Synthesis of Macromolecules

Reflect

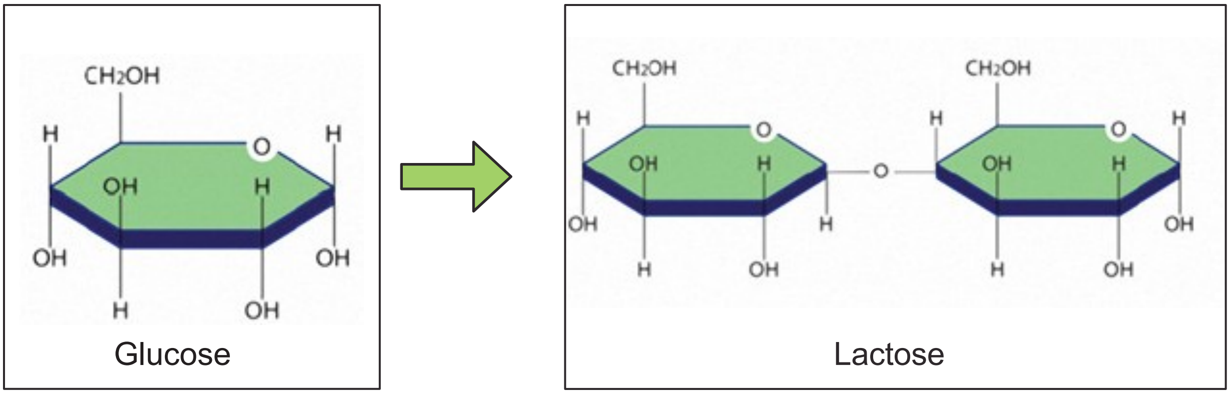
A child's building blocks are relatively simple structures. When they come together, however, they can form magnificent structures. The elaborate city scene on the right is made of small, simple building blocks.

Organisms are built in much the same way. Despite their complexity, organisms are made of relatively simple building blocks. How are these building blocks assembled into complex organisms? What role does each main type of molecule play?

Types of Macromolecules

Macromolecules are molecules that are made by organisms and are essential for performing life functions. They range in size and perform specific functions in and among cells. Their function is often determined by their structure. If the structure is disrupted, the macromolecule can no longer function properly.

Macromolecules are made of building-block monomers. A **monomer** is a small molecule that can be combined chemically with other monomers to form larger molecules. Monomers are made up of relatively simple elements. The most abundant elements in biological monomers are carbon, hydrogen, and oxygen. A **polymer** is a group of monomers linked to form a much larger molecule. The prefix **mono**- means "one," and **poly**- means "many." Think of monomers as the building blocks and polymers as the final product. The process of making a polymer is called **polymerization.**



Glucose

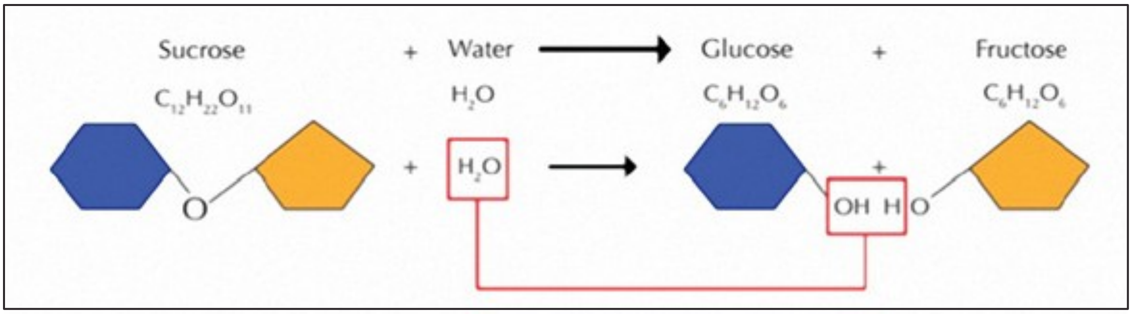
Lactose

The linking of monosaccharide monomers to form lactose
is an example of polymerization.

Synthesis of Macromolecules

Reflect

When a macromolecule is built, monomers link together via strong covalent bonds. Each time two monomers are linked, a water molecule is released. This process is called *dehydration* **synthesis**. When a water molecule is added to a polymer, it breaks apart the polymer during a process called **hydrolysis**.



Sucrose is made of the monomers, glucose and fructose.
Water breaks apart sucrose into these two monomers
through a hydrolysis reaction.

There are four main types of large macromolecules (also called biomolecules): carbohydrates, lipids, proteins, and nucleic acids. As shown in the chart below, they are composed of different types of monomers that link together to form polymers.* These elements combine and recombine many times into different compounds. All of these same elements, when combined in different ways, will form different products.

Type of Macromolecule	Monomer	Polymer or Linked-Monomer Compound
Carbohydrate	Monosaccharide	Polysaccharide
Lipid	Fatty acid	Diglyceride, triglyceride, phospholipid*
Protein	Amino acid	Polypeptide, protein
Nucleic acid	Nucleotide	DNA, RNA

*Lipids are not composed of true polymers because they are smaller, and the monomers do not repeat.

Carbohydrates

Carbohydrates are made of carbon, oxygen, and hydrogen. Carbohydrates usually have a hydrogen:oxygen ratio of 2:1. This, combined with the presence of carbon in the molecule, gives carbohydrates their name.

Another name for a carbohydrate macromolecule is **saccharide**. Carbohydrate monomers are called monosaccharides. Monosaccharides (sugars) include glucose, fructose, and galactose.

Pasta is made of carbohydrates.

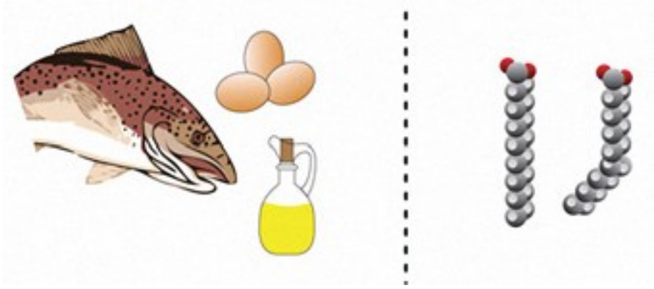
Reflect

Polysaccharides are polymers of monosaccharides linked together by dehydration synthesis reactions. Carbohydrate polysaccharides can be made from the same type of monomers or from different monosaccharides linked together. Look at the example of sucrose in the diagram on the previous page. Sucrose is a polysaccharide, made up of two different monosaccharides, glucose and fructose.

Carbohydrates are important energy storage molecules in cells. In the human diet, carbohydrates are found in flour, sugar, pasta, potatoes, and other “starchy” foods. Carbohydrates also play a number of important structural and signaling roles in all living cells. They form part of the molecular backbone of nucleic acids, and they are critical for maintaining life. Animals store sugars such as **glycogen**, which are made of glucose molecules linked together. Plants store sugars as **starch**.

Lipids

Lipids are a diverse group of hydrophobic macromolecules. Fats, a common type of lipid, are combinations of fatty acids and glycerol. Fatty acids are long chains of carbon and hydrogen linked together into a **hydrocarbon chain**. Some chains are straight, while others bend wherever there is an **unsaturated** carbon in the hydrocarbon chain (carbon is not saturated with hydrogen). A double bond will form between two adjacent unsaturated carbons. The carbons on either side of the double bond have one fewer hydrogen than other carbons in the chain. The term **unsaturated** is used to describe this type of fatty acid. Fatty acids are used to store energy. These monomers are linked together with glycerol to form diglycerides (two monomers) or triglycerides (three monomers).



Fatty acids are the building blocks of fats. Fats are found in many dietary sources, including fish, eggs, and oil.

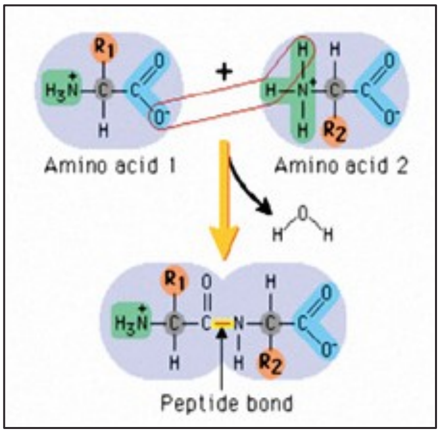
unsaturated: having at least one double or triple bond between carbon atoms

Lipids are the main structural component of the cell membranes of all organisms. Similar to carbohydrates, lipids are used for long-term energy storage. They are nonpolar, which makes them **hydrophobic**, or water-repellent. They do not dissolve in water. Plant lipids are usually liquids, such as olive oil, while animal lipids are usually solids, like the fat in beef.

Reflect

Proteins

Amino acids are the building blocks of proteins. There are hundreds of types of amino acids but just 20 of these make up our proteins. Each amino acid has a common core of a central carbon, an **amine** group containing nitrogen, a **carboxyl** group made of carbon and oxygen, and a side chain (labeled R on amino acid diagrams). The side chain is different for each of the 20 amino acids. Some side chains are hydrophobic, while others are **hydrophilic**, or water-soluble. Some side chains are charged, while others are neutral. The different properties of the side chains give each amino acid different properties.



Amino acids are linked together by strong peptide bonds.

Amino acids are linked together by covalent bonds called **peptide bonds**. This type of bond only forms between amino acids. The reaction to form a peptide bond is a dehydration synthesis reaction. One hydrogen atom and one hydroxyl group (–OH) are removed from the amino acids to form one water molecule for each peptide bond that is formed.

Amino acids are linked together to form a **polypeptide** chain. Inside the cell, an organelle called the **ribosome** is responsible for linking together amino acids to form the polypeptide chain. When a chain contains more than about 50 amino acids arranged in a biologically functional way, it is called a **protein**.

amine: a functional group with the general formula R—NH2

carboxyl: a functional group with the general formula R—COOH

Proteins are essential macromolecules in all cells. They give a cell its structure, communicate information, synthesize molecules, transport molecules, and make up **enzymes**, which are molecules that speed up the chemical reactions necessary for life.

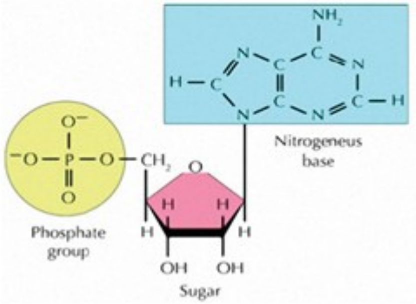
What Do You Think?

Some weight-loss diets focus on eliminating specific foods from the diet such as fats or carbohydrates. While these diets can be effective for weight loss, they deprive the body of essential macromolecules that support life. Do you think this type of dieting is healthy? Why or why not?

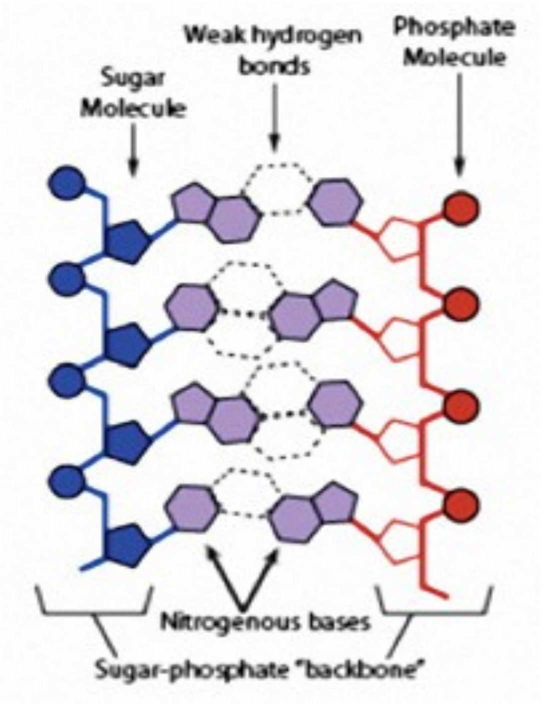
What Do You Think?

Nucleic Acids

Nucleotides are small molecules made of a sugar (monosaccharide), one or more phosphate groups, and a nitrogenous base. The nucleotides ATP (adenosine triphosphate) and GTP (guanosine triphosphate) are important for energy transport within cells. The nitrogenous base of ATP is adenosine, and the phosphate group is a triphosphate (three phosphates linked together). GTP is similar to ATP, with guanosine replacing adenosine as the nitrogenous base. Other nucleotides are enzyme cofactors and signaling molecules.



Nucleic acids have three shared components: a phosphate group, a sugar, and a nitrogenous base.



Nucleotides are the building blocks of nucleic acids ,including DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). DNA includes four nucleotides—guanine, adenine, thymine, and cytosine. In RNA, uracil replaces thymine as a nucleotide. DNA and RNA are essential for storing and utilizing genetic information. DNA and RNA work together to create proteins. As you can see in the diagram on the left, alternating bonds between sugar and phosphate molecules of adjacent nucleotides link the nucleotides that make up DNA. This forms the sugar-phosphate backbone of a strand of DNA. Two DNA strands typically join together via weak hydrogen bonds between nitrogenous bases. The DNA strands twist around further to form the familiar double-helix configuration. In contrast, RNA is typically single stranded and does not form a double helix.

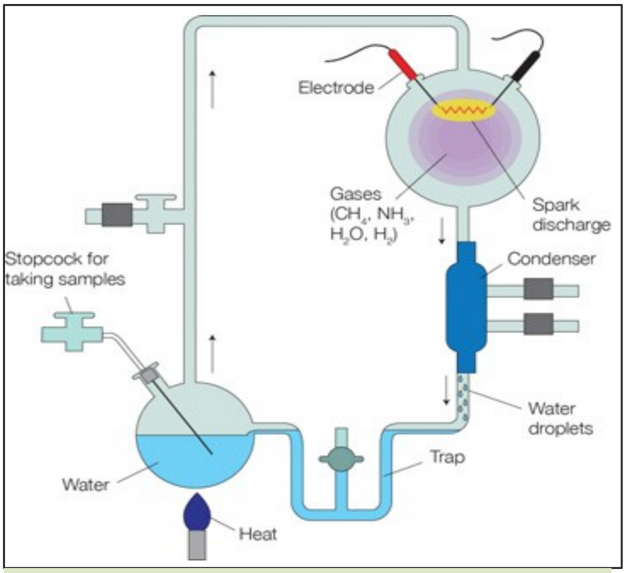
How does DNA encode protein? The arrangement of nucleotides in DNA stores the code by which amino acids should be brought together in the protein. RNA helps by transferring amino acids to ribosomes for protein creation and by helping to build new proteins.

Look Out!

Be careful not to confuse the function of DNA with its structure. A DNA molecule provides information about which amino acids are needed to produce certain proteins. Amino acids are not, however, part of a DNA molecule.

Look Out!

Formation of Macromolecules Scientists have several hypotheses about the origin of macromolecules.
They have focused on figuring out how macromolecules that self-replicate could have come into existence in the primordial soup of the early Earth. Scientists have performed experiments that support each of these hypotheses. It is difficult to know which hypothesis is correct, given the limited amount of available information from the early Earth. The true answer could be a combination of the existing hypotheses. It could also be a completely different alternative that is yet to be discovered.



Combining ammonia, water, and energy creates organic molecules in the lab. This observation led to the Oparin-Haldane hypothesis.

The Oparin-Haldane hypothesis was proposed in the 1920s. According to this hypothesis, the atmosphere of the early Earth was rich in methane, ammonia, and water. When water and ammonia combine in the presence of an energy source (such as lightning or ultraviolet light from the Sun), inorganic molecules react to form organic molecules such as amino acids.

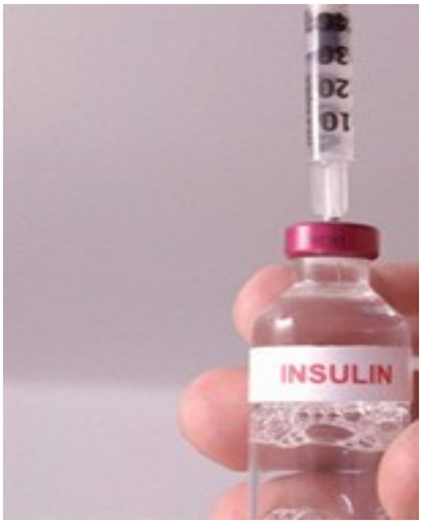
A competing theory is the RNA-world hypothesis. This hypothesis states that RNA developed first. It may have self-replicated and also served as a template for making DNA. Today, RNA serves as the intermediate between DNA and proteins. If this hypothesis is true, DNA took over the role of RNA as the hereditary molecule at some point.

A third competing hypothesis is the iron-sulfur world hypothesis proposed in the late 1980s. In this theory, macromolecules first formed around deep-sea thermal vents. These vents are openings in the ocean floor that emit mineral-rich water that has been superheated by magma. These areas are rich in iron sulfide minerals that can act as catalysts for chemical reactions, especially in the presence of heat. Scientists believe these conditions may have favored the formation of macromolecules.

Look Out!

Getting Technical: Synthetic Macromolecules

Organisms usually make macromolecules. However, macromolecules can also be made synthetically in the lab. Biopharmaceutical companies specialize in creating synthetic macromolecules to treat diseases. For example, in 1922, doctors discovered that injections of the polypeptide insulin could treat diabetes.



Insulin was harvested from animals, mainly pigs, to be given to humans. In the late 1970s, scientists figured out how to insert the human insulin gene into bacteria, creating bacterial “factories” for producing human insulin. The ability to use a nonanimal source for human insulin was a major step forward in treating diabetes.

Try Now

What Do You Know?

The box below lists some of the characteristics of the four main types of large macromolecules.

- Made of nucleotides
- Make up oils and fats
- Made of amino acids
- Store and utilize genetic information
- Main structural component of cell membranes
- Made of monosaccharides
- Make up enzymes
- Main component of bread and pasta
- Made of fatty acids linked with glycerol
- Stored in plants as starch

The table on the next page lists the four main types of large macromolecules. Match each characteristic in the box to the correct macromolecule in the table. Write your answers in the right column of the table.

Try Now

Macromolecule	Characteristics
Carbohydrate	
Lipid	
Protein	
Nucleic acids	

Connecting With Your Child

Identifying Macromolecules in Foods

Macromolecules are the building blocks of life. Not surprisingly, macromolecules are found in foods that humans consume on a daily basis. Carbohydrates, fats (lipids), and proteins are listed on food labels to educate consumers about nutritional content. While nucleic acids are often not listed on labels, most relatively unprocessed foods derived from organisms contain nucleic acids.

Food scientists perform numerous tests to determine the macromolecules contained in food. One of the simpler tests can be performed at home. Be sure to wear gloves and safety glasses when handling iodine, and line the experiment area with newspaper to prevent staining.

To perform this simple experiment to identify starch in foods, gather these materials:

- a small bottle of iodine
- a small cube from a potato, mashed
- a tablespoon of butter
- a tablespoon of olive or other vegetable- based oil
- a tablespoon of applesauce
- a tablespoon of water
- five small, clear, plastic cups

Place the test items (potato, butter, oil, applesauce, and water) into individual cups. Add one or two drops of iodine to each cup, and carefully swirl to mix. If starch is present, the food will turn blue-black.

If no starch is present, the mixture will remain brown. The potato and applesauce should be positive (blue-black), while the butter, oil, and water should be negative (brown). As you progress through the experiment, ask the following questions: Why did the iodine not change color when added to water, butter, and oil? (*No starch was present*.) Why did the applesauce turn blue-black in the iodine experiment? (*Starch was present*.) What other foods would you expect to contain starch? (*Possible correct answers: rice, banana, cashews, oats.*)

Here are some other questions to discuss with your child:

- What are the general structures of the four macromolecules?
- How are proteins and DNA related?
- What are some ideas about how the original macromolecules formed?