Chapter 2 Part 1

The Chemical Basis of Life

PowerPoint Lectures for

Biology: Concepts & Connections, Sixth Edition

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In the beginning all things were simple...

A good place to start.

Atoms – the smallest unit of matter that retains the properties of the element. It literally means “indivisible”.

Elements – types of atoms.

Molecules – atoms bonded together.

2.1 All living organisms are made of about 25 elements in different combinations and concentrations

- All things living and nonliving are made of matter.
- **Matter** is anything that occupies space and has mass (weight)
- From simple to complex life results from the interaction of atoms into molecules, molecules into compounds, compounds into organelles and prokaryotes, organelles and prokaryotes into eukaryotes, and eukaryotes into the great variety of multi-cellular life on earth.
- Life has a chemical basis.

All living organisms are made of about 25 elements in different combinations and concentrations

Please note that amount (concentration) and importance (value to life) are not the same thing.

The most abundant elements in humans are **CHON**

All the trace elements together make up less than 0.01% of the body!

TABLE 2.1 ELEMENTS IN THE HUMAN BODY

Element	Symbol	Percentage of Human Body Weight	
Oxygen	O	65.0	96.3
Carbon	C	18.5	
Hydrogen	H	9.56	
Nitrogen	N	3.3	
Calcium	Ca	1.5	
Phosphorus	P	1.0	
Potassium	K	0.4	
Sulfur	S	0.3	
Sodium	Na	0.2	
Chlorine	Cl	0.2	
Magnesium	Mg	0.1	

Trace elements (less than 0.01%): boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

2.2 Trace elements are just as important as CHON

- Iron and iodine are just two examples of trace elements that are essential for life and good health.
- Iron is the element responsible for hemoglobin's ability to carry oxygen. (hemoglobin is the protein found in red blood cells (RBCs) that make them red.
- Iodine is an essential component of thyroid hormone. Without iodine the Thyroid gland is unable to manufacture thyroid hormone.

2.2 Trace elements are just as important as CHON

Many people in other countries suffer from deficiencies of some trace elements. This person has goiter resulting from an iodine deficiency. Goiter is rare in the U.S. because iodine is added to our salt, and we love salt!

2.3 Elements combine to form molecules and compounds

- A **compound**—is made of at least two different types of matter (two different types of atoms) that are bonded together.
- Bonding of the elements changes the properties, characteristics, and behavior of the original elements. The change can be incredible!

Sodium + **Chlorine** ⟶ **Sodium Chloride**

Na+ is a highly reactive metal.

Cl- is a poisonous gas.

Put them together and what do you have NaCl (salt) on your fries.

2.3 Elements can combine to form compounds

- The four major biological compounds are carbohydrates, lipids, proteins and nucleic acids.
- Carbohydrates contain CHO with a 2:1 H:O ratio.
- Lipids also contain CHO but there is no 2:1 ratio.
- Proteins contain CHON and their building blocks are amino acids.
- Nucleic acids contain CHONP and their building blocks are nucleotides.

2.4 Atoms are the smallest units of matter that retain the characteristics of the element but are not the smallest units of matter.

- An **atom** is made of even smaller units of matter (subatomic particles) protons, electrons, and neutrons.
- A **Proton** has a positive electrical charged and has mass of 1.
- An **Electron** has a negative electrical charge and for us in this class has “no mass”.
- A **Neutron** has no electrical charge and has a mass of 1.

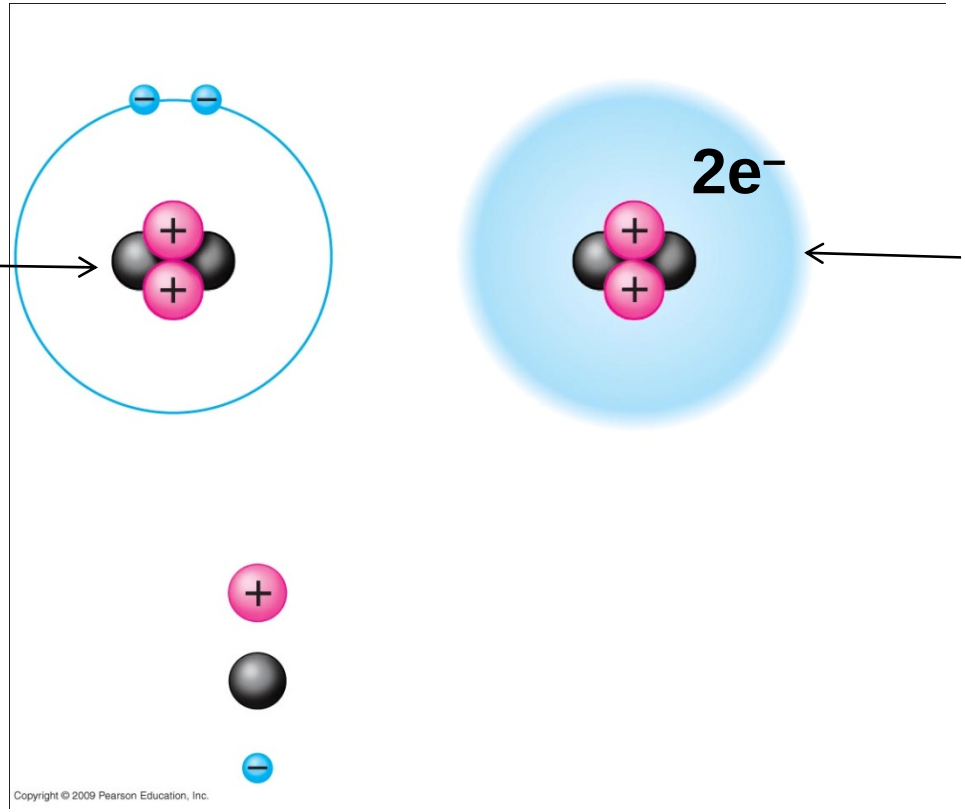
2.4 Subatomic units of matter: Protons, Electrons, and Neutrons

- The **Principle of Complementarily** states that form and function are intimately bonded. Stated a different way it is the structure of an element that determines its behavior.
- Different elements are different because they have different numbers of subatomic particles.
- Carbon is carbon because it has carbon's structure that is six protons, six neutrons, and six electrons. If it had eight protons for example it would not be carbon it would be oxygen.

2.4 Subatomic units of matter: Protons, Electrons, and Neutrons

- The atomic **nucleus** is made up of neutrons and protons and contains all of the mass of the atom.
  - The old rule that opposites attract hold true even at the subatomic level. The electron's negative charge attracts it toward the nucleus and its energy pulls it away. Electrons with more energy are farther away from the nucleus.
  - The number of protons is the atom's nucleus determins its identity also known as its **atomic number.**
  - The **mass number** is the sum of the protons and neutrons in the nucleus of the atom

Subatomic units of matter: Protons, Electrons, and Neutrons

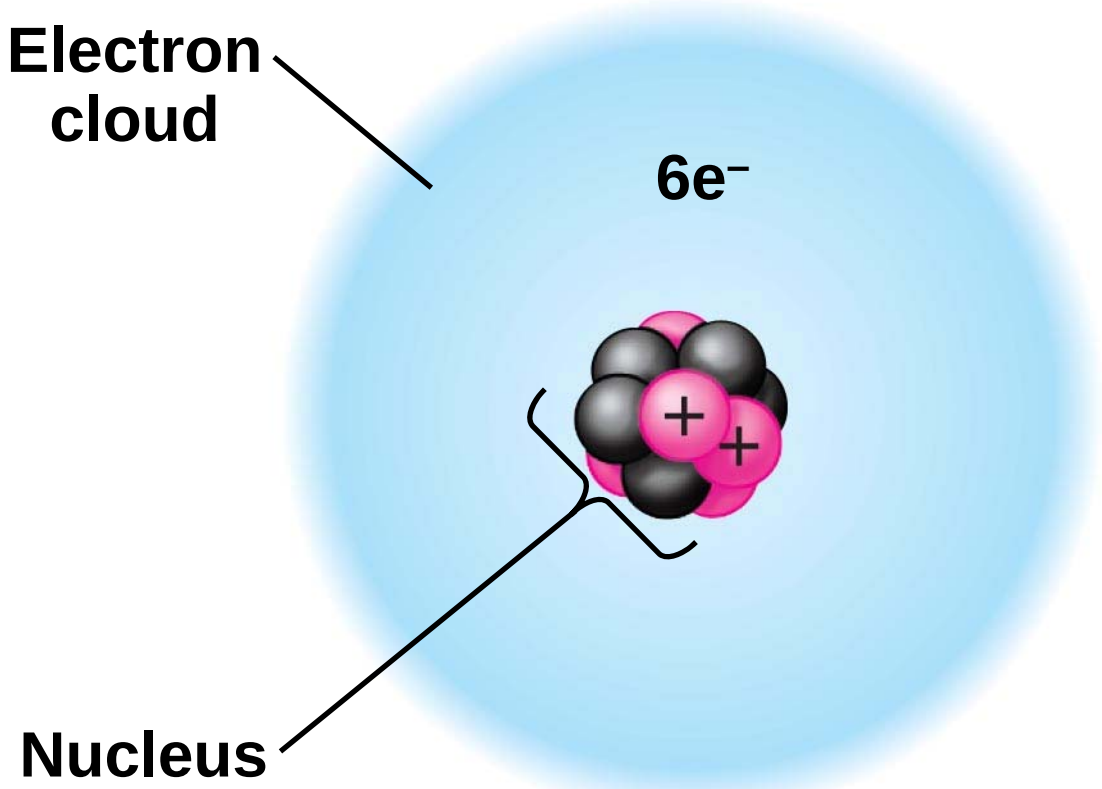


Atomic number 2 Protons

2 Neutrons

} **Mass number = 4**

2 Electrons



Atomic number 6 Protons

6 Neutrons

Mass number = 12

6 Electrons

2.4 Subatomic units of matter: Protons, Electrons, and Neutrons

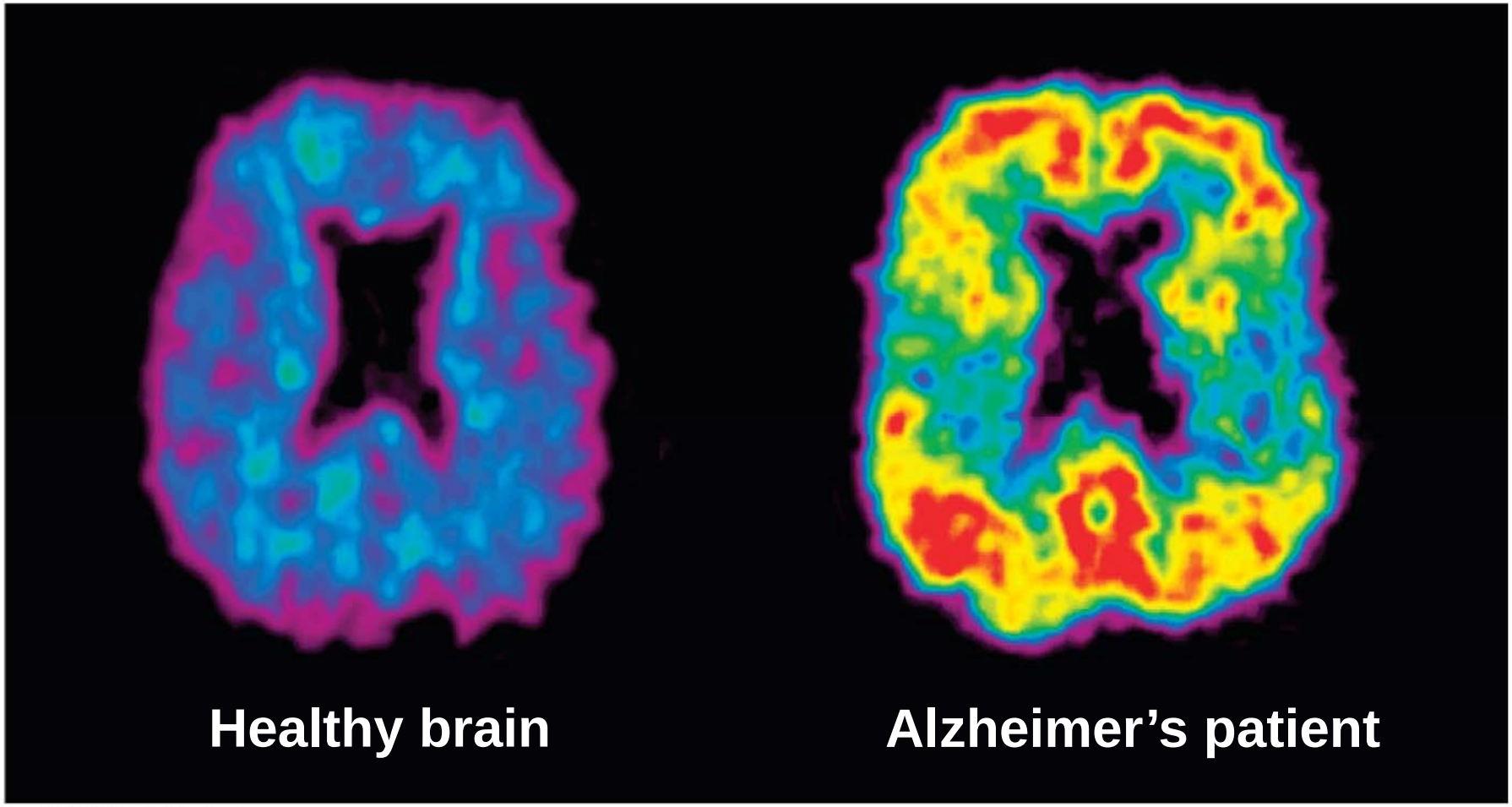
- Because the **atomic number** is the identity of the atom, atoms with different number of neutrons can still be the same element. These atoms of the same element have different **atomic mass**.
  - Atoms of the same element with different atomic masses are called **isotopes**.
    - ^{12}C has 6 protons and 6 neutrons. These are both carbon atoms but with different atomic masses, they are isotopes of carbon.

TABLE 2.4 ISOTOPES OF CARBON

	Carbon-12	Carbon-13	Carbon-14
Protons	6	6	6
Neutrons	6	7	8
Electrons	6	6	6

2.5 Radioactive isotopes as tools

- Science uses radioactive isotopes for scientific research and medicine uses them for diagnosis and treatment of disease.
- The use of ^{14}C for radioactive carbon dating and the use of radioactive iodine in the treatment of hyperthyroid disease are just two examples of how science uses isotopes
- Radioactivity is also harmful when used improperly.



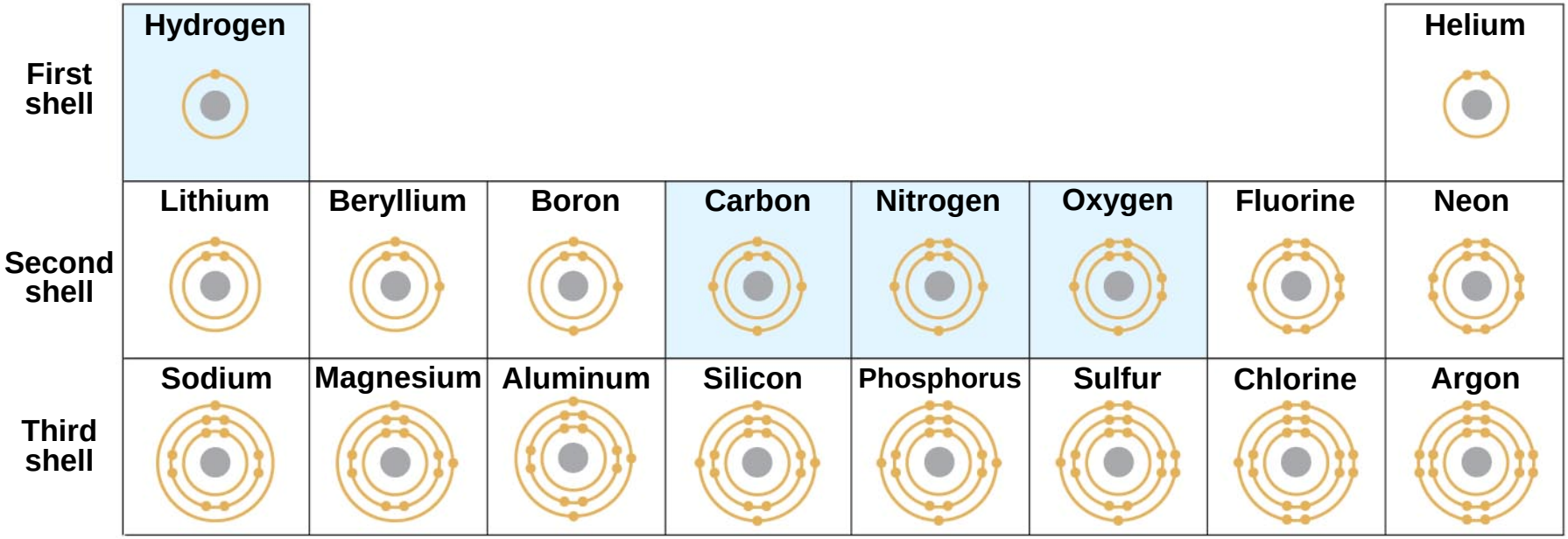
2.6 Principle of Complementarily!

The arrangement of electrons determines the atom's behavior.

- Electrons are arranged around the nucleus in electron shells or energy levels.
- Those with the highest energy are found in the outer shell and are the only ones in the atoms reactivity.
- Think about it, these electrons (valence electrons) are the ones furthest from the nucleus and they have the most energy. What a great formula for reactivity!

The Periodic Table of the Elements

(The Periodic Table of the Types of Matter)



I like this illustration but I also wish they had included the **atomic symbol**, **atomic number**, and **atomic mass** in each of the cells!

2.6 Principle of Complementarily!

The arrangement of electrons determines the atom's behavior.

- Each energy level is filled with a specific number of electrons and only when it is completely full can it be stable.
- The first energy level if filled with two (2) electrons is stable.
- The second and third energy levels fill and are stable with eight (8) electrons.
- Remember it is only the valence electrons that react!
- So why do you think atoms react?

2.6 Principle of Complementarily!

The arrangement of electrons determines the atom's behavior.

- Atoms react with each other for the same reason people react with each other.
- To satisfy a need!
- For the atom the need for a stable outer electron shell.
- Atoms obtain stable electrons shells by manipulation their valance electrons. They can lose, gain, or share electrons and like you and I will tend to do what is easiest.

2.6 Principle of Complementarily!

The arrangement of electrons determines the atom's behavior.

- This exchanging of electrons or sharing of electrons results in electrical forces of attraction called **chemical bonds.**
- There are 4 types of bonds
  - Ionic
  - Covalent
  - Hydrogen
  - James
- We will only be dealing with the first three (3).

2.7 Ionic bonds = losing and gaining electrons

- When the number of protons in an atom is unequal to the number of electrons, that atom has an electrical charge. Charged atoms are called **ions.**
- When an atom needs one electron to fill its outer electron shell and become stable it takes one.
- When an atom need to lose one or two electrons for its outer shell to be stable it gives them up.

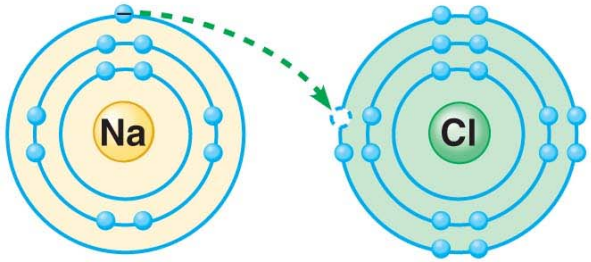
2.7 Ionic bonds = losing and gaining electrons

When an electron is lost,

there are more protons (positively charged particles) than electrons (negatively charged particles) so the atom is

now a positively charged ion.

Transfer of electron



Na
Sodium atom

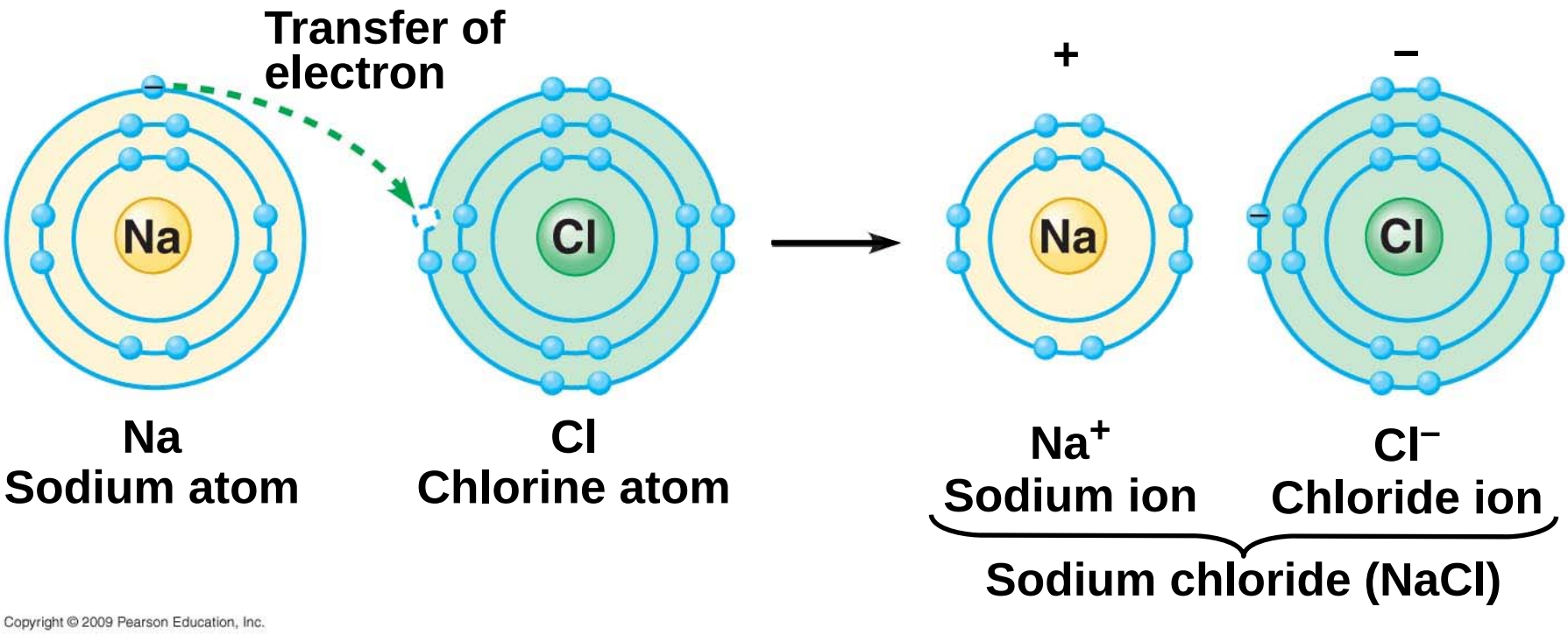
Cl
Chlorine atom

When an electron is gained,

there are fewer protons (positively charged particles) than electrons (negatively charged particles) so the atom is

now a negatively charged ion.

2.7 Ionic bonds = losing and gaining electrons



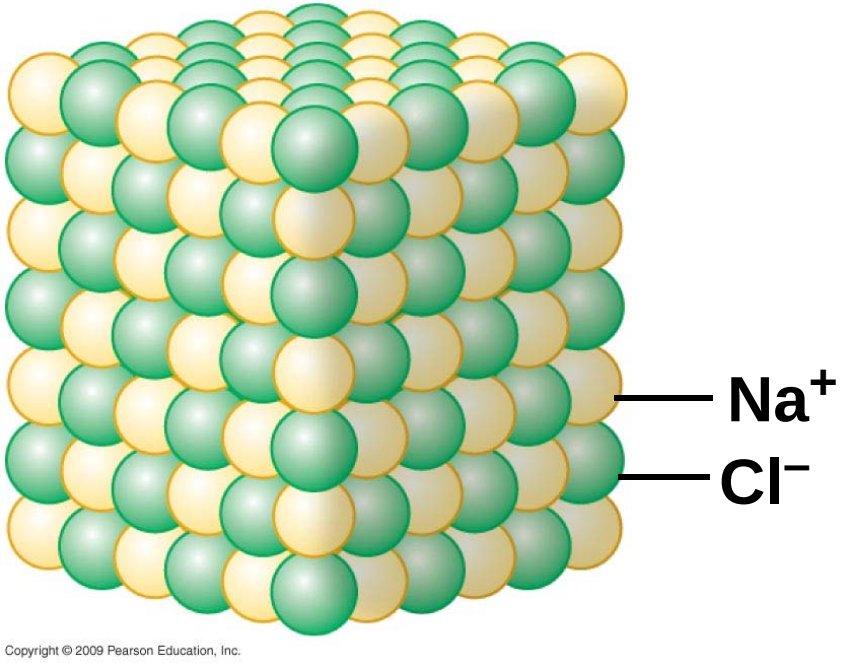
The electrical force of attraction between oppositely charged ions is called an **Ionic bond**

2.7 Ionic bonds = losing and gaining electrons

This is a

Salt

Crystal

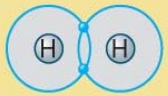
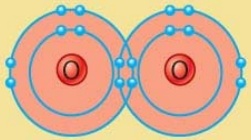
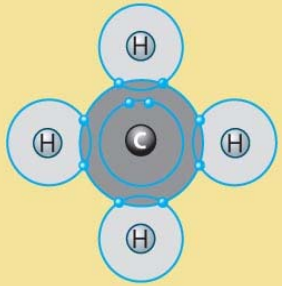
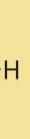
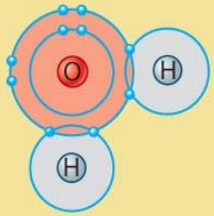


Ionic bonds are not monogamous. Every positively charged particle is attracted to every negatively charged particle around it and vice versa. This type of attraction results in the creation of crystals like the one illustrated above.

2.8 Covalent bonds = Sharing of electrons

- If an atom needs to lose more than two (2) or gain more than one (1) to become stable the easiest thing will be to share.
- Sharing of electrons results in a **covalent bond.**
- Whereas ionic bonds make crystals, covalent bonds make **molecules.**

TABLE 2.8 ALTERNATIVE WAYS TO REPRESENT FOUR COMMON MOLECULES

Molecular Formula	Electron-Distribution Diagram	Structural Formula	Space-Filling Model
H_2		H—H Single bond	
O_2		O=O Double bond	
CH_4 Methane			
H_2O Water			

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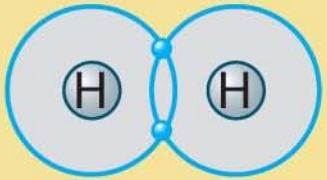
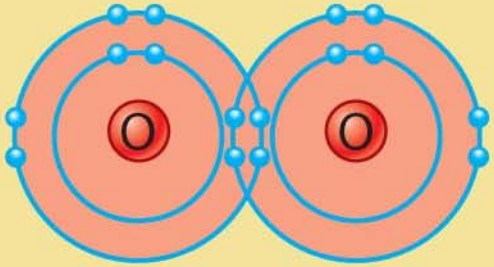
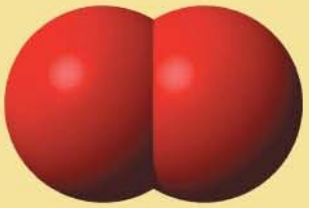
H_2		H—H Single bond	
O_2		O═O Double bond	

TABLE 2.8 ALTERNATIVE WAYS TO REPRESENT FOUR COMMON MOLECULES

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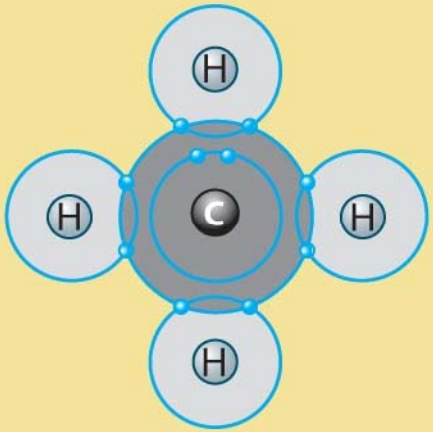
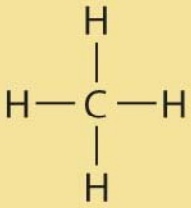
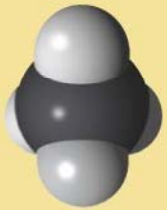
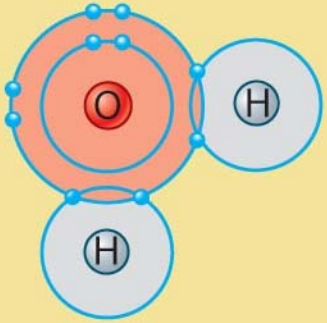
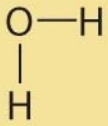
CH_4 Methane			
H_2O Water			

2.9 To share does not mean to share equally

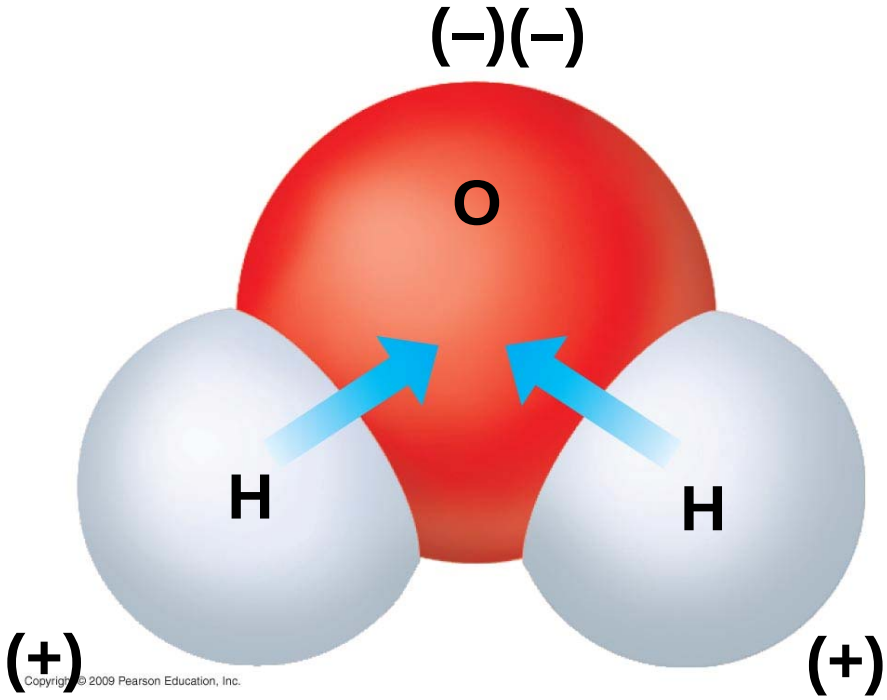
- Atoms do not really want to share they are forced to share. Because of this electrons are not always shared equally.
- Some atoms have a greater attraction for electrons than other atoms, that is they have a greater electronegativity.
- Atoms with greater electronegativity have a greater “pull” on the electrons and keep them most of the time.

2.9 To share does not mean to share equally

- Unequal sharing results in one partner with more electrons (a negative charge) than it should and the other with fewer (a positive charge).
- The molecule will now have a positive side and an negative side or “poles”.
- The type of bond that gives rise to polar molecules is a “Polar Covalent Bond”.

Water, the ultimate polar molecule!

Water is made of two types of atoms, **oxygen** and **hydrogen.**



Oxygen has greater electronegativity and so **“hogs”** the shared electrons most of the time

2.10 “The greatest strength of a Hydrogen bond is its weakness”

- The poles of one polar molecule are attracted to the poles of other polar molecules. This attraction is a weak bond called a hydrogen bond.
- Even though it is weak it is of significant importance!
- Like the glue on the back of a Post-it note a hydrogen bond can “stick” molecules together when needed and allow them to be pulled apart when needed.
- That is why the greatest strength of a hydrogen bond is its weakness!

As we will see in the next lecture it is water's polarity that will give it its characteristics and its life giving ability.