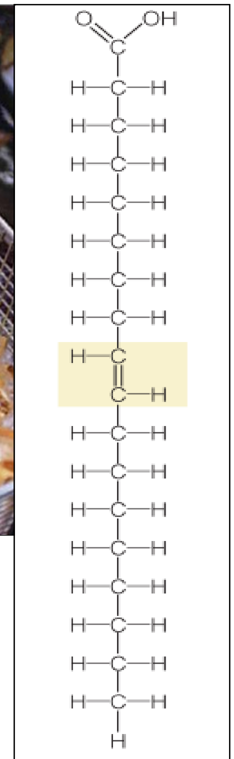
Lecture 4 & 5: Chemistry of life

Fear of frying…

The human body requires only about a tablespoon of fat each day to stay healthy, but most people in developed countries eat far more than that. The average American consumes the equivalent of one stick of butter per day—about 100 pounds of fat per year—which may be part of the reason why the average American is overweight. Being overweight increases one's risk for many health conditions. However, **the total quantity of fat we eat may be of less importance to health than the kinds of fats we eat.**



trans fatty acid

Fats are more than just inert molecules that accumulate in strategic areas of our bodies. They are major constituents of cell membranes, and as such they have powerful effects on cell function. The typical fat molecule has three fatty acids, which have long chains of carbon atoms. Different fats consist of different fatty acids. **Fats with a certain arrangement of hydrogen atoms around that carbon chain are called trans fats.** Small amounts of trans fats occur naturally in red meat and dairy products, but most of the trans fats that humans eat come from partially hydrogenated vegetable oil, an artificial food product.

For decades, hydrogenated vegetable oil was considered healthier than animal fats because it was made from plants. We now know otherwise. The trans-fats in hydrogenated vegetable oils raise the level of cholesterol in our blood more than any other fat, and they directly alter the function of our arteries and veins. The effects of such changes are quite serious. Eating as little as 2 grams a day of hydrogenated vegetable oils increases a person's risk of atherosclerosis (hardening of the arteries), heart attack, and diabetes. A small serving of french fries made with hydrogenated vegetable oil contains about 5 grams of trans fats.

All organisms consist of the same kinds of molecules, **but small differences in the way those molecules are put together can have big effects in a living organism..**

Start with atoms…

Quick Definitions

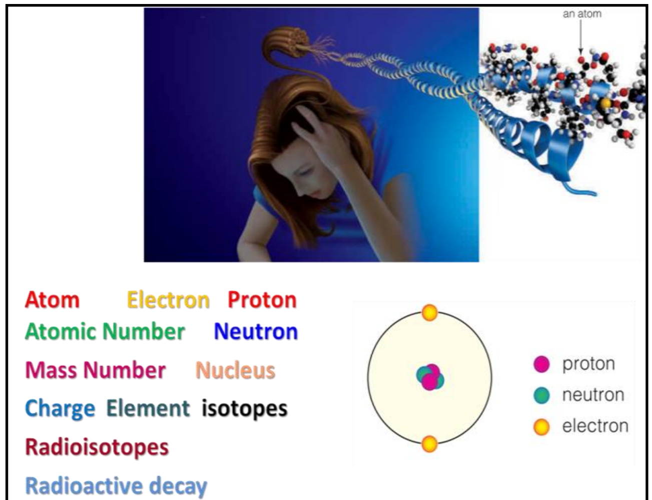


Figure: start with a macromolecule e.g. hair is made up of protein macromolecule called Keratin, then work your way down to atoms.

Atom : Particle that is a fundamental building block of matter.

Atomic number: Number of protons in the atomic nucleus; determines the element.

Charge: Electrical property of some subatomic particles. Opposite charges attract; like charges repel.

Electron: Negatively charged subatomic particle that occupies orbitals around the atomic nucleus.

Element: A pure substance that consists only of atoms with the same number of protons.

Isotopes Forms of an element that differ in the number of neutrons their atoms carry.

Mass number Total number of protons and neutrons in the nucleus of an element's atoms.

Neutron Uncharged subatomic particle in the atomic nucleus.

Nucleus Core of an atom; occupied by protons and neutrons.

Proton Positively charged subatomic particle that occurs in the nucleus of all atoms.

Radioactive decay Process by which atoms of a radioisotope spontaneously emit energy and subatomic particles when their nucleus disintegrates.

Radioisotope Isotope with an unstable nucleus.

Recognizing difference between Atoms, Elements and Isotopes:

Life's unique characteristics start with the properties of different **atoms**, tiny particles that are building blocks of all substances. Even though they are about 20 million times smaller than a grain of sand, atoms consist of even **smaller subatomic particles** positively charged protons (p+), uncharged neutrons, and negatively charged electrons (e~).

Charge is an electrical property: Opposite charges attract, and like charges repel. Protons and neutrons cluster in an atom's central core, or nucleus, and electrons move around the nucleus. Atoms differ in the number of subatomic particles. The number of protons in an atom's nucleus is called the **atomic number**, and it determines the type of atom, or element. **Elements** are pure substances, each consisting only of atoms that have the same number of protons in their nucleus.

For example, the atomic number of carbon is 6, so all atoms with six protons in their nucleus are carbon atoms, no matter how many electrons or neutrons they have. A chunk of carbon consists only of carbon atoms, and all of those atoms have six protons. Each of the 118 known elements has a symbol that is an abbreviation of its Latin name. Carbon's symbol, C, is from carbo, the Latin word for coal. Coal is mostly carbon.

Carbon and all other elements occur in different forms, or isotopes, that differ in their number of neutrons. We refer to an **isotope** by its total number of protons and neutrons, which is the isotope's mass number. Mass number is shown as a superscript to the left of an element's symbol. For example, atoms of the most common carbon isotope, ^{12}C, have six protons and six neutrons; those of ^{14}C have six protons and eight neutrons (6 + 8=14).

^{14}C (carbon 14) is a **radioactive isotope**, or radioisotope, which means that the nucleus of a ^{14}C atom is unstable. Atoms of radioisotopes emit subatomic particles and energy when their nucleus spontaneously disintegrates. This process, **radioactive decay**, can transform one element into another. For example, ^{14}C decays when one of its neutrons splits into a proton and an electron. The proton stays in the nucleus, and the electron is emitted. Thus, an atom of ^{14}C (with six protons and eight neutrons) becomes an atom of ^{14}N, which is nitrogen (with seven protons and seven neutrons).

An atomic nucleus cannot be altered by heat or any other ordinary means. Thus, a radioisotope decays at a constant rate into predictable products, independently of external factors such as temperature, pressure, or whether the atoms are part of molecules.

For example, we know that **half Life** of the ^{14}C atoms in any sample will be ^{14}N atoms after 5,730 years. This predictability can be used to estimate the age of rocks and fossils.

Why Electrons Matters?

Electrons are really, really small. If they were as big as apples, you would be about 3.5 times taller than our solar system is wide. A typical atom has about as many electrons as protons, so a lot of electrons may be zipping around one nucleus. Those electrons never collide, despite moving at nearly the speed of light (300,000 kilometers per second, or 670 million miles per hour). They avoid one another, they travel in different orbitals, which are defined volumes of space around the nucleus.

Shell models help us visualize how electrons populate atoms. If an atom's outermost shell is full of electrons, we say that it has no vacancies. Helium is an example. Atoms of such elements are chemically inactive, which means they are most stable as single atoms. By contrast, if an atom's outermost shell has room for another electron, it has a vacancy. Hydrogen has one vacancy.

Atoms with vacancies tend to interact with other atoms: They give up, acquire, or share electrons until they have no vacancies in their outermost shell. Any atom is in its most stable state when it has no vacancies.

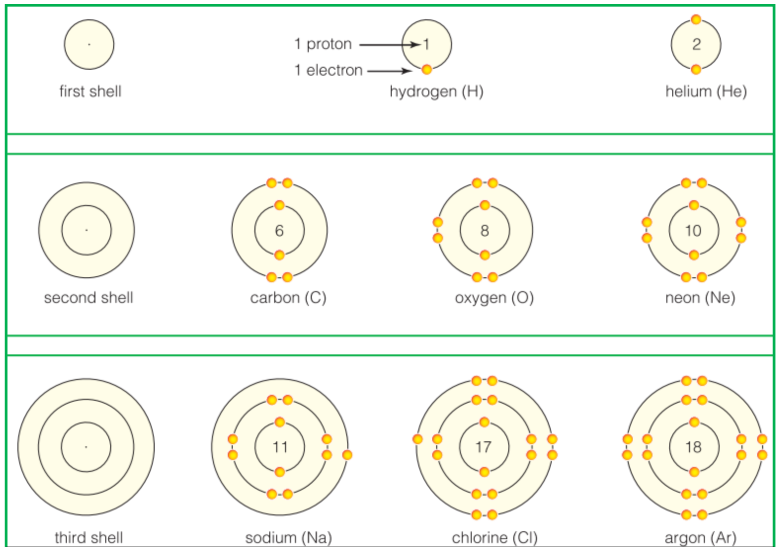


Figure: **Shell models. Each circle (shell) represents all orbitals at one energy level. A model is filled with electrons from the innermost shell out, until there are as many electrons as protons. Atoms with vacancies (room for additional electrons) in their outermost shell tend to interact with other atoms.**

Ions: The negative charge of an electron is the same magnitude as the positive charge of a proton, so the two charges cancel one another. Thus, an atom that has as many electrons as protons has no charge. An atom with different numbers of electrons and protons is called an ion. An ion carries a charge; either it acquired a positive charge by losing an electron, or it acquired a negative charge by pulling an electron away from another atom.

For example, an uncharged chlorine atom has 17 protons and 17 electrons. Seven electrons are in its outermost (third) shell, which can hold eight, so it has one vacancy. Chlorine tends to pull an electron away from another atom to fill that vacancy. When that happens, the atom becomes a chloride ion (Cl^-) with 17 protons, 18 electrons, and a net negative charge. As another example, an uncharged sodium atom has 11 protons and 11 electrons. This atom has one electron in its outer (third) shell, which can hold eight, so it has seven vacancies. A sodium atom tends to lose the single electron in its third shell. When that happens, the atom has two full shells and no vacancies. It is a sodium ion (Na^+), with 11 protons, 10 electrons, and a net positive charge.

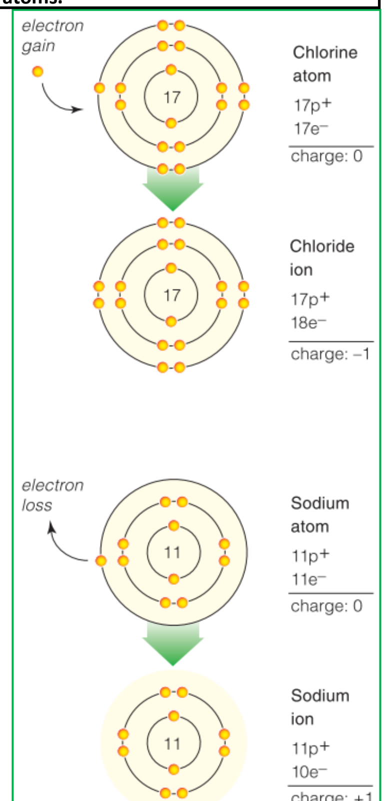


Figure **A A chlorine atom (Cl) becomes a negatively charged chloride ion (Cl–) when it gains an electron and fills the vacancy in its third, outermost shell.**
B A sodium atom (Na) becomes a positively charged sodium ion (Na+) when it loses the electron in its third shell. The atom's full second shell is now its outermost, so it has no vacancies.

From Atoms to Molecules

When we start putting elements together, we get more complex forms of matter, such as molecules and compounds. An atom can get rid of vacancies by participating in a **chemical bond**, which is an attractive force that arises between two atoms when their electrons interact. A **molecule** forms when two or more atoms of the same or different elements join in chemical bonds.

A molecule is a **group of atoms** that are bound tightly together by chemical bonds.

Compound = combination of two or more <u>different</u> elements (e.g. H_2O)

Molecules are held together by chemical bonds. The <u>proportions</u> of <u>elements</u> in a molecular substance <u>do not vary</u>. For example, <u>all water</u> molecules have <u>one</u> oxygen atom <u>bonded</u> to <u>two</u> hydrogen atoms.

Chemical Bond: *A* ***molecule*** *is a particle composed of two or more atoms*. The force that holds the atoms together in a molecule is called a chemical bond.

- *ionic bonds*
- *covalent bonds*

Molecules that consist of two or more different elements are called compounds

The same atoms bonded together in different ways make up different molecules. For example, carbon atoms bonded one way form a soft, slippery mineral called graphite. Carbon atoms bonded a different way make the hardest mineral, diamond. Carbon atoms bonded to oxygen and hydrogen atoms make sugar. The idea that different structures can be assembled from the same basic building blocks is a recurring theme in our world, and also in biology

Chemical Bonds

Although bonding applies to a range of interactions among atoms, we can categorize most bonds into distinct types based on their different properties. Which type forms depends on the atoms that take part in it. There are three types -

- Covalent
- Ionic
- Hydrogen

Chemical bonds involve atoms sharing, donating or accepting electrons.

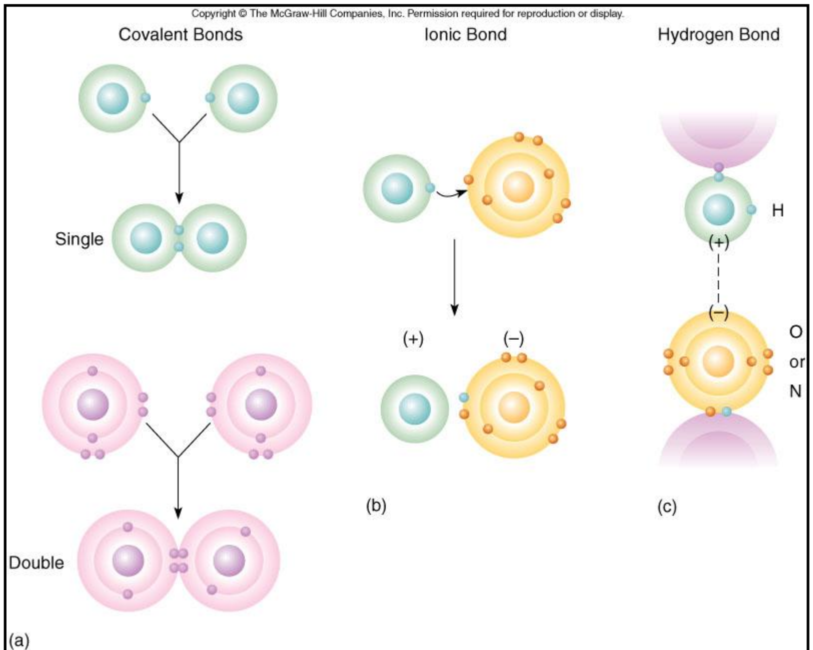


Figure: Three types of Chemical Bonds

Ionic & Covalent Bonds

Ionic Bonds

Sometimes atoms form bonds by transferring electrons. Sodium and chlorine atoms unite this way. Many atoms have a tendency to attract eight electrons into their outermost energy levels. Sodium and chlorine atoms have this tendency. This desired state could be achieved if a sodium atom transfers one electron to a chlorine atom. The transfer leaves the sodium atom with a **positive charge**. The transfer also gives the chlorine atom a **negative charge**. Atoms that have a charge, whether positive or negative, are called **ions**. Since opposite charges attract one another, the sodium ions and chloride ions are attracted to each other, forming a chemical bond.

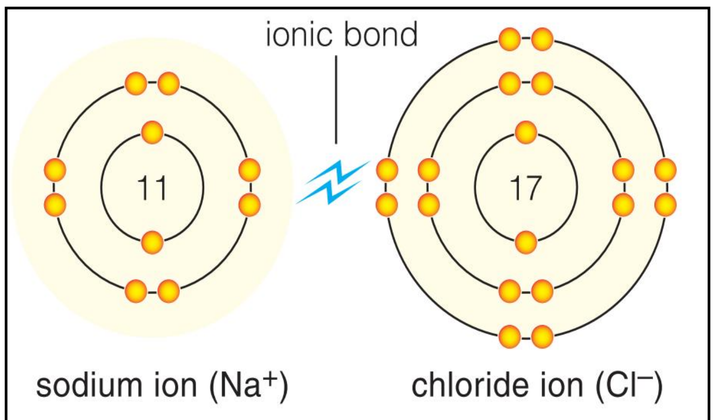


Figure: Ionic bond forms on the basis of attraction between opposite charges.

A *bond that is formed by the transfer of electrons is called an* ***ionic bond***.

Compounds that are formed by ionic bonding are called **ionic compounds**. A crystal of <u>sodium chloride</u> (table salt) is an ionic compound because it consists of a network of sodium ions and chloride ions, held together by ionic bonds.

Covalent Bonds

Atoms usually form bonds using the electrons in their outermost energy levels. In some cases, an atom shares one or more pairs of electrons from this level with another atom. The shared electrons go into new energy levels, or electron clouds, that belong to the molecule, instead of the individual atoms. *Sharing of pairs of electrons is called* ***covalent bonding***. One shared pair of electron is called a **single covalent bond**. Compounds that are formed by covalent bonding are called **covalent compounds**. The energy content of covalent bond is called **bond energy**.

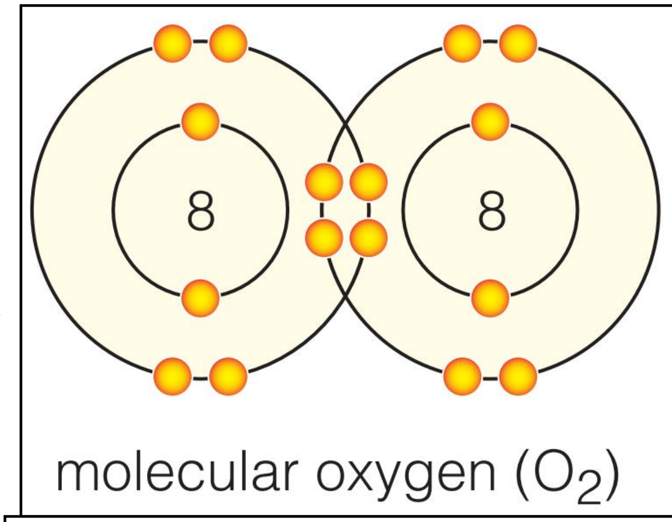
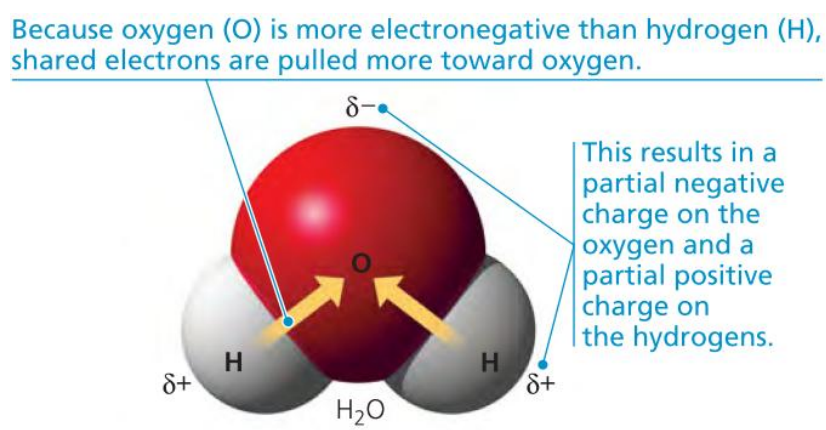


Figure: Covalent bond forms on the basis of Electronegativity.

The diatomic hydrogen molecule (H_2) is the simplest model of a covalent bond. A line between two atoms represents a single covalent bond, in which two atoms share one pair of electrons. Example is molecular hydrogen (H_2), with a single covalent bond between two hydrogen atoms (H—H, *right).* Covalent bonds can be stronger than ionic bonds, but they are not always so.

Electronegativity

Atoms in a molecule attract shared electrons to varying degrees, depending on the element. The attraction of a particular atom for the electrons of a covalent bond is called its electronegativity. The more electronegative an atom is, the more strongly it pulls shared electrons toward itself.



Two Types of Covalent Bonds

Covalent Bonds can be of two types based on polarity. Polarity occurs when atoms share electrons unequally due to differences in electronegativities. This is seen in water (H_2O). More electronegative atoms tend to pull electrons toward them creating a polar molecule.

Nonpolar Covalent Bond: The atoms participating in the bond are sharing electrons equally. There is no difference in charge between the two ends of such bonds.

Nonpolar Covalent Bond Examples: The bonds in molecular hydrogen (H2), oxygen (02), and nitrogen (N2) mentioned earlier are examples. These molecules are some of the gases that make up air. The bonds in methane (CH3), another gas, are also nonpolar.

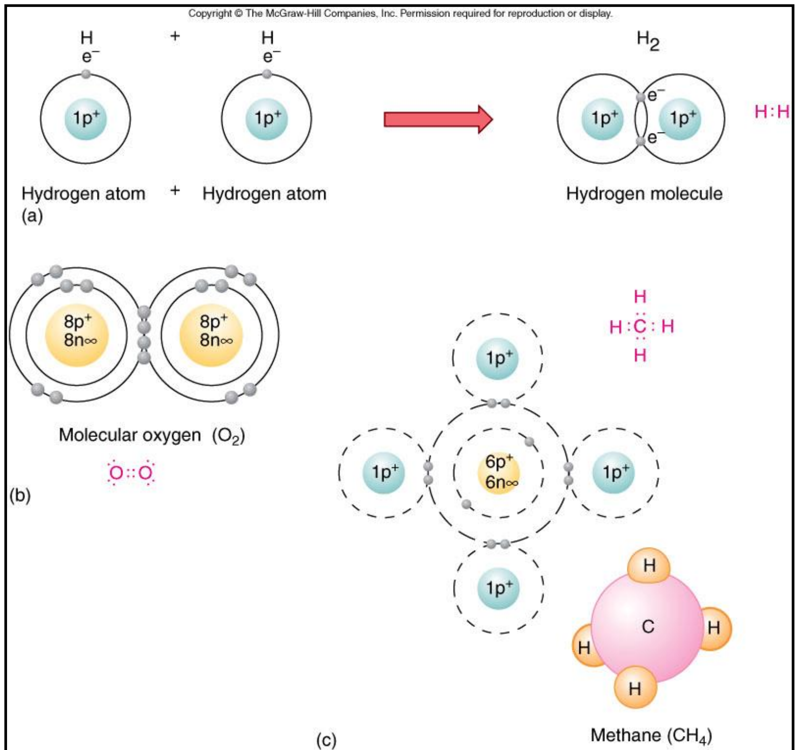


Figure: a) Non-polar covalent bond. b) double covalent bond. c) Polar Covalent bond.

Polar Covalent Bond: Atoms participating in the bonds **do not share electrons equally.**

One atom pulls the electrons a little more toward its "end" of the bond, so that atom bears a slightly negative charge. The atom at the other end of the bond bears a slightly positive charge.

Polar Covalent bond Examples: For example, a water molecule (H—O—H,) has two covalent bonds; both are polar. The oxygen atom in a water molecule carries a slight negative charge, and each of the hydrogen atoms carries a slight positive charge. Any separation of charge into distinct positive and negative regions is called **polarity.**

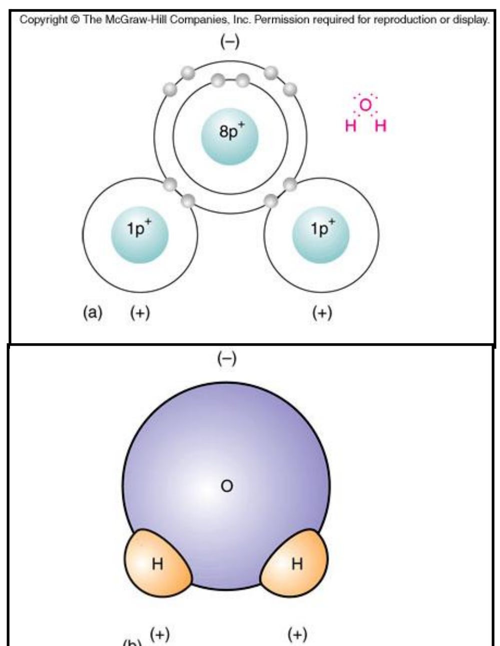


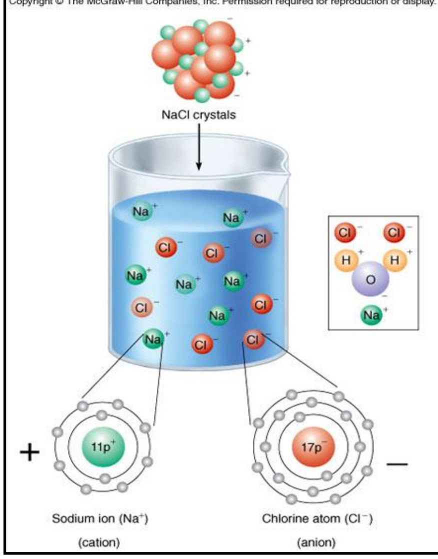
Figure: A water molecule - Two hydrogen atoms share electrons with an oxygen atom in two polar covalent bonds. The oxygen exerts a greater pull on the shared electrons, so it has a slight negative charge. Each hydrogen has a slight positive charge.

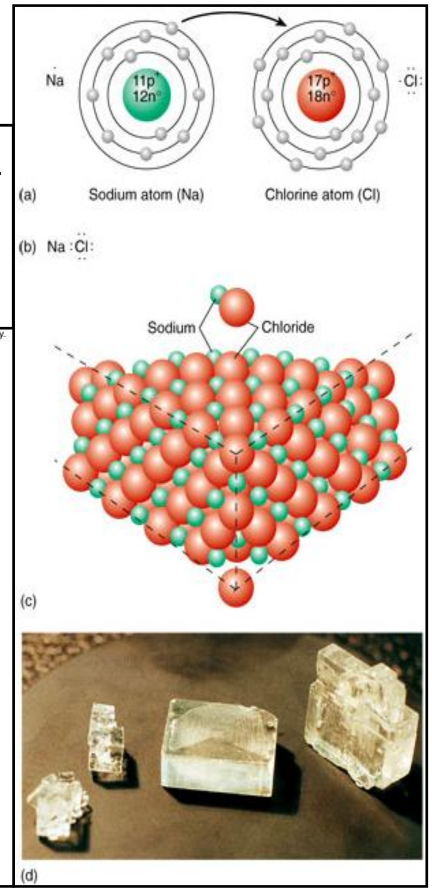
Ionic Bonding

An ionic bond do not form between atoms by transfer of an electron rather, because of their opposite charges. Sodium chloride (table salt) is an example of ionic bonding, that is, electron transfer among atoms or redox reaction.

Ionization: Molecules formed by ionic bonding breakup (ionization) when dissolved in water (solvent), producing separate positive (cation) and negative (anion) ions. These ions conduct electricity and thus called electrolytes.

Figure: (right) Sodium and Chloride form ionic bonds. Many NaCl together form a square lattice which form salt crystals. (Below) Add this NaCl to water and they separate into individual atoms (Ionization).

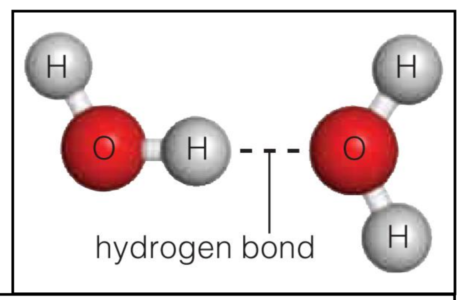




Hydrogen Bonds

- A hydrogen bond is **a weak attraction** between a **hydrogen atom** and **another atom** taking part in **a separate polar covalent bond**
- ***Like ionic bonds, hydrogen bonds form by the mutual attraction of opposite charges.***
- Unlike ionic bonds, **hydrogen bonds do not make new molecules out of atoms**, so they are not chemical bonds

Example: Hydrogen bonds form between water molecules. The hydrogen atom has a slight positive charge and the other atom has a slight negative charge.



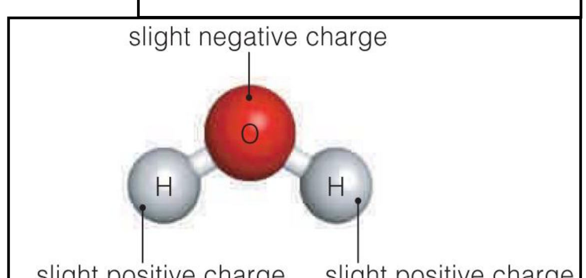


Figure: A hydrogen (H) bond is an attraction between an electronegative atom and a hydrogen atom taking part in a separate polar covalent bond.

Hydrogen bonds cannot make new molecules because they form and break much more easily than *covalent or ionic bonds do*. Even so, many of them form between molecules, or between different parts of a large one. Their collective strength imparts unique properties to many substances such as water. Hydrogen bonds that form among the atoms of biological molecules such as DNA hold these molecules in their characteristic shapes.

- Hydrogen bonding is formed between the partially positive (hydrogen) end of a polar molecule and the negative end of another (e.g. O_2 or N_2).
- Example : Water molecules

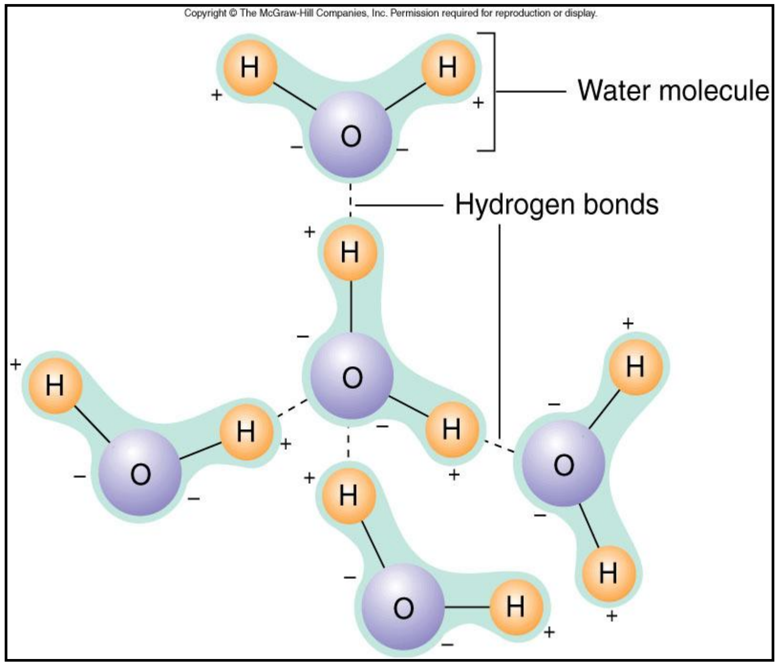
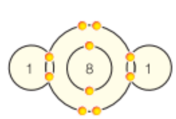


Figure: Water. Many hydrogen bonds (dashed lines) that quickly form and break keep water molecules clustered together tightly. The extensive hydrogen bonding in liquid water gives it unique properties.

Summary: From Atoms to Molecules

Common name	Water	Familiar term.
Chemical name	Dihydrogen monoxide	Systematically describes elemental composition.
Chemical formula	H_2O	Indicates unvarying proportions of elements. Subscripts show number of atoms of an element per molecule. The absence of a subscript means one atom.
Structural formula	H—O—H	Represents each covalent bond as a single line between atoms.
Structural model		Shows the positions and relative sizes of atoms.
Shell model		Shows how pairs of electrons are shared in covalent bonds.

Water and its Properties

Water's special properties as a liquid begin with the two polar covalent bonds in each water molecule. Overall, the molecule has no charge, but the oxygen pulls the shared electrons a bit more than the hydrogen atoms do. Thus, each of the atoms in a water molecule carries a slight charge: The oxygen atom is slightly negative, and the hydrogen atoms are slightly positive. The separation of charge means that the water molecule itself is polar. The polarity is very attractive to other water molecules, and hydrogen bonds form between them in tremendous numbers. Extensive hydrogen bonding between water molecules imparts unique properties to liquid water, and those properties make life possible.

First, water is an excellent solvent. A solvent is a liquid that can dissolve other substances. When a substance dissolves, its individual molecules or ions become solutes as they disperse. Salts, sugars, and many other compounds that dissolve easily in water are polar, so many hydrogen bonds form between them and water molecules. A salt is a compound that dissolves easily in water and releases ions other than H+ and OH" when it does. Hydrogen bonding with water dissolves such hydrophilic (water-loving) substances by pulling their individual molecules away from one another and keeping them apart.

You can see how water interacts with hydrophobic (water-dreading) substances if you shake a bottle filled with water and salad oil, then set it on a table and watch what happens. Salad oil consists of nonpolar molecules, and water molecules do not form many hydrogen bonds with nonpolar molecules. Shaking breaks some of the hydrogen bonds that keep water molecules together. However, the water quickly begins to cluster into drops as new hydrogen bonds form among its molecules. The bonding excludes molecules of oil and pushes them together into droplets that rise to the surface of the water. The same interaction occurs at the thin, oily membrane that separates the water inside of cells from the water outside of them. The organization of membranes—and of life—starts with such interactions.

A second property of water is temperature stability. Temperature is a way to measure the energy of molecular motion: All molecules jiggle nonstop, and they jiggle faster as they absorb heat. However, extensive hydrogen bonding restricts the movement of water molecules—it keeps them from jiggling as much as they would otherwise. Thus, compared with other liquids, water absorbs much more heat before its temperature rises. Temperature stability is an important component of homeostasis, because most of the molecules of life function properly only within a certain range of temperature.

Below 0°C (32°F), water molecules do not jiggle enough to break hydrogen bonds, and they become locked in the rigid, lattice-like bonding pattern of ice. Individual water molecules pack less densely in ice than they do in water, so ice floats on water. During cold winters, ice sheets may form near the surface of ponds, lakes, and streams. Such ice "blankets" insulate liquid water under them, so they help keep fish and other aquatic organisms from freezing.

A third life-sustaining property of liquid water is cohesion, which means that water molecules resist separating from one another. This property is important in many processes that sustain multicelled bodies. As one example, water molecules constantly escape from the surface of liquid water as vapor, a process called evaporation. Evaporation is resisted by the hydrogen bonding that keeps water molecules together. In other words, overcoming water's cohesion takes energy. Thus, evaporation sucks energy in the form of heat from liquid water, which decreases its surface temperature. Evaporative water loss can help you and some other mammals cool off when you sweat in hot, dry weather. Sweat, which is about 99 percent water, cools the skin as it evaporates.

Take-Home Message: Why is water essential to life?
Being polar, water molecules hydrogen-bond to one another and to other polar (hydrophilic) substances, and repel nonpolar (hydrophobic) substances.
Extensive hydrogen bonding between water molecules gives water unique properties that make life possible: cohesion, temperature stability, and a capacity to dissolve many substances.

DIFFUSION & OSMOSIS

Diffusion: The process by which molecules spread from areas of high concentration, to areas of low concentration.

When the molecules are even throughout a space - it is called EQUILIBRIUM.

Concentration gradient - a difference between concentrations in a space. Molecules will always move down the concentration gradient, toward areas of lesser concentration. Think of food coloring that spreads out in a glass of water, or air freshener sprayed in a room.

Selectively Permeable - membranes that allow some things through, the cell membrane is selectively permeable, water and oxygen move freely across the cell's membrane, by diffusion

Osmosis - the diffusion of water (across a membrane). Water will move in the direction where there is a high concentration of solute (and hence a lower concentration of water).

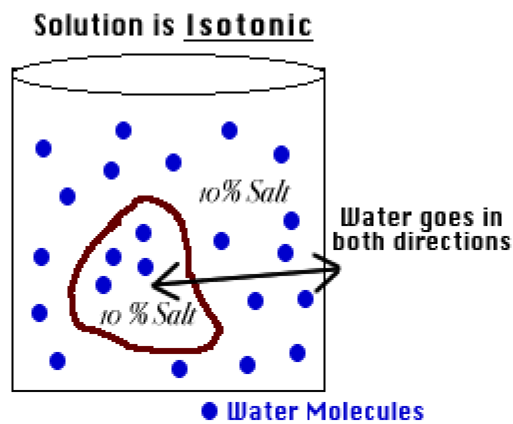
Tonicity: The effect of a solution on the osmotic movement of H_20 is known as tonicity. The tonicity of a solution has no units and is a reflection of its concentration of nonpenetrating solutes relative to the cell's concentration of nonpenetrating solutes.

Type of Solutions

Isotonic Solutions

If the concentration of solute (salt) is equal on both sides, the water will move back in forth but it won't have any result on the overall amount of water on either side.

"ISO" means the same

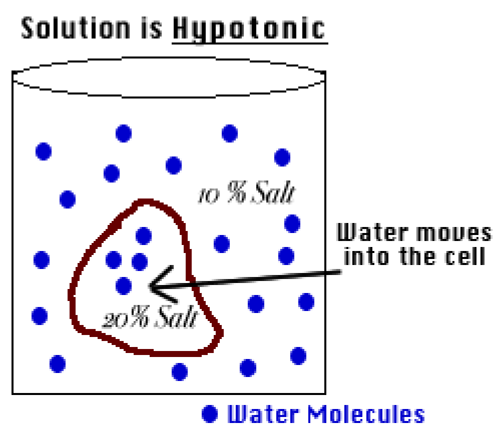


Hypotonic Solutions

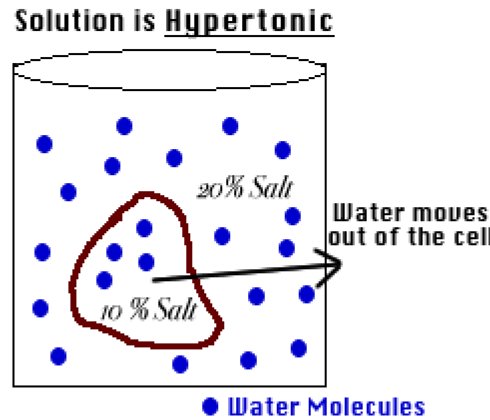
The word "**HYPO**" means less, in this case there are less solute (salt) molecules outside the cell, since salt sucks, water will move into the cell.

The cell will gain water and grow larger. In plant cells, the central vacuoles will fill and the plant becomes stiff and rigid, the cell wall keeps the plant from bursting

In animal cells, the cell may be in danger of bursting, organelles called **CONTRACTILE VACUOLES** will pump water out of the cell to prevent this.



Hypertonic Solutions



The word "**HYPER**" means more, in this case there are more solute (salt) molecules outside the cell, which causes the water to be sucked in that direction.
In plant cells, the central vacuole loses water and the cells shrink, causing wilting. In animal cells, the cells also shrink.In both cases, the cell may die. This is why it is dangerous to drink sea water - its a myth that drinking sea water will cause you to go insane, but people marooned at sea will speed up dehydration (and death) by drinking sea water. This is also why "salting fields" was a common tactic during war, it would kill the crops in the field, thus causing food shortages.

<u>Diffusion and Osmosis are both types of **PASSIVE TRANSPORT** - that is, no energy is required for the molecules to move into or out of the cell.</u>

Osmotic pressure is the pressure which needs to be applied to a solution to prevent the inward flow of water across a semipermeable membrane. It is also defined as the minimum pressure needed to nullify osmosis.
The phenomenon of osmotic pressure arises from the tendency of a pure solvent to move through a semi-permeable membrane and into a solution containing a solute to which the membrane is impermeable. This process is of vital importance in biology as the cell's membrane is selective toward many of the solutes found in living organisms.

pH: pH is a unit of measure which describes the degree of acidity or alkalinity (basic) of a solution. It is measured on a scale of 0 to 14. The formal definition of pH is the negative logarithm of the hydrogen ion activity. $pH = -\log[H^+]$

The pH value of a substance is directly related to the ratio of the hydrogen ion and hydroxyl ion concentrations. If the H^+ concentration is higher than OH^- the material is acidic. If the OH^- concentration is higher than H^+ the material is basic. 7 is neutral, < is acidic, >7 is basic.

Acids and Bases
Acids give up hydrogen ions when they dissolve in water, so they lower the pH of fluids and make them acidic (below pH 7).
Bases accept hydrogen ions, so they can raise the pH of fluids and make them basic, or alkaline (above pH 7).
Buffers are solutions that have constant pH values and the ability to resist changes in pH.

Environmental Concern: Acids or bases that accumulate in the environment can be harmful to organisms because they change the pH of fluids in an ecosystem. For instance, fossil fuel emissions and nitrogen-containing fertilizers release strong acids into the atmosphere. The acids make rain acidic, which in turn can drastically change the pH of water and soil. Such changes are harmful because most enzymes and other biological molecules function properly only within a narrow range of pH. Even a slight deviation from that range can halt cellular processes.