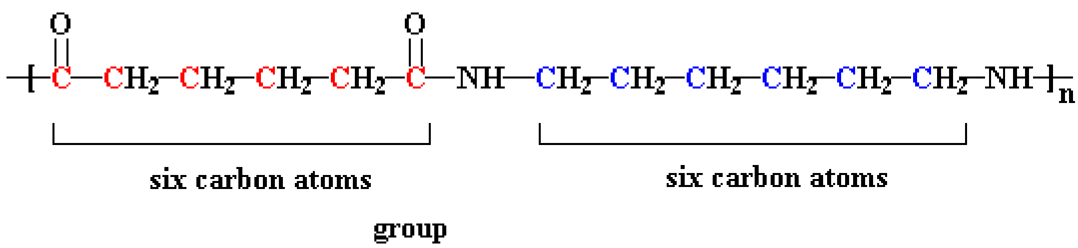
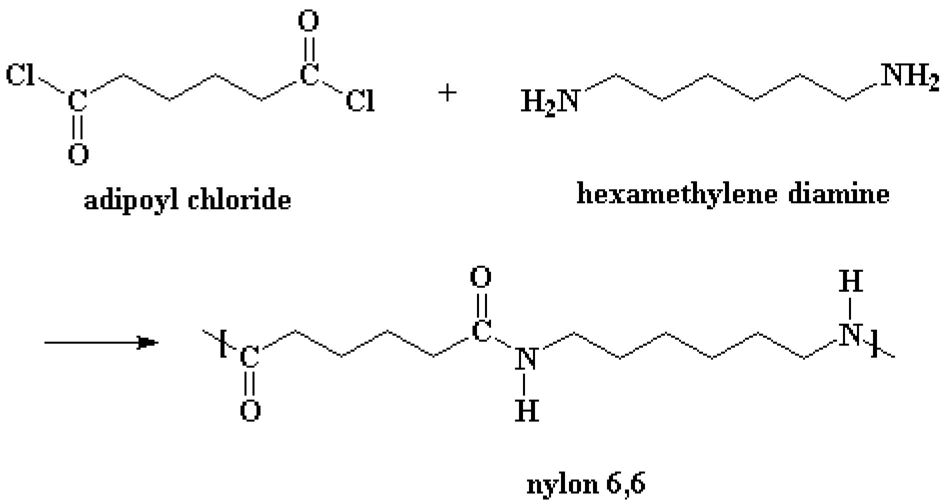
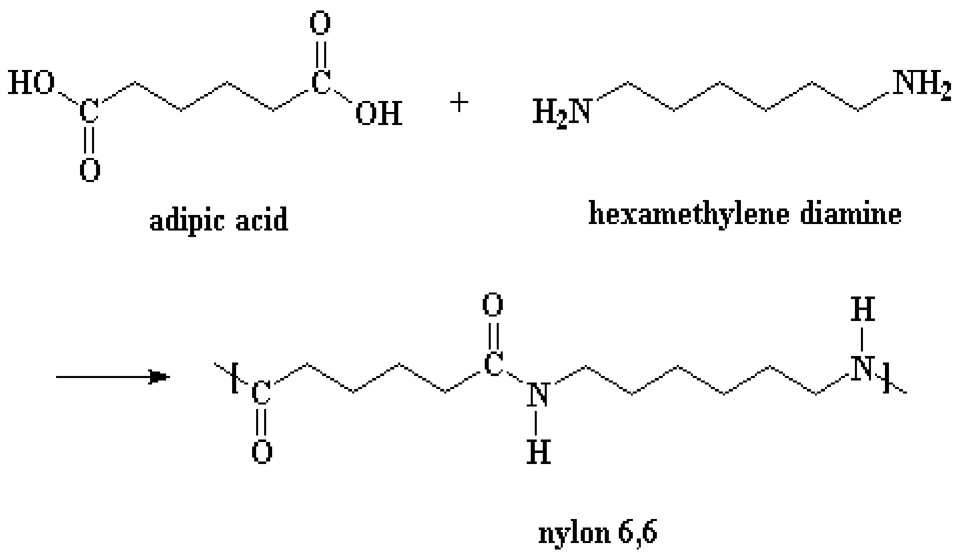


The nylon in the pictures on this page is called nylon 6,6, because each repeat unit of the polymer chain has two stretches of carbon atoms, each being six carbon atoms long. Other nylons can have different numbers of carbon atoms in these stretches.

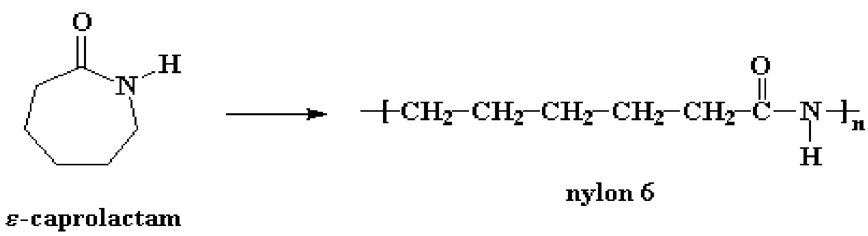
Nylons can be made from diacid chlorides and diamines. Nylon 6,6 is made from the monomers adipoyl chloride and hexamethylene diamine.



This is one way of making nylon 6,6 in the laboratory. But in a nylon plant, it's usually made by reacting adipic acid with hexamethylene diamine:



Another kind of nylon is nylon 6. It's a lot like nylon 6,6 except that it only has one kind of carbon chain, which is six atoms long.



It's made by a ring opening polymerization form the monomer caprolactam. Nylon 6 doesn't behave much differently from nylon 6,6. The only reason both are made is because DuPont patented nylon 6,6, so other companies had to invent nylon 6 in order to get in on the nylon business.

5. References

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