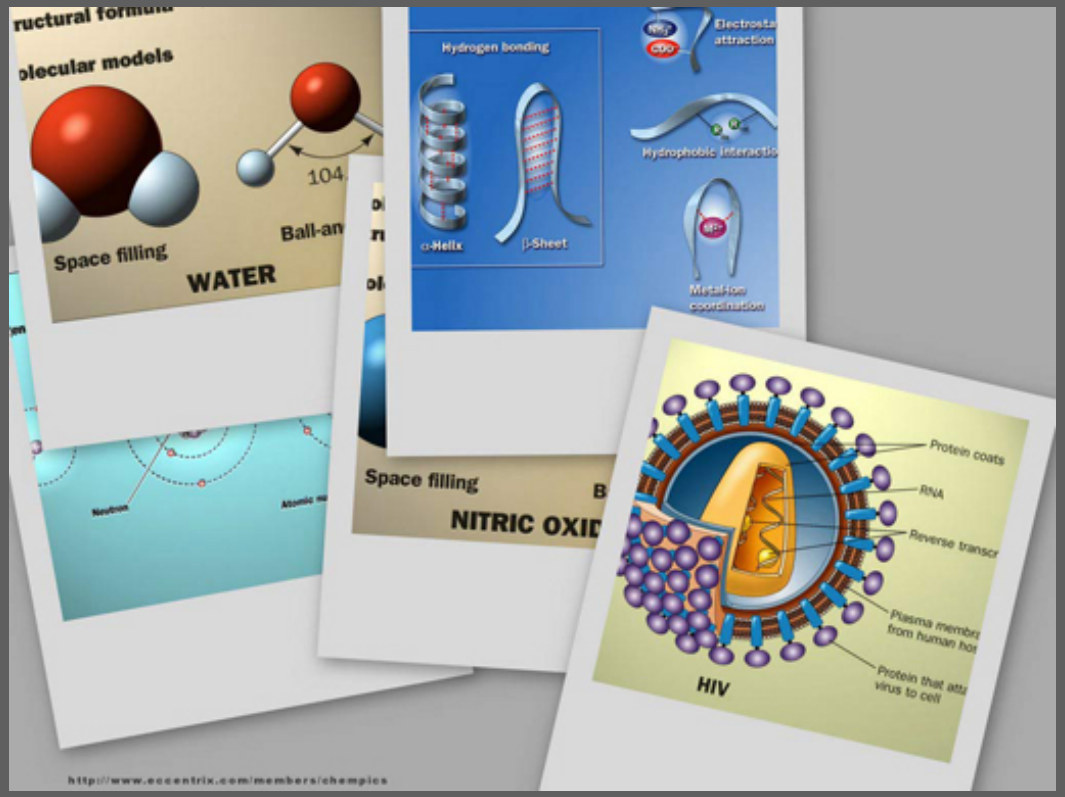
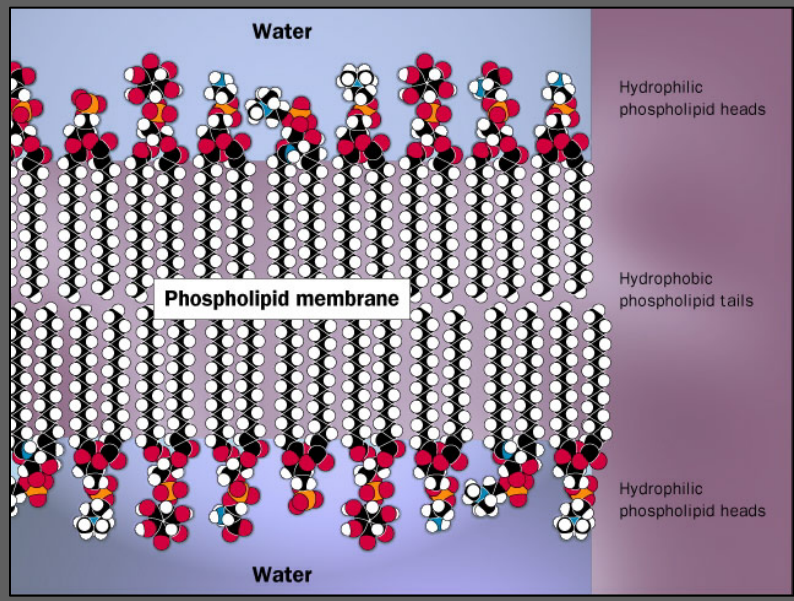
Chapter 2.

The Chemical Context of Life

Why are we studying chemistry?

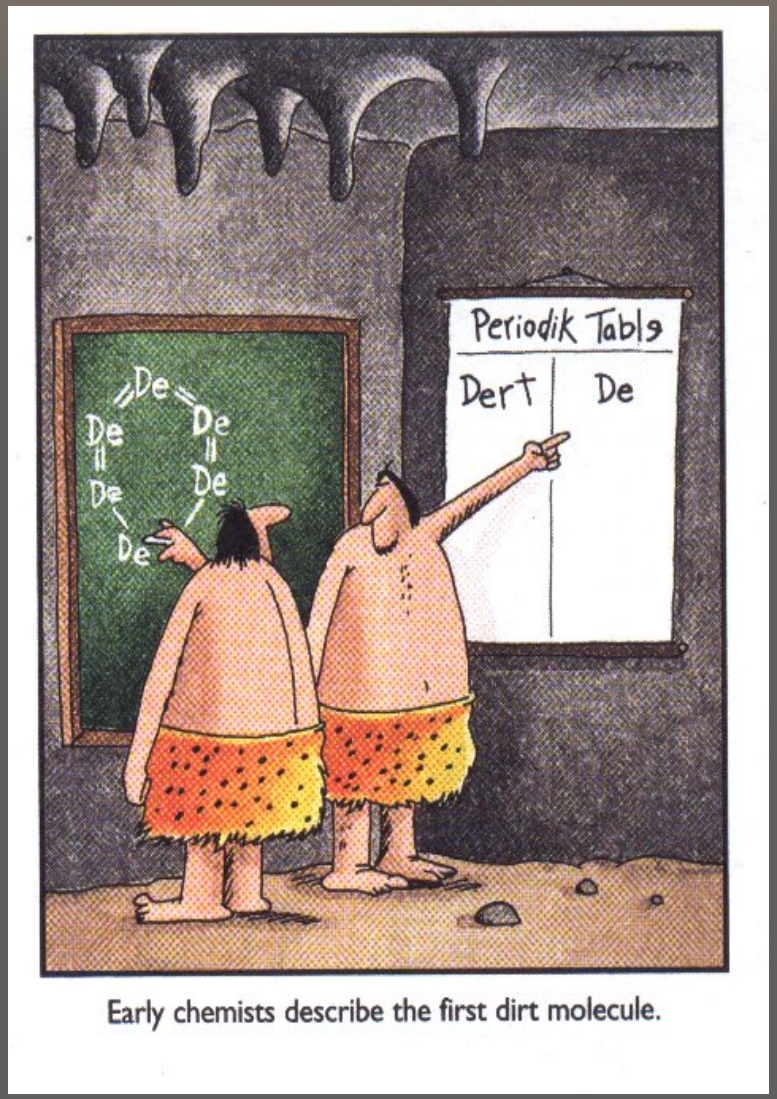
- Biology has chemistry at its foundation





Early Chemistry

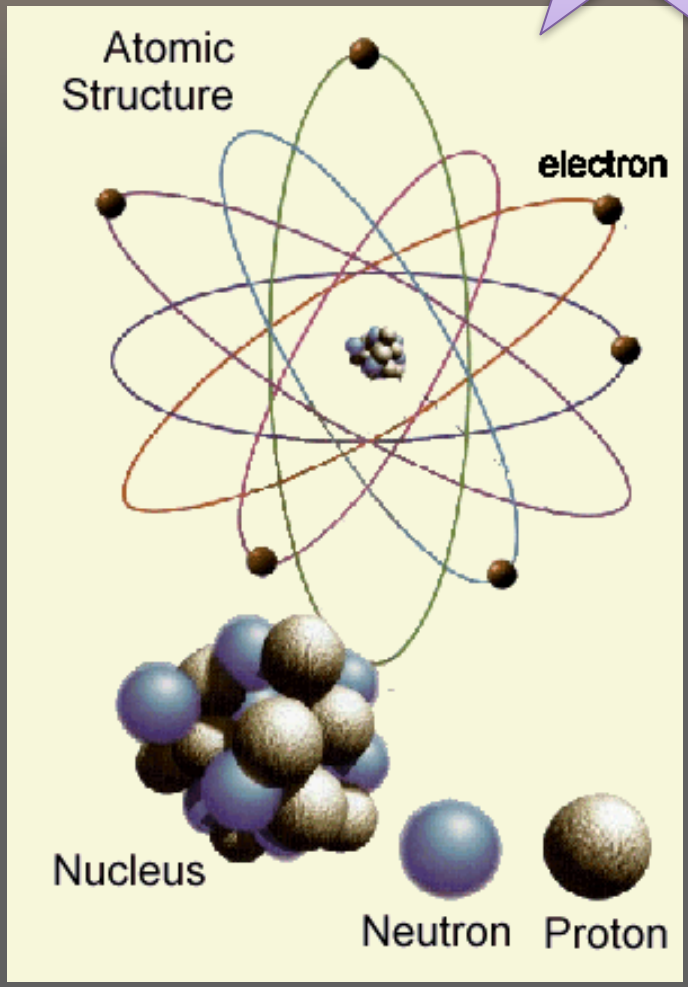
- Early Chemists only believed in 1 element: **Dirt**
- Later Chemists believed in **4 elements**:
  - Air
  - Earth
  - Fire
  - Water
- Various combinations of these produced various **compounds**



Early chemists describe the first dirt molecule.

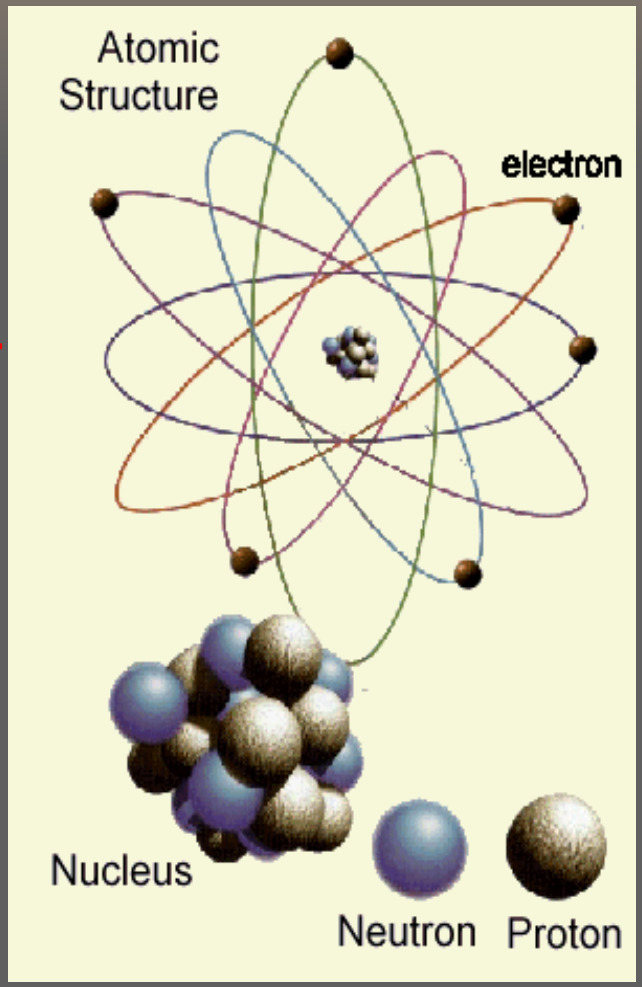
Basic Chemistry

- All Matter in universe is composed of **Atoms**
  - **Elements** are composed of only 1 type of atom.
- Atoms are mostly empty space.

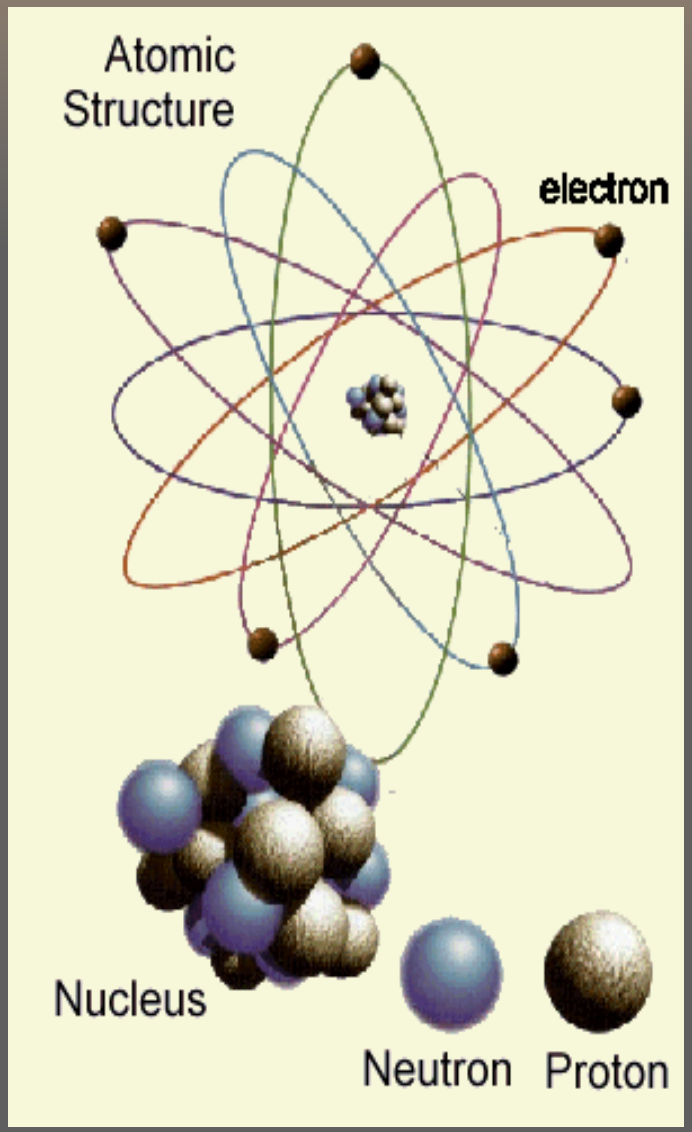


Basic Chemistry

- Atoms have a Nucleus which contain Protons & Neutrons.
  - Protons are Positively Charged and have a mass =1
  - The number of protons in an atom's nucleus determines what element it is
  - Neutrons have no charge and are therefor called Neutral and have a mass = 1.



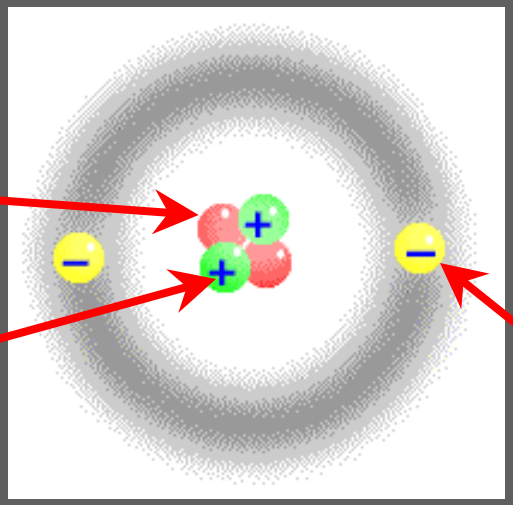
- **Electrons move in orbits** around the center of the atom - in relatively distinct areas called **Energy Levels** (Orbits or shells)
  - The **farther** from the center an electron is the more energy it has.
  - Electrons,(& therefore atoms), **can gain and lose energy** and do this by **moving between energy levels.**



Atoms are made up of smaller subatomic particles

- Protons: positively charged (Located in the nucleus)
- Neutrons: neutrally charged (Located in the nucleus)
- Electrons: negatively charged (Located around the nucleus)

Discovered by James Chadwick in 1932



Discovered by Ernest Rutherford in 1919

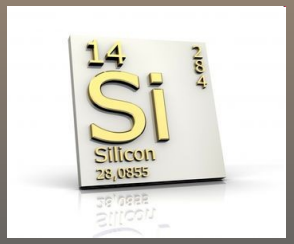
Discovered by J.J. Thomson in 1897

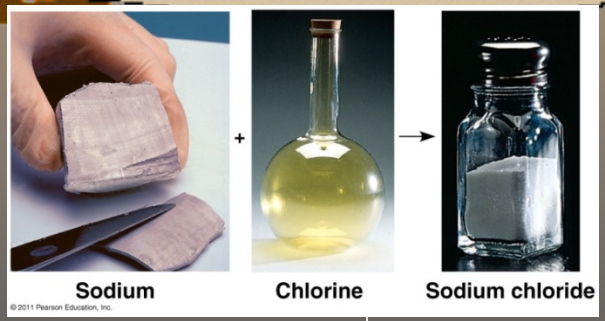
Summary of Subatomic Particles:

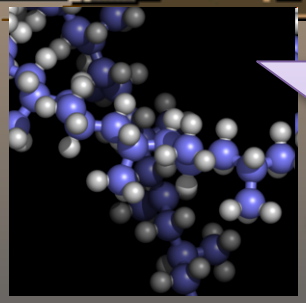
Particle Name	Location	Charge	Mass
Electron	Orbitals	-1	~0
Proton	Nucleus	+1	1
Neutron	Nucleus	No Charge	1

Matter vs. Energy

Matter	Energy
▪ Has mass ▪ Affected by gravity ▪ Consists of elements and compounds	▪ Moves matter ▪ Potential, kinetic ▪ Ability to do work ▪ Conversions ▪ Sound, light, heat





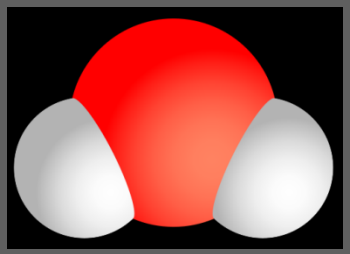


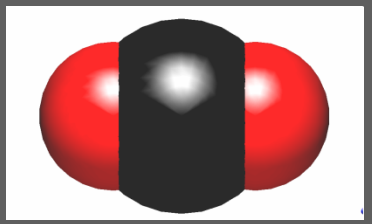
Element

- "pure" substance
- Can't be broken down by "ordinary" means to another substance
- Ex. hydrogen (H), nitrogen (N)

Compound

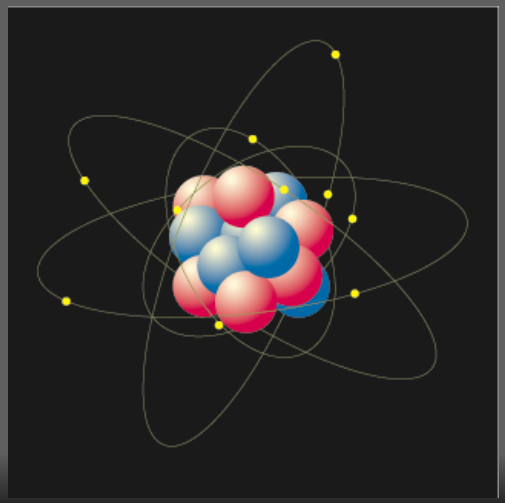
- 2 or more different elements combined in a fixed ratio
- Ex. H_2O, CO_2



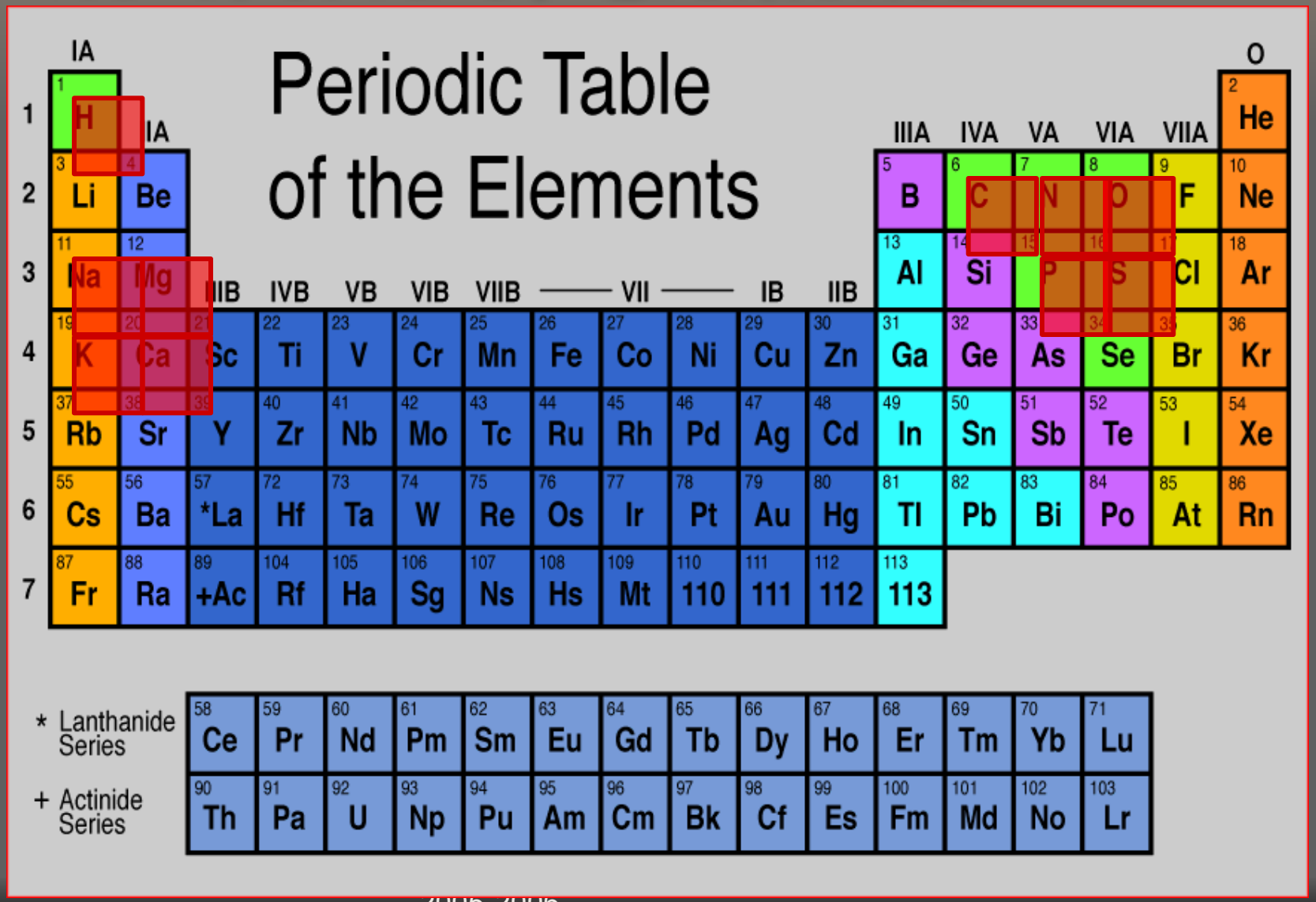


Atomic structure determines behavior

- The number of protons in an atom determines the element
  - # of protons = atomic number
  - this also tells you # of electrons
- All atoms of an element have same chemical properties
  - all behave the same
  - properties don't change

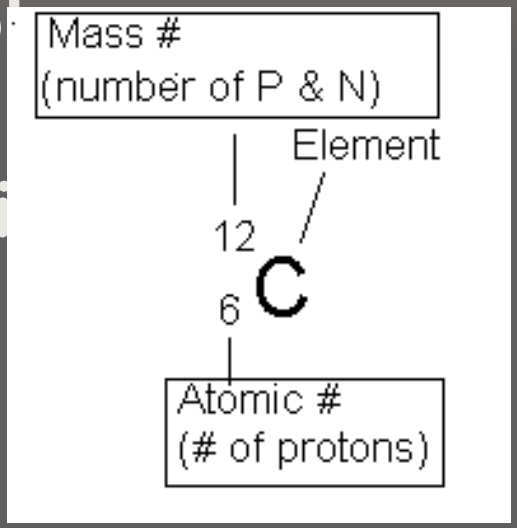


The World of Elements

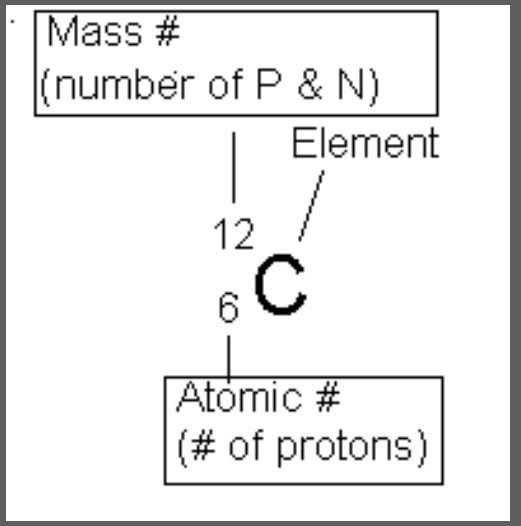


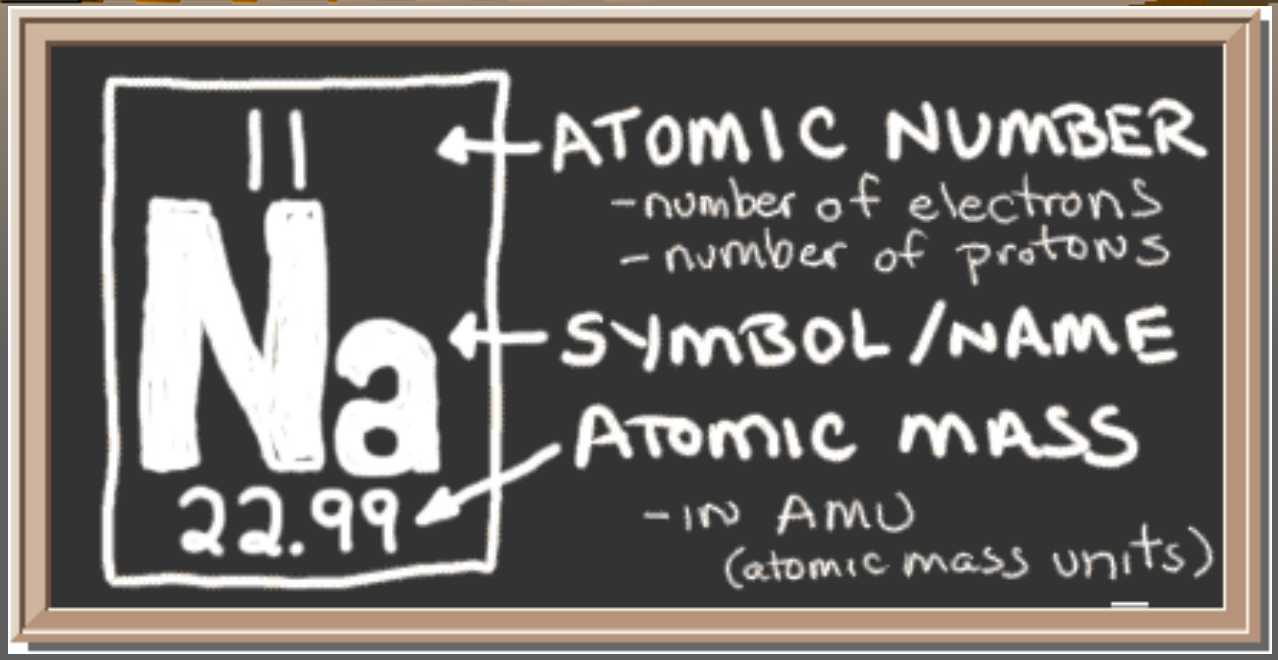
Periodic Table Notation:

- Chemical elements are represented on the periodic tabl using the following format.
  - The letter is an abbreviati of **Element Name**
  - **Atomic Number** is the number is the number of protons the atom has. **It is the number of protons an element has which determines what element it is**.



- **Mass number** is the total mass of an atom in AMU.
- Grams are not useful in describing mass of something miniscule, so we use daltons aka atomic mass unit (amu).
- It is the same as the **number of protons & neutrons** of the element.
- One can calculate the number of neutrons an atom has by **subtracting the atomic number** (# protons) **from the mass number**.
- Mass number CAN change without changing the identity of the element.





Atomic number:= 11

Atomic mass:= 22.99

# of Protons=11

# of Electrons= 11

# of Neutrons= 11.99

Life requires ~25 chemical elements

- About 25 elements are essential for life
  - Four elements make up 96% of living matter:
    - carbon (C)
    - hydrogen (H)
    - oxygen (O)
    - nitrogen (N)
  - Six elements make up most of remaining 4%:
    - phosphorus (P)
    - calcium (Ca)
    - sulfur (S)
    - potassium (K)
    - magnesium (Mg)
    - sodium (Na)

Deficiencies

- If there is a deficiency of an essential element, disease results
- For example-If iodine is missing, a hormone produced by the thyroid gland is impacted resulting in an abnormal size thyroid gland
- Iodized salt- table salt mixed with a minute amount of iodine containing salts

(a) Nitrogen deficiency

(b) Iodine deficiency (Goiter)

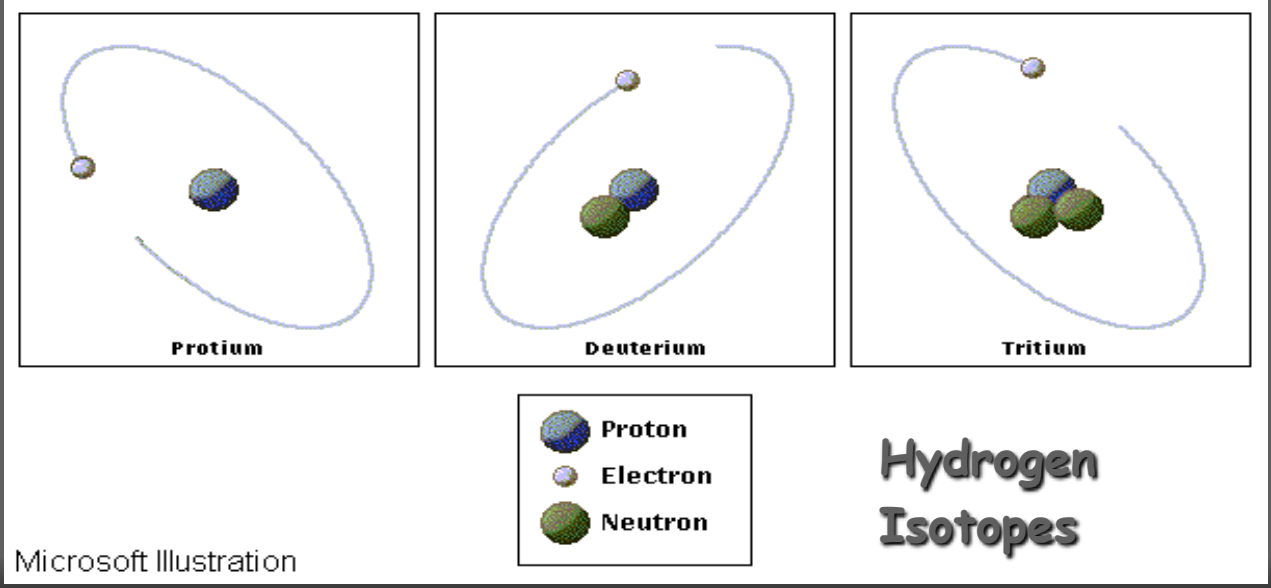
Table 2.1 Naturally Occurring Elements in the Human Body

Symbol	Element	Atomic Number (See p. 29)	Percentage of Human Body Weight
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1

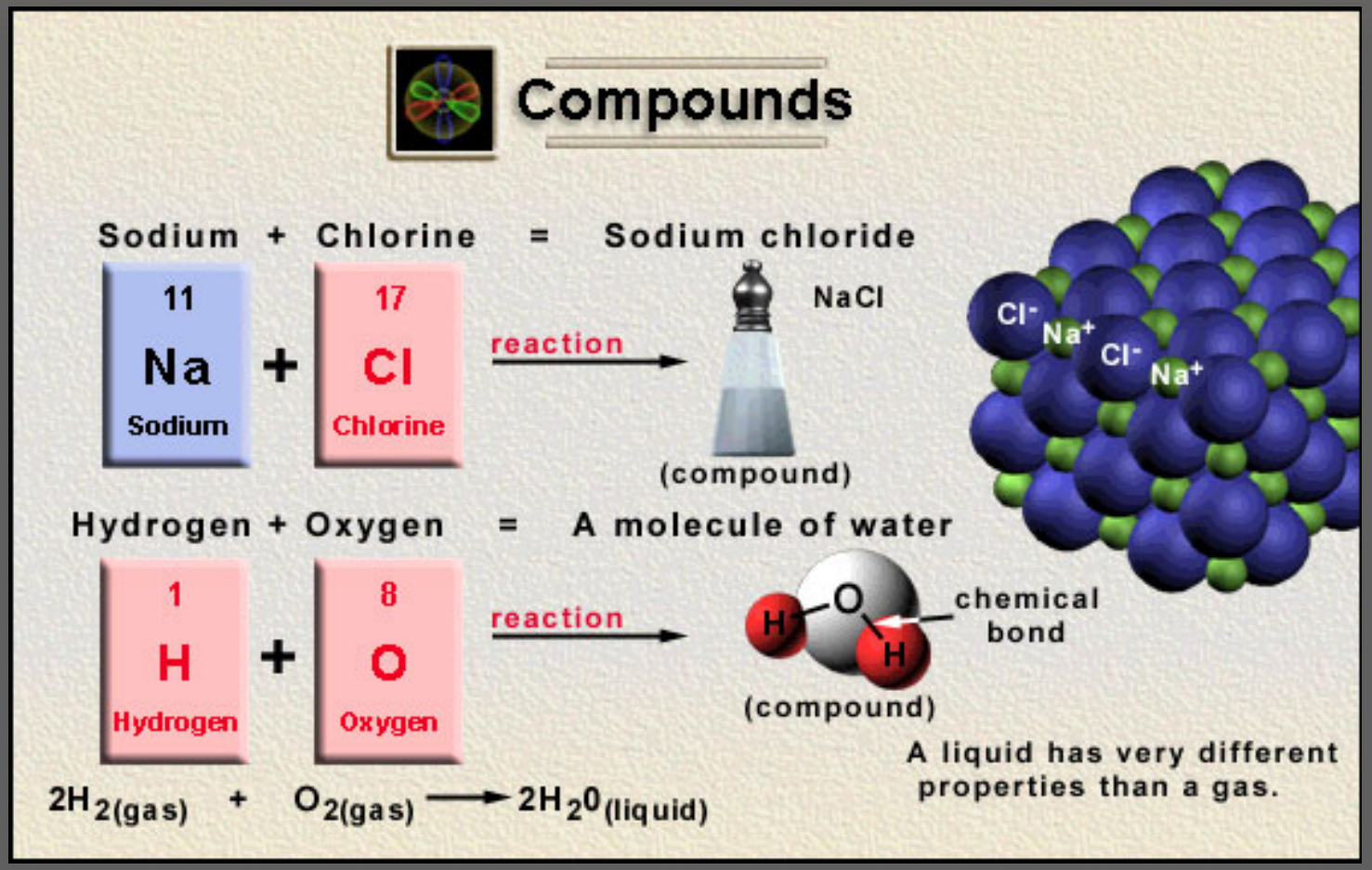
Trace elements (less than 0.01%): boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

Isotopes:

- Atoms having the same atomic numbers and different mass numbers are called **Isotopes**
  - Isotopes are atoms of the same element with **different numbers of neutrons (mass).**
  - They react chemically the same as the "normal" form of the element
  - They are **frequently radioactive**



When elements combine to form substances with two or mo atoms… Compounds are formed



Interactions of Matter:

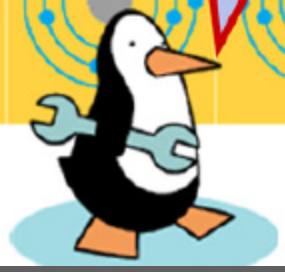
- Atoms interact through the process of **chemical bonding**.
  - Process is determined by the **number of electrons found in the outermost energy level** of an atom.
  - Involves the **transfer & sharing of electrons** between atoms. (covalent & ionic bonding)

Elements & their valence shells

Elements in the same column have the same valence & similar chemical properties

First shell	Hydrogen $_1H$						Helium $_2He$
Second shell	Lithium $_3Li$	Beryllium $_4Be$			Oxygen $_8O$	Fluorine $_9F$	Neon $_{10}Ne$
Third shell	Sodium $_{11}Na$	Magnesium $_{12}Mg$	Aluminum $_{13}Al$	Phosphorus $_{15}P$	Sulfur $_{16}S$	Chlorine $_{17}Cl$	Argon $_{18}Ar$

Remember some food chains are built on reducing O to H_2O & some on reducing S to H_2S



Chemical reactivity

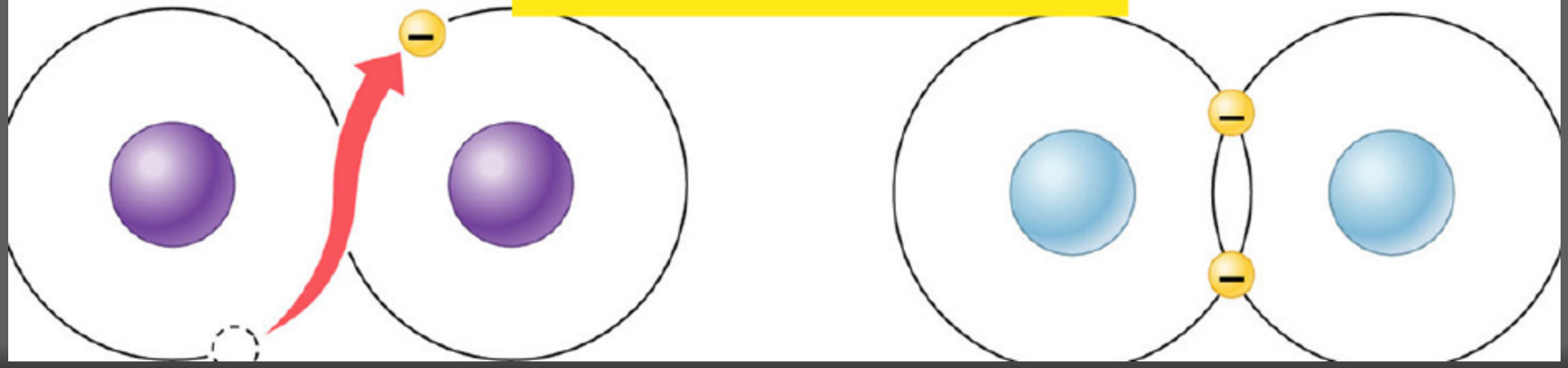
- Atoms tend to
  - complete a partially filled valence shell

  or

  - empty a partially filled valence shell

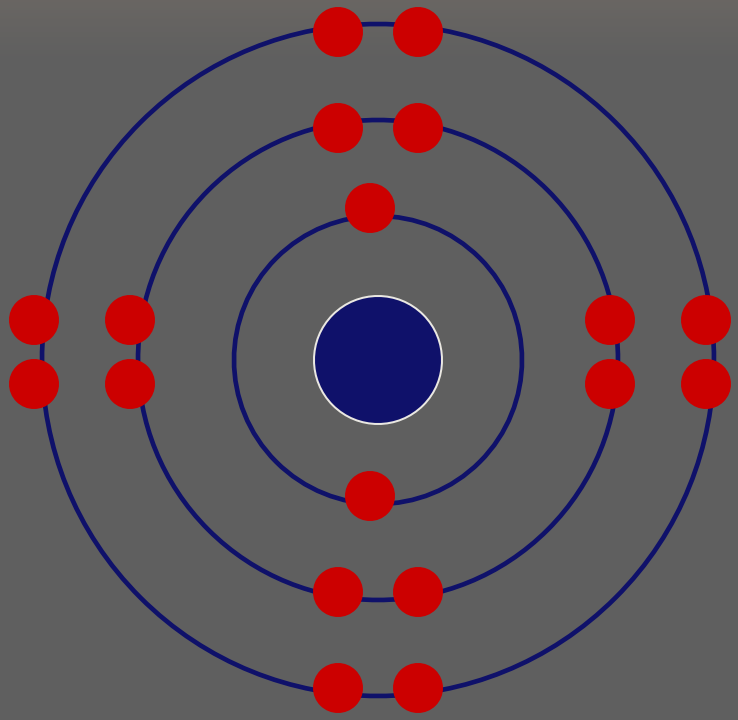
This tendency drives chemical reactions…

and creates bonds



Bonding properties

- Effect of electrons
  - chemical behavior of an atom depends on its electron arrangement
  - depends on the number of electrons in its outermost shell, the valence shell

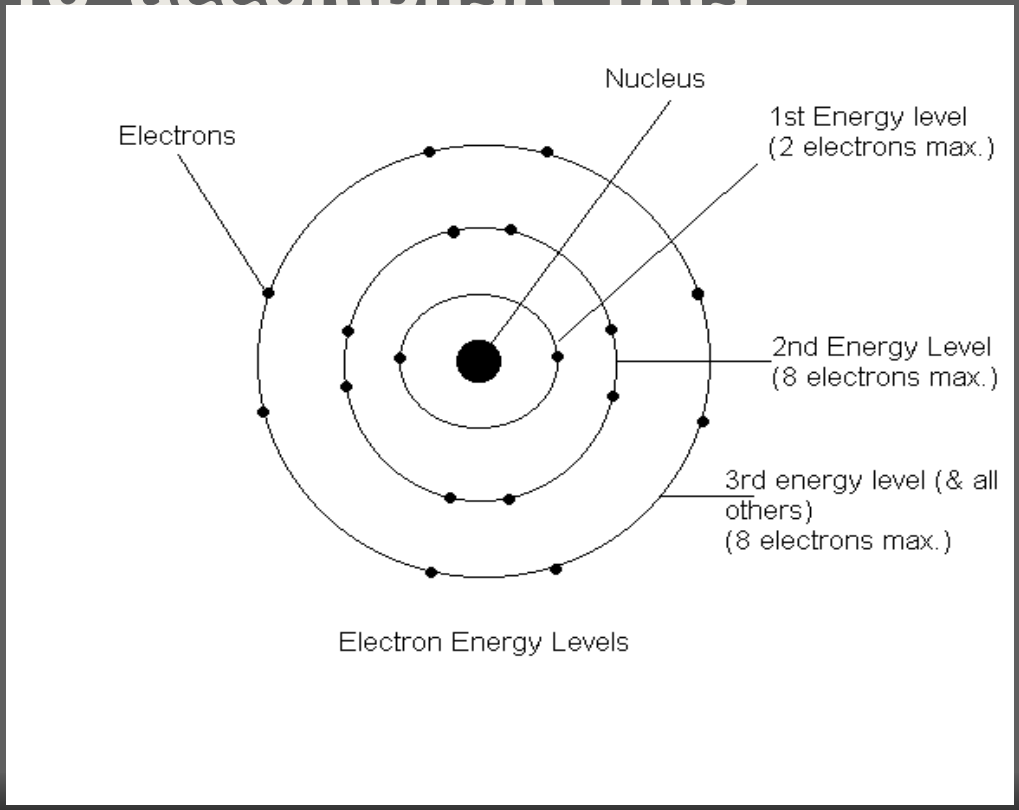


ELECTRON / ENERGY LEVEL RULES:

- Atoms in a **neutral** state have an **equal number** of protons and electrons.
- Atoms "fill up" their energy levels from the **lowest to the highest**. Electrons rarely "skip" levels.
  - The **1st Energy level** can only hold **2** electrons
  - The **2nd (& all higher)** energy levels can only hold **8 electrons**

ELECTRON / ENERGY LEVEL RULES:

- Atoms seek to have a **"full" outermost** energy level. All chemical reactions happen to accomplish this



Electron Energy Levels

Chemical Bonds

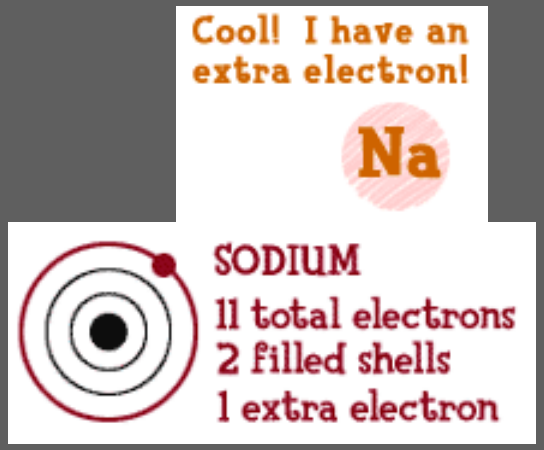
- When a **Chemical Reaction** occurs atoms **gain, lose or share electrons**.
- Atoms always want to have their outer energy level "full" of electrons
- When an atom has a different number of protons & electrons it is called an **Ion**.

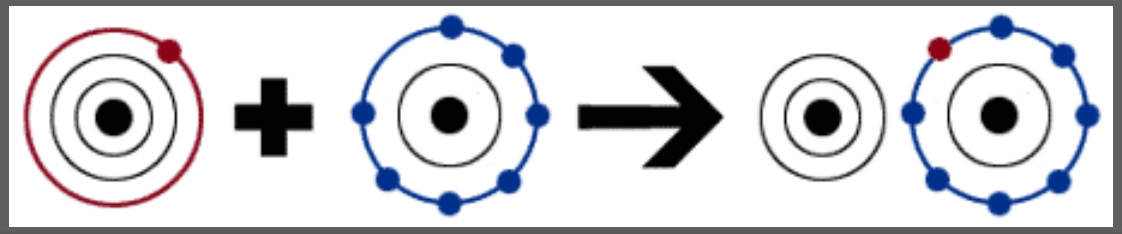
Chemical Bonds

- If an ion has more protons than electrons - it is Positively Charged
- If an atom has more electrons than protons it is Negatively Charged.
- Atoms of opposite charge are attracted to each other.
- There are three types of chemical bonds. Ionic bonds, Covalent Bonds, & Hydrogen bonds.

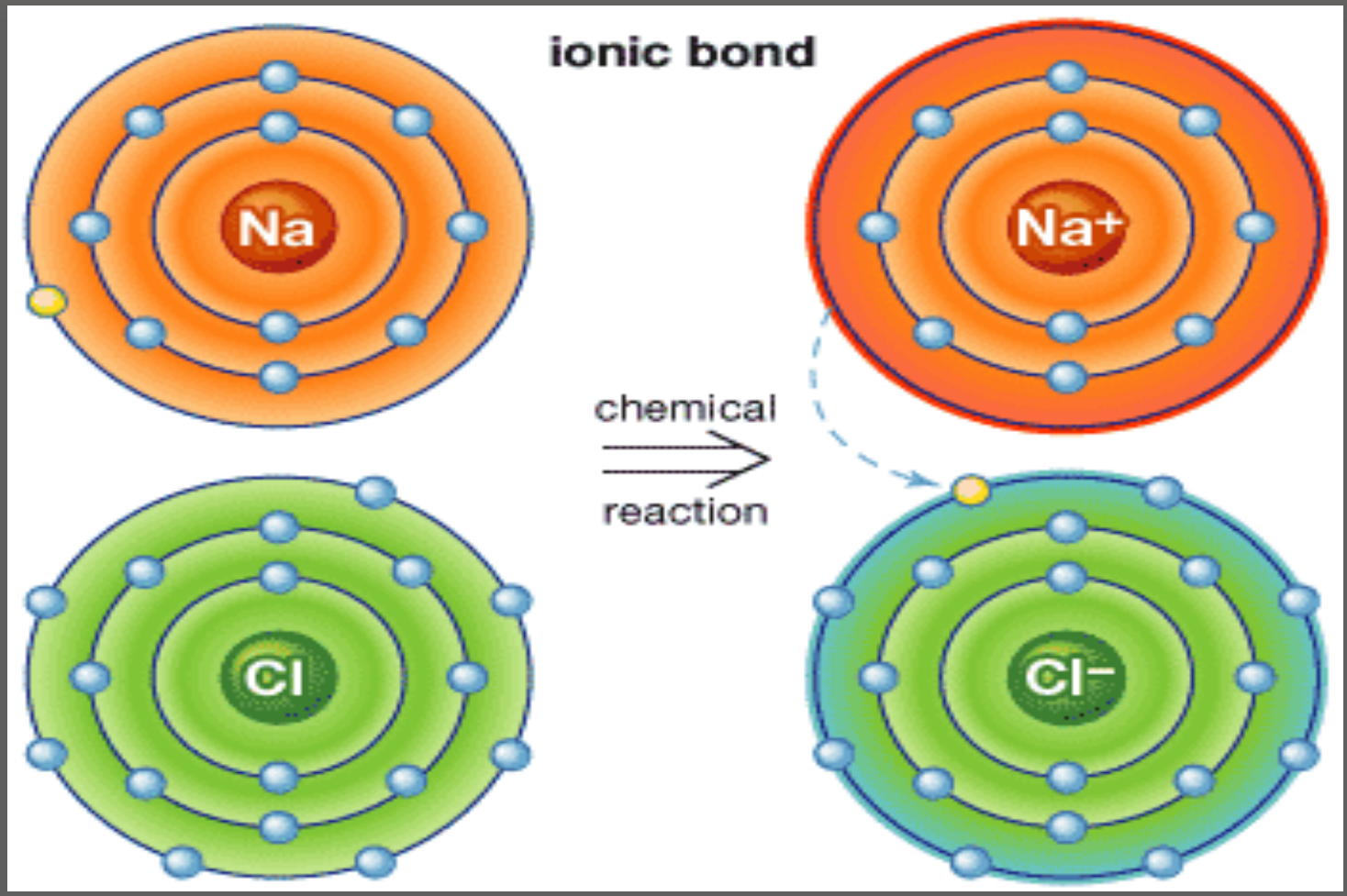
Ionic Bonds:

- **Ionic bonds** form when 1 atom "**gives**" one or more electrons to another atom to complete their outer energy levels.
  - This results in **1 positively charged ion** & **1 negatively charged ion**
  - Since **opposite charges attract**, they come together and bond.





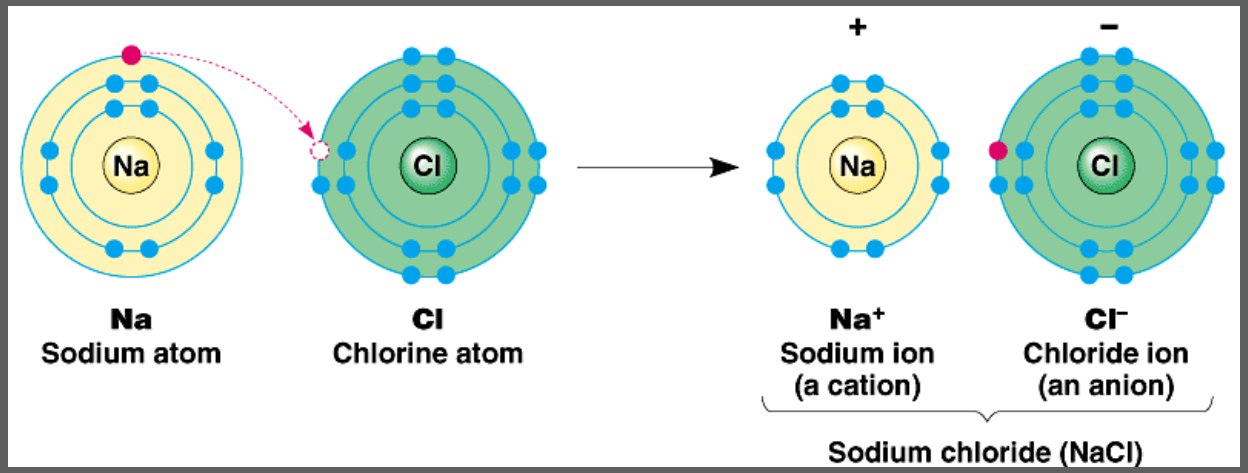
one atom strips an e^- from another



Ionic bonds

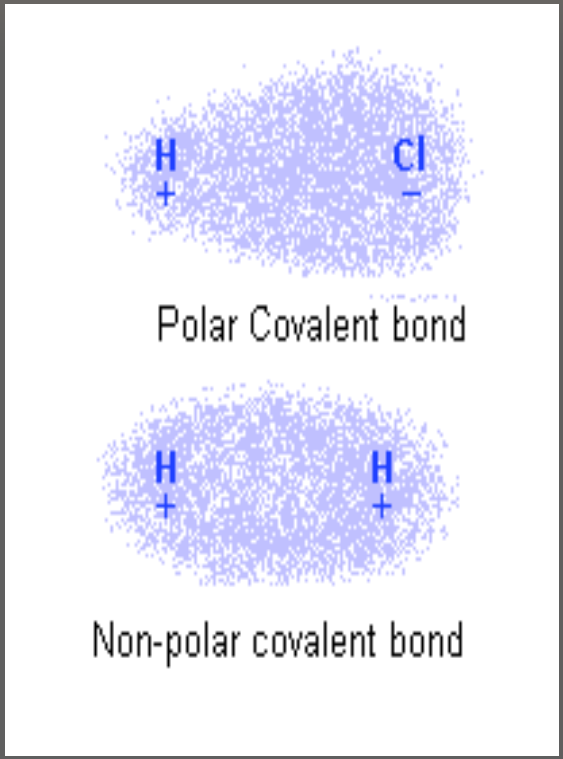
- Transfer of an electron
- Forms + & - ions
  - + = cation
  - – = anion
- Weak bond

- example:
  - salt = dissolves easily in water due to the weak bond

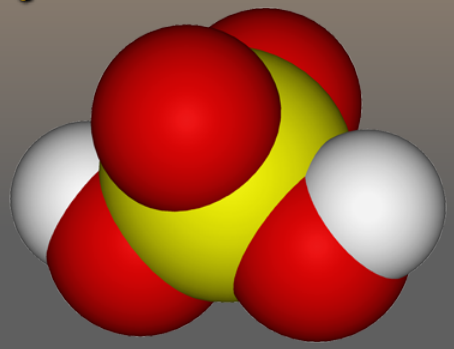


Covalent Bonds:

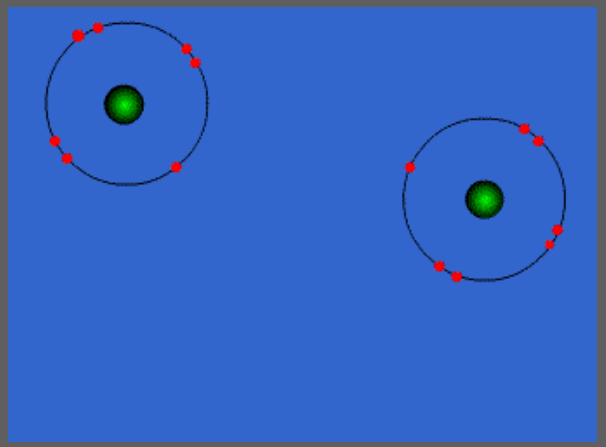
- Covalent bonds form when 2 atoms "share" one or more electrons between them.
- Type of strong bond-both atoms holding onto the electrons
- There are 2 types of covalent bonds:
  - Non-Polar Covalent bonds form when two atoms share electrons equally
  - Polar Covalent bonds form when two atoms share electrons unequally.



Covalent Bonds:

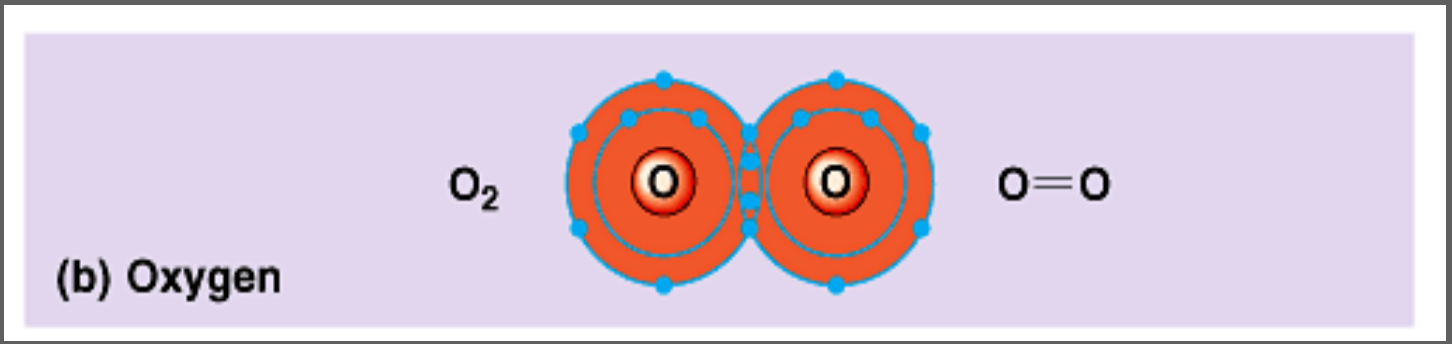


- Atoms can share more than 1 electron between them forming **double** and **triple bonds**
- A **Molecule** is a group of 2 or more atoms held together by covalent bonds.



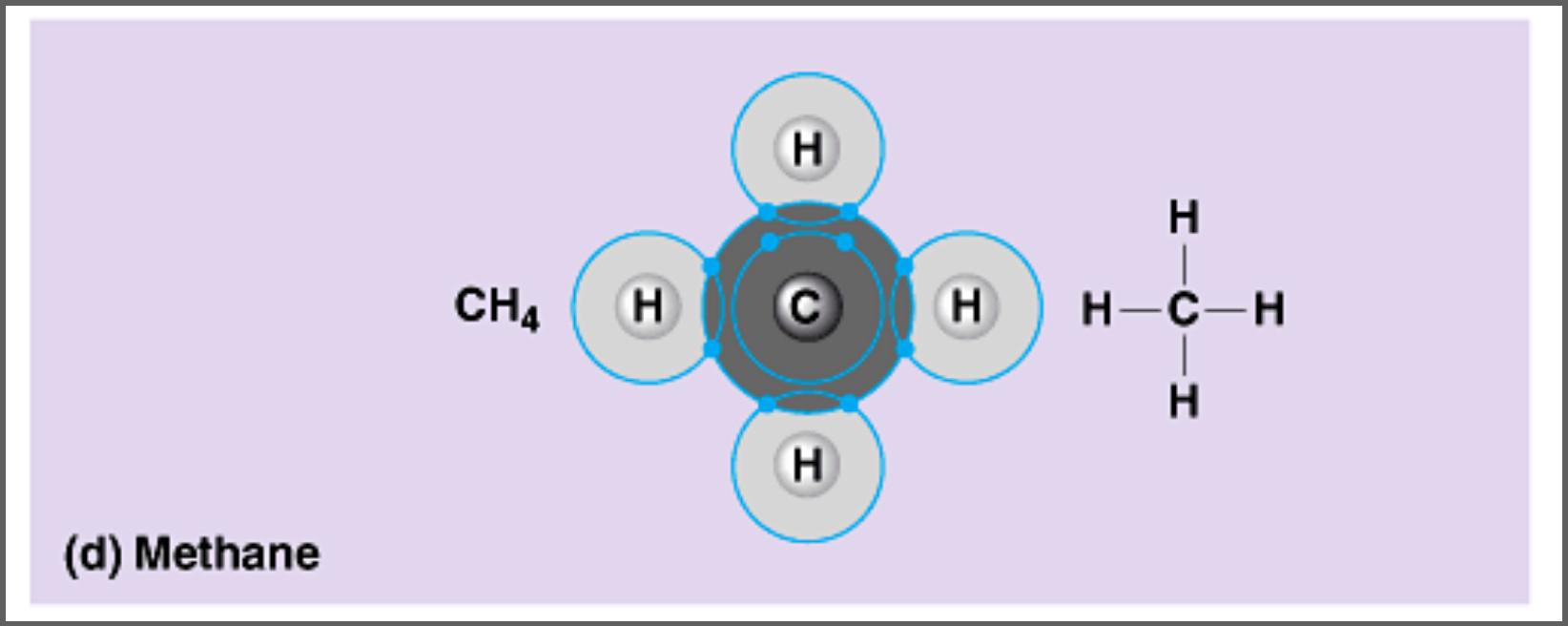
Double covalent bonds

- Two atoms can share more than one pair of electrons
  - double bonds (2 pairs of electrons)
  - triple bonds (3 pairs of electrons)
- Very strong bonds



Multiple covalent bonds

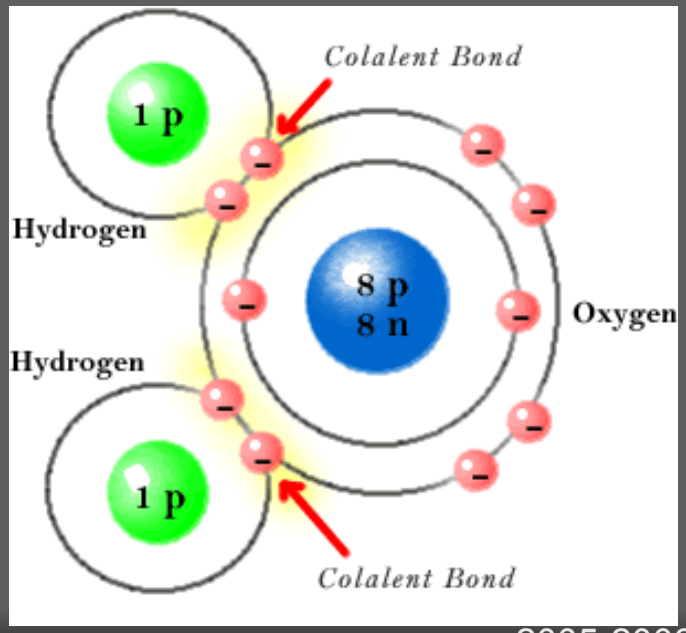
- 1 atom can form covalent bonds with two or more other atoms
  - forms larger molecules
  - ex. carbon



(d) Methane

Polar covalent bonds

- Pair of electrons not shared equally by 2 atoms
- Water = O + H
  - **oxygen has stronger "attraction" for the shared electrons than hydrogen**
  - **oxygen has higher electronegativity (attraction power)**



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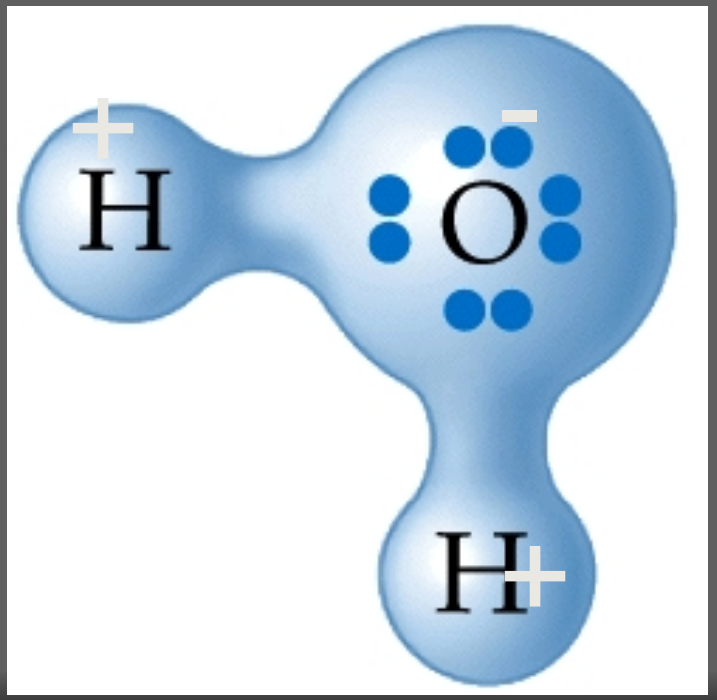
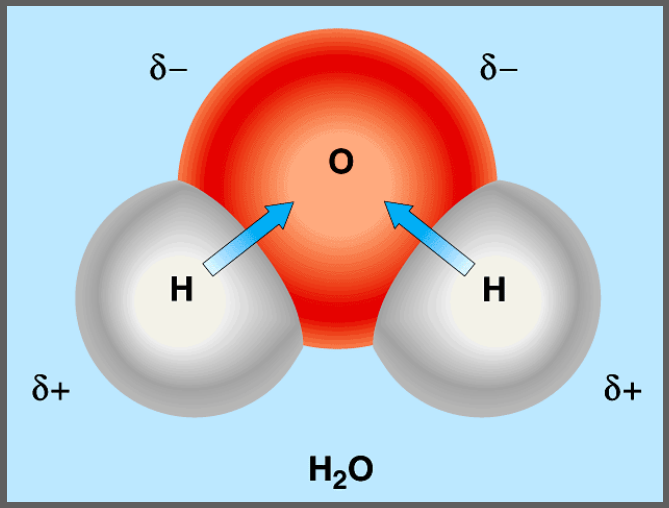


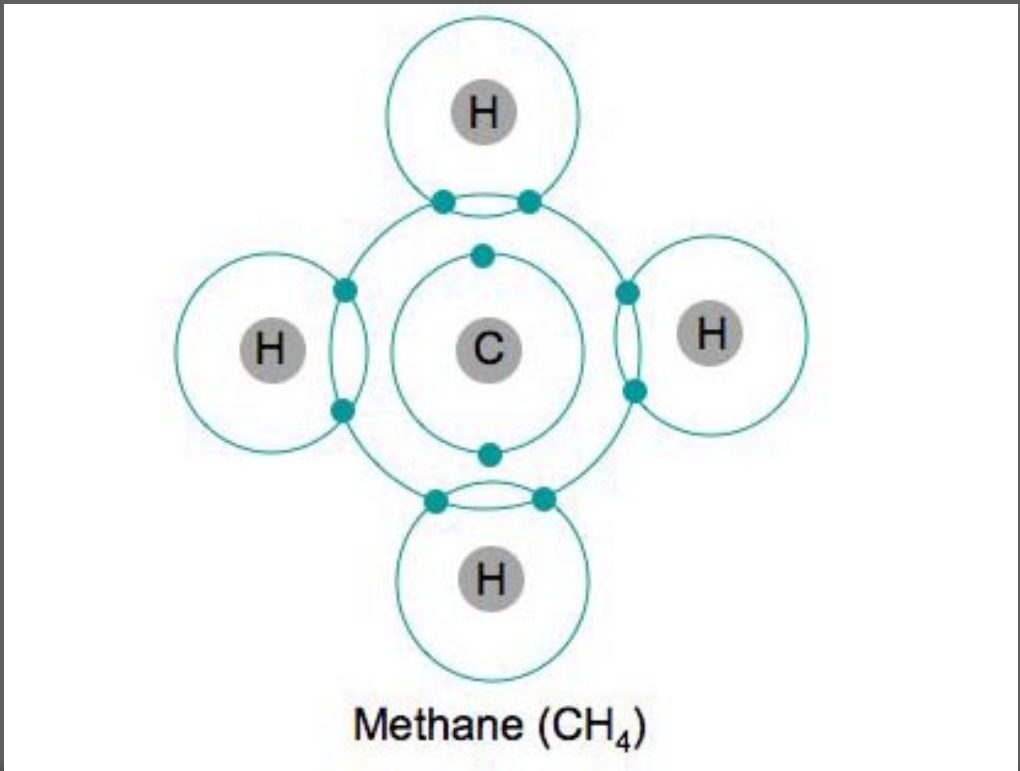
Polar covalent bonds

- 2 hydrogens in the water molecule form an angle
- Water molecule is polar
  - oxygen end is –
  - hydrogen end is +
- Leads to many interesting properties of water….

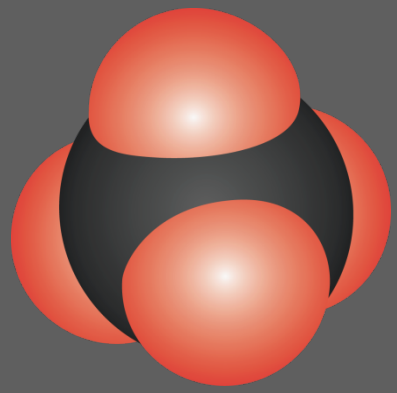


Nonpolar covalent bond

- Pair of electrons shared equally by 2 atoms
  - example: hydrocarbons = C_xH_x
    - methane (CH_4)

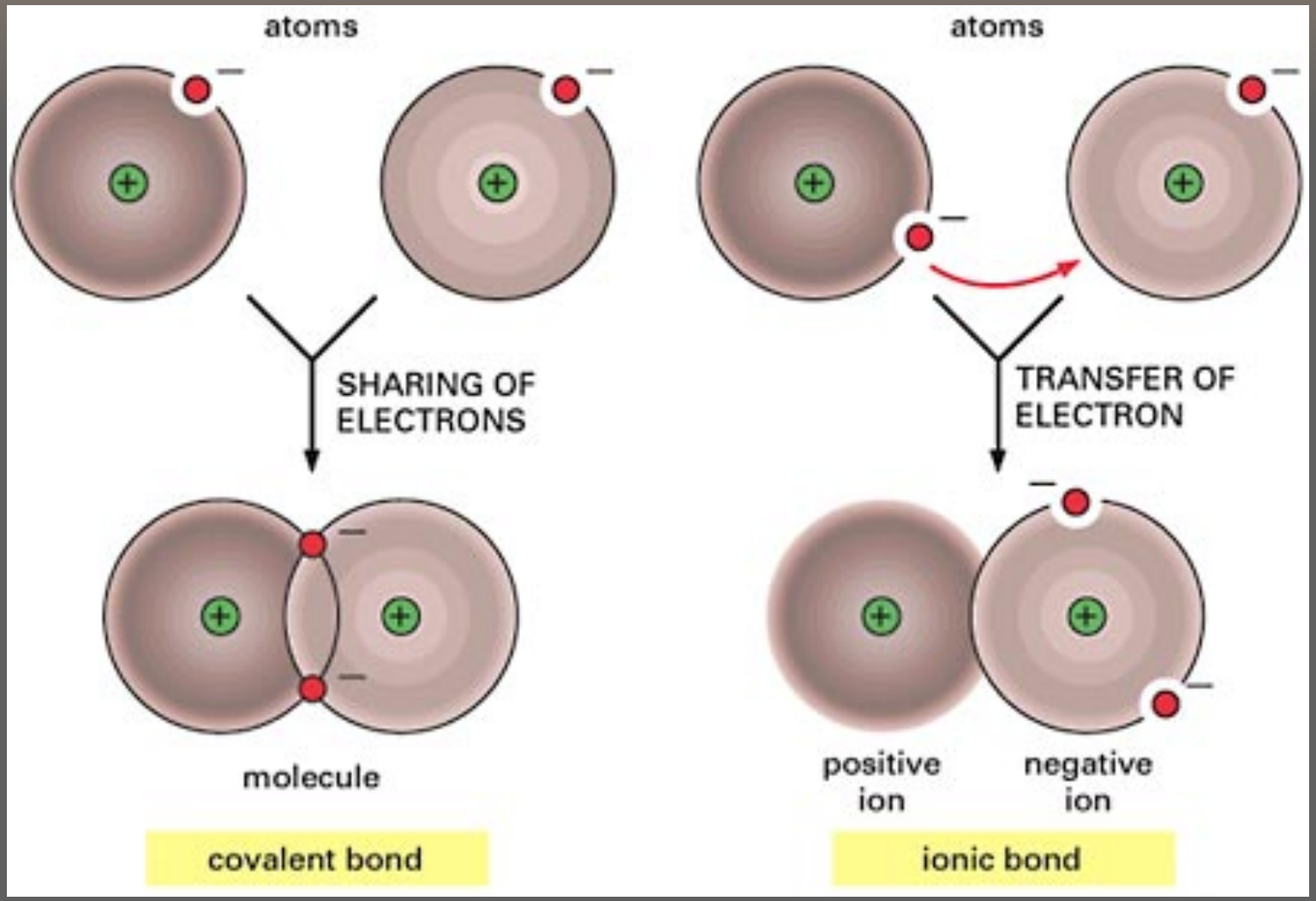


Methane (CH_4)



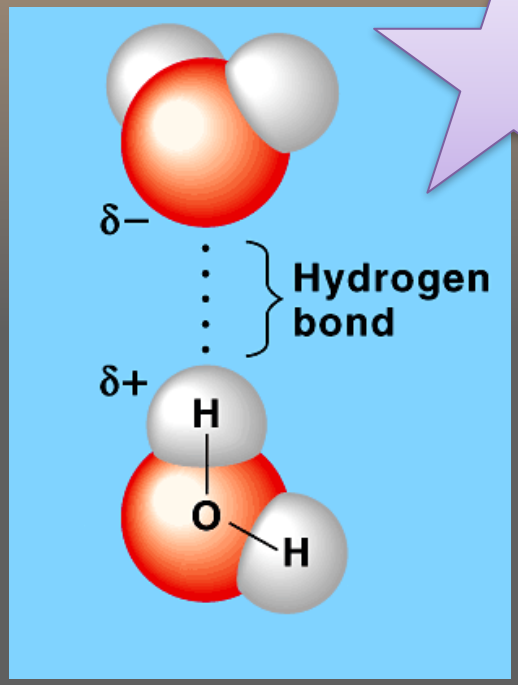
balanced, stable, good building block

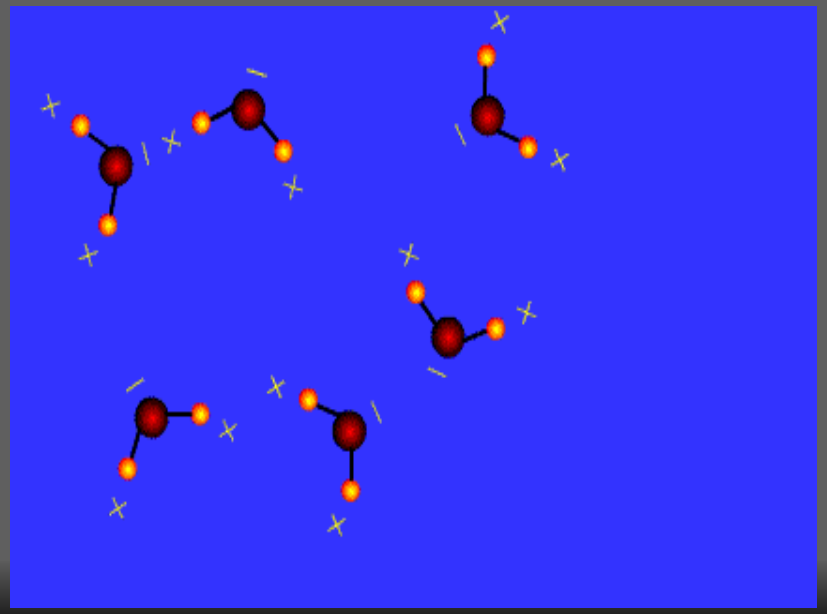
Summary of Ionic & Covalent Bonds



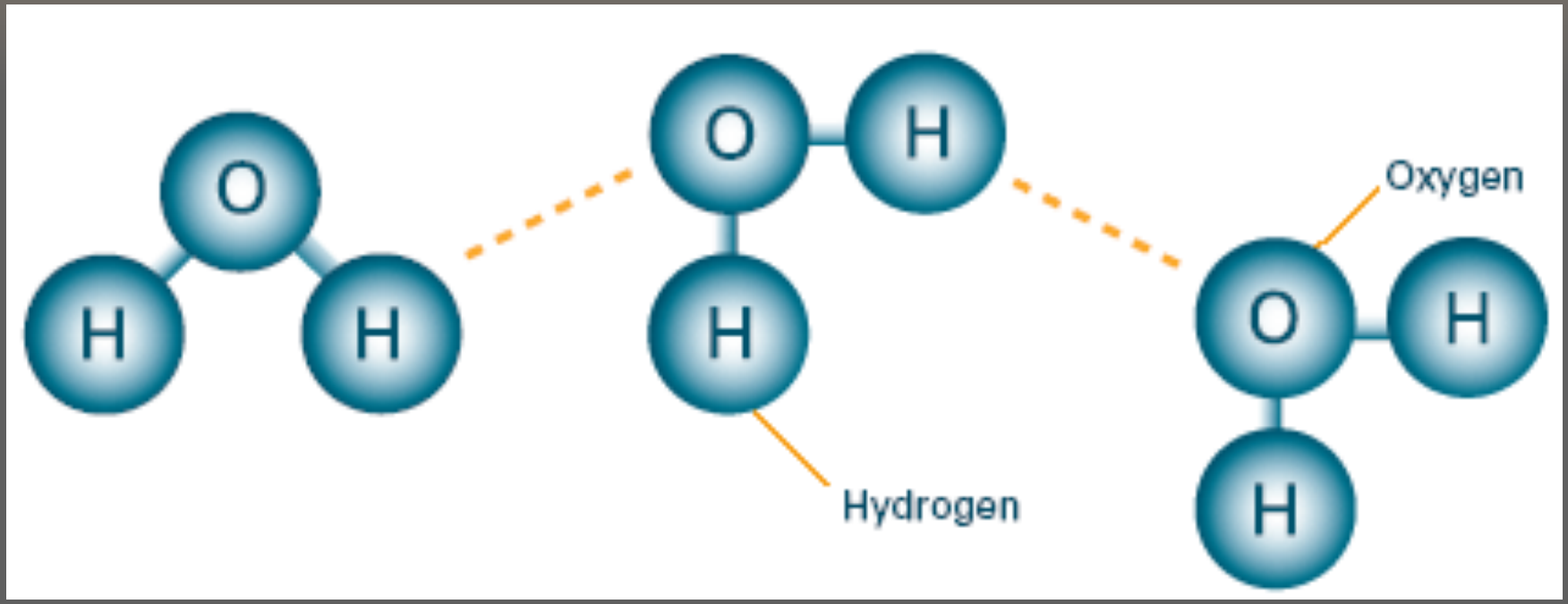
Hydrogen bonds

- Positive H atom in 1 water molecule is attracted to negative O in another
- Can occur wherever an -OH exists in a larger molecule
- Weak bonds



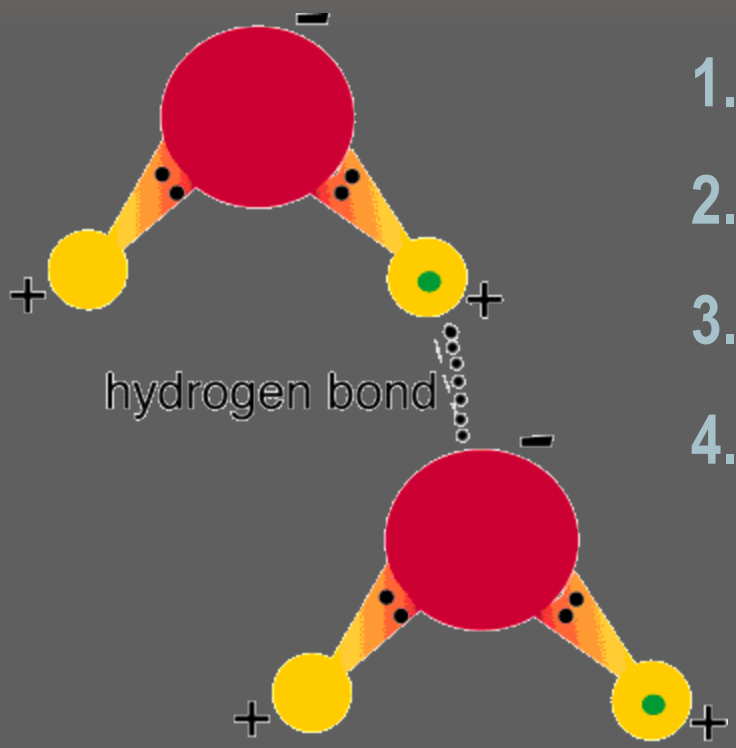


hydrogen bonds



when a charged part of a molecule having polar covalent bonds forms an electrostatic interaction with a substance of opposite charge

Hydrogen bonds between water molecules



1. "attraction interaction"-
2. no e^- stripped or shared
3. last only a millisecond
4. MANY water molecules with MANY hydrogen bonds between them → giving water unique properties

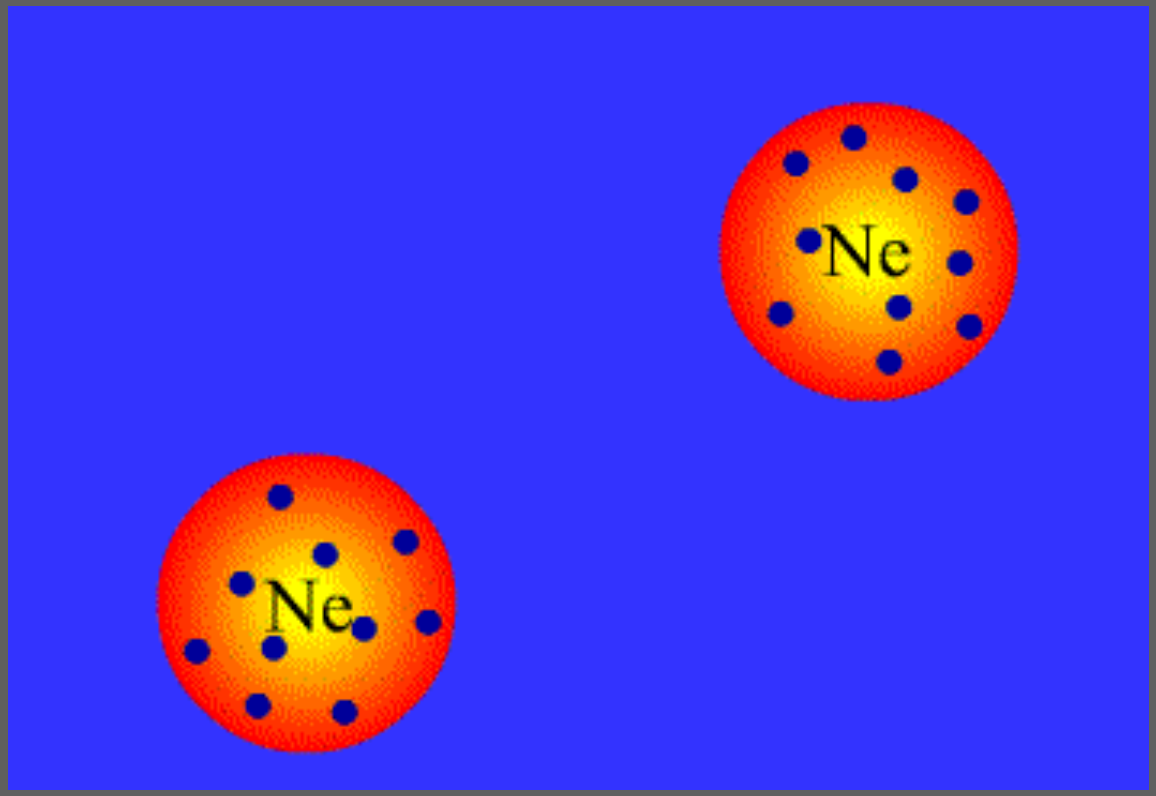
Bond Review

Covalent	Ionic	Hydrogen
All important to life		
Form cell's molecules	Quick reactions/ responses	H bonds to other electronegative atoms
Strong bond	Weaker bond (esp. in H_2O)	Even weaker
Made and broken by chemical reactions		

Special Type of Weak Bond-

Van der Waals Interactions

- weak attractive forces that hold non-polar molecules together

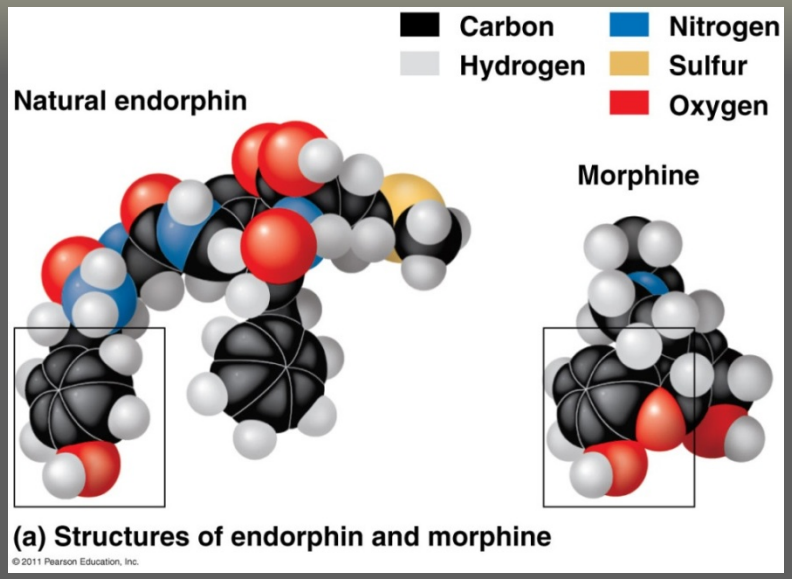


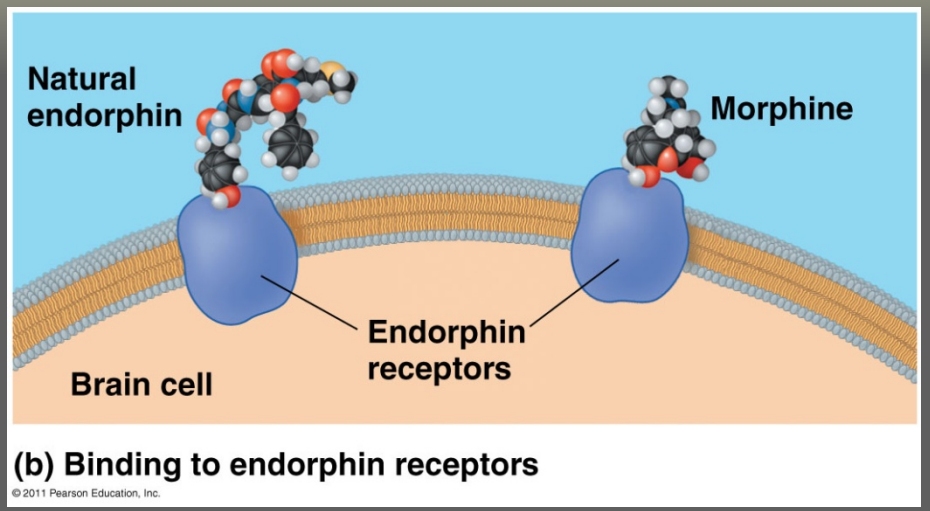
Weaker Bonds:

Van der Waals Interactions: slight, fleeting attractions between atoms and molecules close together

- Weakest bond
- Eg. gecko toe hairs + wall surface

All bonds affect molecule's SHAPE → affect molecule's FUNCTION

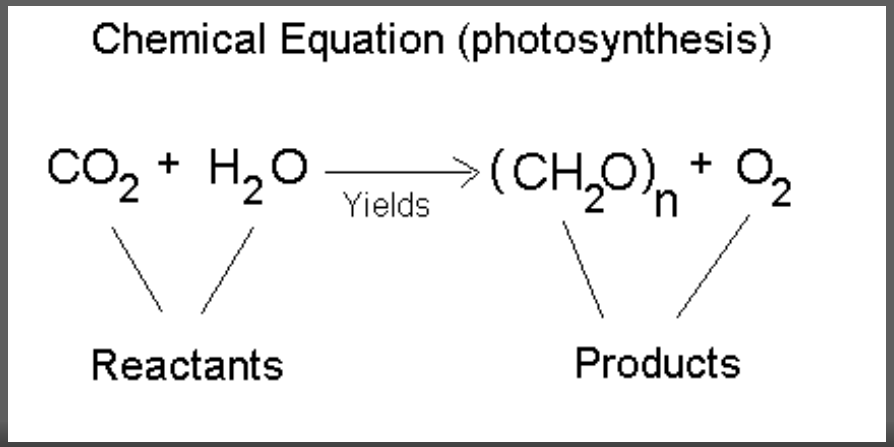




- **Similar shapes = mimic**
  - morphine, heroin, opiates mimic endorphin (euphoria, relieve pain)

Chemical Reactions:

- A **Chemical Reaction** = whenever a chemical bond is formed or broken.
- 2 types (sometimes 3) of chemical reactants
  - **Reactants** = Substances existing before the reaction
  - **Products** = Substances existing after the reaction
  - **Catalysts** = Substances which speed up the rate of a reaction



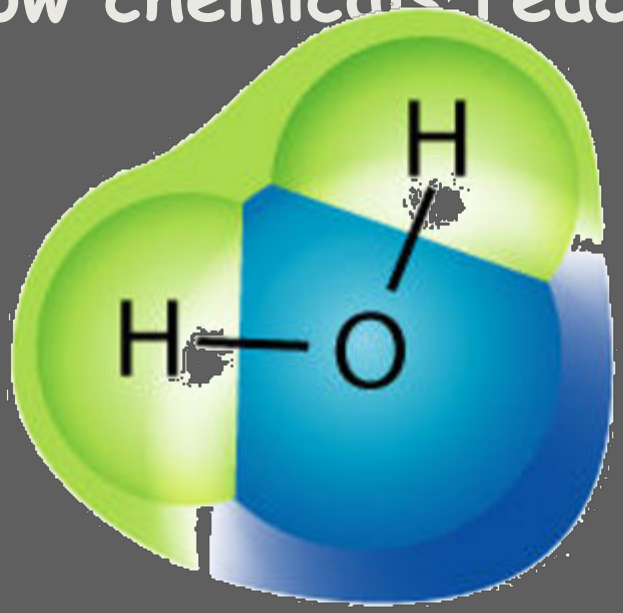
Chemical Reactions:

- **Catalysts** = Substances which speed up the rate of a reaction
- **Chemical Equations** are a shorthand way of showing chemical reactions.
  - Separates Products and reactants.
  - Usually follow flow of energy.
- Rx's **naturally occur** when they **release energy (exergonic)**
- Can however occur when energy is added. (endergonic)

Structural and Chemical Formulas:

- **Chemical formulas** show the number of and types of atoms in a molecule
- **Structural Formulas** are used to graphically represent a chemical formula
- Useful in visualizing how chemicals react and form new ones.

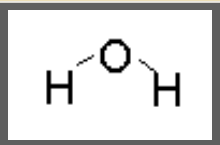
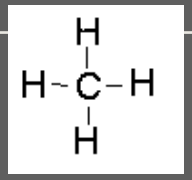
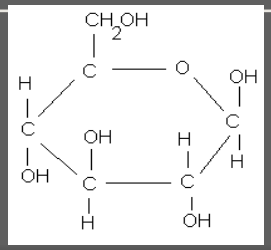
H_2O



Structural and Chemical Formulas:

- When drawing **Structural Formulas** use the following rules:
- The Periodic table **abbreviation** is used to represent the atoms.
- A single strait line **(---)** represents a single bond
- Two parallel strait lines **(==)** represent double bonds

Example Formulas:

Chemical Name	Chemical Formula	Structural Formula
Water	H_2O	
Carbon Dioxide	CO_2	
Methane	CH_4	
Glucose	$C_6H_{12}O_6$	

Reductionist view of biology

- Matter is made of atoms
- Life requires ~25 chemical elements
- Atomic structure determines behavior of an element
- Atoms combine by chemical bonding to form molecules
- Weak chemical bonds play important roles in chemistry of life
- A molecule's biological function is related to its shape
- Chemical reactions make & break chemical bonds