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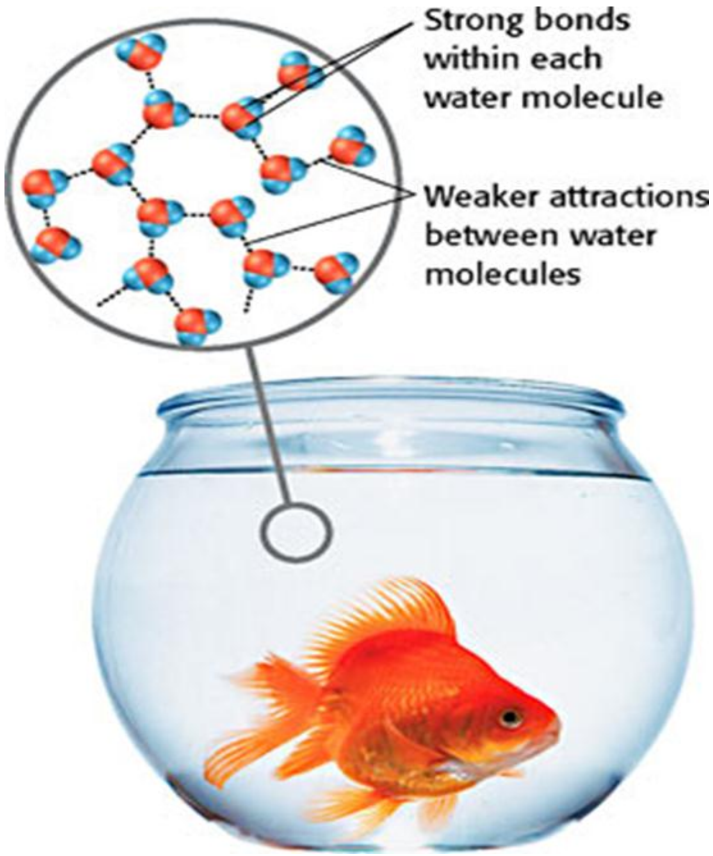
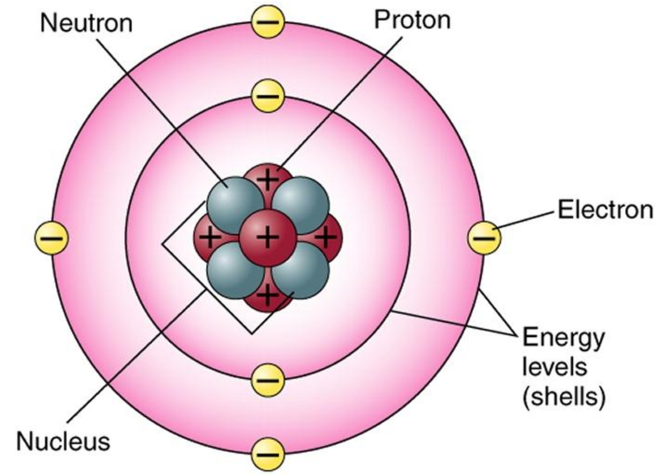


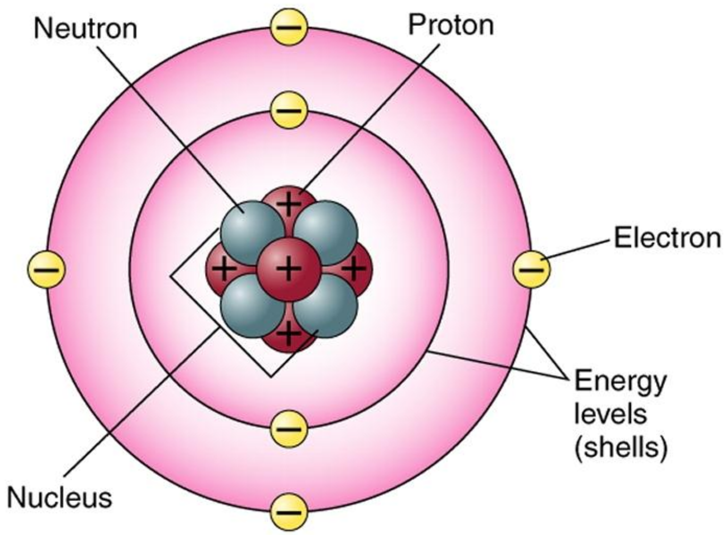
Chemistry of Life

All **matter** is composed of tiny particles called **atoms**. There are 109 types of atoms. A substance made up of one kind of atom is called an **element**.

An atom is the smallest part of an element that still has the properties of that element.



Atomic Structure



Each atom is made up of smaller parts called **protons**, **electrons** and **neutrons**. Protons and neutrons are found in the central portion of the atom called the **nucleus**.

Each proton has a positive (+) electrical charge. The neutrons have no charge (are neutral). The weight or mass of the atom is the sum of the number of protons and neutrons in the nucleus.

Electrons are found in orbits or shells at different distances around the nucleus. The electron has a negative electric charge.

Molecules and Compounds

Atoms frequently bond with each other to form **molecules**. A molecule can contain atoms of the same kind as when two atoms of **oxygen** bond with each other to form an **oxygen molecule**

Molecules can also form from the combination of two or more different kinds of atoms.

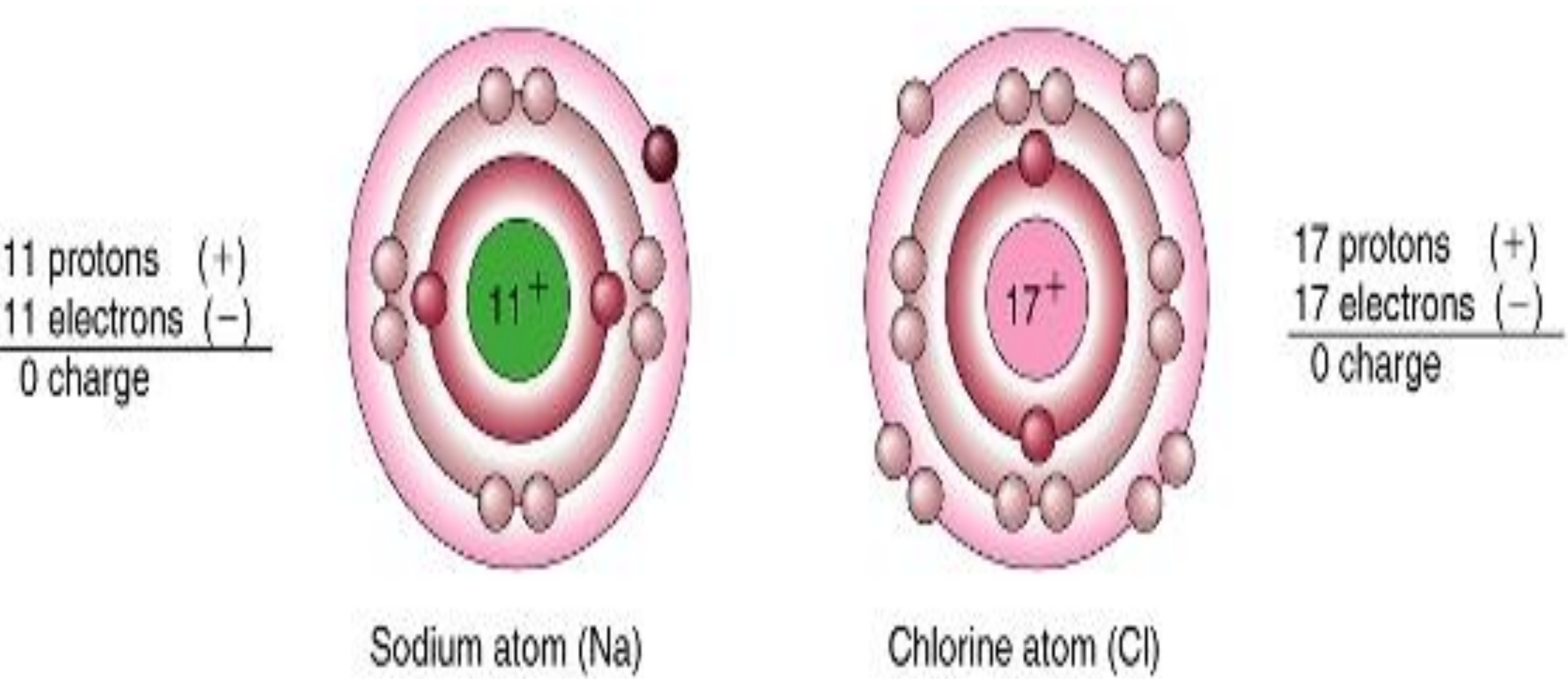
This kind of molecules is called a **compound**.

CO_2 for **carbon dioxide**

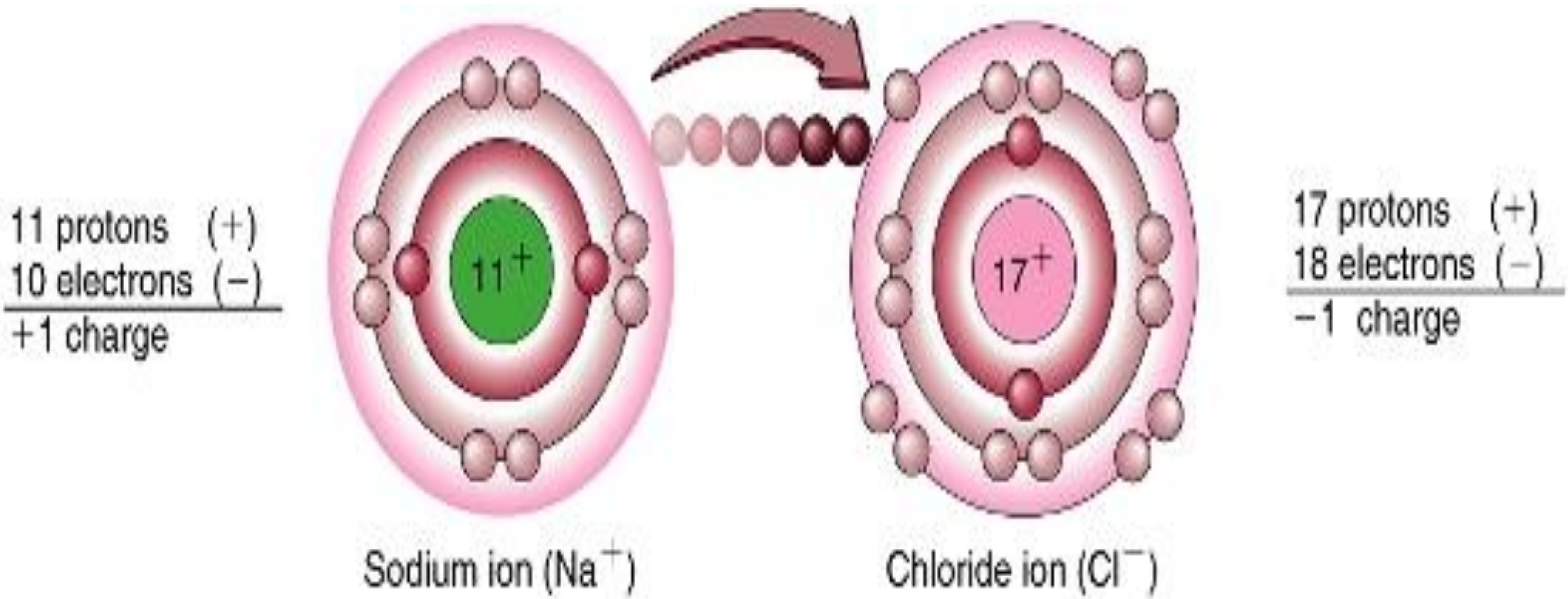
NaCl **for sodium chloride.**

In a compound, the different elements seem to lose their individual characteristics. For example, sodium is an explosive, dangerous substance. Chlorine is a highly poisonous gas. When the two are combined chemically they form sodium chloride, a nonpoisonous substance we commonly sprinkle on our food.

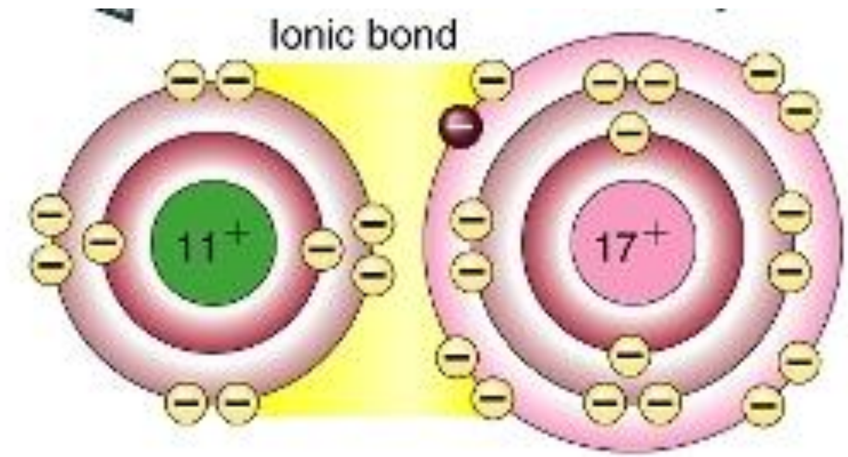
Ionic Bond


11 protons (+)
11 electrons (−)
0 charge
11+
17+
17 protons (+)
17 electrons (−)
0 charge
Sodium atom (Na)
Chlorine atom (Cl)

Ionic Bond


11 protons (+)
10 electrons (−)
+1 charge
11+
17+
17 protons (+)
18 electrons (−)
−1 charge
Sodium ion (Na+)
Chloride ion (Cl−)

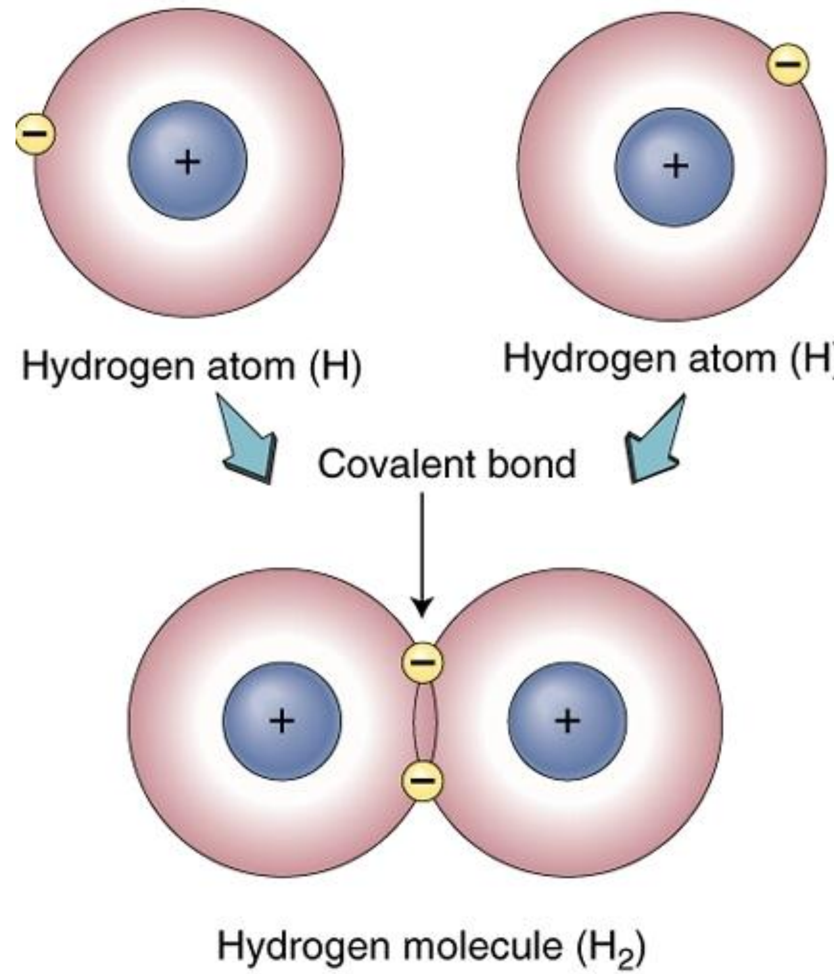
Molecules and Compounds – Ionic Bond



Sodium chloride molecule (NaCl)

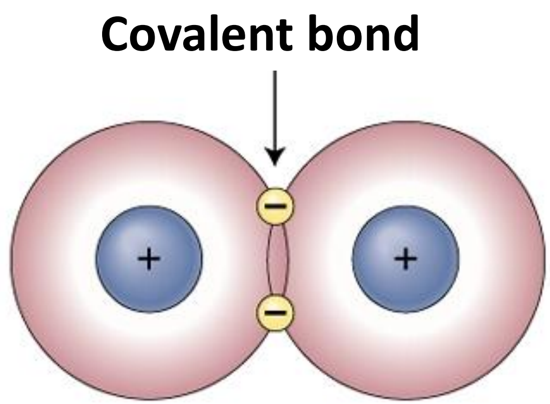
Molecules and Compounds – Covalent Bond

Atoms may also satisfy their outer shells of electrons by sharing pairs of electrons. This can be seen in the example to the right. Here two atoms of hydrogen are brought very close to each other. Each atom needs one electron to satisfy its **electron shell**. The sharing of electrons between the hydrogen's forms a **covalent bond**.



Covalent Bond

Covalent bonds are much stronger than ionic bonds. Dissolving sodium chloride (**table salt**) in water breaks the ionic bonds between sodium and chloride ions. The covalent bond holding the hydrogen molecule together is not broken when **hydrogen gas** (H_2) is dissolved in water



Hydrogen molecule (H_2)

Mixture

A mixture is a loose combination of different substances. Unlike a compound, these substances can be physically separated and when they are combined, the amounts of each substance are not fixed.

A mixture would be like a green salad where the different vegetables can be put together in a bowl, but can be easily separated. A compound is more like a baked cake where it would be very difficult to separate out the ingredients once the cake is baked.

Properties of a Mixture and a Compound

The different parts of a mixture keep their own properties when put together. Substances go through a **chemical change** to form a compound. In a compound, the different elements seem to lose their individual characteristics.

For example, sodium is an explosive, dangerous substance. chlorine is a highly poisonous gas. When the two are combined chemically they form sodium chloride, salt, a nonpoisonous substance we sprinkle on our food.

Solution

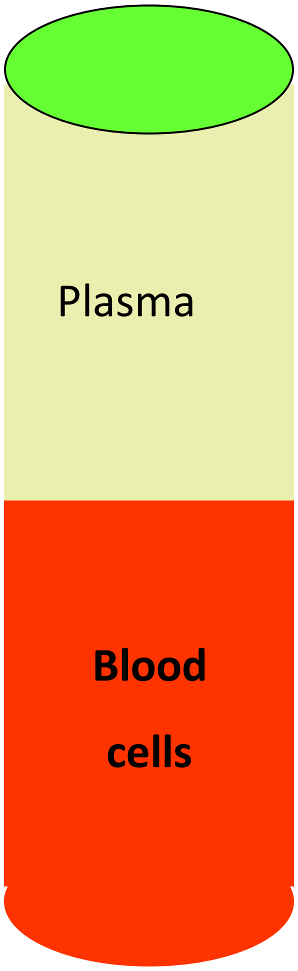
One kind of mixture is **a solution**. A solution is a mixture of two or more substances in which one of these substances **(the solute)** is **dissolved** in another substance such as water or another sort of liquid **(solvent). A solute** can be a gas, solid or liquid. Some **common solutions include ammonia and vinegar as well as salt water.** The amount of the solute compared to the solvent in a solution is the **concentration** of the solution. When the solvent contains the most solute it can hold, it is said to be **saturated**; if it has less solute than it can hold, it is **unsaturated**.

Suspension

A **suspension** is a mixture in which the particles that are in the suspension are able to be seen by the naked eye.

After waiting a while, the particles in a suspension will settle to the bottom of the container. For example if a test tube of blood is allowed to stand undisturbed, the blood cells will settle to the bottom of the test tube leaving a clear solution above called the **plasma.**

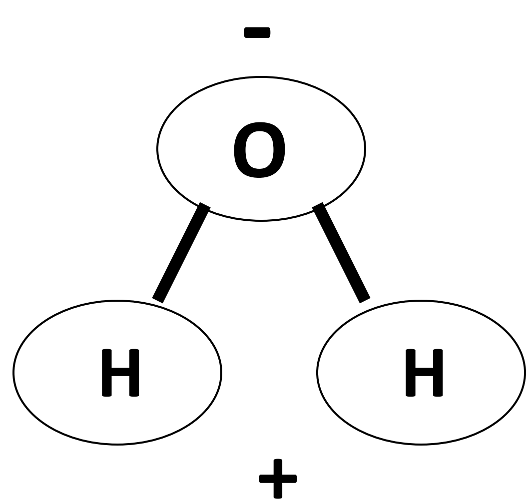
The parts of mixtures can be separated from each other by **evaporation**, **precipitation** or **filtration**.



Water

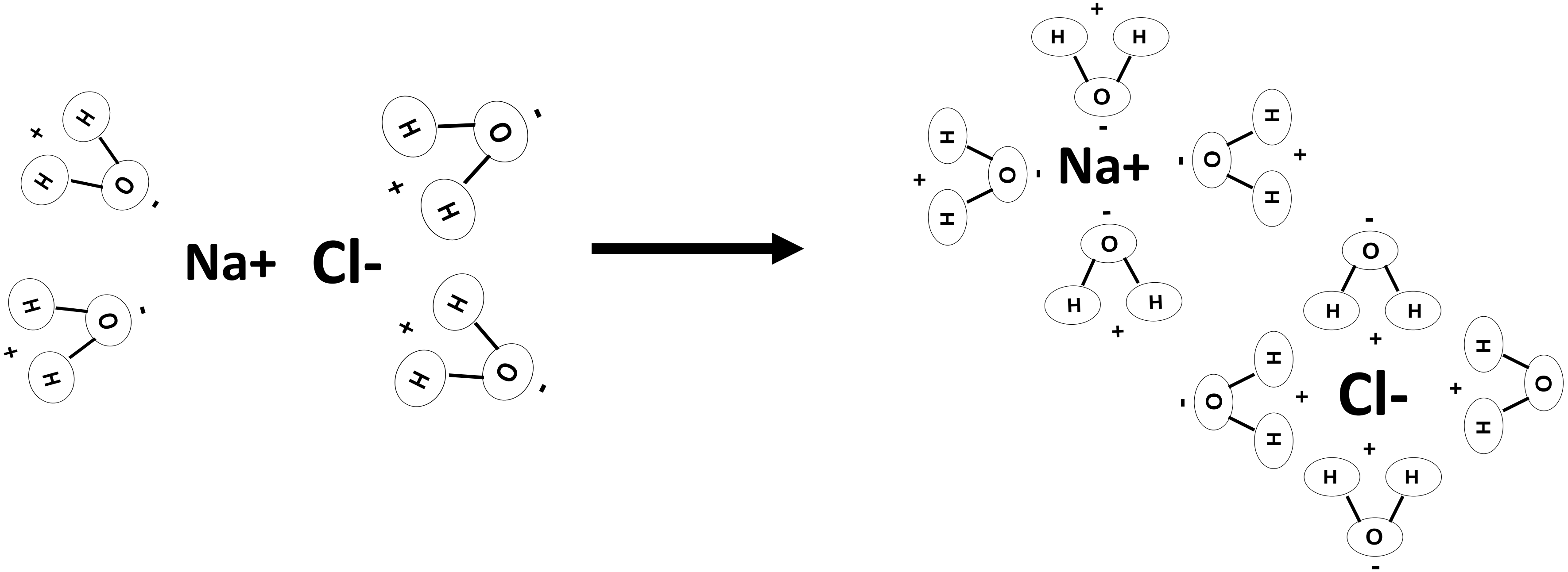
Water is the most abundant molecule in the body. Water forms the internal ocean that baths every cell of the human body. It makes up around 65% of the body weight. The water molecule is composed of one atom of oxygen and two atoms of hydrogen held together by covalent bonds.

The shape of the water molecule and the atoms in it give water a special property called polarity. This means that one end of the molecule is slightly positive while the other end is slightly negative.



Universal Solvent

The water of the body contains many substances in solution. In a solution one or more substances are dissolved. The dissolved substances are called **solutes**. The water which dissolves the solutes is called the **solvent**. Water is so effective at dissolving substances that it is referred to as the **universal solvent**. In the diagram below it can be seen how the polar water molecules surround and pull apart the ions in a molecule of sodium chloride. Notice how the negative ends of water attract sodium and the positive ends attract chloride.



An Ion

An ion is an atom or group of atoms that have a net electrical charge. An ion is formed when electrons are gained or lost by an atom. A neutral atom has equal numbers of protons and electrons so there is no net electrical charge.

A simple ion is made up of only one charged atom with either a positive or negative charge. A complex ion is one with a number of atoms with a net charge that is positive or negative. If an atom loses electrons, the ion has a positive charge. This kind of ion is called a **cation**. If an atom or atoms gain electrons, the ion will have a negative charge. This kind of ion is called an **anion**.

Examples of cations: Sodium ion (Na^{+}), **Calcium** ion (Ca^{++})

Examples of anions: Chloride ion (Cl^{-}), **Bicarbonate** ion (HCO_3^{-})

Electrolytes

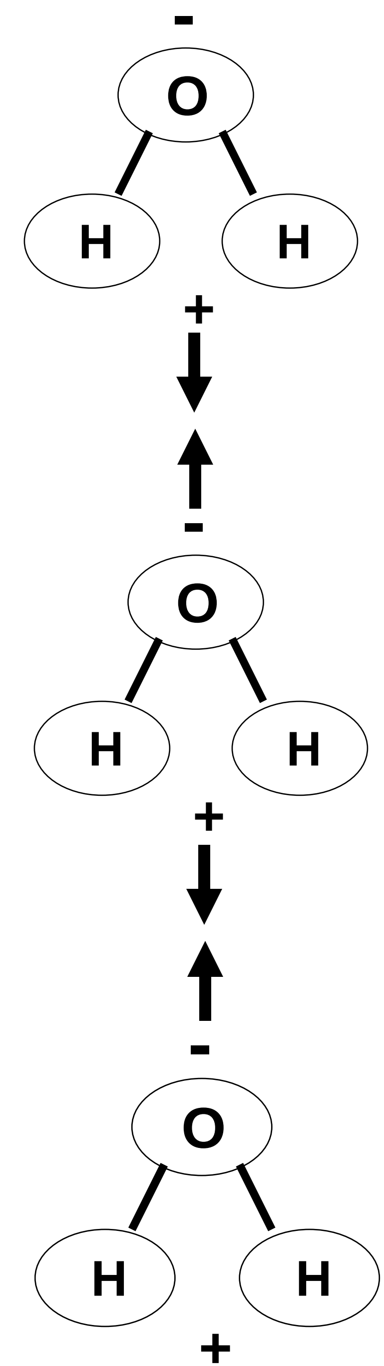
Substances that form ions in solutions are called **electrolytes.** Those that don't form ions in solutions are called **non-electrolytes**. When electrolytes such as sodium chloride dissolve in water, their ions will conduct electricity through the solution. A substance such as table sugar or sucrose will not form ions in solution and will not conduct electricity.

A demonstration in class will allow you to see if a substance is an electrolyte or not.

Polarity

When water molecules are close, they tend to attract each other because of their polarity. This attraction between water molecules is responsible for most of the properties of water.

Due to the fact that the molecules hold each other, the temperature of water does not rise or fall very easily. Since the blood is 92% water, this attraction also makes water an excellent material to transport **nutrients** and **wastes** through the blood.

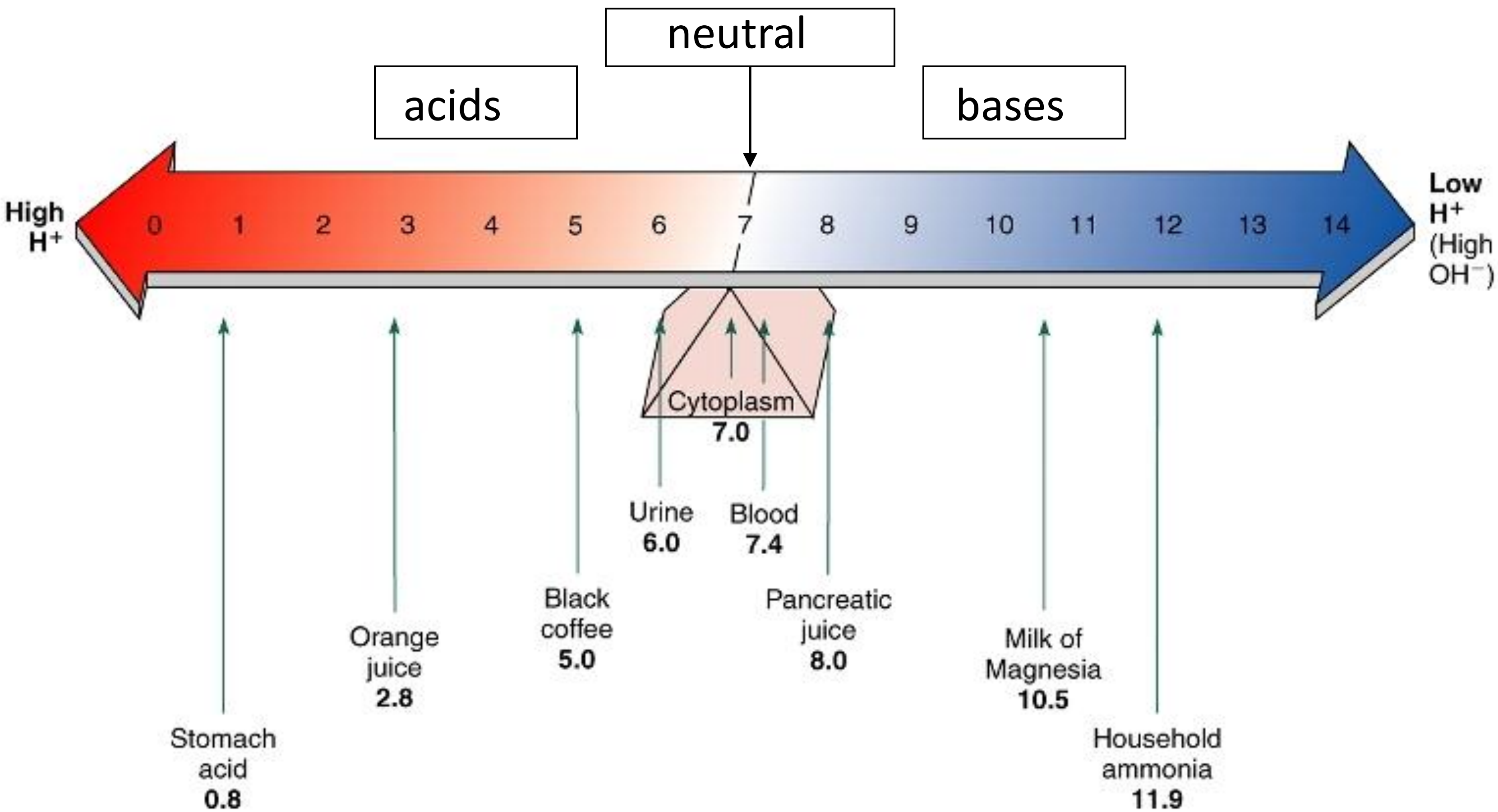


pH Scale

The **pH scale** is a shorthand method of describing the concentration of hydrogen ions in any solution. The pH scale uses numbers from 0 to 14. A solution with a pH number below 7 has an excess concentration of **hydrogen ions** (H+) and is referred to as an **acid**. If the pH number is greater than 7, the solution has an excess of **hydroxide ions** (OH^-) and is called **basic or alkaline**. A substance, such as water, with equal concentrations of hydrogen and hydroxide ions has a pH of 7 and is said to be **neutral**. Notice that the normal pH of the blood is 7.4.

The pH Scale

The diagram below indicates the pH values of some body fluids and household liquids.



Acids and Bases

Acids in water solutions show certain properties. They taste **sour** and turn **litmus paper** red. They react with metals like **zinc** to give off hydrogen.

Bases in water solutions also show certain properties or characteristics. They taste **bitter** and turn litmus paper blue. They also have a slimy or slippery texture to them.

Differences in Acids and Bases in Solutions	
Acids	**Bases**
Tastes sour	Tastes bitter
Turns litmus paper red	Turns litmus paper blue
Reacts with some metals to give off hydrogen gas.	Feels slimy or slippery to the touch.

Acids and Bases

Water molecules can breakdown or **dissociate** into hydrogen and hydroxide ion ions as seen below:

$$\mathbf{HOH} \rightleftharpoons \mathbf{H^{+}} + \mathbf{OH^{-}}$$

hydrogen ion hydroxide ion

When a water molecule dissociates equal numbers of these ions are produced. When hydrochloric acid molecules dissociate:

$$\mathbf{HCl} \rightleftharpoons \mathbf{H^{+}} + \mathbf{Cl^{-}}$$

chloride ion

This produces an excess of hydrogen ions. A substance that forms an excess of hydrogen ions is called an **acid**. A substance that forms an excess of hydroxide ions when it dissociates, such as **NaOH,** is called a **base** or **alkaline** substance.

Organic Chemistry

Organic chemistry is the study of compounds containing **carbon**. All organic molecules contain carbon. In order to understand life processes, it is necessary to have an understanding of organic chemistry. This is because living organisms are made up of organic molecules and use organic molecules to function.

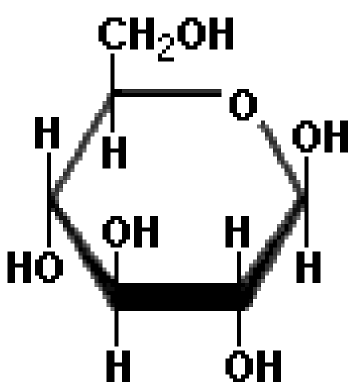
The chief reason why carbon is so important to organic chemistry and life is due to its ability to form chemical bonds with four other atoms, including other carbon atoms. This allows carbon to form a great variety of organic compounds. There are four basic groups of organic compounds in the body: **Carbohydrates, Lipids (fats), Proteins and Nucleic acids.**

Organic Substances of the Body

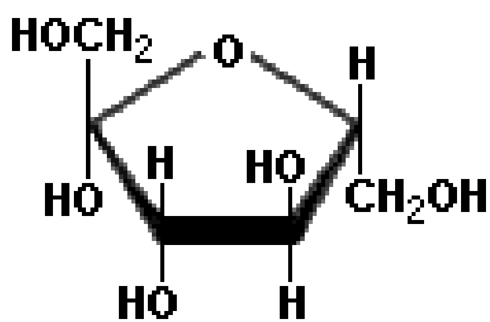
Organic Compound	Elements	Building Blocks
Carbohydrates	Carbon, Hydrogen and Oxygen	Simple sugars **(monosaccharides**)
Lipids	Carbon, Hydrogen and Oxygen	**Glycerol** and **Fatty Acids**
Proteins	Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus and **Sulfur**	**Amino Acids**
Nucleic Acids (DNA and RNA)	Carbon, Hydrogen, Oxygen, **Nitrogen** and **Phosphorus**	Nucleotides

Carbohydrates – The Monosaccharides

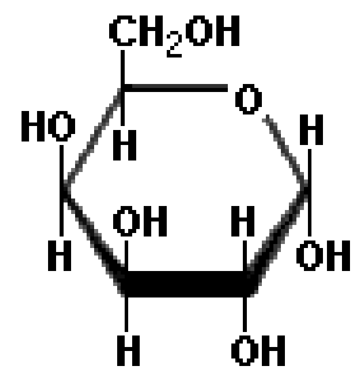
A **carbohydrate** is a compound containing the elements carbon, hydrogen and oxygen in which the ratio of hydrogen to oxygen is the same as in water – two hydrogen's to one oxygen. The basic building blocks of carbohydrate molecules are the **monosaccharides** –**glucose, fructose and galactose.**



glucose



fructose

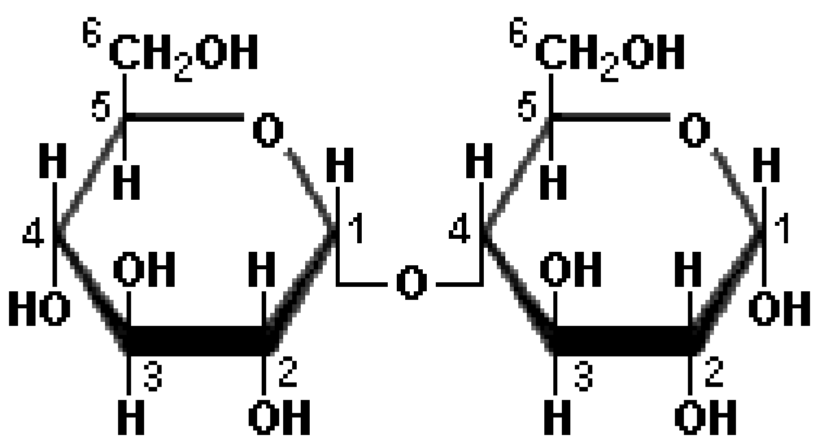


galactose

Carbohydrates – The Disaccharides

Two monosaccharides can form a covalent bond between them to form a **disaccharide sugar**. There are three kinds of disaccharides. **Sucrose** is a compound containing a glucose joined to a fructose. Sucrose is commonly called table sugar.

Maltose is a disaccharide containing two glucose molecules held together by a covalent bond. **Lactose is** a sugar found in milk formed by the combination of glucose and **galactose.**



Molecule of Maltose sugar

Carbohydrates – The Polysaccharides

When many monosaccharide molecules are joined together with covalent bonds, we have a **polysaccharide.** **Glycogen** is a polysaccharide containing many hundreds of monosaccharide subunits. Glycogen is a food stored in the body for energy.

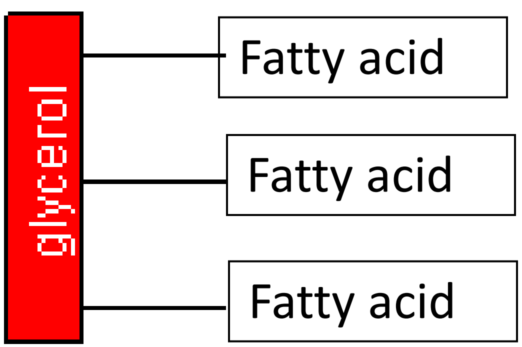
An important structural polysaccharide is **cellulose.** Cellulose is in wood and the cell walls of plants. You know that shirt you're wearing? If it is cotton, that's cellulose, too! Even though cellulose is formed from sugar, we cannot digest it. Do you know of an animal that can digest plant cellulose?

Polysaccharides are also found in the shells of such crustaceans as crabs and lobsters as a material called **chitin.**

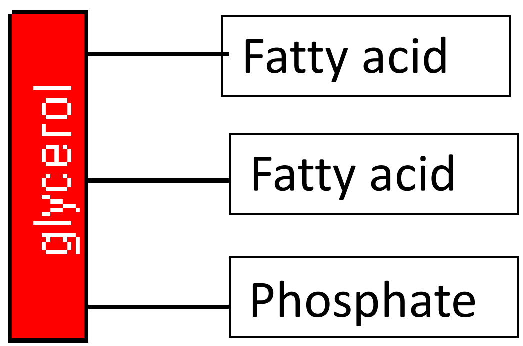
Polysaccharide

Organic Chemistry - Lipids

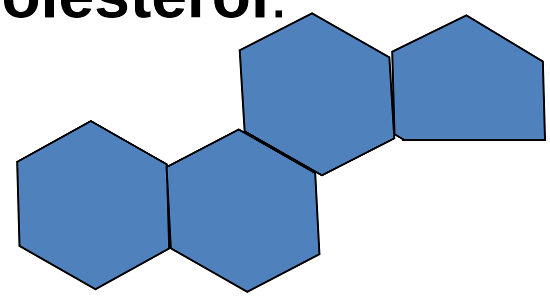
Lipids or fats are organic compounds containing carbon, hydrogen and oxygen. Lipids are essential structural components of all cells especially the **cell membranes**. Lipids also represent an important energy reserve molecule. **Gram** for gram, lipids provide twice as much energy as carbohydrates. Three important lipids in the body are: **triglycerides, phospholipids and cholesterol**.



Triglyceride



Phospholipid

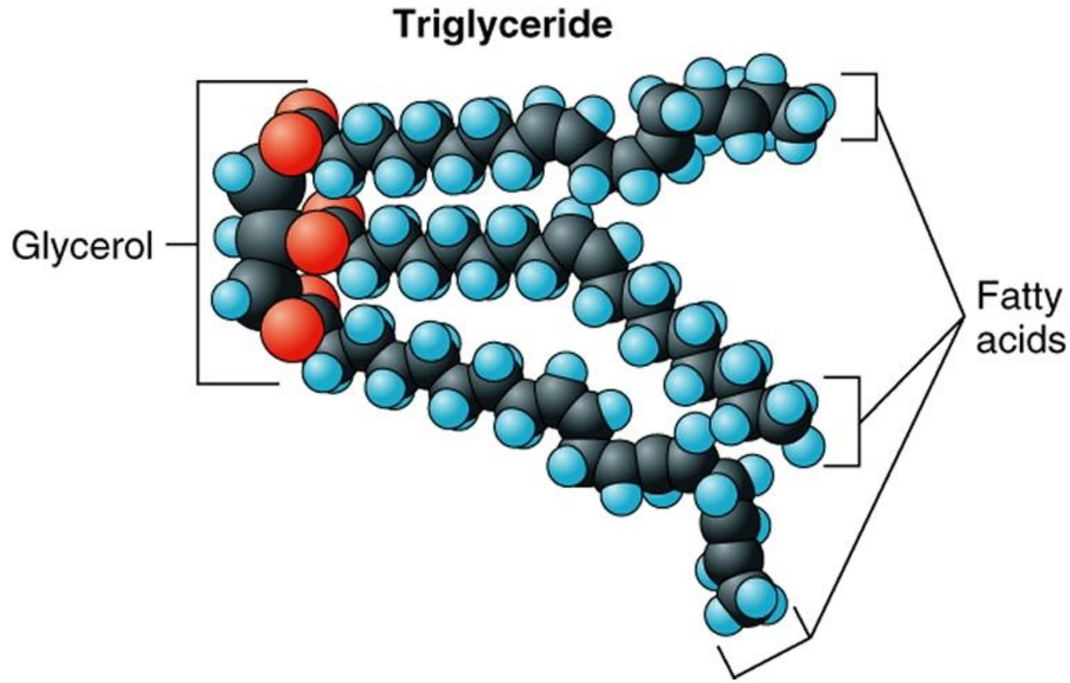


Cholesterol

Triglycerides

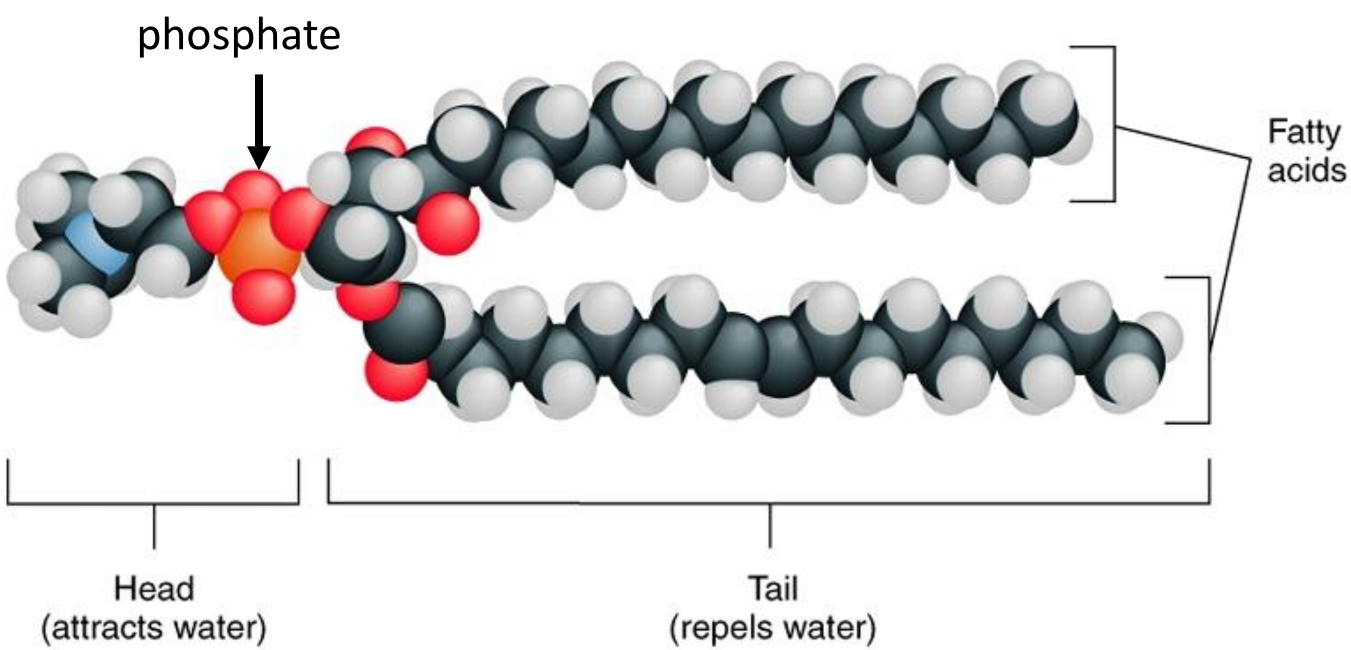
Triglycerides are lipid molecules formed from two building blocks, **glycerol** and three **fatty acids**. Triglycerides store a great deal of energy for the body.

When the covalent bonds between the atoms in a triglyceride molecule are broken down, energy is released for life activities.



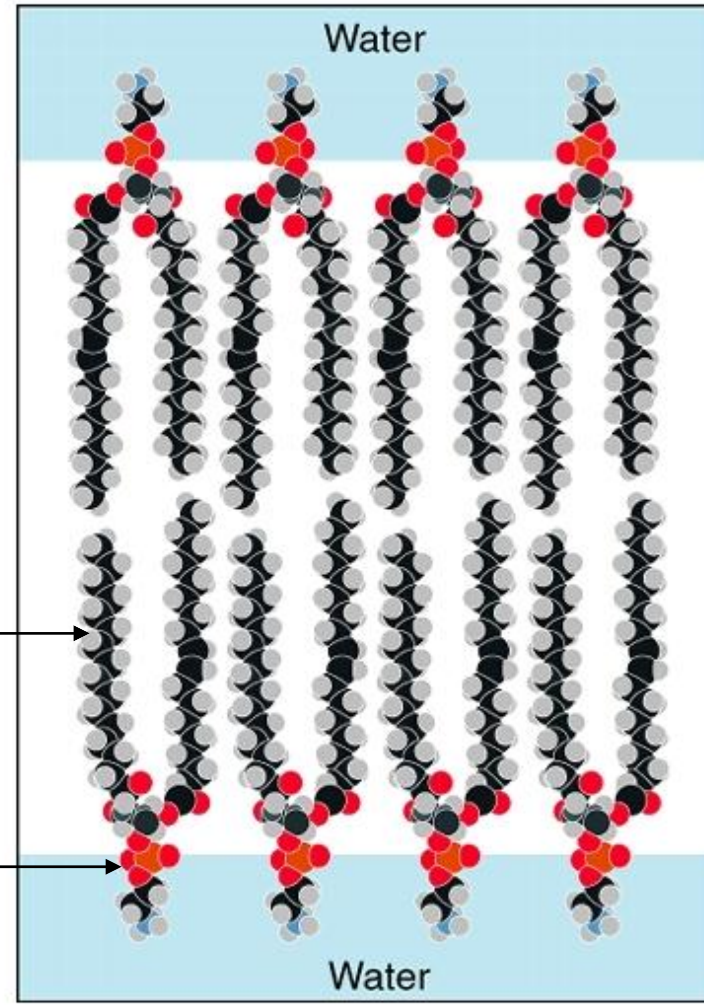
Phospholipids

The **phospholipid** molecule is similar to a triglyceride except that the third fatty acid is replaced by a **phosphate group**. Phosphate consists of one phosphorus and four oxygen atoms. The phosphate end of the molecule will dissolve in water and is said to be **hydrophilic** ("likes water"). The fatty acid end of the molecule repels water and is called **hydrophobic** ("fears water").



Phospholipid bilayer

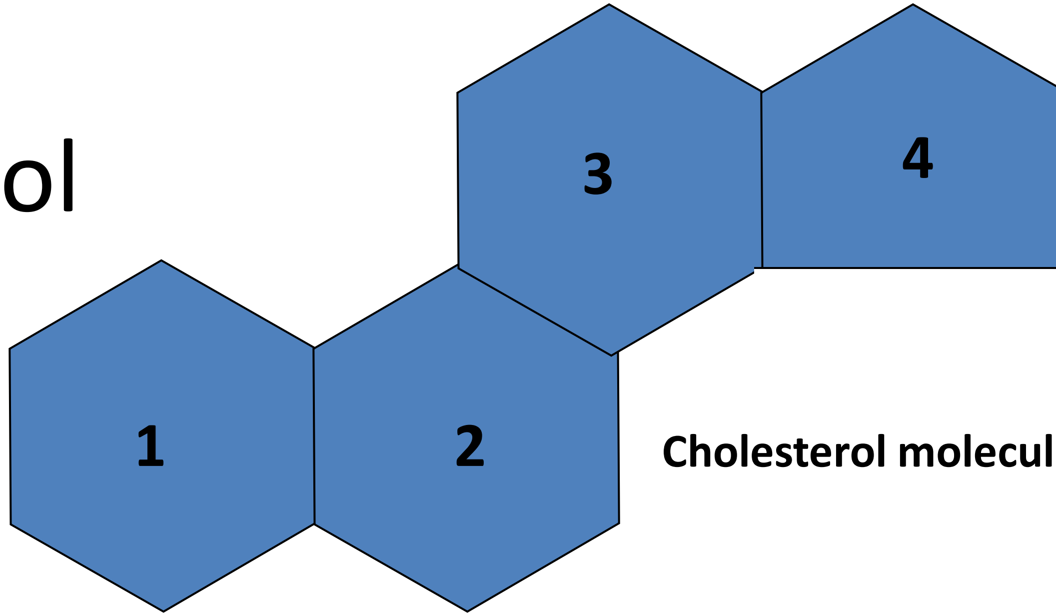
When phospholipid molecules are mixed in water, they will form a stable **bilayer** structure with the phosphate heads facing the water and the water “fearing” fatty acid tails facing each other. This **phospholipid bilayer** arrangement is the basic structure of the cell membrane.



Hydrophobic tails

Hydrophilic heads

Cholesterol



Cholesterol molecule

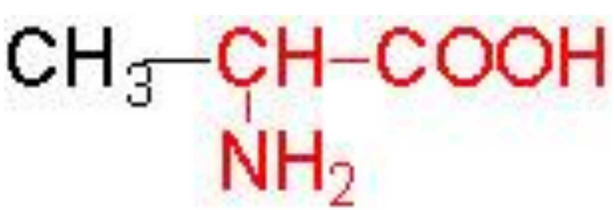
Cholesterol is an unusual type of lipid. It is made up of four rings (1, 2, 3, 4) of carbon atoms joined together by covalent bonds. Cholesterol is needed for the structure of the **plasma membranes** of cells. It is also used to manufacture a class of hormones called the **steroids**. Many baseball and football players have been accused of using steroids to illegally increase their strength.

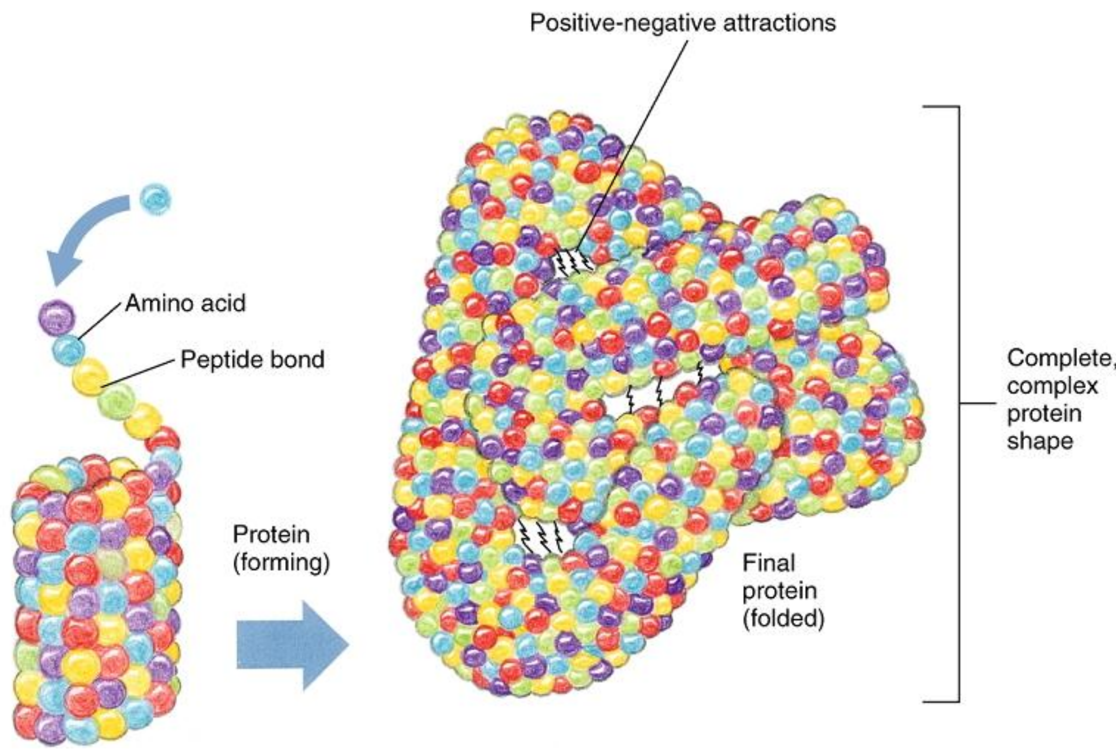
Some people have a problem with too much cholesterol in their blood. High cholesterol and triglycerides in the blood are a major cause of **heart disease**

Organic Chemistry – The Proteins

Proteins are very large, complex molecules composed of the elements carbon, hydrogen, oxygen and nitrogen. Other elements are found in proteins in very small amounts. Protein molecules are constructed from building blocks called **amino acids**. There are twenty different kinds of amino acids. As amino acids are joined to each other with special covalent **peptide bonds**, the protein molecule grows larger and its shape becomes more and more complex. An example of a very complex protein would be **hemoglobin** found in the red blood cells.

Typical amino acid





The Proteins - Functions

Proteins carry out a wide range of functions in the body:

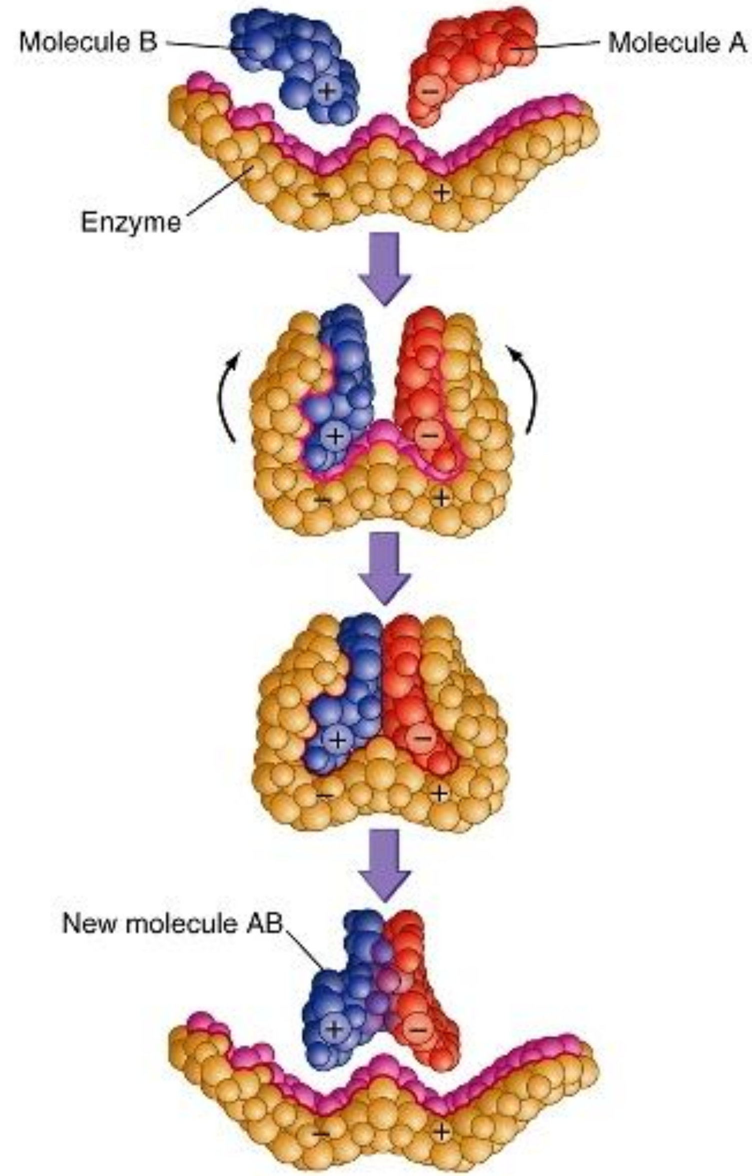
1. **Collagen** and **keratin** are structural proteins. Collagen holds the **tissues** together throughout the body and strengthens **ligaments** and **tendons.**
2. Keratin is a protein that toughens and waterproofs the skin.
3. Many hormones that regulate body functions are proteins.
4. The proteins **actin** and **myosin** permit our **muscles** to contract.
5. Hemoglobin is a blood protein that transports oxygen and carbon dioxide throughout the body.
6. **Antibodies** are proteins in the blood and body fluids that help to fight infections.
7. **Enzymes** are a special class of proteins that assist other chemicals to react with each other. These reactions are the basis of all life chemistry.

Enzymes

Enzymes are referred to as **catalysts.** A catalyst is a substance that assists other chemical reactions to occur without being chemically changed itself.

In the example to the right, molecule A and molecule B are joined together to form a new substance AB. Enzymes are needed to permit every chemical reaction in the body to occur.

The most important characteristic of an enzyme molecule is its shape. The shape of the enzyme molecule must fit the shape of the specific molecules the enzyme works on like a key fits into a lock.



Basic Enzyme Reaction

A basic **enzyme reaction** must have the following components:

1. The **substrate** – the material that the enzyme will act upon.
2. The **enzyme** – the catalyst that allows the reaction to occur.
3. The **products** – the substances produced through the reaction of the enzyme with the substrate.

An example of the action of a typical enzyme would be the reaction produced when the enzyme **catalase** is exposed to **hydrogen peroxide**.

$$\textbf{Hydrogen peroxide} \xrightarrow{\textbf{Catalase}} \textbf{Water + Oxygen}$$

Catalase is found in all animal tissues. This reaction is commonly seen when peroxide is applied to an open wound. The release of oxygen in the wound kills dangerous **germs**.

Enzyme Characteristics

1. Enzymes are used to regulate the rate (speed) of chemical reactions.

2. All enzymes are proteins, but not all proteins are enzymes.

3. Each chemical reaction in an organism requires its own specific enzyme.

4. Each chemical that is worked on by an enzyme is called a **substrate.**

5. Each enzyme can also be called an organic **calalyst.**

6. Enzymes are never changed by their reactions! They are reusable

Basis of Enzyme Action

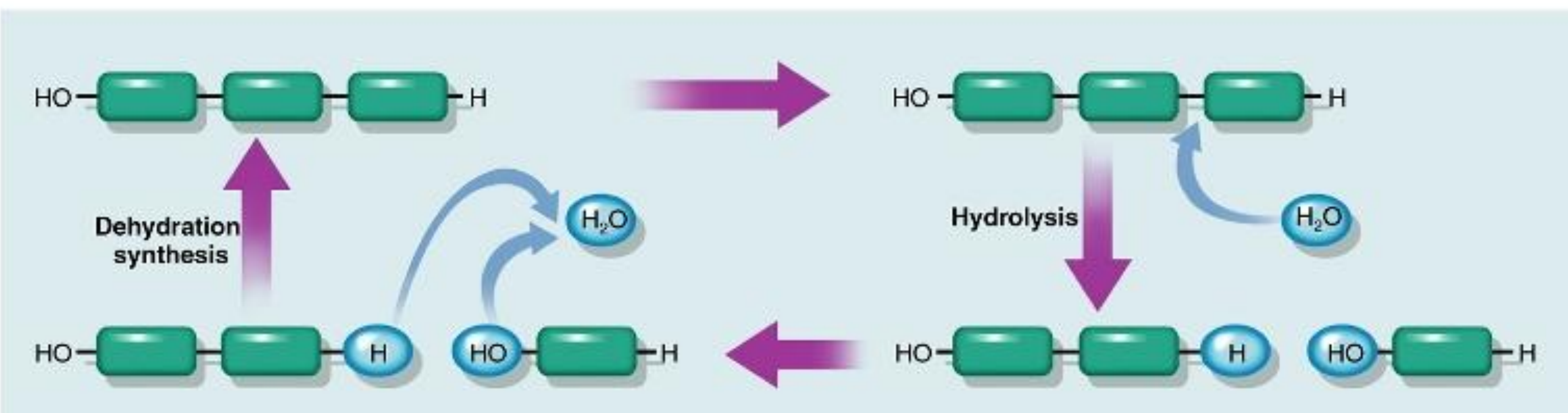
Each enzyme has a specific area for linking up with its own specific substrate. This is called an **active site** (the place where substrate and enzyme are attached)

THE LOCK AND KEY MODEL

1.) An enzyme and substrate that are compatible link up at the active site. The shapes of the enzyme and substrate fit together like a lock and key
2.) This forms the **enzyme-substrate complex** where the enzyme goes to work (can put together or take apart a substrate.)
3.) The enzyme and products separate: the enzyme is ready to work on another substrate.

Examples of Enzyme Activities – Dehydration Synthesis and Hydrolysis

Two very common chemical reactions assisted by enzymes are **dehydration synthesis** and **hydrolysis**. When the subunits of carbohydrates, lipids and proteins are being put together to form larger molecules, water is removed by the action of an enzyme. This process is called dehydration synthesis. When large organic compounds are being broken down into their subunits, an enzyme controlled reaction adds water between the subunits. This is called hydrolysis.



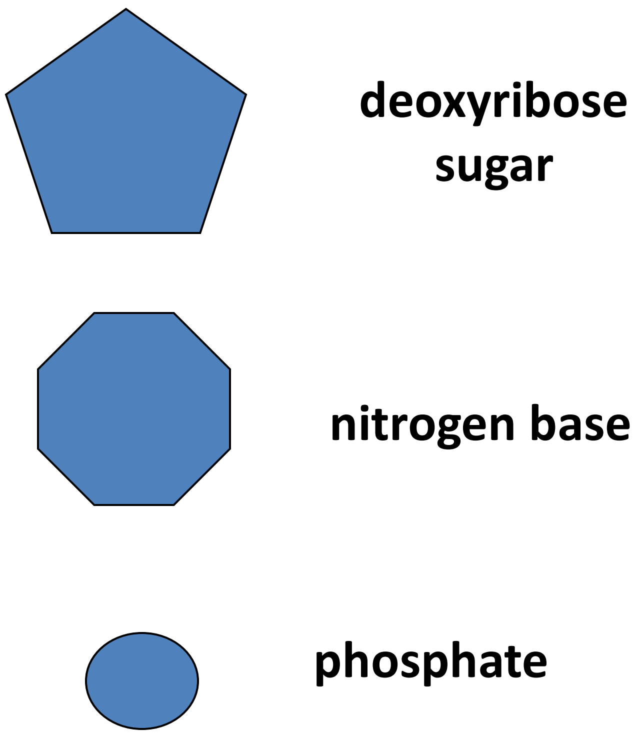
The Nucleic Acids – DNA and RNA

Deoxyribonucleic acid (DNA) is a very complex double stranded molecule which stores all of the information needed by the cell and the entire organism to carry out life activities. DNA is found primarily in the **nucleus** of the **cell**.

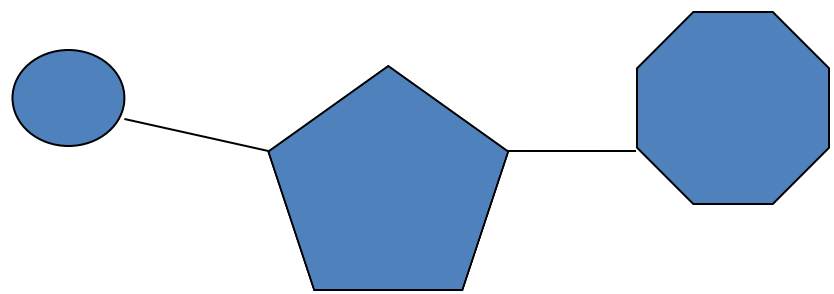
Ribonucleic acid (RNA) is a single stranded molecule which is found in several locations within the cell. RNA carries a copy of the coded information in DNA to the place in the cell where that information will be used to manufacture enzymes needed to allow all of the chemical processes of life to occur in the cell.

Deoxyribonucleic Acid - DNA

DNA is a very large molecule **(macromolecule)** which stores hereditary information that controls the activities of every cell of the body. DNA is built up from building blocks called **nucleotides**. A nucleotide is made up of three kinds of particles: a sugar molecule, a **nitrogen base** and a phosphate.

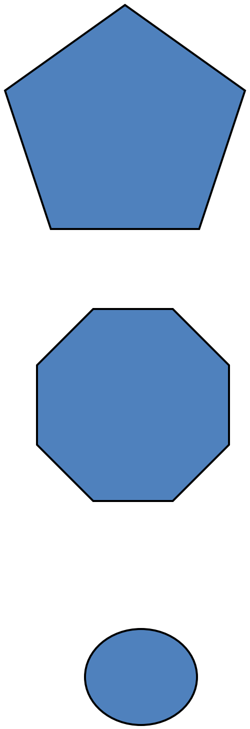


A DNA Nucleotide



Ribonucleic Acid - RNA

RNA can be thought of as one half of a DNA molecule which carries coded hereditary information from the nucleus of the cell to the **cytoplasm**. RNA is built up from building blocks called nucleotides. A nucleotide of RNA is made up of three kinds of particles: a **ribose sugar** molecule, a nitrogen base and a phosphate.

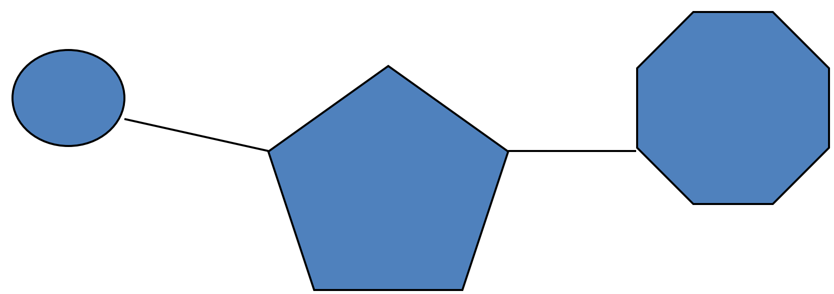


ribose sugar

nitrogen base

phosphate

An RNA Nucleotide



Structure of DNA

There are four kinds of nitrogen bases in DNA: **adenine, guanine, cytosine and thymine**. The nucleotides containing these bases are put together to form a structure called a **double helix**. A double helix has the shape of a ladder that has been twisted lengthwise so that the sides of the ladder coil around each other. The sides of the ladder are formed by sugar and phosphate groups. The rungs of the ladder consist of nitrogen bases.