2.1 Introducing Polymers

For thousands of years, people have prized silk fabric for its luxurious qualities. Silk is made of fibres produced by silkworms (**Figure 1**). For many centuries, the Chinese royal family kept secret the process of producing silk. During that time, silk was the foundation of the Chinese export economy, bringing great wealth from Asia and Europe.

Each silkworm (which is actually a caterpillar) produces a cocoon made of a single fibre hundreds of metres long. A silk fibre is thinner than a human hair, but much stronger and lighter in weight than a similar-sized steel wire. The silk workers get hold of a fibre from each of several cocoons and reel these fibres together to make a thread. This thread can then be woven into fabric or used for sewing or embroidery. Silk fabric is desirable because of its unique combination of properties, such as strength, light weight, soft texture, shiny appearance, and flexibility or "drape." Among other uses, silk's applications include packaging, medical devices, parachutes, and clothing. Silk fibres are examples of a remarkable group of compounds—polymers.

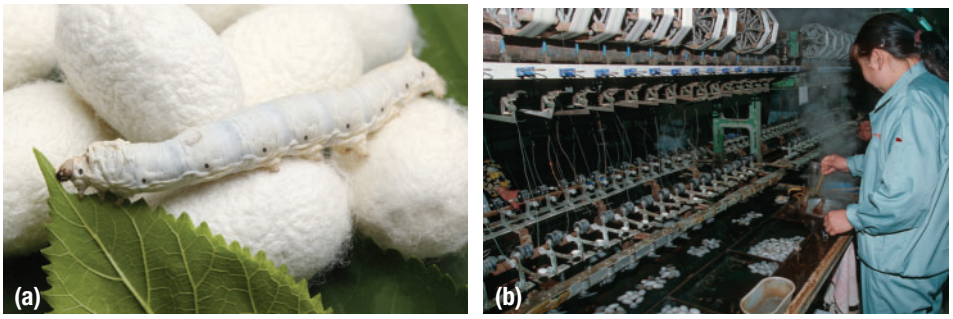


Figure 1 (a) Silk is a natural fibre produced when caterpillars of *Bombyx mori* moths make their cocoons. (b) Many countries now produce silk, harvesting the silk fibres from the cocoons.

The General Structure of Polymers

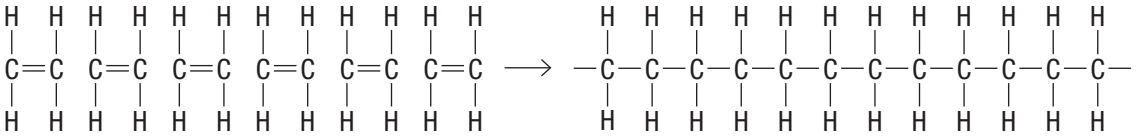
polymer a large, usually chain-like molecule that is built from small molecules

monomer one of the repeating small molecules that make up polymers

A **polymer** is a very large molecule that is built from monomers. A **monomer** is one of the repeating units that make up a polymer. Many biological molecules, such as silk, are natural polymers that are built inside living organisms. In the last couple of centuries, humans began manufacturing synthetic polymers for a wide range of applications, including textile fibres, rubber, and plastics. The polymer industry is now critically important to our economy and standard of living.

homopolymer a polymer of a single type of monomer

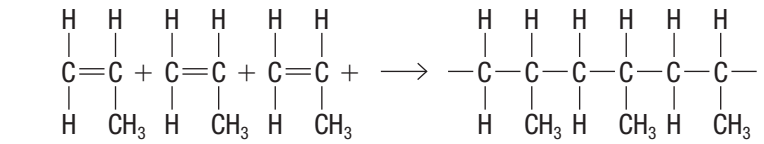
Figure 2 illustrates one of the simplest reactions to form a synthetic polymer. In this addition reaction, the double bond in each monomer is converted into a single bond, freeing up two electrons that form carbon-carbon single bonds with other monomers. Polyethene (more commonly known as polyethylene) is an example of a **homopolymer**: a polymer formed by reactions involving a single type of monomer.



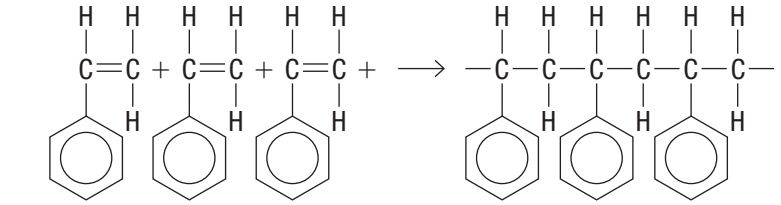
ethene monomers — polyethene (polyethylene) polymer

Figure 2 Polymerization of ethene molecules produces polyethene (polyethylene).

Substituents on the chain of carbon atoms give the polymer different properties. Other polymers that form by addition reactions include polypropene (polypropylene) and polystyrene (**Figure 3**).



(a) propene monomers → polypropene (polypropylene)



(b) styrene monomers → polystyrene

Figure 3 Homopolymers formed by addition reactions: (a) polypropene from propene monomers and (b) polystyrene from styrene monomers

Other polymers are chains of two or more types of monomers. A **copolymer** has different types of monomers combined to form the polymer chain. They may join in an addition reaction or in a condensation reaction, in which a molecule of water is eliminated as each new bond forms. **Figure 4** shows the chemical equation for the condensation reaction of three different amino acids to form part of a silk polymer. (Amino acids are the monomers in silk.) This reaction happens millions of times in the formation of a strand of silk.

copolymer a polymer made of two or more different types of monomers combined

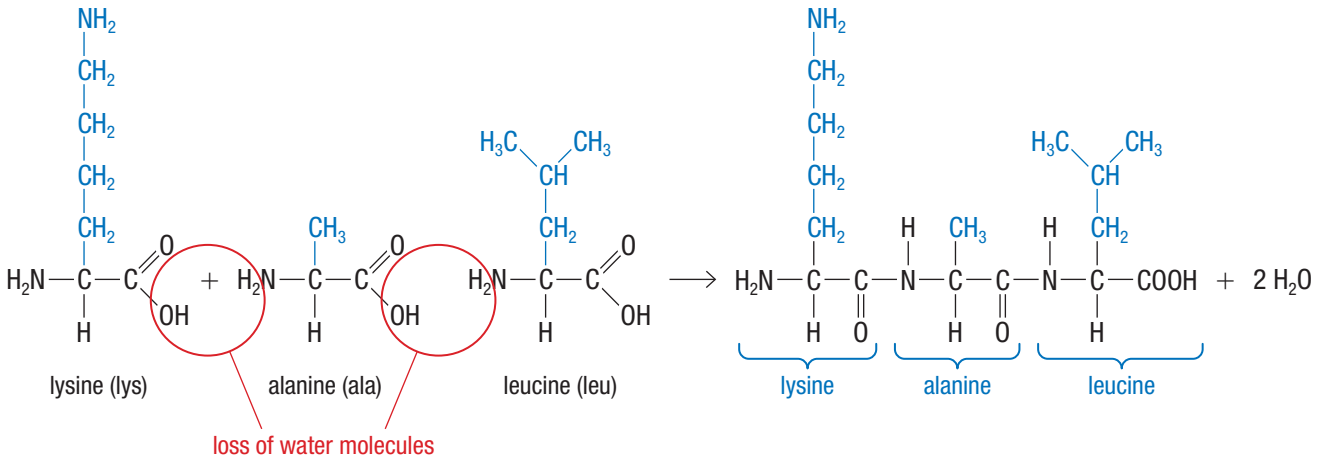


Figure 4 Silk is a protein: a natural polymer. Amino acids are the monomers of proteins. They join into chains in a condensation reaction. A molecule of water is released when two amino acids connect.

Natural and Synthetic Polymers

Natural polymers are made by all living things, from bacteria to mammals. Those manufactured in the cells of plants include starch and cellulose, which are homopolymers of the monomer glucose. Other natural polymers include the molecules RNA and DNA (**Figure 5**) that are produced within cell nuclei. You will learn more about natural polymers in Section 2.6.

Scientists developing new synthetic polymers often look to natural polymers, such as silk, for desirable properties. Synthetic polymers are usually made from monomers sourced from plants or from petrochemicals. Examples of synthetic polymers include polyester and polyamide fabrics, containers made of polyethene or polypropene (Figures 2 and 3), fluoropolymers used as non-stick coatings on cookware, the rubber of automobile tires, and the super-strong Kevlar fibres used in body armour.

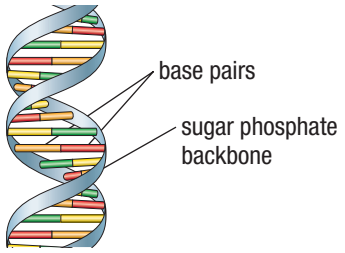


Figure 5 DNA is a polymer. The monomers, called nucleotides, are each made up of a base, phosphate, and a sugar. There are billions of unique strands of DNA.

A Short History of Synthetic Polymers

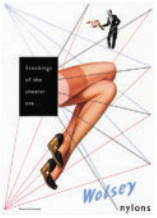
The first commonly used polymers were naturally occurring materials, such as bitumen, amber, waxes, rubber, and animal horns. These products were moulded or shaped with tools to create objects, or used as coatings. Then, chemists began to modify natural polymers to make products with different properties. WEB LINK

Sometimes polymers with useful properties are created by accident. In 1968, organic chemist Spencer Silver created an adhesive that did not appear to have a useful function because it did not stick very well. In 1974, another scientist, Arthur Fry, suggested using the adhesive to make small, sticky pieces of notepaper that could be easily removed. The adhesive was applied to paper squares and the squares were pressed onto other surfaces. The adhesive was sticky enough that the squares stayed in place, but not so sticky that they could not be easily removed.

1839: Vulcanized rubber was developed by American Charles Goodyear to make natural rubber stronger. Natural rubber is a polymer produced from the liquid sap of rubber trees. Natural rubber tends to be brittle when cold and soft when warm. Heating natural rubber with sulfur—vulcanizing—made the product harder and raised its melting point. Vulcanized rubber was used for battery boxes, pumps, dental plates, fountain pens, and, eventually, automobile tires.

1909: Bakelite, invented by Leo Hendrik Baekeland, was the first fully synthetic polymer. It was widely used to replace wood, ivory, and ebony (thereby reducing the pressure on some endangered species). A lightweight plastic, it was non-conductive, heat and moisture resistant, chemically unreactive, and could be coloured. It revolutionized the design of consumer and industrial products. Many things made of Bakelite, such as jewellery, dishes, telephones, and toys, are collectables today.

1929: Vinyl (PVC), invented by Waldo Semon, came to be used worldwide in products such as flooring, shower curtains, and plumbing pipes. It was the first durable material that was used to record and play back music.



1935: Nylon, invented by Wallace Carothers to replace silk in parachutes and stockings, became widely used in many consumer goods.

1830 1840 1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

1868: Celluloid was invented to replace ivory in billiard balls. In the form of celluloid film, this polymer played a central role in the development of the movie industry

1910: Formica was invented for use as an electrical insulator. The polymer was modified during the 1930s to make it more durable. Formica is widely used as a laminate on household surfaces, such as kitchen or bathroom counters.

1933: Saran was invented by Ralph Whiley. It was originally used as a coating: sprayed onto fighter planes to protect the surfaces against corrosion from sea salt. It was eventually approved for use in food packaging.

1997/1998: The existence of the Great Pacific Garbage Patch was predicted and confirmed. In an attempt to reduce the quantity of discarded plastics, polymer chemists worked to develop better biodegradable plastics.

As the chemistry of polymerization was better understood, scientists were able to design many more synthetic polymers with specific, desired properties. Some more familiar trade names of some of these polymers are Lycra, Dacron, Styrofoam, and Kevlar. Developments of these and other polymers have had a significant impact on the environment and society. CAREER LINK

The development and use of so many polymer products have brought drawbacks, however. There are concerns regarding the breakdown of some polymers during use, releasing potentially carcinogenic compounds. Some people are particularly worried about this possibility in products used to transport, store, or cook food, such as plastic water bottles and non-stick cookware surfaces. There is also the issue of disposing of the vast volumes of synthetic products at the end of their useful lives. Unlike materials such as wood, paper, cotton, and leather, synthetic compounds do not break down quickly. They can remain unchanged for decades or centuries.

2.1 Review

Summary

- Polymers are very large molecules—natural or synthetic—made up of many monomers linked together.
- Monomers are small molecules with functional groups that allow them to link together to form polymers.
- Homopolymers are polymers made of only a single type of monomer. Copolymers are polymers made of two or more types of monomers.
- Polymers may form in addition reactions or condensation reactions.
- Synthetic polymers bring both benefits and drawbacks.

Questions

1. Classify each of the following substances as a natural or a synthetic polymer. Explain. K/U
   (a) DNA
   (b) polyethene
   (c) celluloid
   (d) cellulose
   (e) protein
   (f) rubber
   (g) Kevlar
   (h) bitumen
2. Explain the difference between the terms in each pair. K/U
   (a) monomers and polymers
   (b) homopolymers and copolymers
3. What do the three different monomers shown in Figures 2, 3, and 4 have in common? Explain how this feature allows them to form polymers. K/U T/I
4. **Figure 6** shows the structure of a polymer called cellulose. Draw a diagram of the monomer that makes up this polymer. K/U C

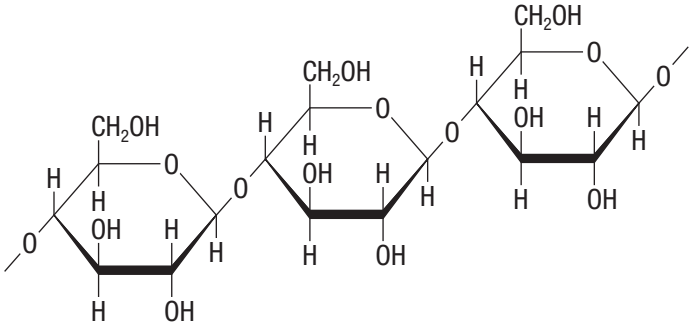


Figure 6 Cellulose

5. Use a graphic organizer to describe the similarities and the differences between natural and synthetic polymers. Include an example of each. K/U C
6. Suggest properties that might make polymers useful additions to paint, auto, or wood finishes. A
7. The rubber tree produces a resin, called latex, that is the raw material for making natural rubber. Research the developments that led to the process of making synthetic rubber and the social and environmental circumstances that occurred around the time this process was invented. Communicate your findings in a format of your choice. T/I C A
8. Research the Great Pacific Garbage Patch. What is it? Why is it so hard to track and map? What impact does it have on the marine ecosystem? What is being done to clean it up? Present your findings in an illustrated report for inclusion in an environmental magazine or on a web page. T/I C A
9. The monomer 2,2-bis(4-hydroxyphenol)propane, better known as BPA, is used in the production of hard plastics. In recent years there has been some concern that it could leach out of plastics and have negative health effects. According to Health Canada, "the current dietary exposure to BPA through food packaging uses is not expected to pose a health risk to the general population, including newborns and infants." Research the pros and cons of BPA, summarizing your research in a table or similar graphic organizer. T/I C A
10. Research two types of plastic, other than those illustrated in the timeline, and prepare a short illustrated history for each one. T/I C A

WEB LINK