# All life is made of molecules, which are made of atoms



Every living organism is, at a fundamental level, a chemical system. Interactions among basic chemical ingredients drive all of life's processes. Viewed this way, you are just a big watery bag of chemicals undergoing countless reactions. Therefore, knowledge of basic **chemistry**, the scientific study of matter, is necessary to understand many important biological concepts.

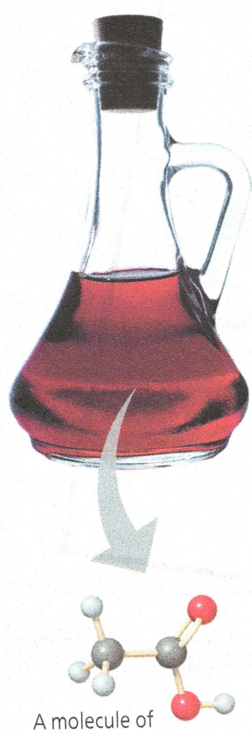
## MATTER, ATOMS, AND MOLECULES

Every object in the universe—all the "stuff" around you—is composed of **matter**, defined as anything that occupies space and has mass (substance). All matter consists of **atoms**, the smallest units that retain all of the properties of their type of matter. In nature, atoms are not often found in isolation. Instead, atoms are usually bonded to each other to form **molecules**. On Earth, matter can be in the form of a gas, liquid, or solid, referred to as the three phases of matter. An example of each phase can be seen in these three familiar molecules.

GAS
Propane gas is used in backyard grills.

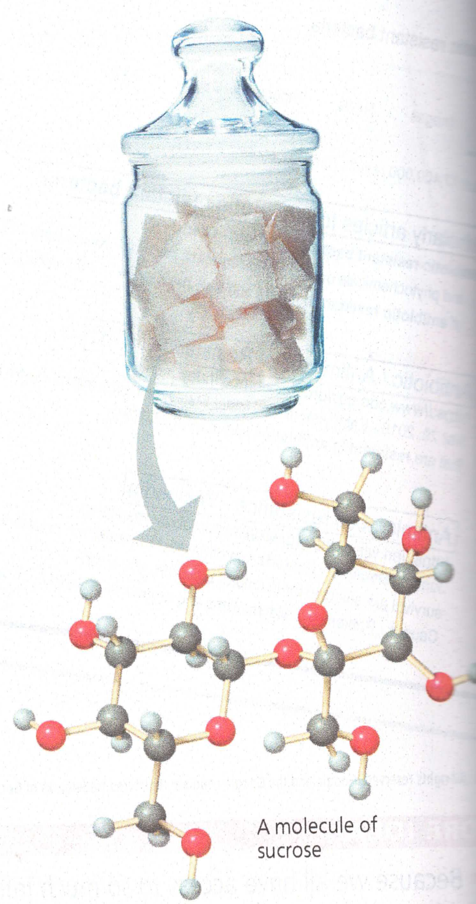
A molecule of propane gas

LIQUID
Acetic acid gives vinegar its sharp taste.



A molecule of acetic acid

SOLID
Common table sugar is made up of sucrose.



A molecule of sucrose

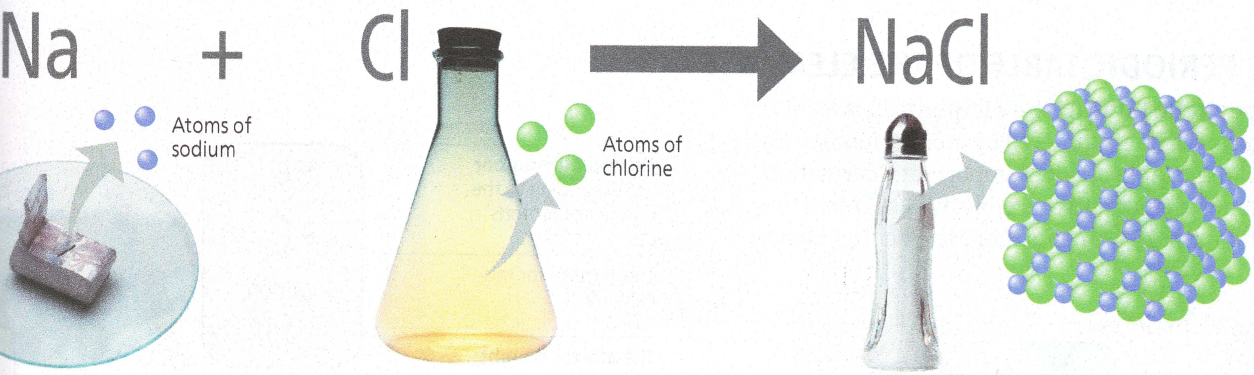
KEY
Carbon
Hydrogen
Oxygen

## LEMENTS AND COMPOUNDS

l matter is composed of individual **elements**, substances that cannot be broken down
to other substances by chemical reactions. The Periodic Table of the Elements is a
t of all known elements. Familiar examples include hydrogen, carbon, uranium, and
ld. Although elements are occasionally found by themselves—neon gas that lights up
ign, for example, is just a collection of neon atoms—they more often combine to form
**mpounds**, substances with two or more elements in a fixed ratio.

! A deadly gas (chlorine) and an explosive solid (sodium) combine to form a tasty ingredient: sodium chloride, or table salt.

DIUM CHLORIDE



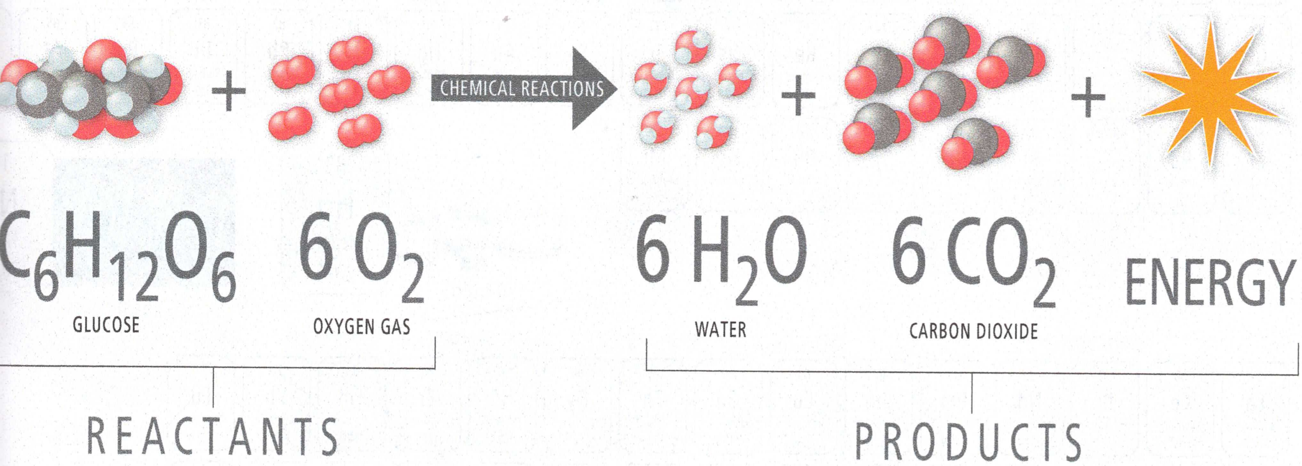

ement: sodium, metal

Element: chlorine, a gas

Compound: sodium chloride (table salt)

## HEMICAL REACTIONS

e composition of living matter is constantly changing through **chemical reactions**. During
hemical reaction, atoms remain whole, but they are swapped as molecules are broken down
d built up. Chemical reactions are written with the **reactants** (starting matter) on the left and
e **products** (ending matter) on the right. The arrow between the reactants and the products
presents one or more chemical reactions. Notice that chemical reactions rearrange atoms, but
oms are never created nor destroyed. (Add up and compare the number of each type of atom
the reactants versus the products to verify this yourself.) This particular series of chemical
actions, called cellular respiration, uses oxygen gas and a sugar called glucose to provide
ergy to your living cells, releasing water and carbon dioxide as by-products.




**RE IDEA**

All matter consists of atoms, which are often bonded together into
lecules. Individual elements combine in a fixed ratio to form compounds.
actants are transformed into products through chemical reactions.

**?** Two molecules of glucose ($C_6H_{12}O_6$) can combine to produce one molecule of water and one of maltose. Remembering that no atoms are created or destroyed, write this reaction.

ANSWER: $C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow H_2O + C_{12}H_{22}O_{11}$.

# All matter consists of chemical elements

All living organisms are composed of matter, and all matter is composed of **elements**, substances that cannot be broken down into other substances by chemical reactions. There are 92 naturally occurring elements on Earth, and several others have been artificially created in the laboratory. Here, you will see examples of familiar elements and learn their importance in living systems.

## THE PERIODIC TABLE OF THE ELEMENTS

The **periodic table of the elements** lists all of the chemical elements, ordered by atomic number. Each entry in the table provides important information about one element. In this table, we use colors to highlight the 25 elements that are essential to life.

The **atomic number**, corresponding to the number of protons — 6

The **symbol** for this element — C

Carbon

The **atomic weight**, corresponding to the number of protons plus neutrons. The decimal results from the fact that the atomic weight is an average of all naturally occurring forms of the element, which may vary in the number of neutrons. — 12.01

Graphite, pure carbon

20 Ca Calcium 40.08

(solid)

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H Hydrogen 1.008 | | | | | | | | | | | | | | | | | 2 He Helium 4.003 |
| 3 Li Lithium 6.941 | 4 Be Beryllium 9.012 | | | | | | | | | | | 5 B Boron 10.81 | 6 C Carbon 12.01 | 7 N Nitrogen 14.01 | 8 O Oxygen 16.00 | 9 F Fluorine 19.00 | 10 Ne Neon 20.18 |
| 11 Na Sodium 22.99 | 12 Mg Magnesium 24.31 | | | | | | | | | | | 13 Al Aluminum 26.98 | 14 Si Silicon 28.09 | 15 P Phosphorus 30.97 | 16 S Sulphur 32.07 | 17 Cl Chlorine 35.45 | 18 Ar Argon 39.95 |
| 19 K Potassium 39.10 | 20 Ca Calcium 40.08 | 21 Sc Scandium 44.96 | 22 Ti Titanium 47.97 | 23 V Vanadium 50.94 | 24 Cr Chromium 52.00 | 25 Mn Manganese 54.94 | 26 Fe Iron 55.85 | 27 Co Cobalt 58.93 | 28 Ni Nickel 58.69 | 29 Cu Copper 63.55 | 30 Zn Zinc 65.38 | 31 Ga Gallium 69.72 | 32 Ge Germanium 72.64 | 33 As Arsenic 74.92 | 34 Se Selenium 78.96 | 35 Br Bromine 79.90 | 36 Kr Krypton 83.80 |
| 37 Rb Rubidium 85.47 | 38 Sr Strontium 87.62 | 39 Y Yttrium 88.91 | 40 Zr Zirconium 91.22 | 41 Nb Niobium 92.91 | 42 Mo Molybdenum 95.96 | 43 Tc Technetium 98.00 | 44 Ru Ruthenium 101.1 | 45 Rh Rhodium 102.9 | 46 Pd Palladium 106.4 | 47 Ag Silver 107.9 | 48 Cd Cadmium 112.4 | 49 In Indium 114.8 | 50 Sn Tin 118.7 | 51 Sb Antimony 121.8 | 52 Te Tellurium 127.6 | 53 I Iodine 126.9 | 54 Xe Xenon 131.3 |
| 55 Cs Cesium 132.9 | 56 Ba Barium 137.3 | 57–71 | 72 Hf Hafnium 178.5 | 73 Ta Tantalum 180.9 | 74 W Tungsten 183.8 | 75 Re Rhenium 186.2 | 76 Os Osmium 190.2 | 77 Ir Iridium 192.2 | 78 Pt Platinum 195.1 | 79 Au Gold 197.0 | 80 Hg Mercury 200.6 | 81 Tl Thallium 204.4 | 82 Pb Lead 207.2 | 83 Bi Bismuth 209 | 84 Po Polonium 209 | 85 At Astatine 210 | 86 Rn Radon 222 |
| 87 Fr Francium 223 | 88 Ra Radium 226 | 89–103 | 104 Rf Rutherfordium 267 | 105 Db Dubnium 268 | 106 Sg Seaborgium 271 | 107 Bh Bohrium 272 | 108 Hs Hassium 277 | 109 Mt Meitnerium 276 | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 La Lanthanum 138.9 | 58 Ce Cerium 140.1 | 59 Pr Praseodymium 140.9 | 60 Nd Neodymium 144.2 | 61 Pm Promethium 145.0 | 62 Sm Samarium 150.4 | 63 Eu Europium 152.0 | 64 Gd Gadolinium 157.3 | 65 Tb Terbium 158.9 | 66 Dy Dysprosium 162.5 | 67 Ho Holmium 164.9 | 68 Er Erbium 167.3 | 69 Tm Thulium 168.9 | 70 Yb Ytterbium 173.1 | 71 Lu Lutetium 175.0 |
| 89 Ac Actinium 227 | 90 Th Thorium 232 | 91 Pa Protactinium 231 | 92 U Uranium 238 | 93 Np Neptunium 237 | 94 Pu Plutonium 244 | 95 Am Americium 243 | 96 Cm Curium 247 | 97 Bk Berkelium 247 | 98 Cf Californium 251 | 99 Es Einsteinium 252 | 100 Fm Fermium 257 | 101 Md Mendelevium 258 | 102 No Nobelium 259 | 103 Lr Lawrencium 262 |

80 Hg Mercury 200.6

(liquid)

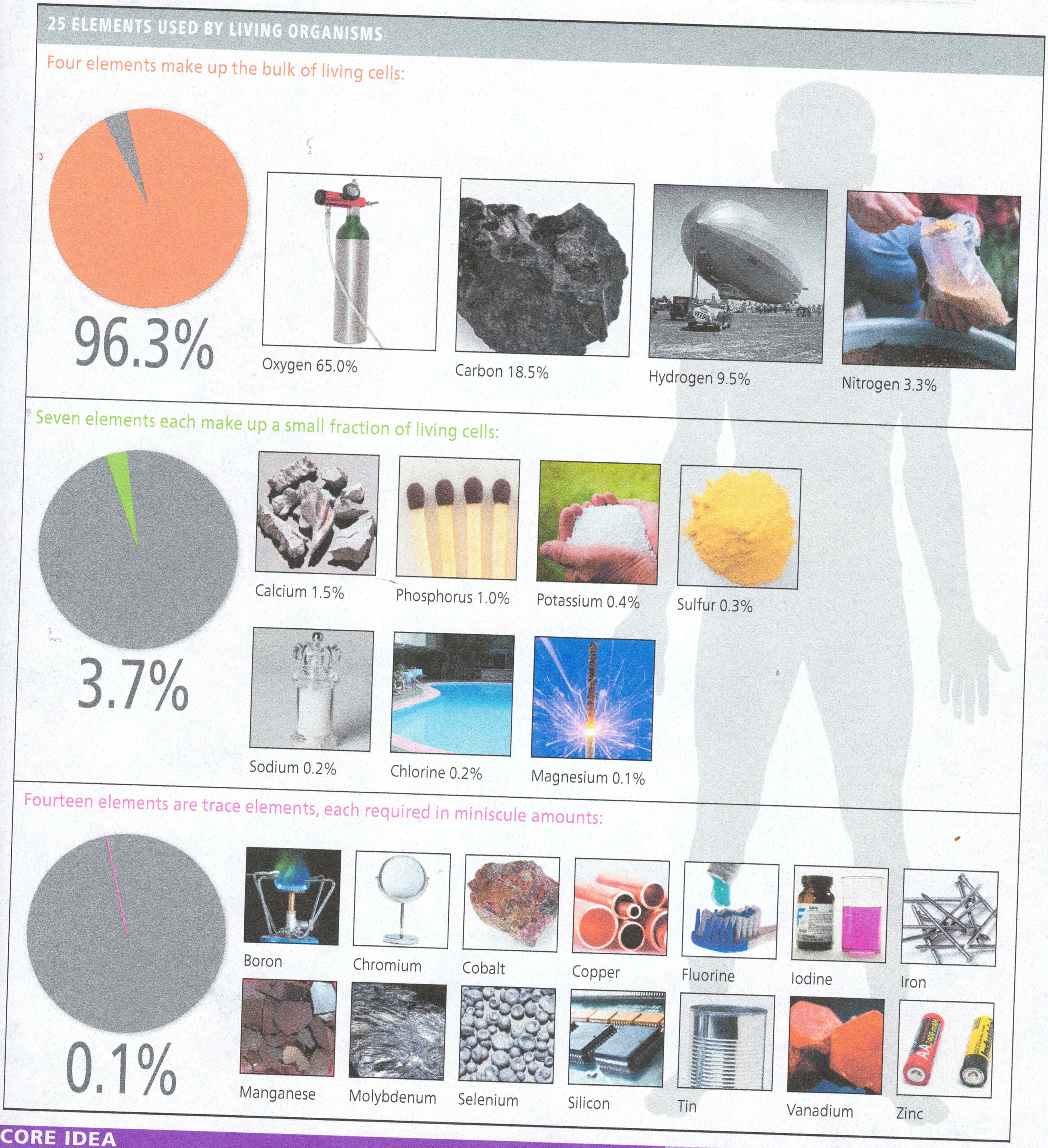

10 Ne Neon 20.18

(gas)

## ELEMENTS ESSENTIAL TO LIFE

Four of the 92 naturally occurring elements make up the vast majority of matter within living organisms. Another 7 elements account for much of the remaining mass. Finally, 14 **trace elements** are present in very tiny amounts, but cells cannot survive without them.

! Your body contains only 0.0002 ounces of molybdenum, but too little in your diet can cause neurological damage.




**CORE IDEA**

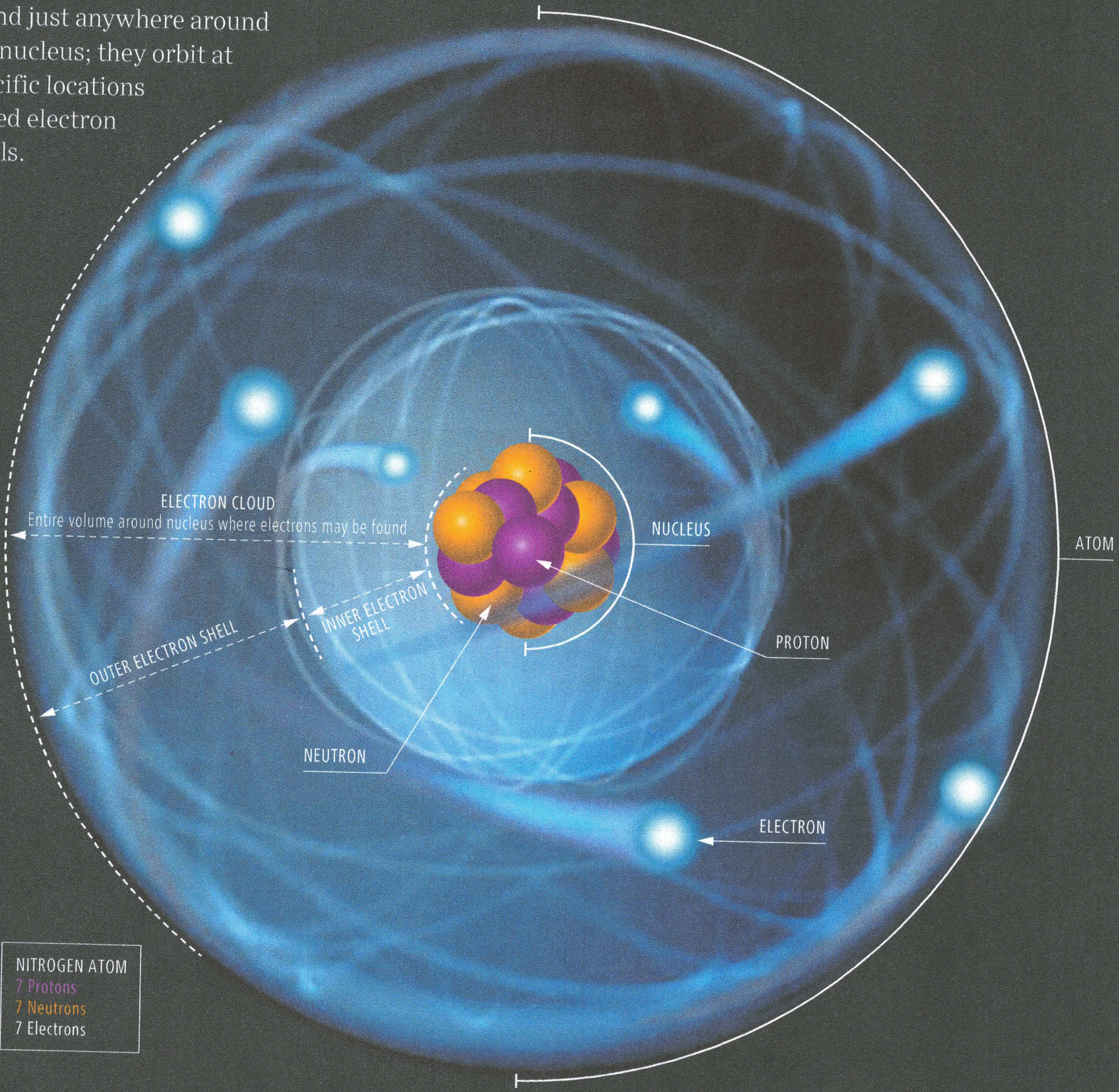
All matter is composed of elements, which are listed in the Periodic Table by atomic number. Of the 92 natural elements, only 25 are used by living cells. Of these, four make up the bulk of the cell, seven are required in small quantities, and 14 are required in only tiny amounts.

? Is a dietary supplement that contains gold beneficial to your body?

ANSWER: No. Gold is not one of the 25 elements used by living cells.

# 2.3 Atoms are composed of subatomic particles

All matter is composed of atoms. Atoms themselves are composed of even smaller **subatomic particles**. Two of these particles (**neutrons** and **protons**) have about equal mass and are located in the **nucleus** at the center of the atom. The number of protons in an atom determines the chemical element, differentiating one element from another. Particles of the third type (**electrons**) have very little mass and orbit the nucleus at high speeds. Electrons are not found just anywhere around the nucleus; they orbit at specific locations called electron shells.




## ATOM OF NITROGEN

This model shows the subatomic structure of an atom of nitrogen, with protons and neutrons in the central nucleus and individual fast-moving electrons forming an electron cloud around the nucleus. Electrons orbit the nucleus within specific regions called electron shells. Notice that this atom has two electrons in the inner shell and five electrons in an outer shell. The electrons in the outer shell may interact with the electrons of other atoms, determining how this atom will participate in chemical bonds.

**SUBATOMIC PARTICLES**

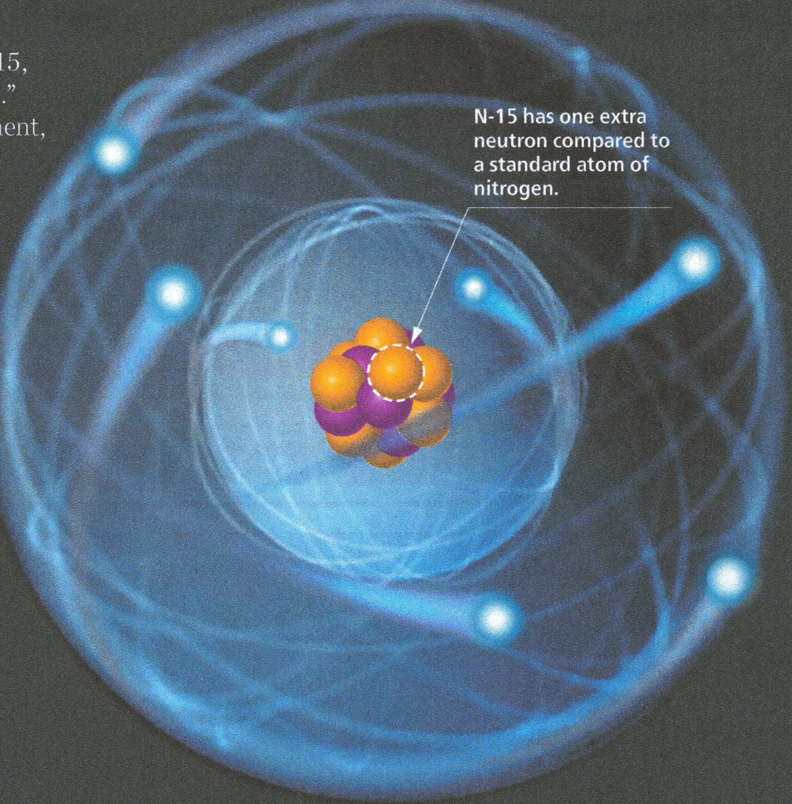
| *PARTICLE* | *MASS* | *CHARGE* |
|---|---|---|
| PROTON<br>*Protons determine element.* | 1 | +1 |
| NEUTRON<br>*Neutrons determine isotope.* | 1 | 0 |
| ELECTRON<br>*Electrons determine ion.* | 0 | –1 |

## NITROGEN-15 ISOTOPE

This model shows the subatomic structure of the most common isotope of nitrogen: nitrogen-15, which can alternately be written as "N-15" or "$^{15}N$." Because protons determine the identity of the element, all forms of nitrogen have 7 protons. **Isotopes** of the same element vary in the number of neutrons and are named according to atomic mass. For example, the "15" in the name "nitrogen-15" refers to its atomic mass: 7 protons plus 8 neutrons equals a mass of 15. In contrast, the isotope nitrogen-13 has 7 protons and 6 neutrons, for an atomic mass of 13.

! Some isotopes are radioactive but have beneficial uses—fluorine-18, for example, can be used to detect defects in the brain.

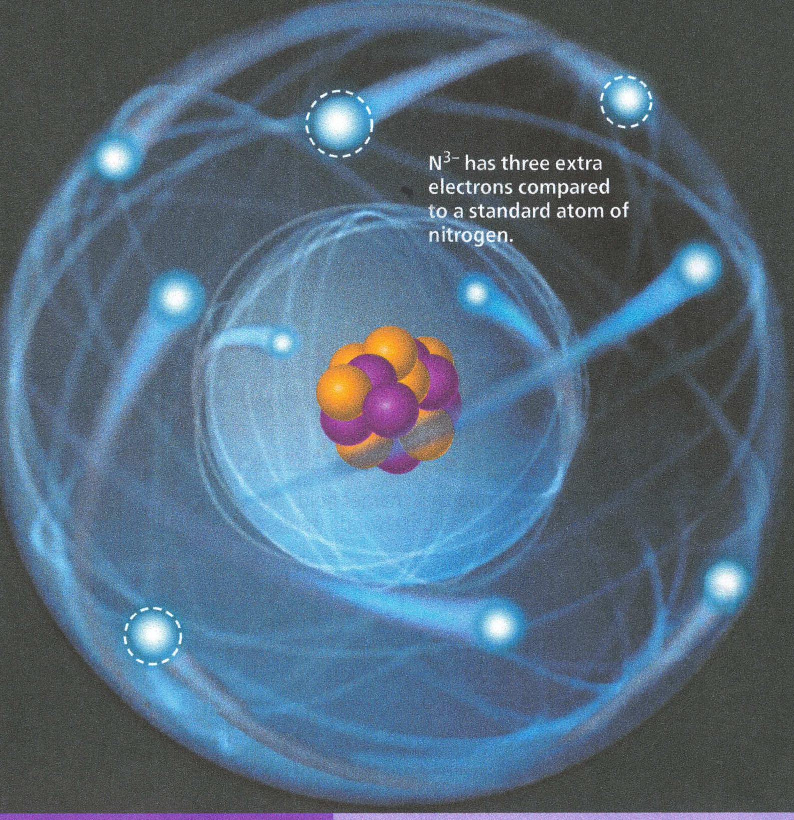
NITROGEN-15 ISOTOPE
7 Protons
8 Neutrons
7 Electrons




## NITROGEN ION

This model shows the subatomic structure of a common ion of nitrogen: $N^{3-}$. **Ions** vary in the number of electrons in the electron cloud. Atoms are neutrally charged (with the same number of protons as electrons), but ions carry a charge. The name of the ion indicates its total charge, with one extra negative charge for each extra electron, or one extra positive charge for each missing electron. For example, $N^{3-}$ carries three extra electrons.

NITROGEN ION
7 Protons
7 Neutrons
10 Electrons




**CORE IDEA**

All atoms are composed of protons, neutrons, and electrons. The number of protons determines the element; the number of neutrons determines the isotope; and the number of electrons determines the ion state and bonding properties.

? Carbon always has six protons. How many neutrons and electrons are there in a neutrally charged C-14 isotope?

ANSWER: Eight neutrons and six electrons.

# 2.5 The structure of water gives it unique properties

Mastering Biology
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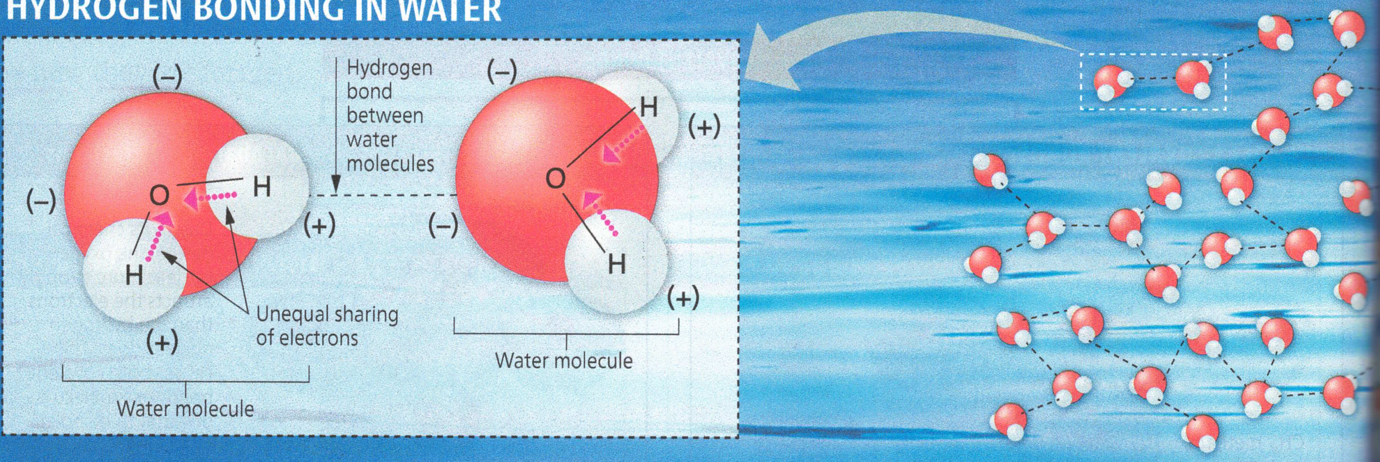
All life depends on water. In fact, life first appeared in water and evolved there for billions of years before moving onto land. Additionally, nearly all cells are, by weight, mostly water. What is it about water that makes it so central to life? Water has special properties that are a consequence of its unique chemical structure.

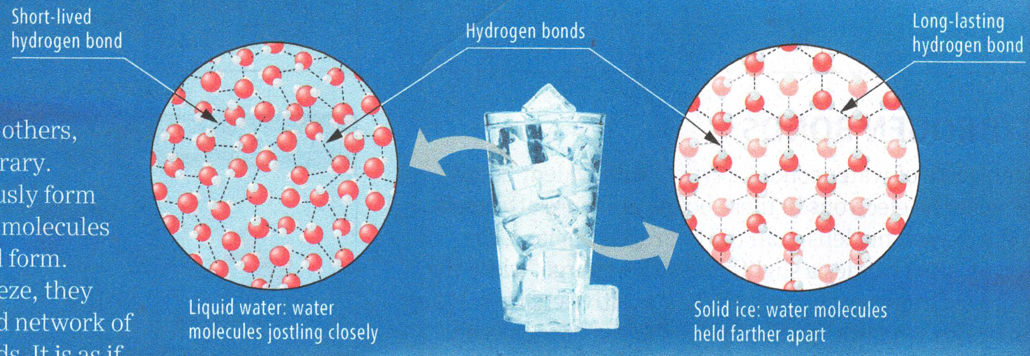
## HYDROGEN BONDING IN WATER

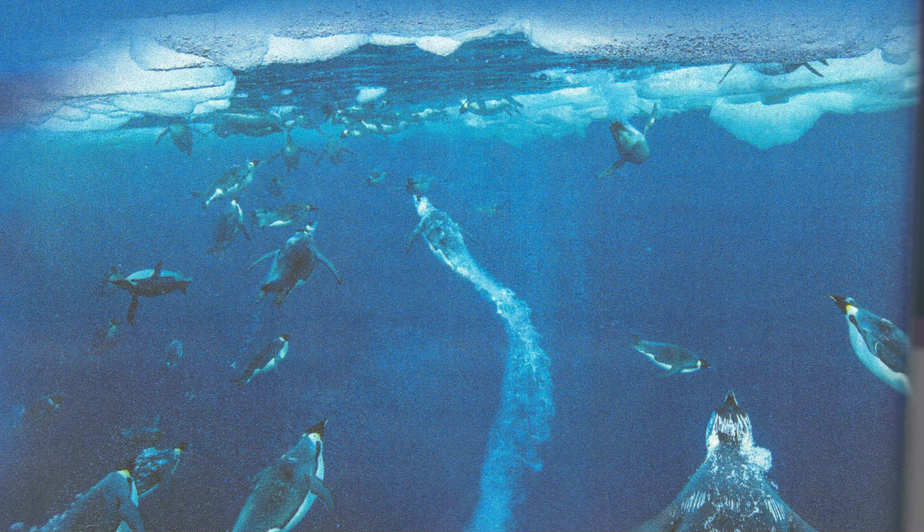



For each O—H bond in a molecule of water, one pair of electrons is shared between the two atoms. But this sharing is unequal: The electrons are more attracted to the O nucleus than they are to the H nucleus. As a result, water is a polar (unequally charged) molecule, with a slightly negative charge on its oxygen and slightly positive charges on its hydrogens. This allows a molecule of water to form hydrogen bonds with one or several other water molecules. Liquid water contains extensive networks of hydrogen bonds between the individual molecules.

## ICE FLOATING

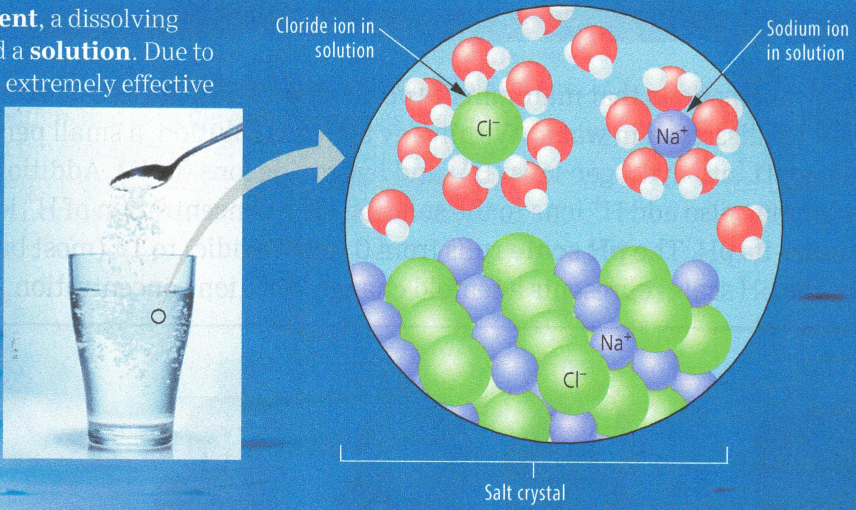
In its liquid state, each water molecule forms hydrogen bonds to several others, but these bonds are temporary. Hydrogen bonds continuously form and break, allowing water molecules to jostle about in the liquid form. When water molecules freeze, they move apart, forming a rigid network of long-lasting hydrogen bonds. It is as if each water molecule holds all others at "arm's length." Thus, unlike nearly every other liquid, water expands when it freezes, making solid ice less dense than liquid water. As a result, ice floats. This is extremely biologically relevant: During winter, a thin layer of floating ice insulates the water below the surface, allowing life to survive until the spring thaw.

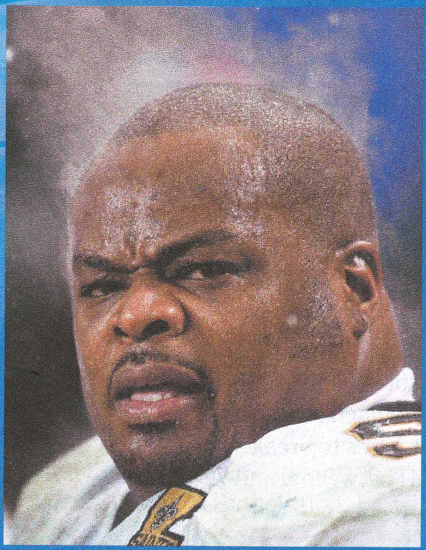


## WATER AS A SOLVENT

Many liquids can act as a **solvent**, a dissolving agent, to form a mixture called a **solution**. Due to its polar structure, water is an extremely effective solvent, able to dissolve just about anything. In a glass of salt water, for example, water molecules surround sodium and chloride ions, causing them to break free of the salt crystal and dissolve in the water. Within cells, water's polar nature allows it to hold many substances in solution, making them available to cells.



## TEMPERATURE REGULATION

Liquid water readily absorbs and releases heat. Water therefore resists temperature changes more than most substances. The presence of water can thereby act to moderate temperatures. On a global scale, the oceans help moderate the temperature of Earth's surface, keeping it within a livable range. On a more personal scale, sweating helps moderate your temperature by cooling off your skin.

**!** In 2018, scientists discovered an underground Martian lake beneath a glacier near the red planet's south pole.

## COHESION AND ADHESION

Due to hydrogen bonding, water molecules tend to stick to each other, a property called **cohesion**. The cumulative effect of all these hydrogen bonds is to create surface tension, a film-like surface on which items (such as this spider) can be suspended. **Adhesion**, the clinging of one substance to another, causes water to stick to surfaces, such as rain droplets on a car windshield.

**CORE IDEA**

▶ The polar nature of water molecules allows them to form networks of hydrogen bonds. This special ability endows water with many life-supporting properties.

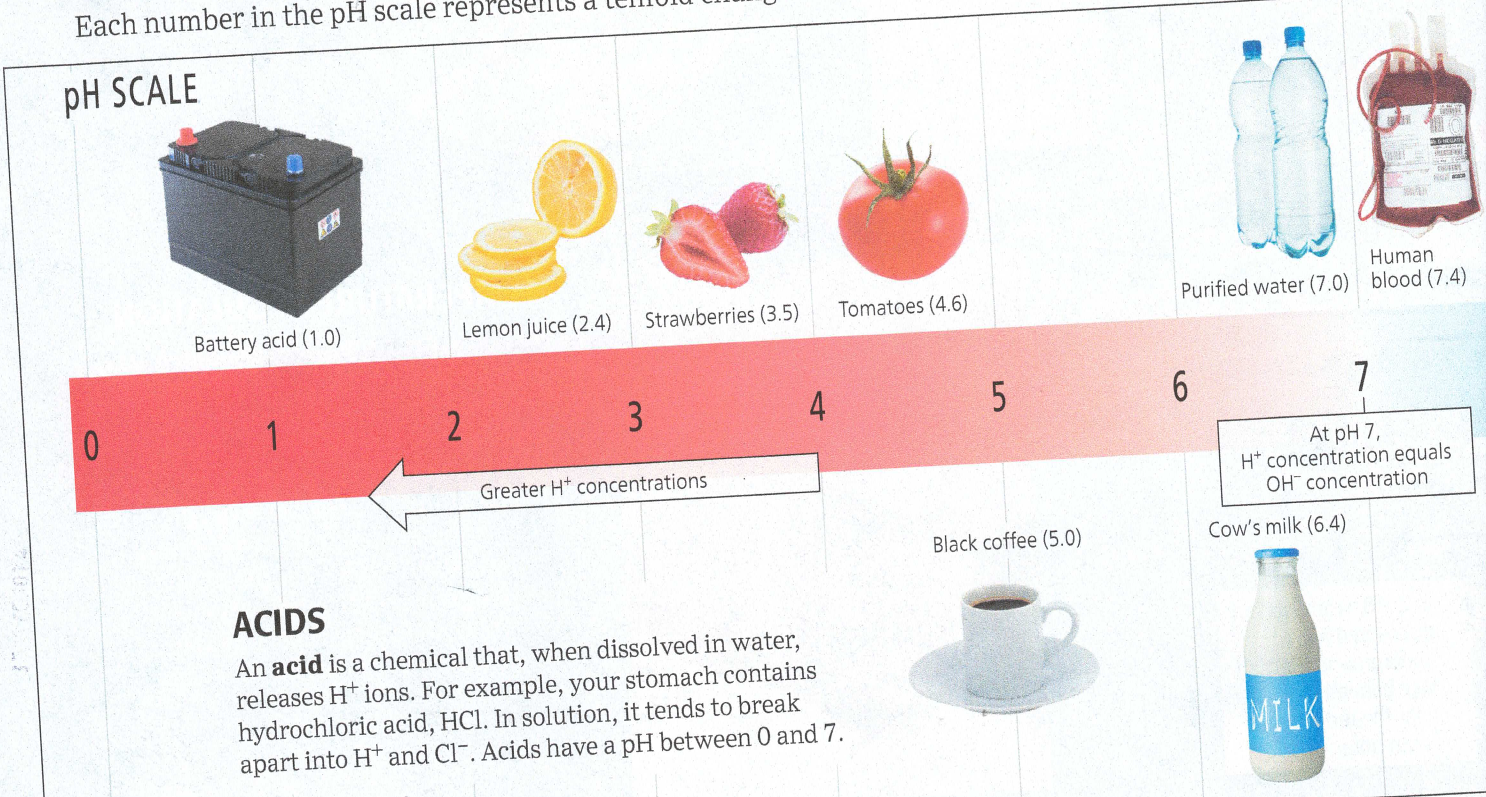
**?** What force allows a "water walker" insect to stay on top of a pond?

ANSWER: A network of hydrogen bonds produces cohesion between water molecules within liquid water.

2.6

# pH is a measure of the acidity of a solution

Most of the chemical reactions that maintain life occur in water. An **aqueous solution** is one that contains a substance dissolved in water. Within any aqueous solution, a small percentage of the water molecules break apart into hydrogen ions ($H^+$) and hydroxide ions ($OH^-$). Additionally, substances dissolved in water may also add $H^+$ ions to the solution. The concentration of $H^+$ ions in an aqueous solution determines its pH. The **pH scale** runs from 0 (most acidic) to 14 (most basic), with 7 as neutral. Each number in the pH scale represents a tenfold change in $H^+$ ion concentration.




## ACIDS

An **acid** is a chemical that, when dissolved in water, releases $H^+$ ions. For example, your stomach contains hydrochloric acid, HCl. In solution, it tends to break apart into $H^+$ and $Cl^-$. Acids have a pH between 0 and 7.

**!** Stomach acid is strong enough to dissolve iron nails.

## ACID PRECIPITATION

Burning fossil fuels releases chemicals that react with water in the air to form strong acids. As they fall back to Earth in the form of snow, rain, or fog, this acid precipitation damages lakes, streams, forests, and soil. The U.S. Clean Air Act has been effective at reducing acid precipitation.

## BUFFERS

Most cells regulate their pH through the use of **buffers**, chemicals that minimize changes in pH by accepting $H^+$ ions when they are present in excess and donating $H^+$ ions when they are in short supply. Within human blood and other fluids, there are several different types of buffers that keep the body's solutions at a nearly neutral pH, despite changes in the concentration of $H^+$. For example, buffers within your blood counteract a drop in pH that occurs whenever you exercise. Buffers in contact lens solution helps protect the surface of the eye from potentially painful changes in pH.


Contact lens solution


Ammonia (11.6)

Household bleach (12.6)

Lye (13.0)

9 10 11 12 13 14

Lower $H^+$ concentrations

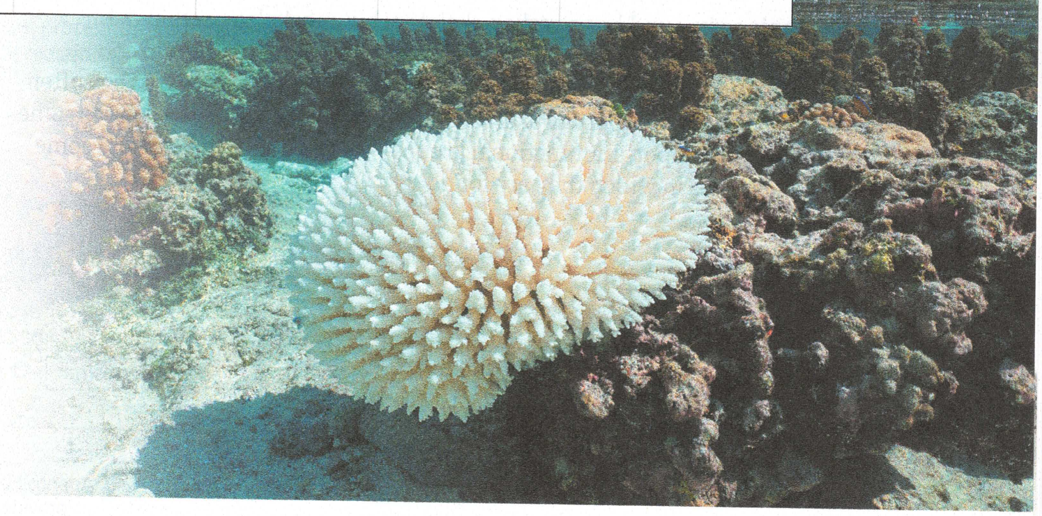
Baking soda (9.0)


## BASES

A **base** is a chemical that, when dissolved in water, removes $H^+$ ions from solution, usually by combining them with $OH^-$ to form water molecules. For example, lye is sodium hydroxide, NaOH. In water, the molecule falls apart, and the released $OH^-$ combines with $H^+$, decreasing the concentration of $H^+$ ions in the solution. Bases have a pH between 7 and 14.

## OCEAN ACIDIFICATION

As $CO_2$ levels rise in the atmosphere, about 25% of the excess $CO_2$ is absorbed by the oceans. As it dissolves, $CO_2$ undergoes a chemical reaction that lowers the pH of the ocean. This in turn damages coral reefs and other ecosystems by limiting the ability of organisms to perform the chemical reactions used to build their skeletons or shells.



**CORE IDEA**

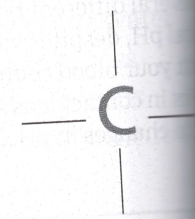
The concentration of $H^+$ ions in an aqueous solution determines the pH, from acidic (0 to 7) to neutral (7) to basic (7 to 14). Buffers can help reduce changes in pH. pH changes in the environment can affect the health of ecosystems.

**?** How does the pH of lemonade compare to the pH of water? How does the concentration of $H^+$ ions compare between the two?

ANSWER: Lemonade is more acidic and so will have a lower pH, meaning that more free $H^+$ ions are dissolved in lemonade than in water.

# Life on Earth is based on carbon

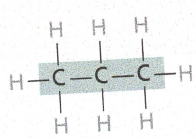
Perhaps you have heard that all organisms on Earth are "carbon-based life-forms." That is because, besides water, most of the molecules that make up living matter are **organic compounds**, molecules that contain carbon bonded to other elements. Why is life carbon-based and not, say, nitrogen-based? Unlike other elements, carbon can bond with up to four other atoms. Carbon is therefore able to form large, highly branched, diverse chains that can serve as the basic skeletons for a wide variety of chemical compounds. Here, you can see a survey of some of the many carbon compounds that are found in living matter.



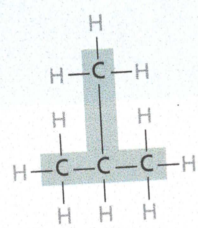

A single carbon
has four bonds

## CARBON SKELETONS

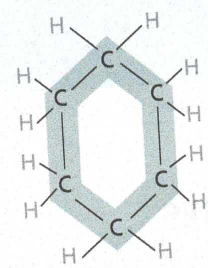
Every organic compound contains a skeleton of carbon atoms. Carbon skeletons vary in length and branching pattern, and some fuse together to form rings. Notice that each carbon atom forms four bonds to other atoms.



3-carbon skeleton (propane)



Branched carbon skeleton (isobutane)

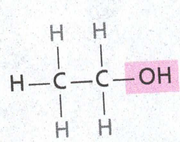


Ring carbon skeleton (cyclohexane)

## FUNCTIONAL GROUPS

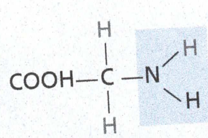
Every organic compound has a carbon skeleton, but most also contain one or more **functional groups**, sets of atoms that are attached to the carbon skeleton. Because functional groups participate in chemical reactions, they often determine the overall properties of an organic compound. Here, you can see some of the biologically important functional groups—highlighted in color—and some common molecules in which they are found.

HYDROXYL GROUP



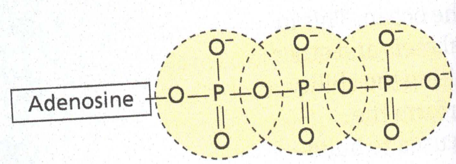
Ethyl alcohol, also called ethanol, is found in alcoholic drinks.

AMINO GROUP



Amino acids like this one are the basic building blocks of all proteins.

PHOSPHATE GROUP

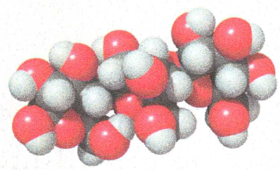
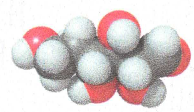
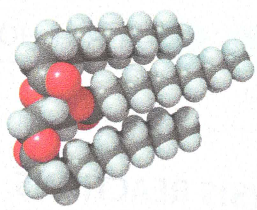
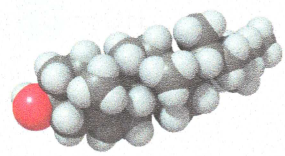
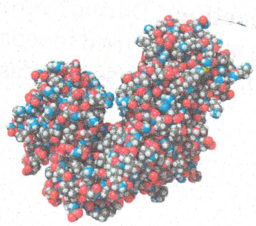
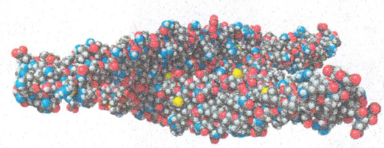
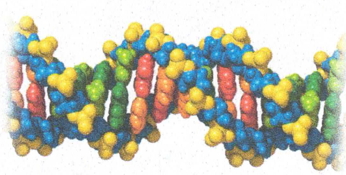
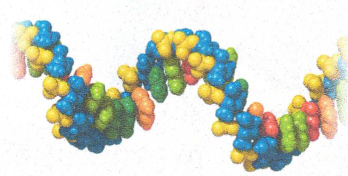


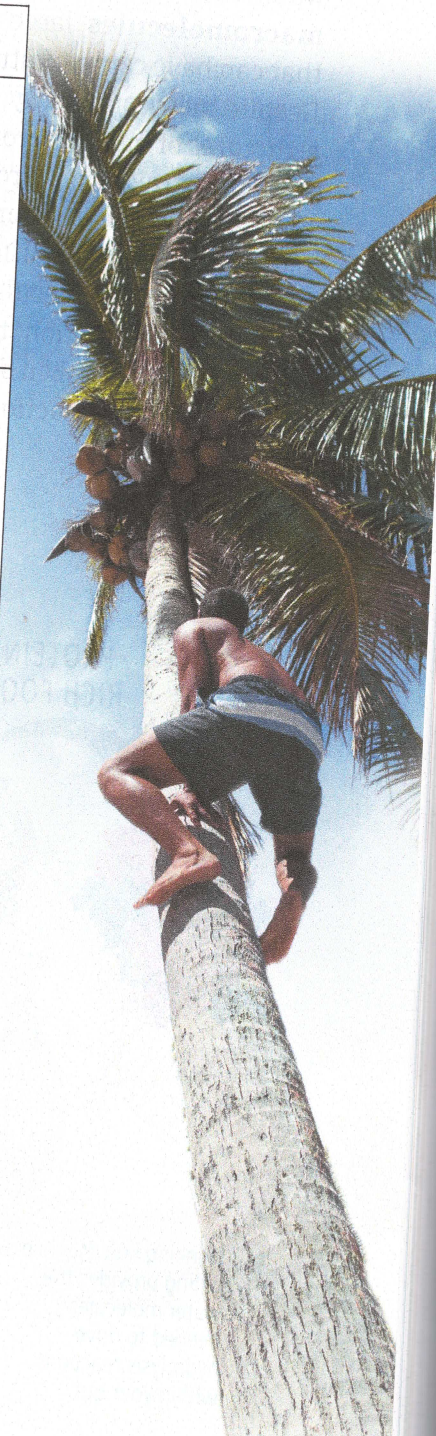

Adenosine triphosphate (ATP) provides energy to cells.

## BIOLOGICALLY IMPORTANT ORGANIC COMPOUNDS

All cells contain a huge variety of biologically important organic molecules. There are four classes of large organic molecules that are particularly important to life on Earth: carbohydrates, lipids, proteins, and nucleic acids.

❗ "An apple a day keeps the doctor away" refers to the health benefits of cellulose (fiber) in fresh fruits and vegetables.

| CLASS | EXAMPLES | |
|---|---|---|
| CARBOHYDRATES |  **Cellulose** is a large, complex carbohydrate that forms much of the structure of a plant. |  **Glucose** is a sugar (a simple carbohydrate) that acts as an energy source for all living cells. |
| LIPIDS |  **Coconut oil** is a lipid that is rich in fat and serves as an important dietary staple in much of the tropical world. |  **Cholesterol** is a lipid that circulates in the bloodstream and acts as a molecular ingredient to make steroid hormones. |
| PROTEINS |  **Hexokinase** is an enzyme, a protein that helps drive a chemical reaction, found in most living cells. |  **Keratin** is a structural protein found in hair, nails, and skin. |
| NUCLEIC ACIDS |  **DNA** is a nucleic acid that serves as the hereditary material of all life on Earth. |  **RNA** is a nucleic acid that acts as a messenger between DNA and other parts of the cell. |



### CORE IDEA

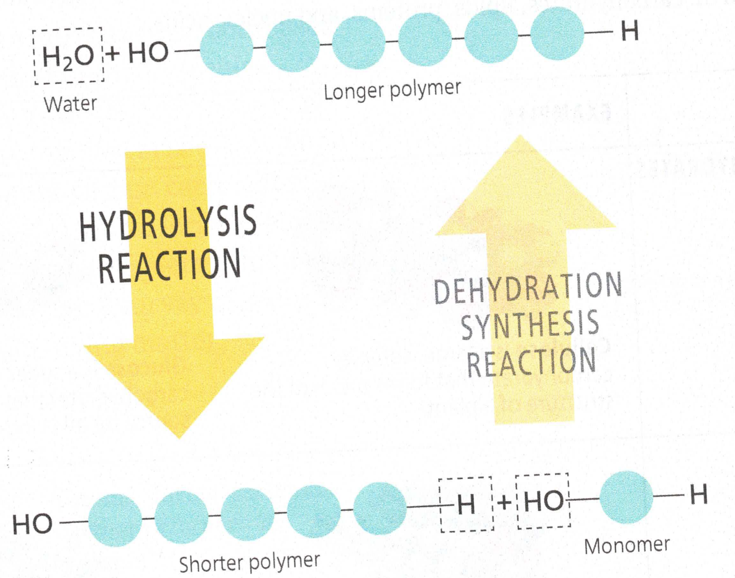
▶ All organisms have an abundance of organic compounds consisting of carbon skeletons that may have functional groups attached. Classes of organic compounds that are important to life include: carbohydrates, lipids, proteins, and nucleic acids.

**?** What property of carbon makes it well suited to form the basis of life's molecules?

other atoms, allowing it to be the base of complex molecules.

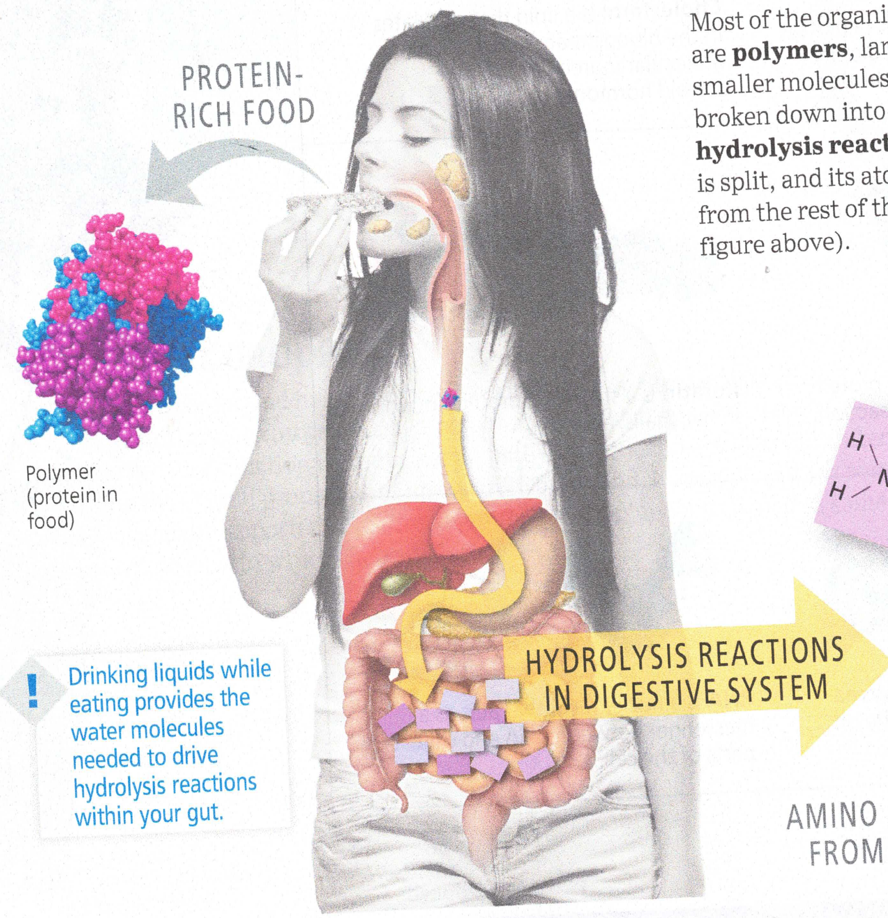
# 2.8 Most biological macromolecules are polymers

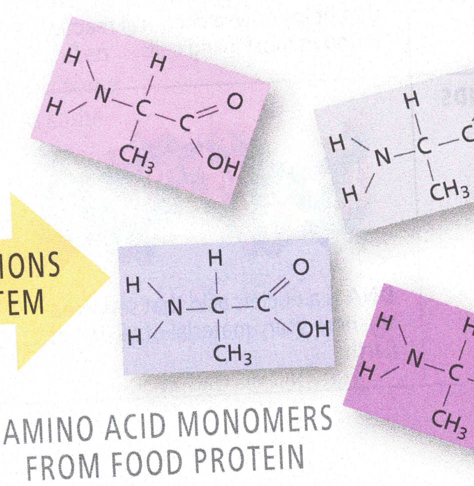
The majority of your body weight is water. Most of the rest consists of **macromolecules**, large molecules that can have complex structures. Despite their complexity, the structures of most macromolecules are fairly straightforward since they are made by repeating smaller building blocks. Although the different classes of macromolecules vary in structure and function, they are all built up and broken down via similar chemical reactions.

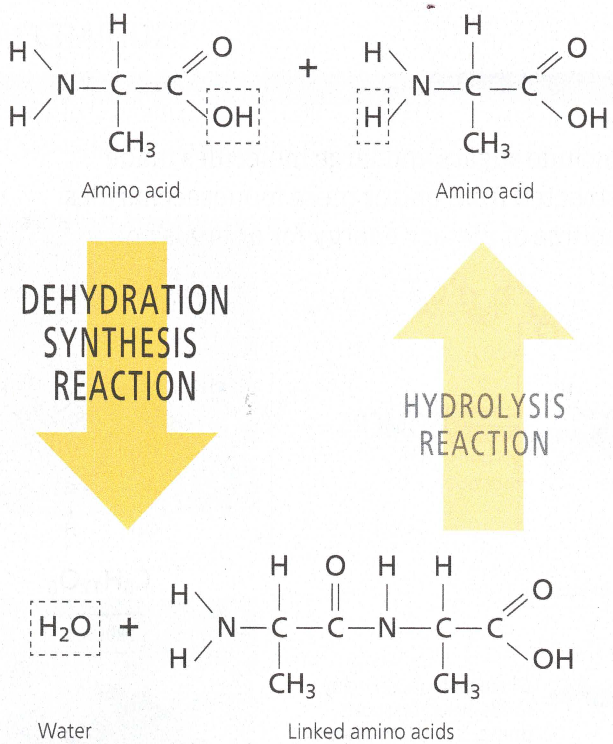



## HYDROLYSIS REACTIONS

Most of the organic macromolecules in living cells are **polymers**, large molecules made by joining many smaller molecules called **monomers**. Polymers can be broken down into the monomers that make them up via **hydrolysis reactions**. During hydrolysis, a water molecule is split, and its atoms are used to separate a monomer from the rest of the chain (see the dashed boxes in the figure above).



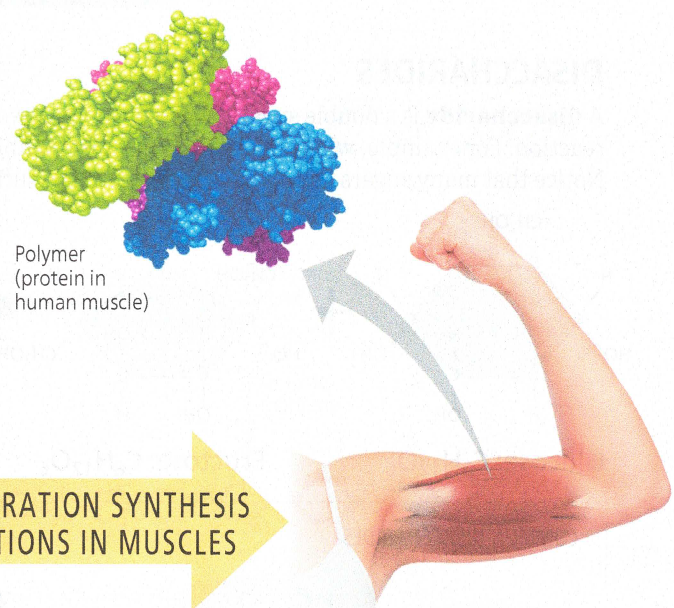


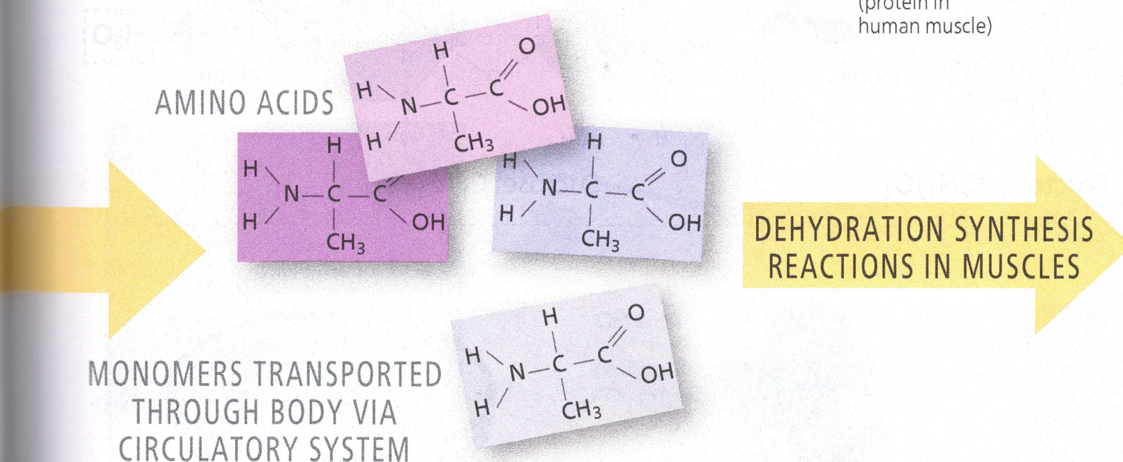

## DEHYDRATION SYNTHESIS REACTIONS

Monomers are linked together to form larger polymers through a chemical reaction called a **dehydration synthesis reaction**. As each new monomer building block is added to a chain, a hydrogen atom (H) from one monomer and a hydroxyl group (OH) from another monomer (see the dashed boxes in the figure to the left) are removed, creating a new chemical bond between the two monomers and releasing a molecule of water ($H_2O$). One molecule of water is released for each monomer added to the chain. Notice that a dehydration synthesis reaction (which builds up polymers) is the opposite of a hydrolysis reaction (which breaks down polymers).

## METABOLISM

Your **metabolism** is the sum total of all the chemical reactions that take place in your body. Many important metabolic reactions involve the breaking down and building up of polymers. Your digestive system breaks down the macromolecules you eat (protein in peanut butter, for example) into the monomers that make them up (in this case amino acids, the building blocks of all proteins). Your cells then use these monomer building blocks to construct new polymers (by building new muscle proteins, for example).




**CORE IDEA**

Macromolecules (large molecules) are often polymers made by joining together monomers via dehydration synthesis reactions. Polymers can be broken down into the monomers that make them up via hydrolysis reactions.

**?** Why are the building-up reactions called dehydration reactions?

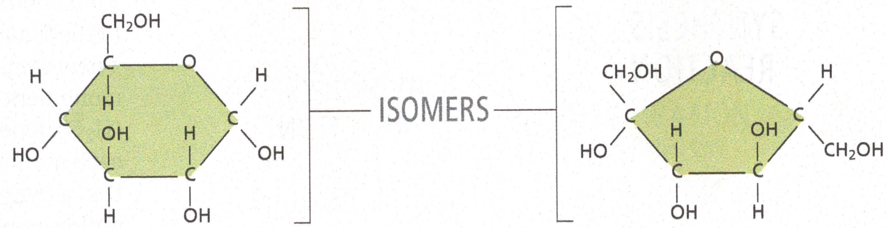
ANSWER: Because a molecule of water is removed from the molecules involved.

# 2.9 Carbohydrates are composed of monosaccharides

**Carbohydrates**—commonly known as "carbs"—include sugars and large molecules made from sugars. All carbohydrates are molecules constructed from one or more monosaccharides (simple sugars). Carbohydrates are an important source of dietary energy for animals and a key structural component of plants.

## MONOSACCHARIDES

**Monosaccharides** are the building blocks of carbohydrates. Every carbohydrate consists of one or more monosaccharides. Notice that two common monosaccharides—glucose and fructose—are **isomers**, meaning they have the same numbers and kinds of atoms but differ in the arrangement of atoms.



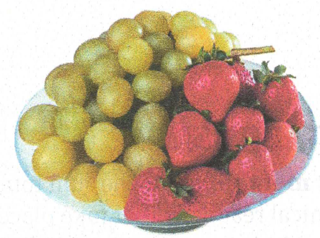

$C_6H_{12}O_6$

GLUCOSE

$C_6H_{12}O_6$

FRUCTOSE

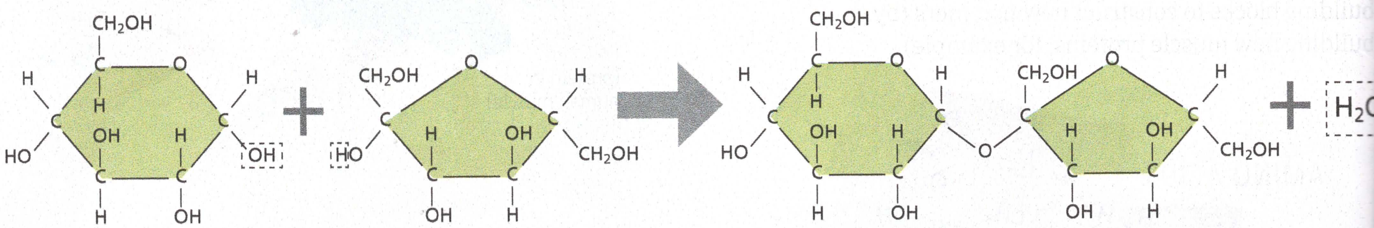
**Glucose**, found in many foods including sports drinks, is also administered intravenously to trauma victims and surgery patients to provide a ready source of energy.



**Fructose**, sometimes called fruit sugar, is also found in honey.

## DISACCHARIDES

A **disaccharide** is a double sugar formed by joining two monosaccharides through a dehydration synthesis reaction. For example, when glucose and fructose combine to form sucrose, a molecule of water is released. Notice that many sugars have names that end in the suffix "-ose," making them easy to recognize on a food label.



Glucose: $C_6H_{12}O_6$ Fructose: $C_6H_{12}O_6$ Sucrose: $C_{12}H_{22}O_{11}$

COMMON DISACCHARIDES

**Lactose**: also known as milk sugar

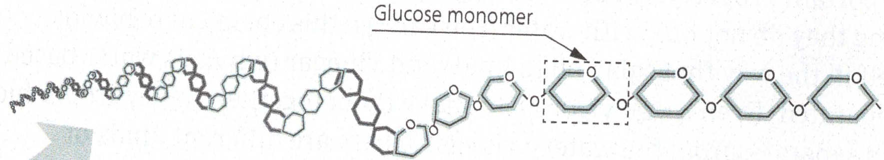
**Maltose**: used for brewing and in malted milk candy

**Sucrose**: common table sugar

## POLYSACCHARIDES

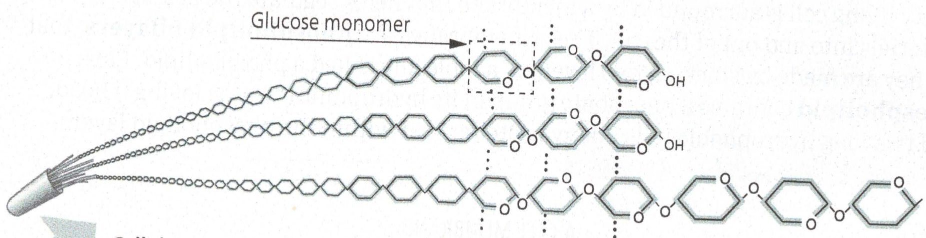
A **polysaccharide** is a complex carbohydrate made by joining many monosaccharides together into a long chain. Here you can see four familiar polysaccharides, all of which are made from long chains of glucose monomers.

### STARCH



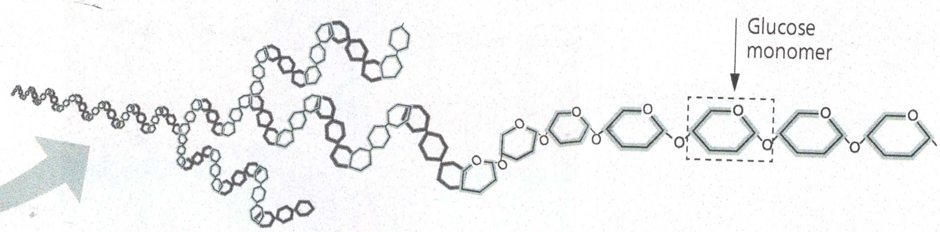

Plants store some of the excess sugar they produce as the polysaccharide **starch**, consisting of long, twisted, unbranched chains of glucose molecules. Many animals consume starch as a source of dietary energy.

### CELLULOSE



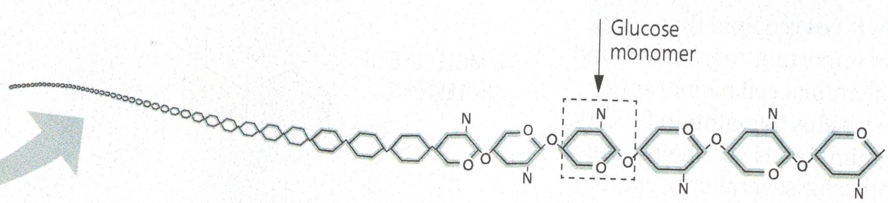

**Cellulose** makes up much of a plant's body in the form of cable-like fibers in the walls of plant cells. A molecule of cellulose contains many long straight chains of glucose, with bonds joining the chains. Cellulose is the major component of wood, and it is the "fiber" in your diet.

### GLYCOGEN




**Glycogen** consists of branched chains of glucose molecules. In most animals, excess sugar is stored as glycogen granules in liver and muscle cells, where it is available if needed for about 24 hours.

### CHITIN




**Chitin** is a carbohydrate that forms the outer skeleton of arthropods (such as insects and lobsters) and many fungi. Chitin is similar to cellulose except that the glucose monomer of chitin has a nitrogen-containing appendage.

**!** The building block of chitin is glucosamine, which many people take as a supplement to aid joints.

**CORE IDEA**

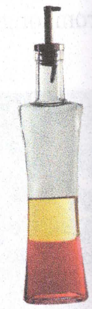
Carbohydrates consist of one or more monosaccharides joined together. Simple sugars (monosaccharides) include glucose and fructose; disaccharides include sucrose; and polysaccharides include starch and cellulose.

**?** What do starch and glycogen have in common in terms of their structure? How are they different?

ANSWER: They are both large chains made by joining many glucose molecules together, but starch consists of straight chains, whereas glycogen consists of branched chains.

# 2.10 Lipids are a diverse group of hydrophobic molecules

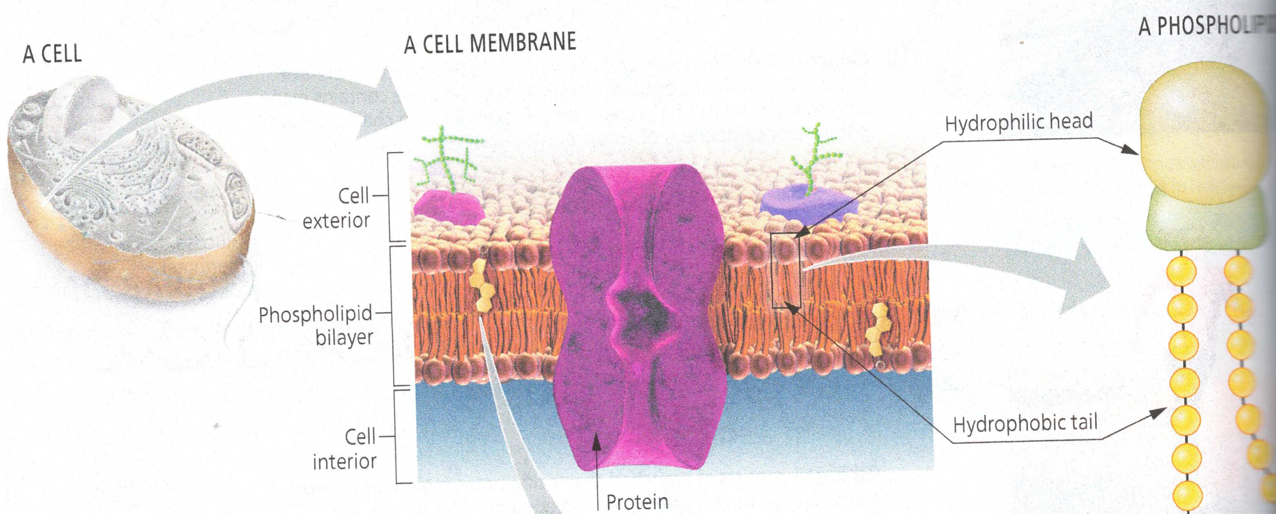
**Lipids** are a diverse group of organic compounds, but they share one important property: All lipids are **hydrophobic** ("water-fearing"), meaning they do not mix with water. You can see this chemical behavior yourself in the way that salad oil (a lipid) and vinegar (which is water based) stay separated. Even if you vigorously shake them together, the hydrophobic oil soon separates from the watery vinegar. There are different kinds of lipids, several of which may be familiar.



Oil and vinegar

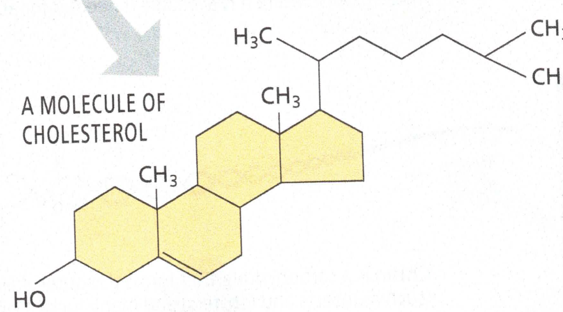
## PHOSPHOLIPIDS

Every living cell is surrounded by a membrane that helps regulate the passage of materials into and out of the cell. These membranes are **phospholipid bilayers**; that is, they are made by stacking two layers of a molecule called a phospholipid. Each **phospholipid** contains a phosphate group in its hydrophilic ("water-loving") head, and two long hydrophobic tails. Many proteins float within the phospholipid layers.




## CHOLESTEROL

**Cholesterol** is a lipid that plays several important roles. It is found in most animal cell membranes, where it helps to maintain fluidity. Also, animal cells use cholesterol to synthesize several important lipid hormones. In addition to being produced in your body, cholesterol is found in animal-derived foods such as eggs and red meat.



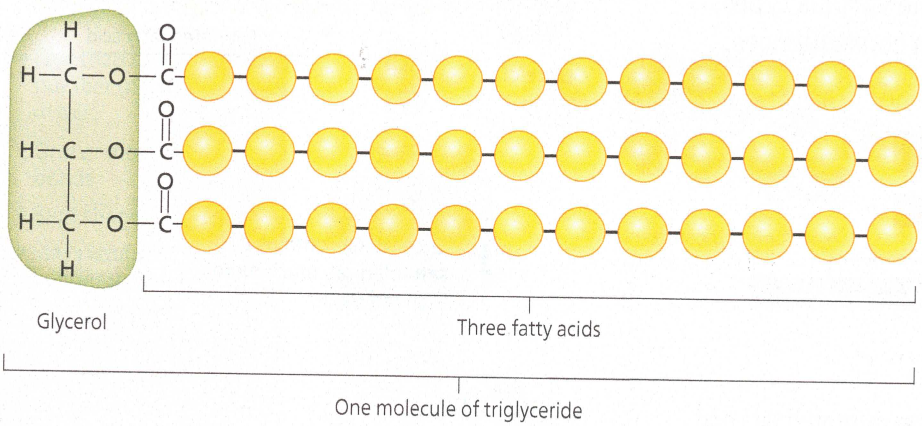

**TYPES OF CHOLESTEROL**

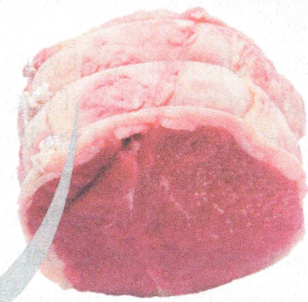
| Name | What it stands for | Common name | Health implications |
|---|---|---|---|
| LDL | Low-density lipoprotein | "Bad cholesterol" | Levels can be increased through ... high levels increase risk of heart ... |
| HDL | High-density lipoprotein | "Good cholesterol" | Levels can be increased through ... high levels reduce risk of heart ... |

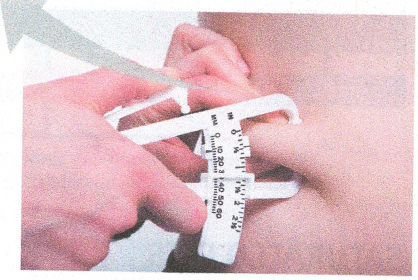
## TRIGLYCERIDES

Lipids include fats, and when you think of "fat" you probably think of your diet. A typical dietary fat consists of a molecule called a **triglyceride**, which is made from one molecule of glycerol joined to three fatty acid molecules. Within a triglyceride, the carbon/hydrogen chains in the **fatty acid** tails store a lot of energy. Fatty foods therefore have many calories, and excess calories in the body are stored by adding triglycerides to adipose tissue, also called body fat.

A MOLECULE OF TRIGLYCERIDE



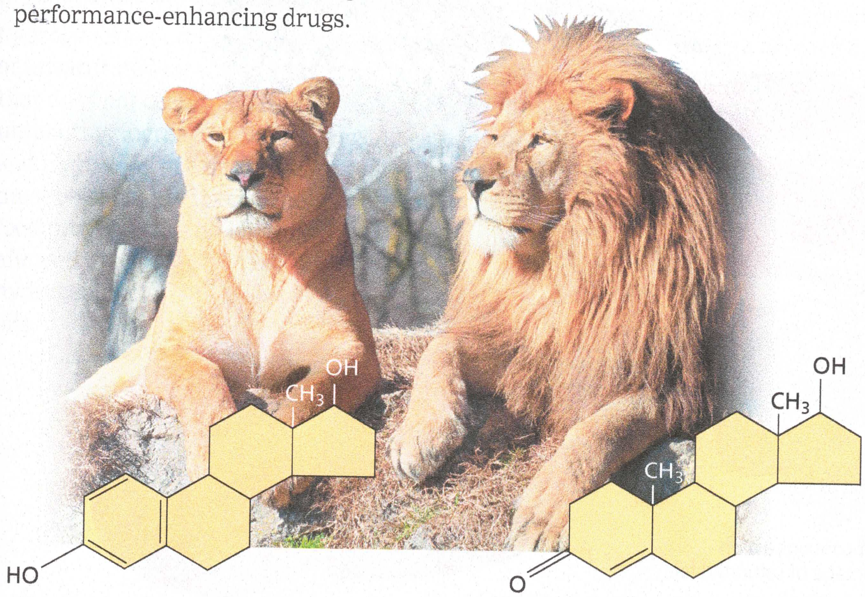


Beef


Human adipose (fat) tissue

## STEROID HORMONES

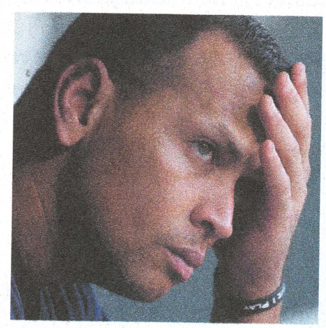
**Steroids** are lipids that contain four fused chemical rings made primarily of carbon. Cholesterol is one familiar steroid. Within the body, cholesterol is used to produce a variety of steroid hormones, such as the sex hormones estrogen and testosterone. **Anabolic steroids** are synthetic variants of testosterone that mimic its effects, increasing body mass, but also causing potentially dangerous side effects. Many athletes have admitted to using these performance-enhancing drugs.

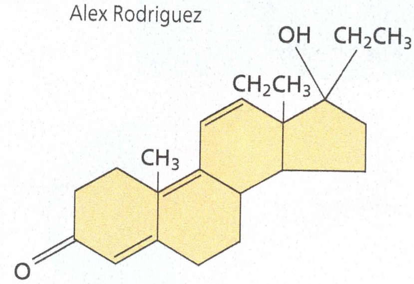
Body fat is extremely calorie-dense: One pound of body fat stores 3,500 calories.



A type of estrogen

Testosterone


Alex Rodriguez



THG, an anabolic steroid

**CORE IDEA**

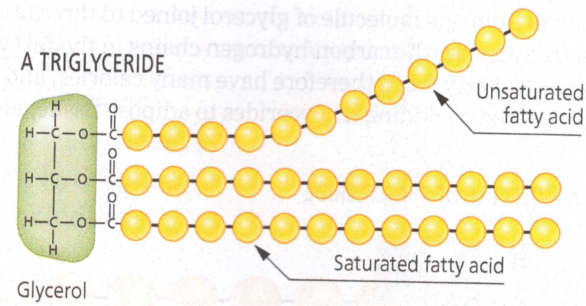
Lipids are a diverse group of hydrophobic organic compounds. Lipids include phospholipids, cholesterol, triglycerides, and steroid hormones (both natural sex hormones and synthetic anabolic steroids).

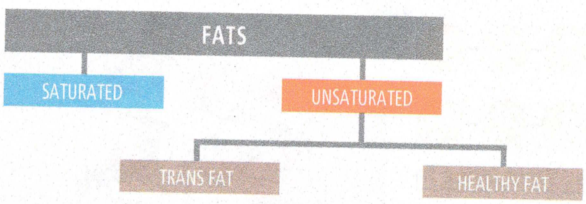
? What physical property is shared by dietary fats, cholesterol, and anabolic steroids?

ANSWER: They are all hydrophobic.

# Your diet contains several different kinds of fats

Most of the lipids that you consume in your diet consist of molecules of triglyceride. Each triglyceride molecule contains three long fatty acid chains connected to a molecule of glycerol. Although the different kinds of dietary fats share structural features, there are important differences between the various types, and these differences have health consequences.

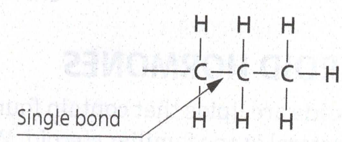


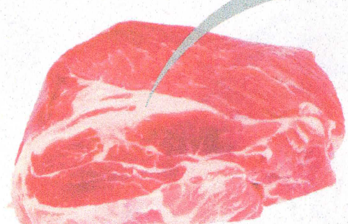

**!** Coconut oil contains 92% saturated fat, much more than red meat.

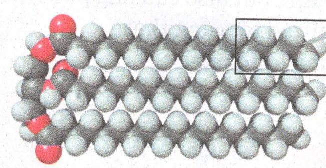
## SATURATED FATS

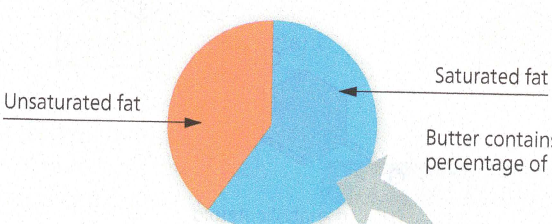
Dietary fats come in two basic varieties: saturated fats and unsaturated fats. **Saturated fats** have the maximum number of hydrogens along the fatty acid tail, which corresponds to all single chemical bonds in the chain. As a result, the fatty acid tails in saturated fats are straight. This shape allows them to easily stack together and form solids, so highly saturated fats tend to be solid at room temperature. Saturated fats are found in highest quantities (but not exclusively) in animal products.




- Maximum number of hydrogens in tail
- All single bonds
- Straight shape
- Solid at room temperature
- Found in higher amounts in animal products
- Less healthy

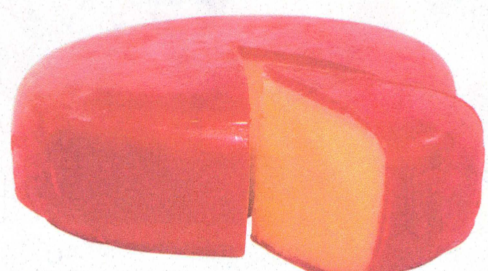

A fatty steak


Saturated fat molecule with straight-chain tails



Butter contains a high percentage of saturated fat.

Butter

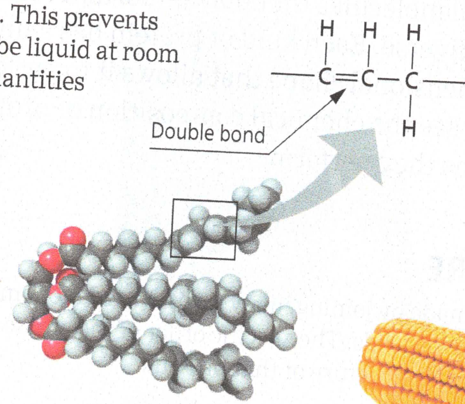

Cheese

## UNSATURATED FATS

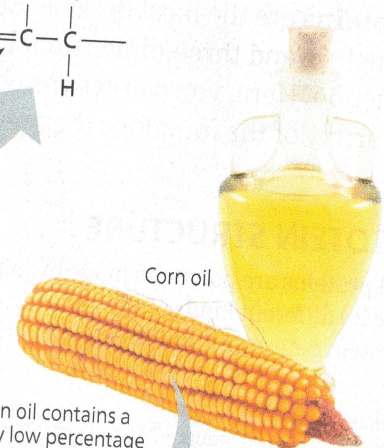
**Unsaturated fats** have one or more double bonds in the fatty acid tail, causing them to have fewer than the maximum number of hydrogens. As a result, the fatty acid tails of unsaturated fats have a bend or kink at each double bond, giving the molecule a twisted shape. This prevents them from stacking easily, so unsaturated fats tend to be liquid at room temperature. Unsaturated fats are found in greatest quantities (but not exclusively) in vegetable and fish oils.

- Less than the maximum number of hydrogens in tail
- One or more double bonds
- Bent shape
- Stays liquid at room temperature
- Found in higher amounts in plant products
- Healthier

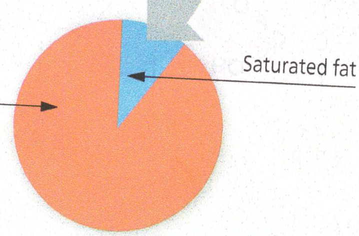

Olive oil



Unsaturated fat molecule with bent tails


Corn oil

Corn oil contains a very low percentage of saturated fat.



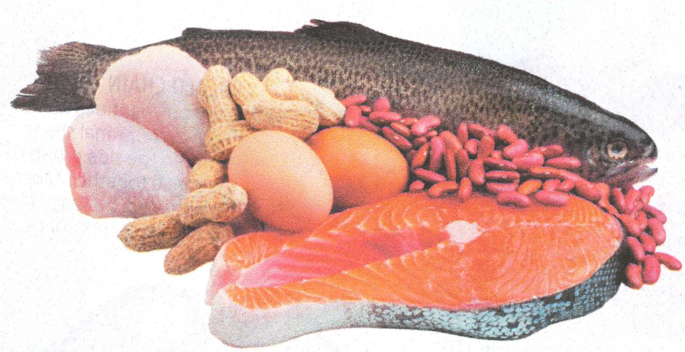

## TRANS FATS

An unsaturated fat can be rendered solid through a manufacturing process called **hydrogenation**. The hydrogenation process can produce **trans fat**, a type of unsaturated fat that contains an unusual bond that does not occur naturally. Trans fats are quite unhealthy, increasing risk of heart disease, diabetes, and high blood pressure. Accordingly, trans fats must be explicitly listed on food labels. As of 2018, food providers are no longer allowed to use hydrogenated oils.


Deep-fried fast foods may contain trans fats.

## HEALTHY FATS

Not all fats are unhealthy. In fact, some fats are essential to a healthy diet. For example, **omega-3 fatty acids** are known to reduce the risk of heart disease. Foods rich in essential fats should be part of a well-balanced diet.


Selection of omega-3–rich foods: fish, chicken, eggs, peanuts, and beans

**CORE IDEA**

Lipids include dietary fats: saturated fats and unsaturated fats (including trans fats and omega-3 fats). Unsaturated fats tend to be healthier than saturated fats, but trans unsaturated fats are particularly unhealthy.

**?** What is wrong with this statement: Animal fats are saturated, whereas plant fats are unsaturated.

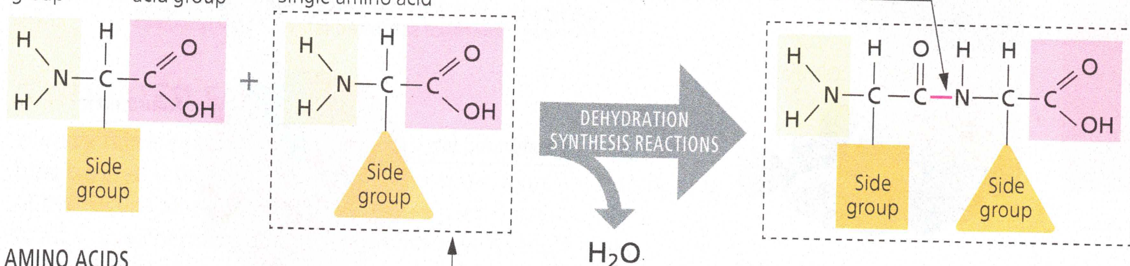
saturated and unsaturated fats, but in different proportions.

# 2.12 Proteins perform many of life's functions

Of all the large biological molecules that play important roles in your body, **proteins** are the most diverse. Each kind of protein has a unique chemical structure and three-dimensional shape that allows it to perform a specific function. Here, you can see the chemical composition of proteins and survey a variety of the functions they perform.

## PROTEIN STRUCTURE

All proteins are polymers made by joining many **amino acid** monomers together. There are 20 different kinds of amino acids. The specific order of the amino acids within a protein determines the overall structure of that protein.

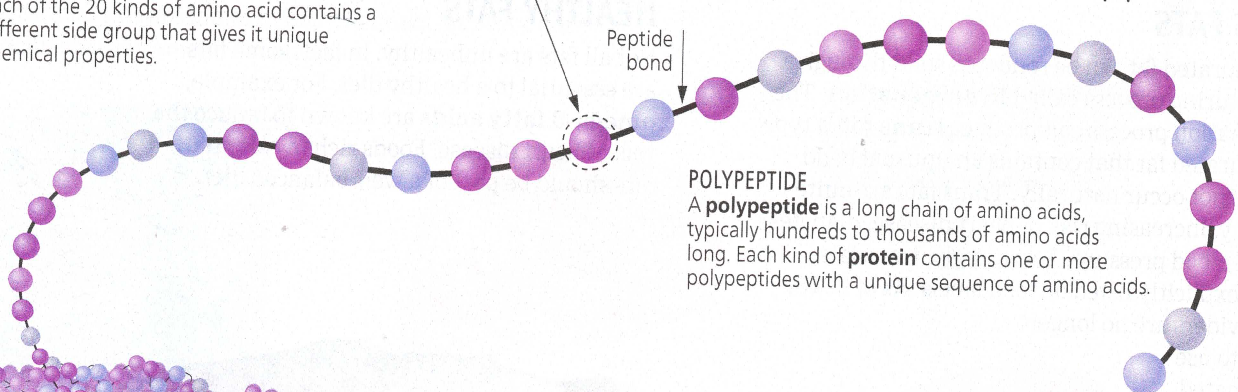



### AMINO ACIDS

All proteins consist of amino acids. Every amino acid contains a central carbon atom, an amino group, and a carboxylic acid group. Each of the 20 kinds of amino acid contains a different side group that gives it unique chemical properties.

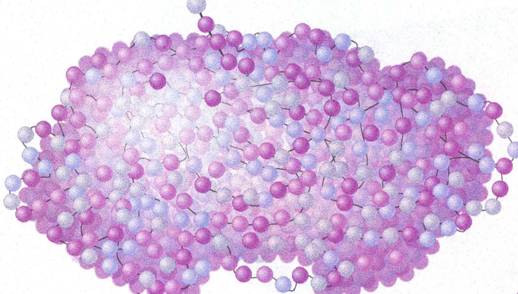
### PEPTIDE BOND

Amino acids are joined through dehydration synthesis reactions. The newly formed bond is called a **peptide bond**.



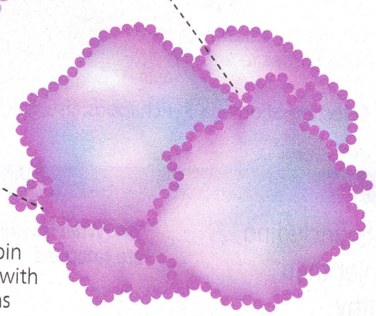

### POLYPEPTIDE

A **polypeptide** is a long chain of amino acids, typically hundreds to thousands of amino acids long. Each kind of **protein** contains one or more polypeptides with a unique sequence of amino acids.




### FOLDED CHAIN

Every polypeptide twists and folds into a unique three-dimensional shape. Chemical bonds between the side groups of the amino acids hold the shape together. Most proteins are generally blob-shaped, but each kind of protein differs in the details of that shape.

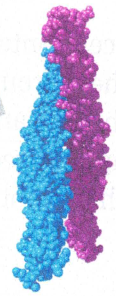



### MULTIPLE CHAINS

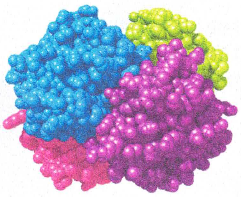
Some proteins contain multiple polypeptide chains joined together into a large complex. For example, one molecule of hemoglobin contains four polypeptide chains.

## FUNCTIONS OF PROTEINS

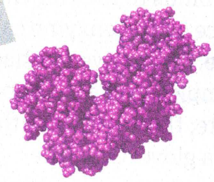
Proteins perform a huge variety of tasks within your body and the bodies of all organisms. If something is getting done in your body, chances are there is a protein doing it. Here, you can see just some of the functions performed by proteins in animal bodies. Notice that each kind of protein has a unique shape that enables it to perform its unique function. In the examples, each polypeptide chain is shown in a different color.



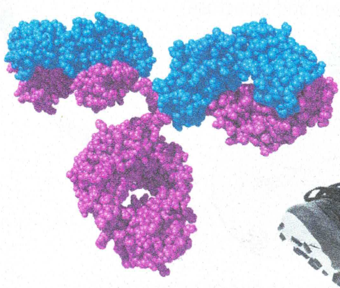
**Structure**: Keratin is an important component of hair, skin, nails, and fur.



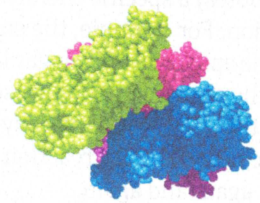
**Transport**: Hemoglobin, found within red blood cells, carries oxygen through the body via the bloodstream.



**Enzymes**: Lactase is an enzyme within your digestive system that breaks down the milk sugar lactose.



**Defense**: Antibodies are proteins within your immune system that bind to foreign invaders, marking them for destruction.



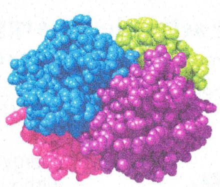
**Movement**: Actin is one of the proteins that enables muscles to contract.

! The most common cause of the disease cystic fibrosis is a change in just one of 1,480 amino acids in an important protein.

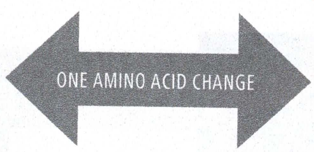
## PROTEIN FORM AND FUNCTION

The precise amino acid sequence of a protein determines its overall shape and hence its function. Change the amino acid sequence, even a little, and you may alter the ability of the protein to perform its normal task. For example, changing just one of the 146 amino acids that make up one of the polypeptides (protein chains) in hemoglobin causes the protein to misfold. The altered protein cannot perform its function properly, leading to sickle-cell disease.

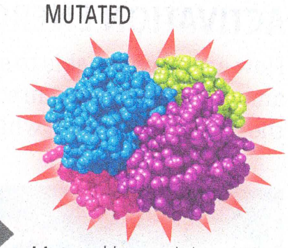
NORMAL



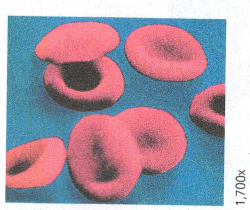
Normal hemoglobin



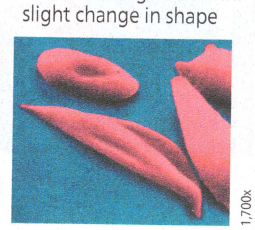

MUTATED



Mutated hemoglobin with slight change in shape




Normal red blood cells




Sickled red blood cells

**CORE IDEA**

Proteins are a diverse set of molecules made from amino acids joined by peptide bonds. Proteins perform most of the tasks required for life. Each kind of protein has a unique shape that determines its function.

**?** What is a polypeptide? What does the name mean?

ANSWER: A polypeptide is a chain of amino acids joined by many (or "poly") peptide bonds.