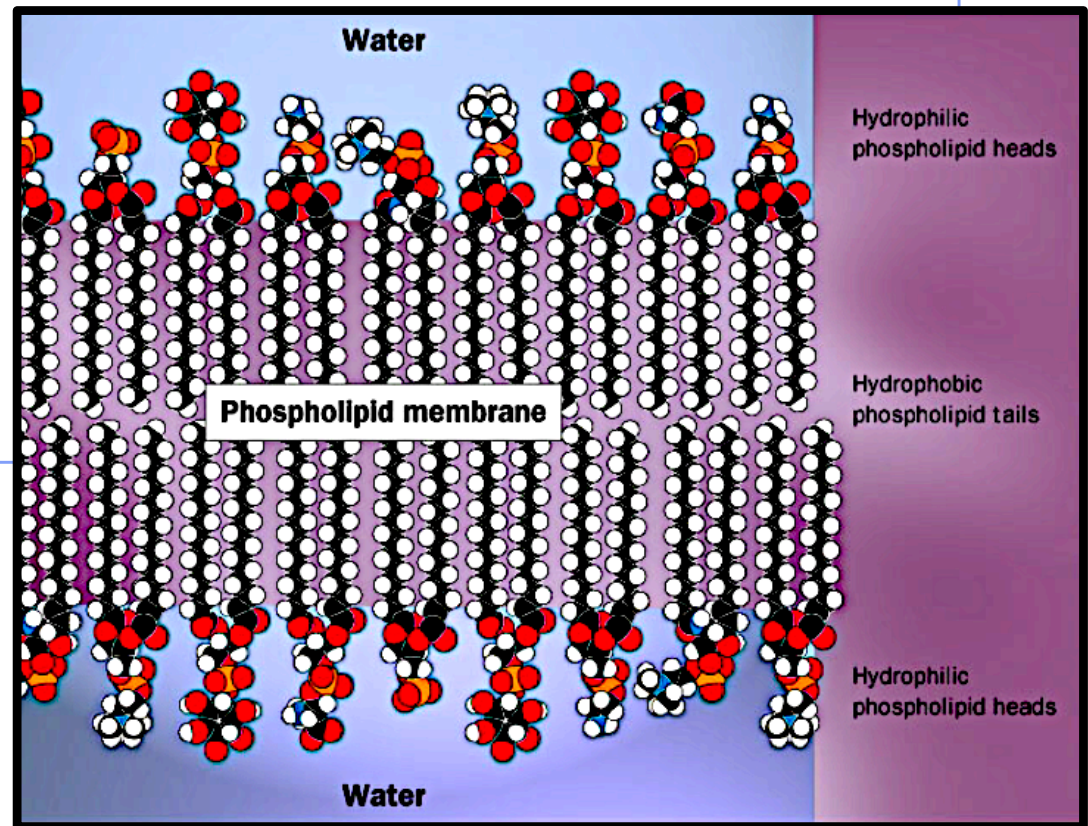
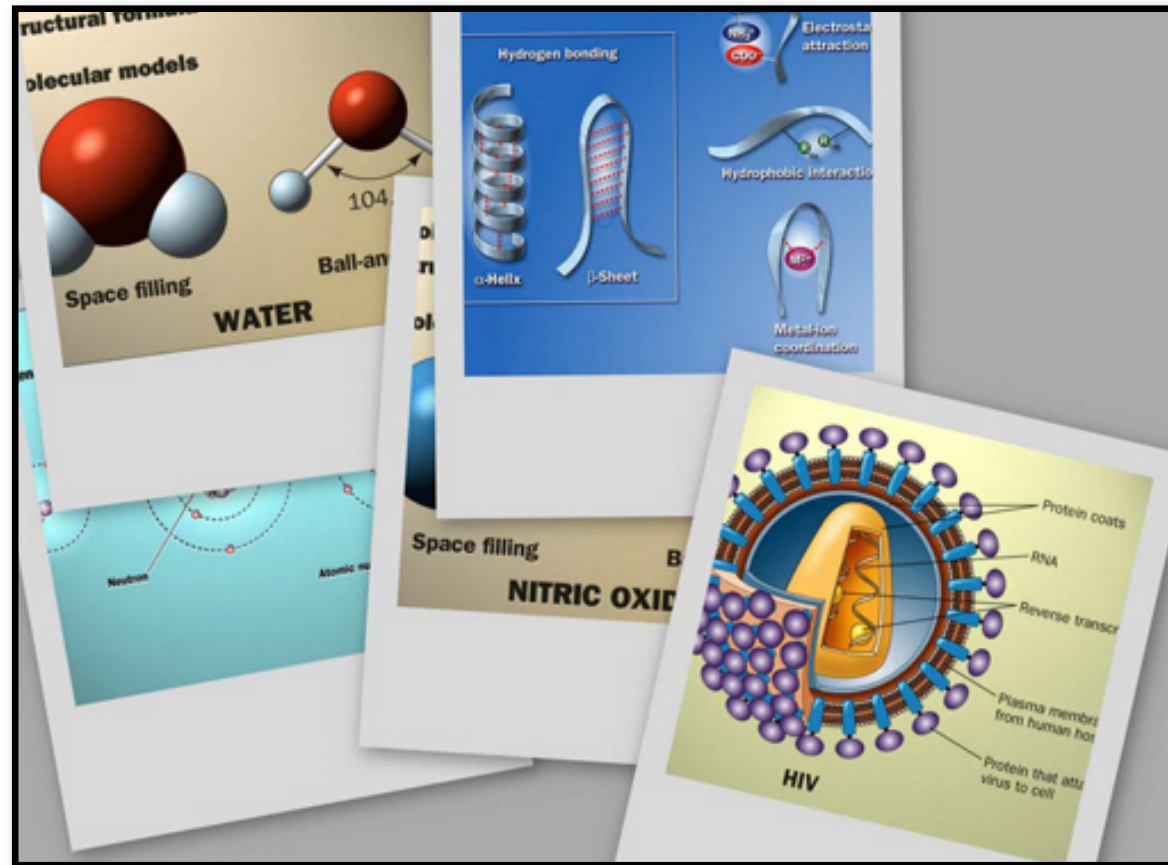


# The Chemistry of Life



# Why are we studying chemistry?

Chemistry is the foundation of Biology



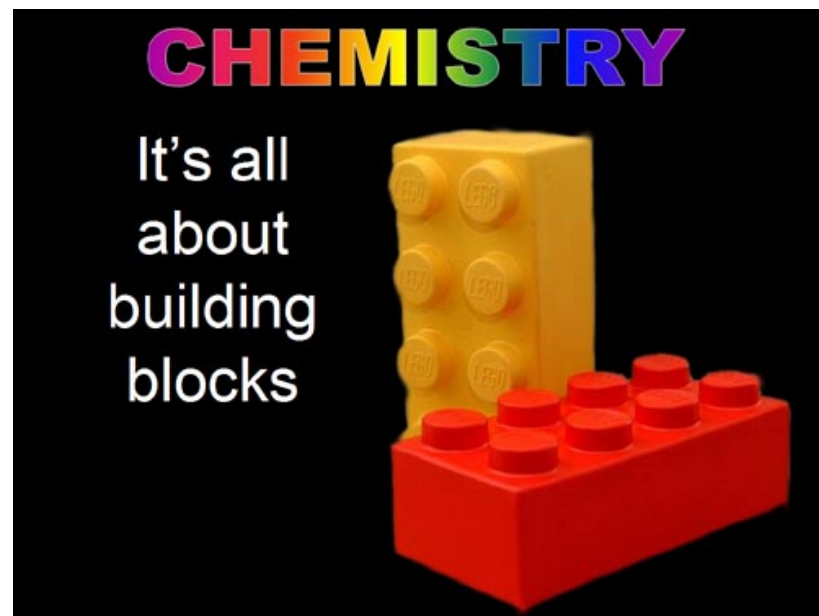
Life only happens because of the millions of chemical reactions taking place inside our bodies every second.

# Matter is made of one or more elements

- An ELEMENT is a fundamental substance that cannot be chemically changed or broken down into a simpler substance by ordinary means.

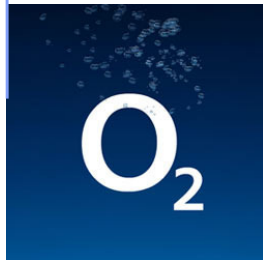
◆ Example: Table salt is made up of the elements sodium and chlorine.

◆ Example: Glucose is made up of the elements hydrogen, carbon, and oxygen.



# Matter is made of one or more elements

**EXERCISE:** Scientists attempt to decompose three gases (oxygen, nitrogen, carbon dioxide) into simpler substances using chemical reactions. Oxygen and Nitrogen **CANNOT** be split into simpler substances. Carbon dioxide **DOES** decompose and releases Carbon and Oxygen. *Based on these results which gases are elements?*



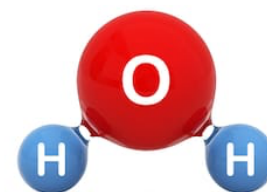
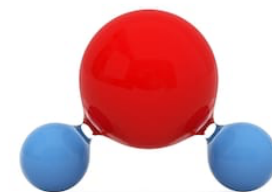
**ANSWER:** Oxygen and nitrogen are elements. They cannot be broken down into simpler substances.

Carbon dioxide is not one of the simplest building blocks because it can be broken down into 2 components.



# Matter is made of one or more elements

**EXERCISE:** It is possible using an electrical current to decompose a sample of water producing hydrogen gas and oxygen gas. Is water an element? Why?



**ANSWER:** No, because water is decomposed into two simpler substances in this chemical reaction and elements cannot be broken down into a simpler substance. Therefore, water is not an element.



# Matter is made of one or more elements

- For simplicity, chemists refer to specific elements using one or two letter CHEMICAL SYMBOLS.
  - ◆ The first letter is capitalized and the second is lower case.
- An ATOM is the smallest particle of an element that still retains the properties of that element.
  - ◆ 1 to 2 million atoms would fit in a period at the end of this sentence!!!
    - These atoms are the building blocks of the matter of the universe.
      - ◆ An element's symbol also refers to an atom of that element

Hydrogen	H
Iodine	I
Lithium	Li
Magnesium	Mg
Manganese	Mn
Nitrogen	N
Oxygen	O
Phosphorus	P
Silicon	Si

# Element Symbols are Arranged Into the Periodic Table

## Periodic Table of the Elements

1	IA <b>H</b>																0 2 <b>He</b>	
2	3 <b>Li</b>	IIA 4 <b>Be</b>											5 <b>B</b>	6 <b>C</b>	7 <b>N</b>	8 <b>O</b>	9 <b>F</b>	10 <b>Ne</b>
3	<b>Na</b>	<b>Mg</b>	III B	IV B	V B	VIB	VII B	VII			IB	IIB	13 <b>Al</b>	14 <b>Si</b>	15 <b>P</b>	16 <b>S</b>	17 <b>Cl</b>	18 <b>Ar</b>
4	<b>K</b>	<b>Ca</b>	21 <b>Sc</b>	22 <b>Ti</b>	23 <b>V</b>	24 <b>Cr</b>	25 <b>Mn</b>	26 <b>Fe</b>	27 <b>Co</b>	28 <b>Ni</b>	29 <b>Cu</b>	30 <b>Zn</b>	31 <b>Ga</b>	32 <b>Ge</b>	33 <b>As</b>	34 <b>Se</b>	35 <b>Br</b>	36 <b>Kr</b>
5	37 <b>Rb</b>	38 <b>Sr</b>	39 <b>Y</b>	40 <b>Zr</b>	41 <b>Nb</b>	42 <b>Mo</b>	43 <b>Tc</b>	44 <b>Ru</b>	45 <b>Rh</b>	46 <b>Pd</b>	47 <b>Ag</b>	48 <b>Cd</b>	49 <b>In</b>	50 <b>Sn</b>	51 <b>Sb</b>	52 <b>Te</b>	53 <b>I</b>	54 <b>Xe</b>
6	55 <b>Cs</b>	56 <b>Ba</b>	57 <b>*La</b>	72 <b>Hf</b>	73 <b>Ta</b>	74 <b>W</b>	75 <b>Re</b>	76 <b>Os</b>	77 <b>Ir</b>	78 <b>Pt</b>	79 <b>Au</b>	80 <b>Hg</b>	81 <b>Tl</b>	82 <b>Pb</b>	83 <b>Bi</b>	84 <b>Po</b>	85 <b>At</b>	86 <b>Rn</b>
7	87 <b>Fr</b>	88 <b>Ra</b>	<p><b>Different kinds of atoms make up the different elements</b></p>															

\* Lanthanide Series

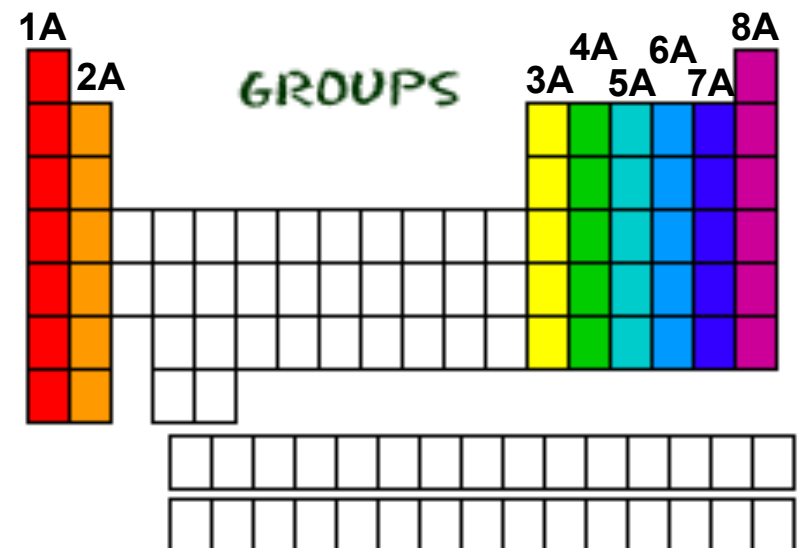
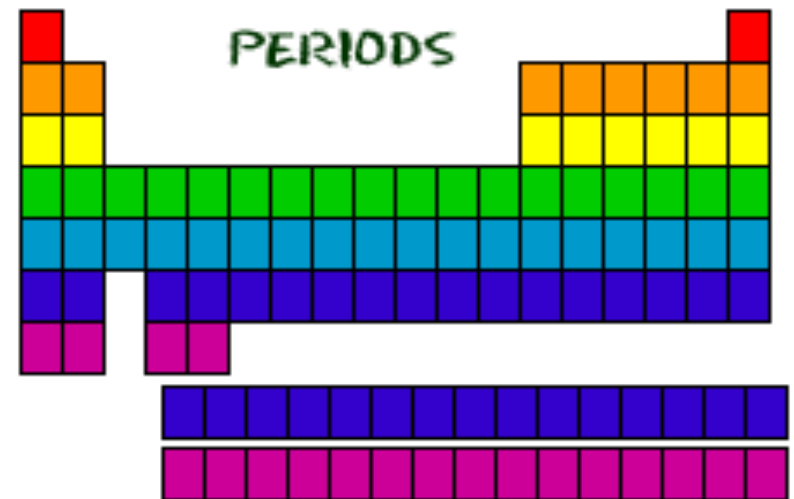
58 <b>Ce</b>	59 <b>Pr</b>	60 <b>Nd</b>	61 <b>Pm</b>	62 <b>Sm</b>	63 <b>Eu</b>	64 <b>Gd</b>	65 <b>Tb</b>	66 <b>Dy</b>	67 <b>Ho</b>	68 <b>Er</b>	69 <b>Tm</b>	70 <b>Yb</b>	71 <b>Lu</b>
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+ Actinide Series

90 <b>Th</b>	91 <b>Pa</b>	92 <b>U</b>	93 <b>Np</b>	94 <b>Pu</b>	95 <b>Am</b>	96 <b>Cm</b>	97 <b>Bk</b>	98 <b>Cf</b>	99 <b>Es</b>	100 <b>Fm</b>	101 <b>Md</b>	102 <b>No</b>	103 <b>Lr</b>
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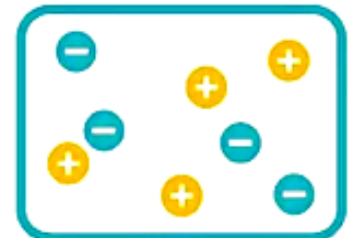
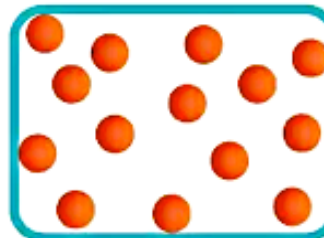
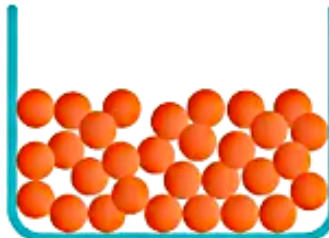
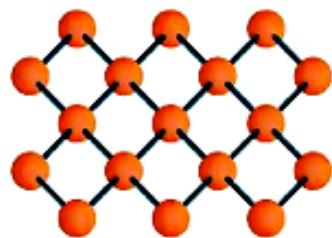
# Matter is made of one or more elements

- Elements are placed on a grid with 7 horizontal rows called PERIODS.
- There are also vertical columns called GROUPS.
  - ◆ The colored groups are groups 1A, 2A, 3A, 4A, 5A, 6A, 7A, and 8A and are referred to as the MAIN GROUPS.

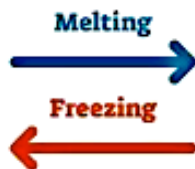


# Matter is made of one or more elements

- MATTER: Anything that occupies SPACE & has MASS.
  - ◆ Anything with a physical presence and is made up of one or more atoms of one or more elements
- Matter can exist in different states or phases, the first three are of particular importance in biology



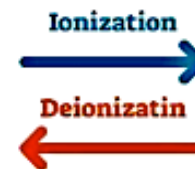
**SOLID**



**LIQUID**



**GAS**



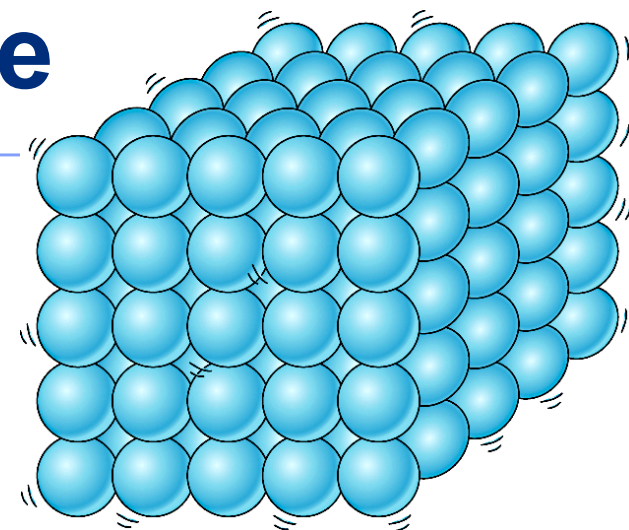
**PLASMA**

Energy  
Temperature

Energy  
Temperature

Energy  
Temperature

# The Solid Phase

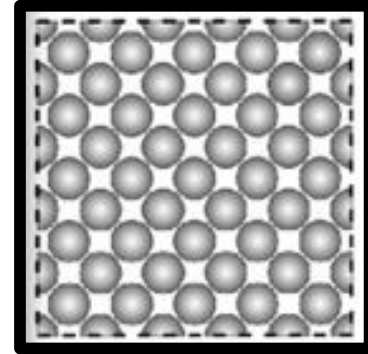


- 1. High density** (*water is an exception*)
- 2. Hard to expand or compress**
- 3. Rigid shape**
- 4. Fixed volume**
- 5. Particles that make up a solid are often tightly packed or packed in a regular pattern**
- 6. Particles are held strongly in place, unable to move past each other, but can vibrate within a limited area**

**EXAMPLE:** Sugar Cube ( $C_{12}H_{22}O_{11}$ )



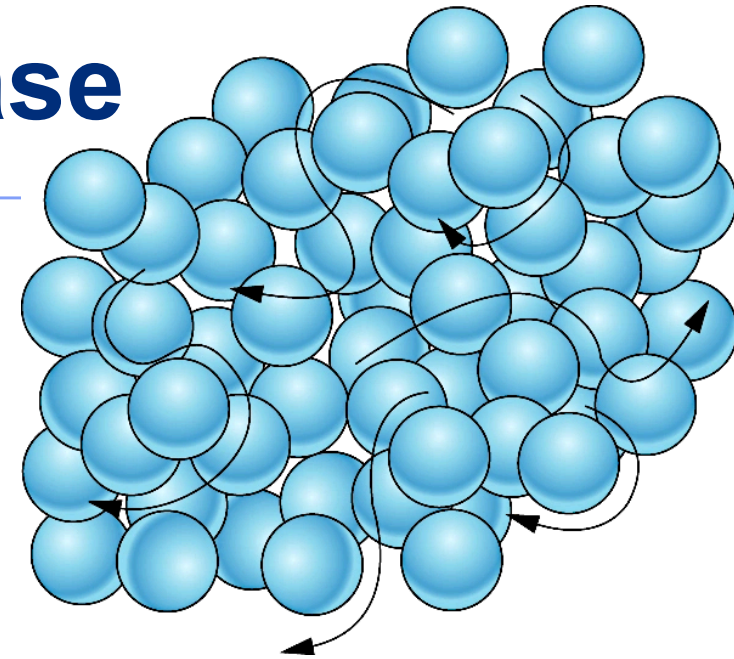
# The Solid Phase



- Particles (and the atoms that make them up) in a solid substance **vibrate** in place (*because there is always some thermal energy in the system*), but these particles do **not** slide past each other, moving in location within the rigid block of solid substance.
- Particles in a solid sit closer together because they are either:
  1. under **extreme positive pressure** or...
  2. because there is **not enough thermal energy** (and thus not enough particular motion) in the system for the particles **to overcome the intermolecular forces** that attract these particles to each other.
- The weak intermolecular attractions between particles are **long-lasting and permanent**, preventing the particles from sliding past each other (as in liquids) or from moving very far apart from each other (as in gases)

# The Liquid Phase

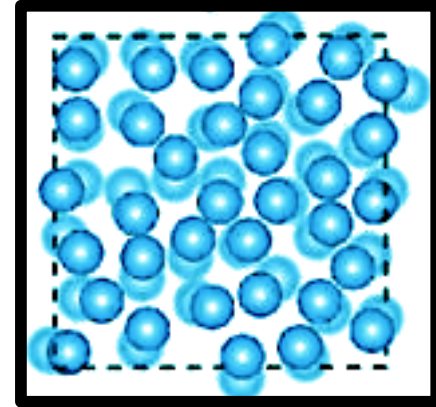
1. High density
2. Fixed volume
3. Hard to expand and compress
4. Particles are held close together by attractive forces but assume no regular pattern
5. Particles flow and can easily move or slide past one another
6. Liquids assume the shape of their containers



**EXAMPLE: LIQUID WATER**  
**(H<sub>2</sub>O)**

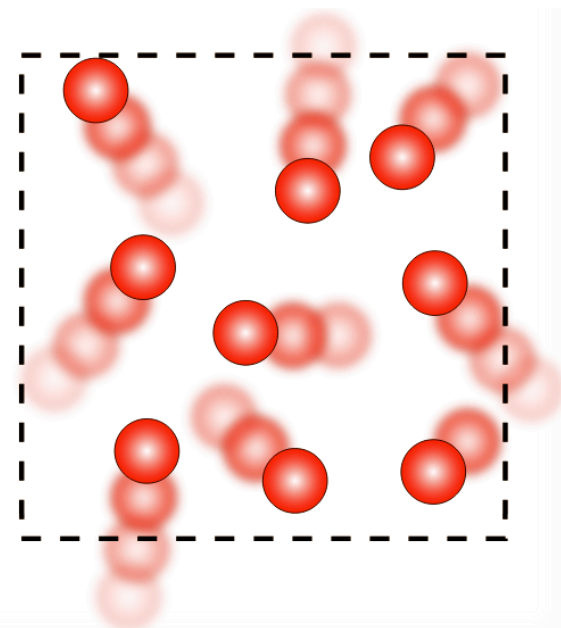


# The Liquid Phase



- Particles of a liquid substance are still close together, but they are also able to slide past one another, moving locations due to the random collisions between particles within the liquid.
- Particles in a liquid move past, yet still within close proximity to, each other because there is enough thermal energy (and thus enough random particular motion and collisions between particles) in the system so that the weak intermolecular attractions between particles are continually breaking, though they also keep continually reforming, allowing the particles to slide past one another, but still preventing them from moving very far apart from each other (as in gases).

# The Gas Phase

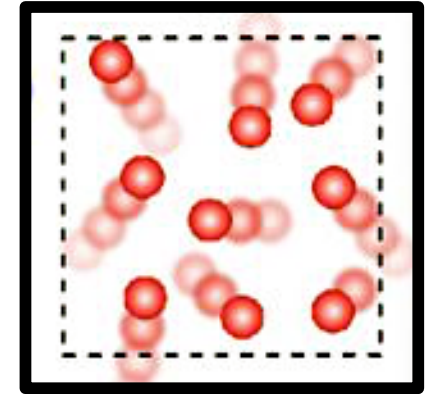


1. Low density
2. Easy to expand and compress
3. Assume the shape of the container
4. Assume the shape of the container
5. Fills the container with no regular pattern.
6. Assume the volume of the container
7. Particles vibrate and fly in all directions at great speeds
8. Particles are so far apart that the attractive forces between them are insignificant.

**EXAMPLE: STEAM or WATER VAPOR (H<sub>2</sub>O)**



# The Gas Phase



- Particles in a gas move far away from one another since the high amount of thermal energy in the system prevents the weak intermolecular attractions between particles from holding the particles close together.
  1. Because there is a high amount of thermal energy (compared to the amount in the liquid version of this substance), there exists a lot of vigorous random motion of now fast moving particles in the system, allowing the particles to move far apart and fully overcome the weak intermolecular forces that attract these particles to each other permanently in a solid and temporarily, yet repeatedly, in a liquid, both of which have lower thermal energy that causes less random motion of particles and particles to move at slower speeds.
  2. Due to the continual random collision between particles moving at much higher speeds, on average, than the particles do in liquid form, particles move far apart, too far for weak intermolecular forces of attraction to have a significant effect.
  3. Without the intermolecular forces being able to hold particles together in the presence of the high thermal energy, particles spread apart into any empty space, filling the volume of the container they are in.

# Density

- The **density** of an object equals its total mass divided by its total volume.
  - Generally, solids of a substance are more dense than liquids of that substance and liquids of a substance are more dense than gases of that substance.
  - Units of density relate mass to volume such grams per cubic centimeter ( $\text{g}/\text{cm}^3$ ) or grams per cubic milliliter ( $\text{g}/\text{mL}$ ).
- If masses are equal, a more dense object (such as iron) will occupy less volume than a less dense substance (such as water).
  - When you mix substances, the most dense substance sinks to the bottom, whilst the least dense substance is more buoyant and floats to the top.

$$D = \frac{m}{V}$$

Density Lab  
Volume by Formula



$$\rho = \frac{m}{V}$$

density

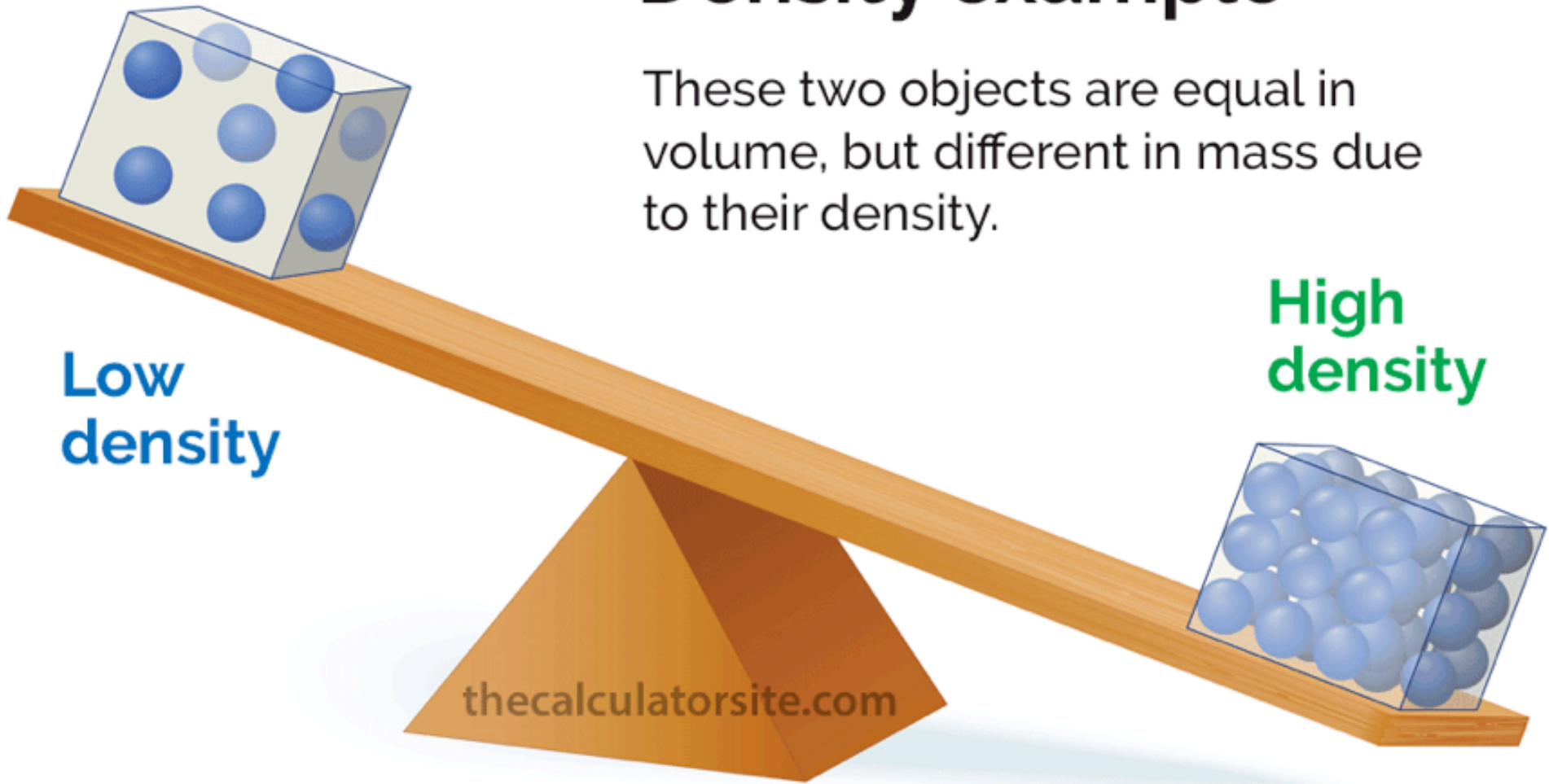
mass

volume

If volumes are equal, a more dense object will contain more mass than a less dense substance.

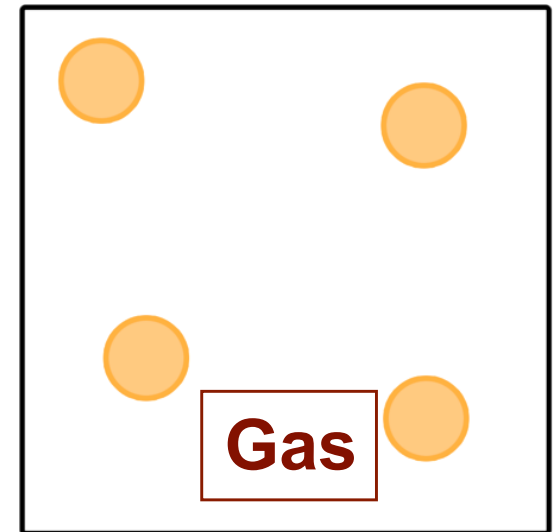
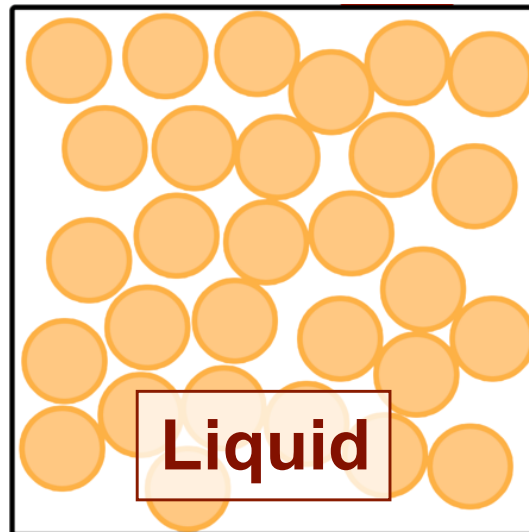
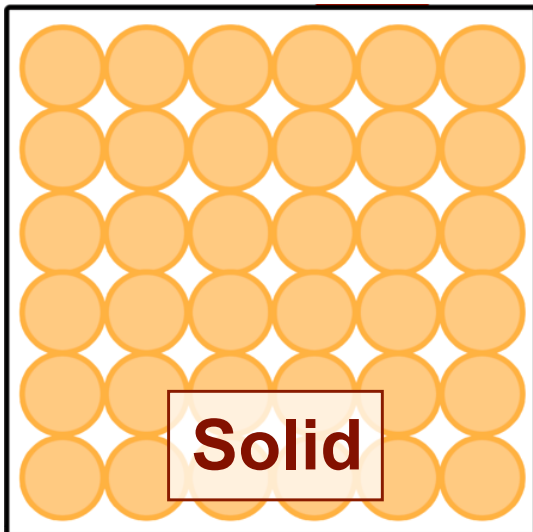
## Density example

These two objects are equal in volume, but different in mass due to their density.



# Changes in the Density of Solids, Liquids, & Gases

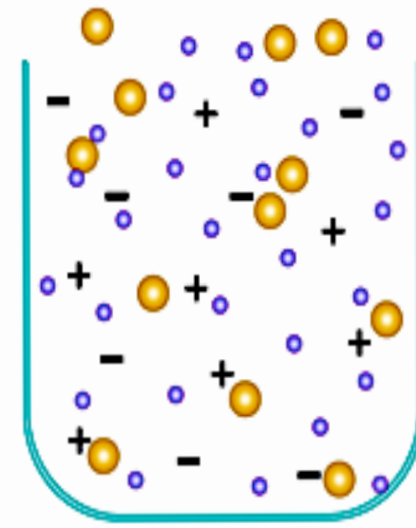
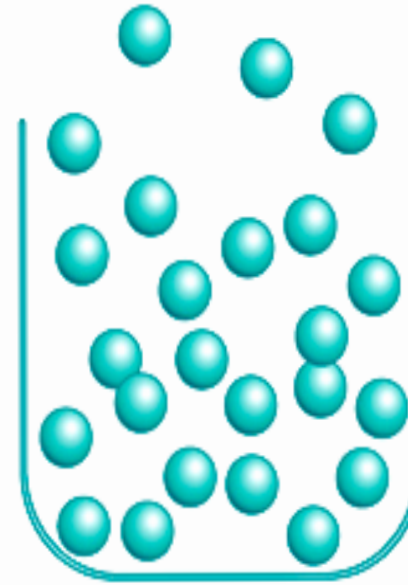
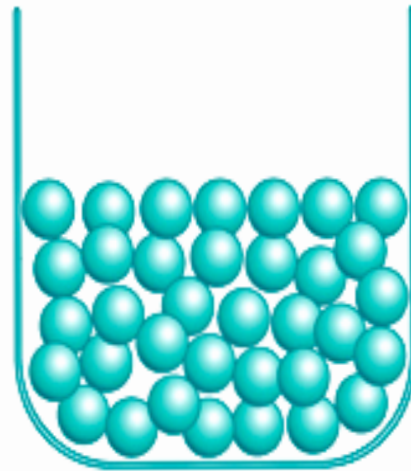
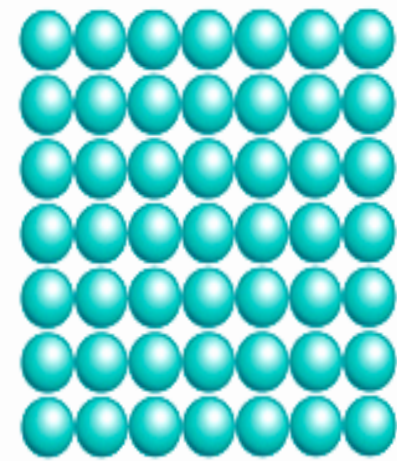
- ❖ Let's say we have three cubes of equal volume filled with the same substance in three different phases of matter: solid, liquid, and gas.
- ❖ In general, in solid form, more particles of a certain substance would fit into that cube's volume compared to what would fit if that substance was in liquid form. *(We will see how solid vs liquid water is an exception to this general rule in Ch.3)*
- ❖ In liquid form, many more particles of a certain substance would fit into that cube's volume compared to what would fit if that substance was in a gaseous state.



## Physical states

decreasing thermal energy

increasing thermal energy



### Solid

The molecules that make up a solid are arranged in regular, repeating patterns. They are held firmly in place but can vibrate within a limited area.

### Liquid

The molecules that make up a liquid flow easily around one another. They are kept from flying apart by attractive forces between them. Liquids assume the shape of their containers.

### Gas

The molecules that make up a gas fly in all directions at great speeds. They are so far apart that the attractive forces between them are insignificant.

### Plasma

At the very high temperatures of stars, atoms lose their electrons. The mixture of electrons and nuclei that results is the plasma state of matter.

Before we talk about Atoms...

Let's review

**ENERGY**

**ENERGY:** The ability to produce change or do work.  
Whenever a change occurs energy is involved.

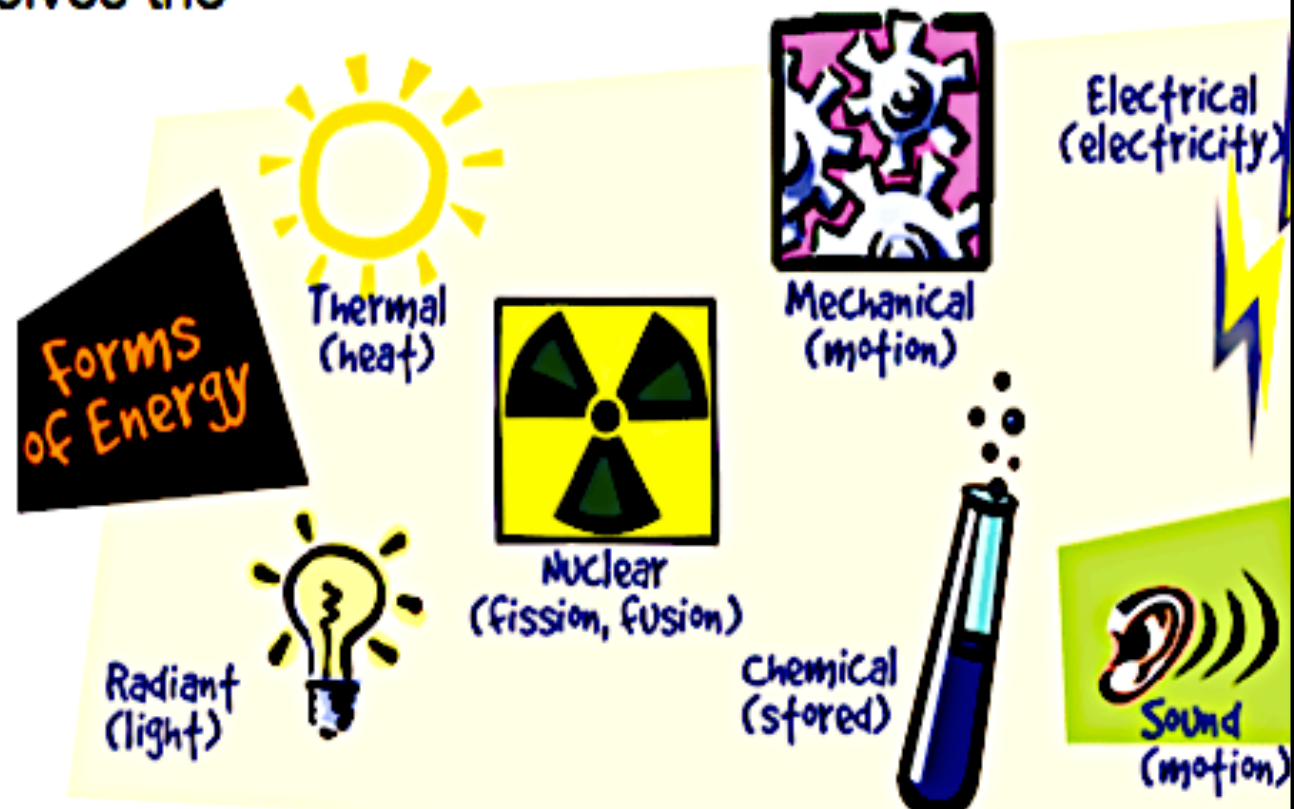
Energy is found and stored in different forms such as an object's position, light, heat, sound, motion etc...

Everything in the world involves the exchange of energy.

One form can be changed to another.

**Forms of Energy:**

1. Kinetic Energy
2. Potential Energy

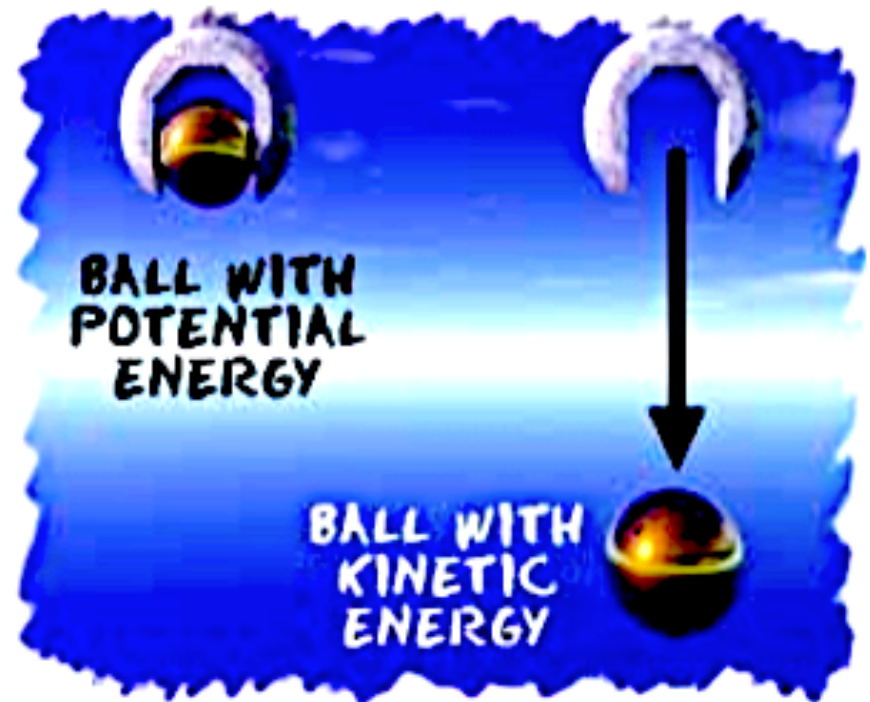


## KINETIC ENERGY:

Energy of Motion —  
Motion of waves, electrons  
atoms, molecules,  
substances, and objects.

## POTENTIAL ENERGY:

Stored energy and the  
energy of position —  
gravitational energy.



**KINETIC ENERGY:** Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.

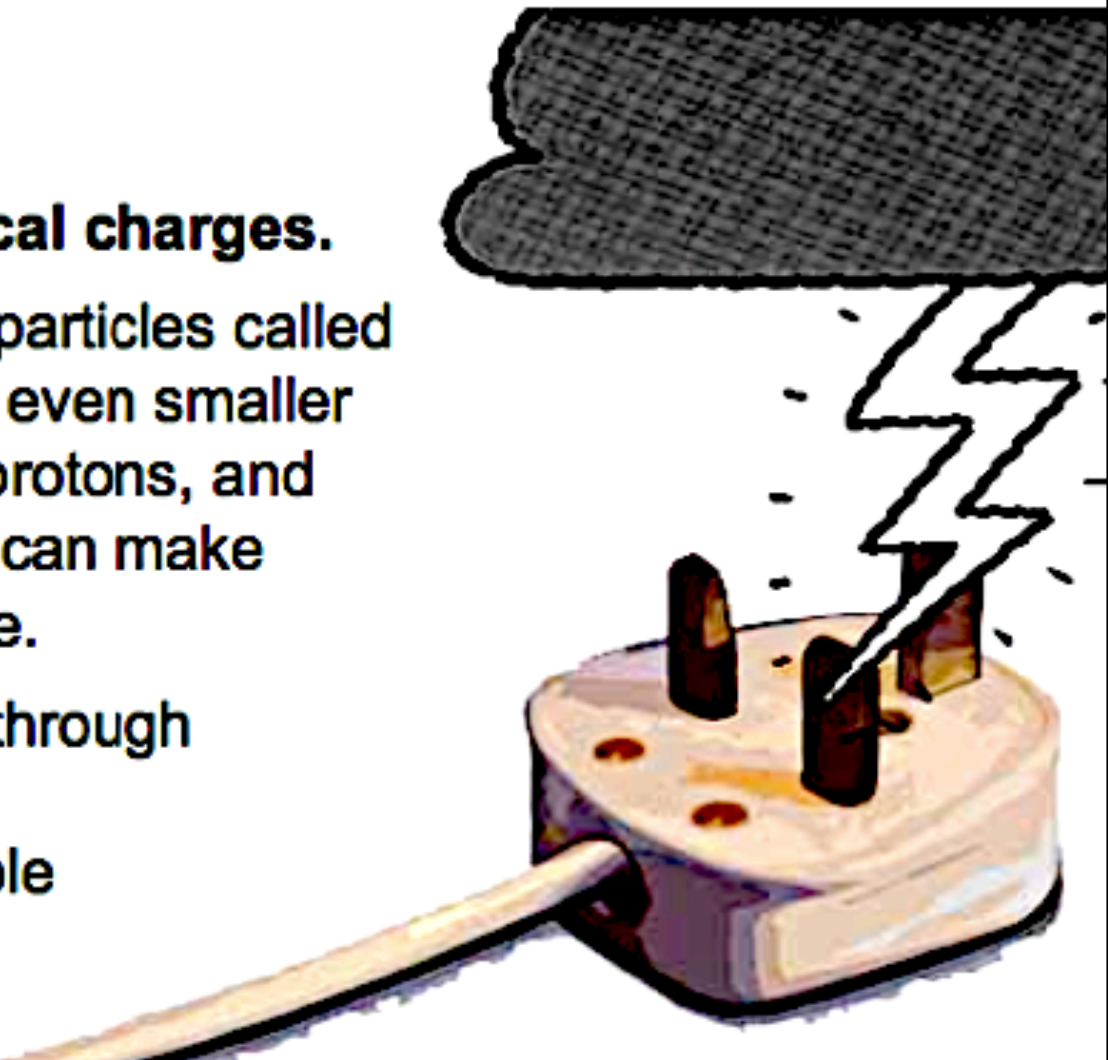
1. **Electrical Energy:**

**The movement of electrical charges.**

Everything is made of tiny particles called atoms. Atoms are made of even smaller particles called electrons, protons, and neutrons. Applying a force can make some of the electrons move.

Electrical charges moving through a wire is called electricity.

Lightning is another example of electrical energy.



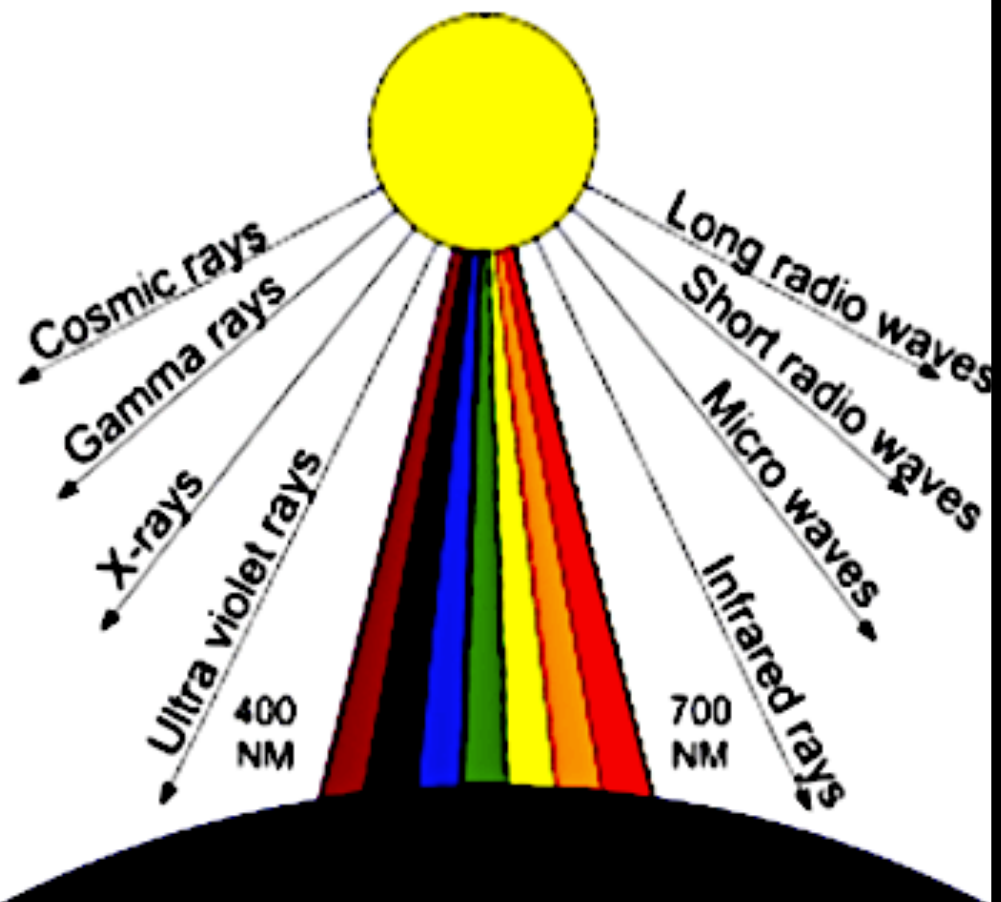
**KINETIC ENERGY:** Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.

## 2. Radiant Energy:

**Electromagnetic energy that travels in transverse waves**

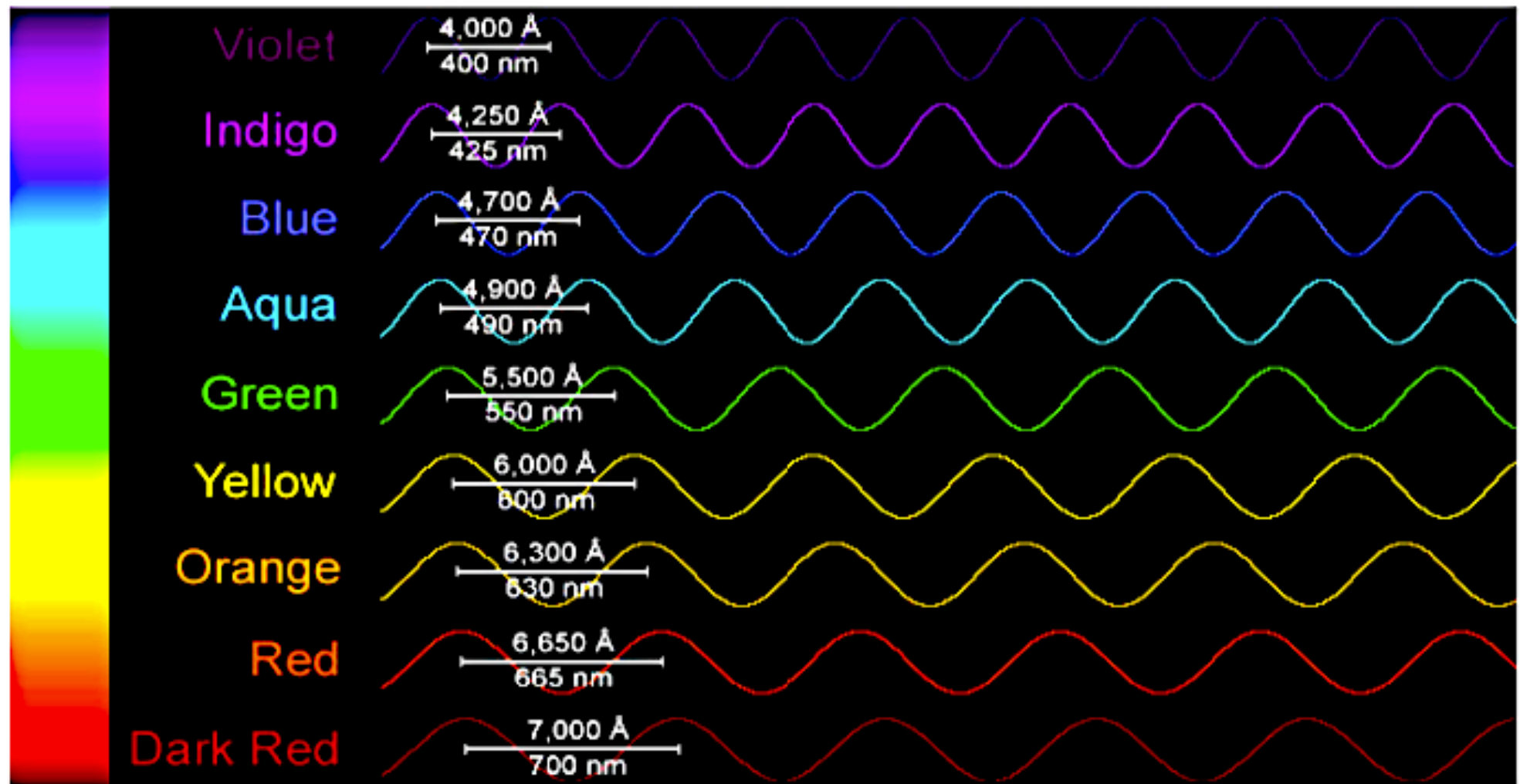
Radiant energy includes visible light, x-rays, gamma rays and radio waves.

Light is one type of radiant energy. Solar energy is another.

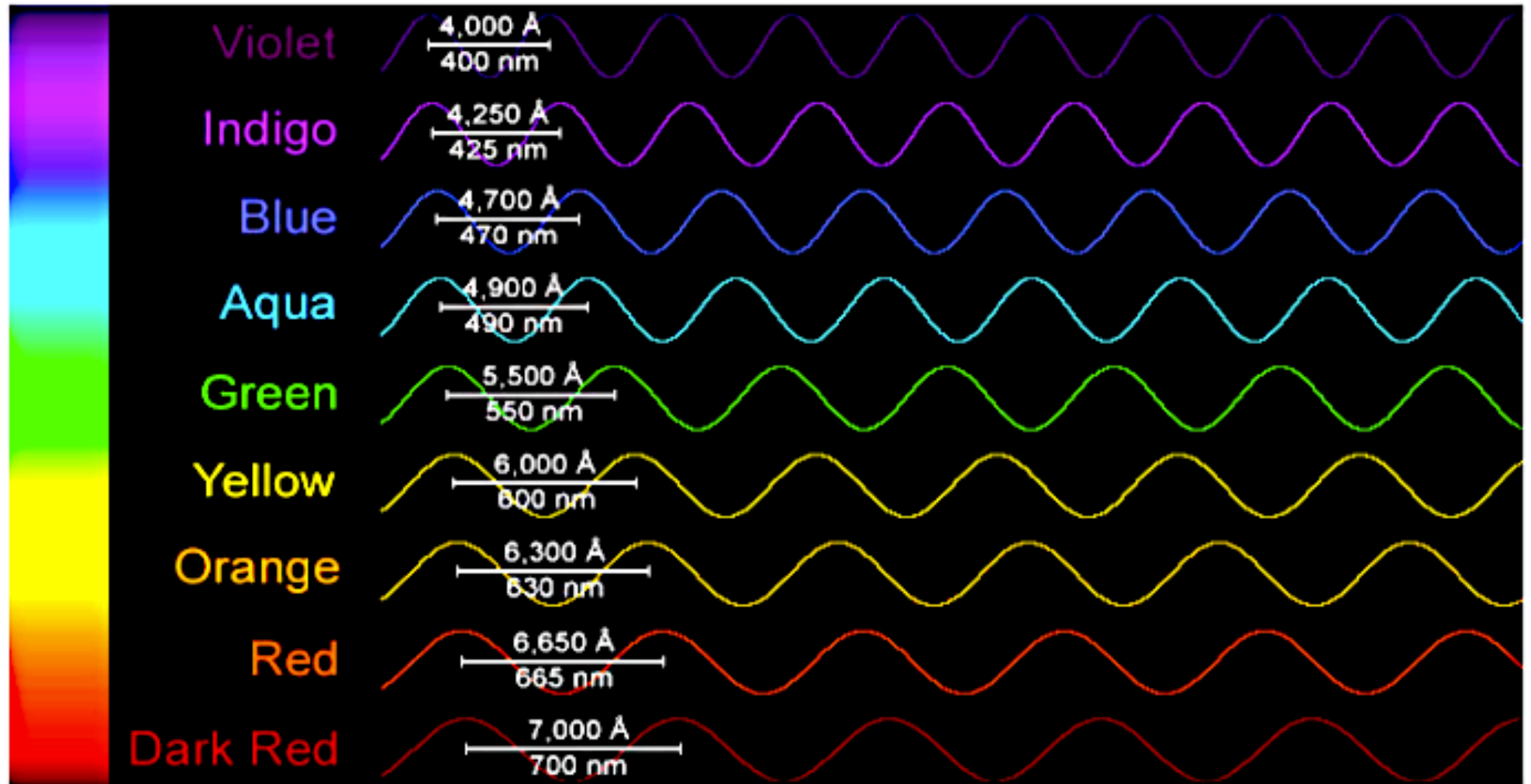


# Light travels as waves of energy!

**WAVELENGTH**: The distance between the top of one wave and the top of the next.



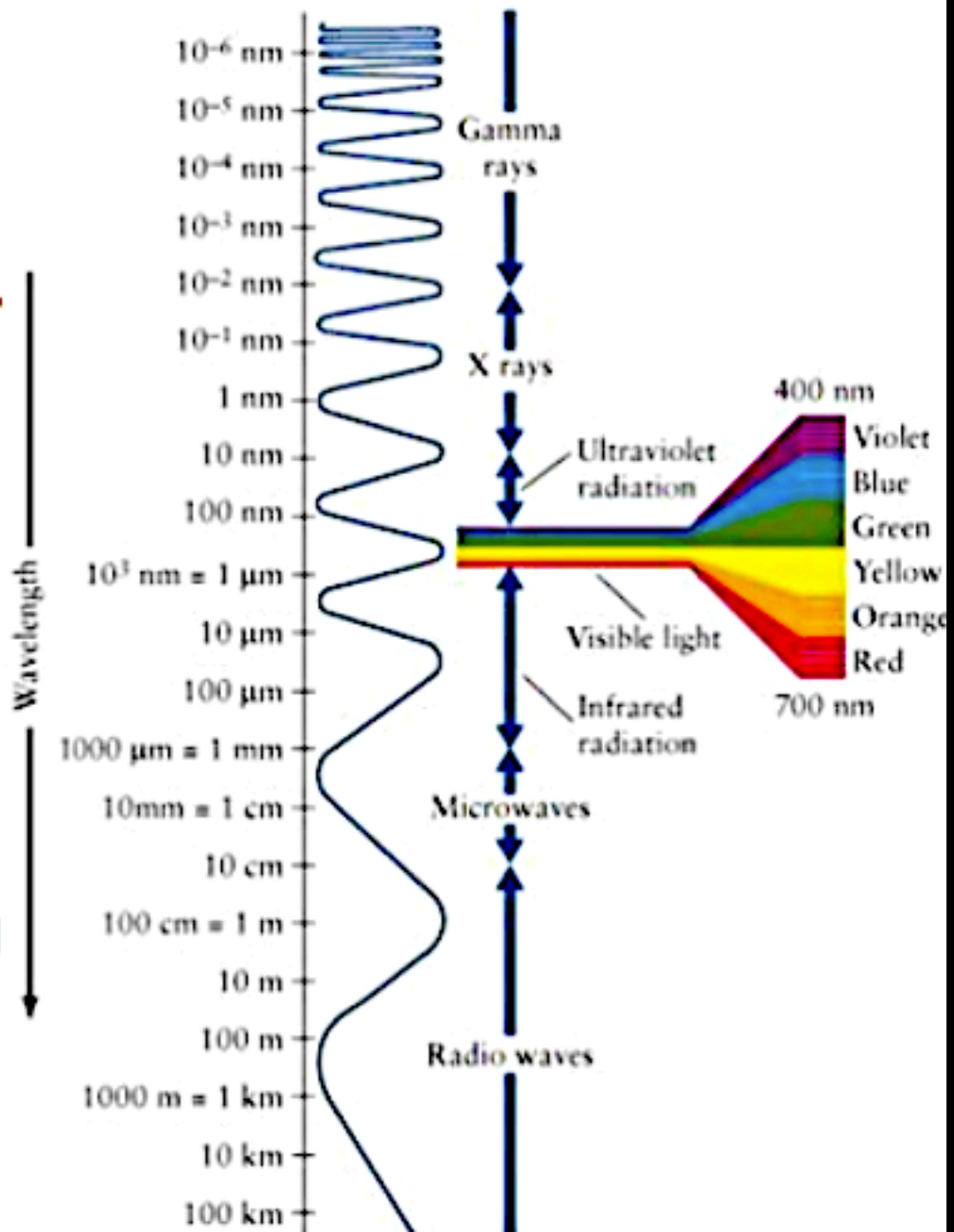
**FREQUENCY:** A measure of the number of occurrences of a repeating event per unit time. Here, it refers to how often the wave moves up in or down in a set period. Frequency increases as we move toward purple light and decreases as we move toward red light.



**THE ELECTROMAGNETIC (EM) SPECTRUM:** The range of all possible electromagnetic radiation or waves of light energy.

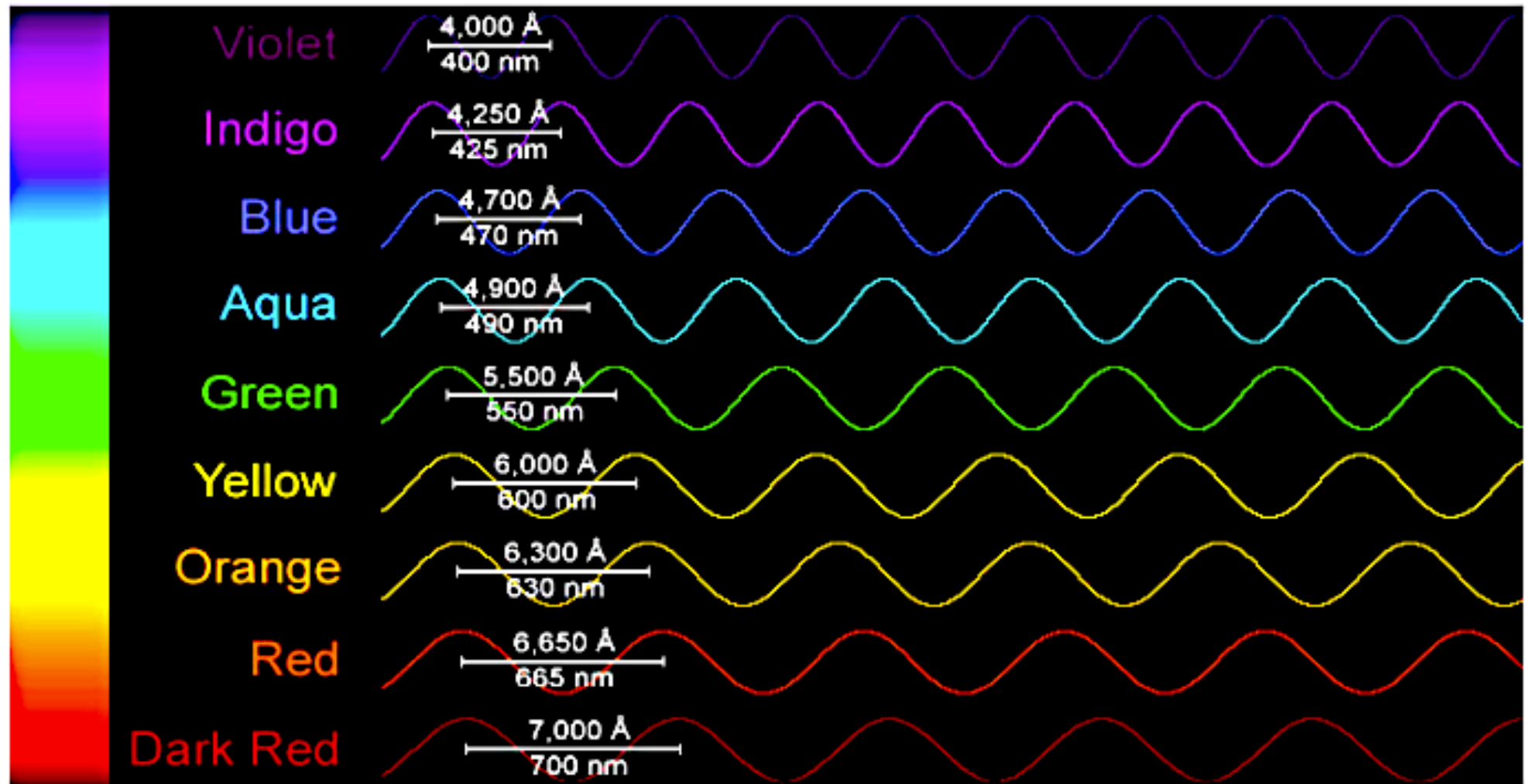
The EM extends from below the frequencies used for modern radio (at the long-wavelength end) through gamma radiation (at the short-wavelength end).

The **VISIBLE SPECTRUM** is the portion of the EM that can be detected by the human eye. Electromagnetic radiation in this range of wavelengths (380 to 750 nm) is called **VISIBLE LIGHT**.



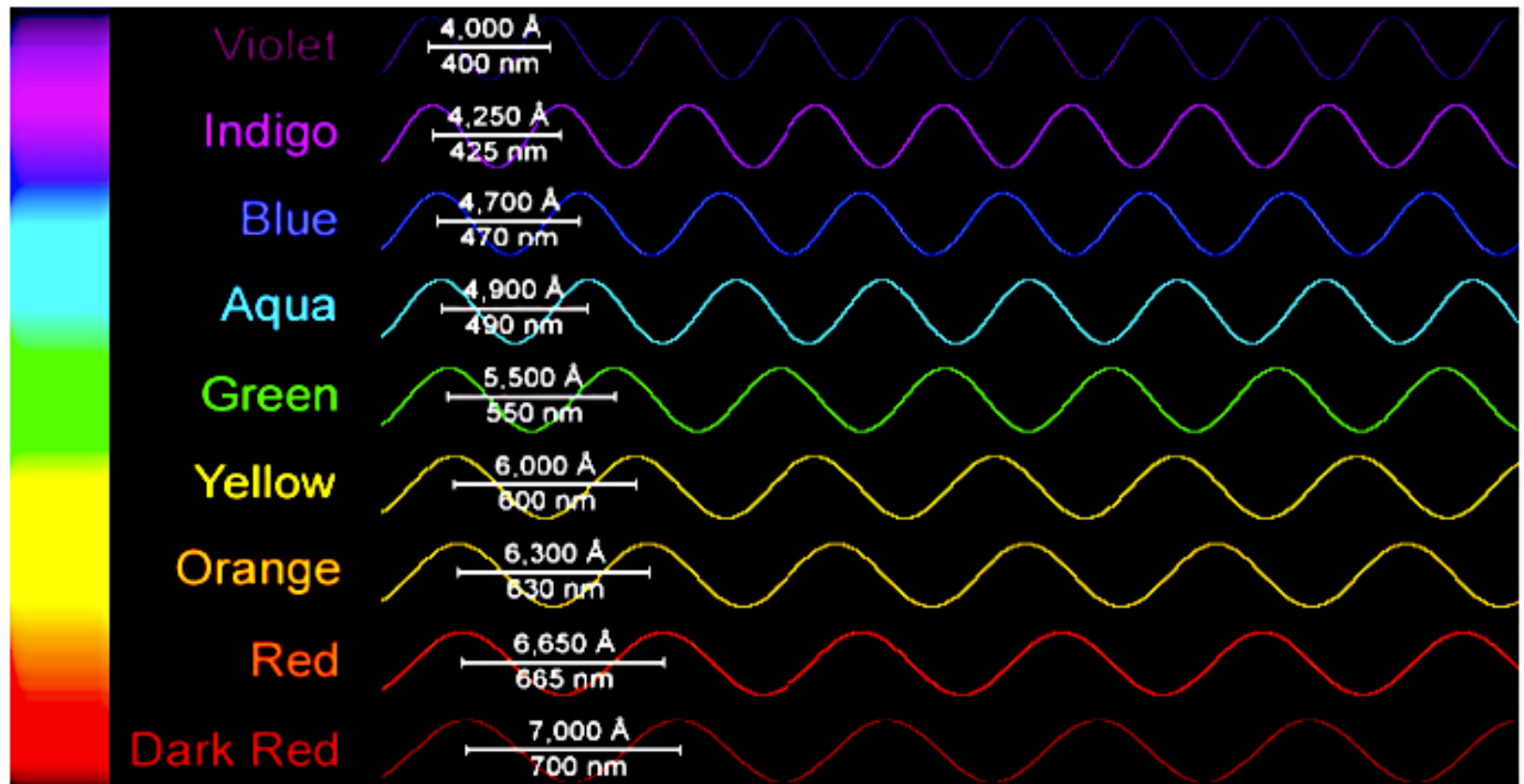
## Different colors of light have different wavelengths and frequencies!

Purple and blue light waves have short wavelengths and higher frequencies. This corresponds to higher energies. Within the visible spectrum, the shortest purple waves are 400 nanometers long.



## Different colors of light have different wavelengths and frequencies!

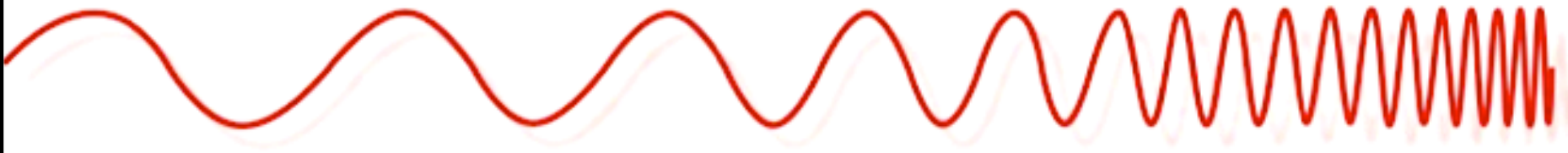
Within the visible spectrum, red light has a longer wavelength and lower frequencies. This corresponds to lower energies. The longest red waves are about 700 nanometers long.



**Electromagnetic waves with wavelengths below 400 nm are in the ultraviolet (UV) portion of the electromagnetic spectrum, while waves longer than 700 nm are in the infrared (IR) region of the spectrum.**

Wavelength (meters)

Radio  $10^3$       Microwave  $10^{-2}$       Infrared  $10^{-5}$       **Visible**  $.5 \times 10^{-6}$       Ultraviolet  $10^{-8}$       X-ray  $10^{-10}$       Gamma Ray  $10^{-12}$

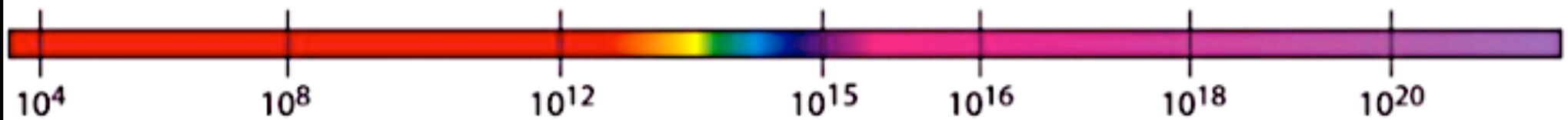


About the size of...



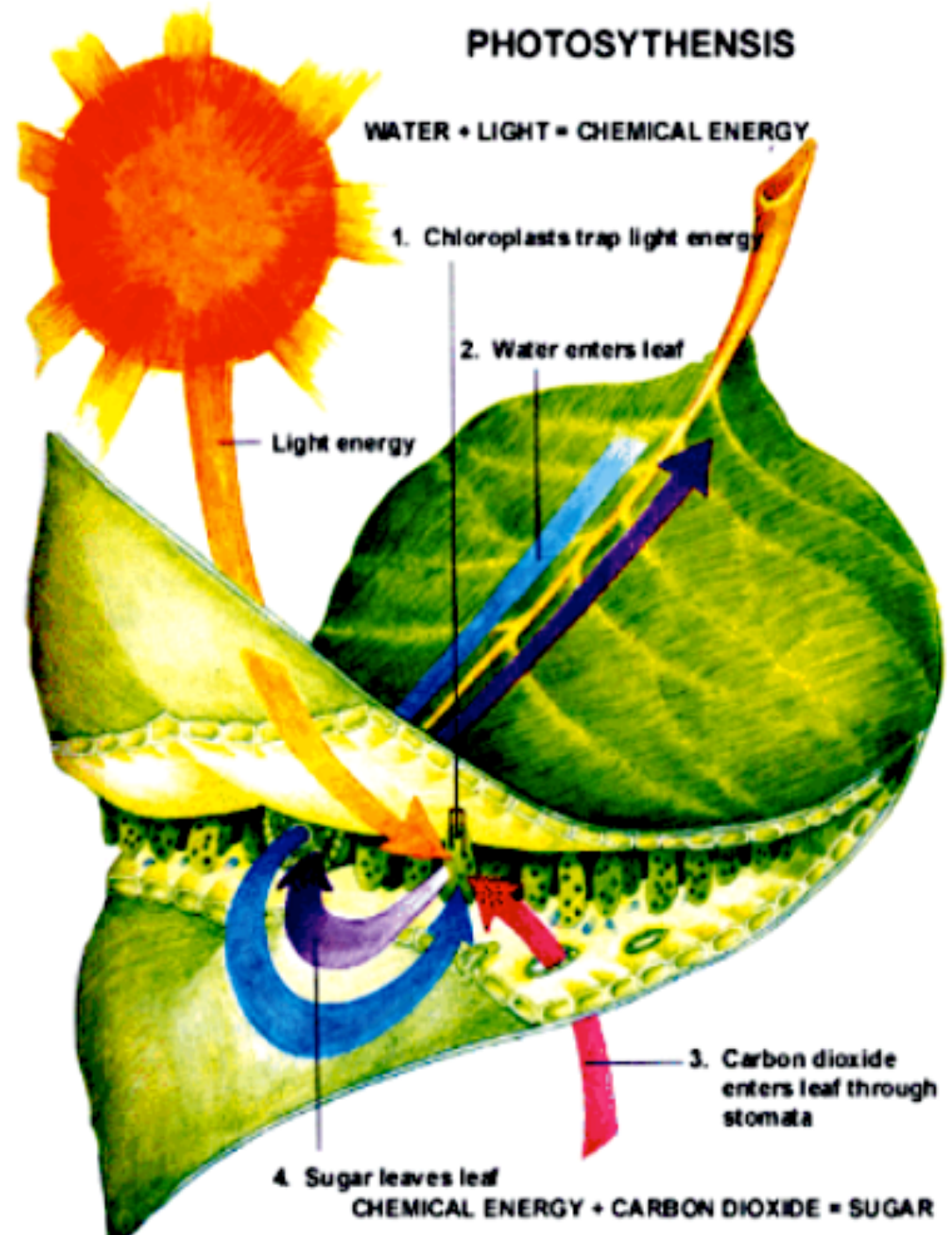
Buildings      Humans      Honey Bee      Pinpoint      Protozoans      Molecules      Atoms      Atomic Nuclei

Frequency (Hz)



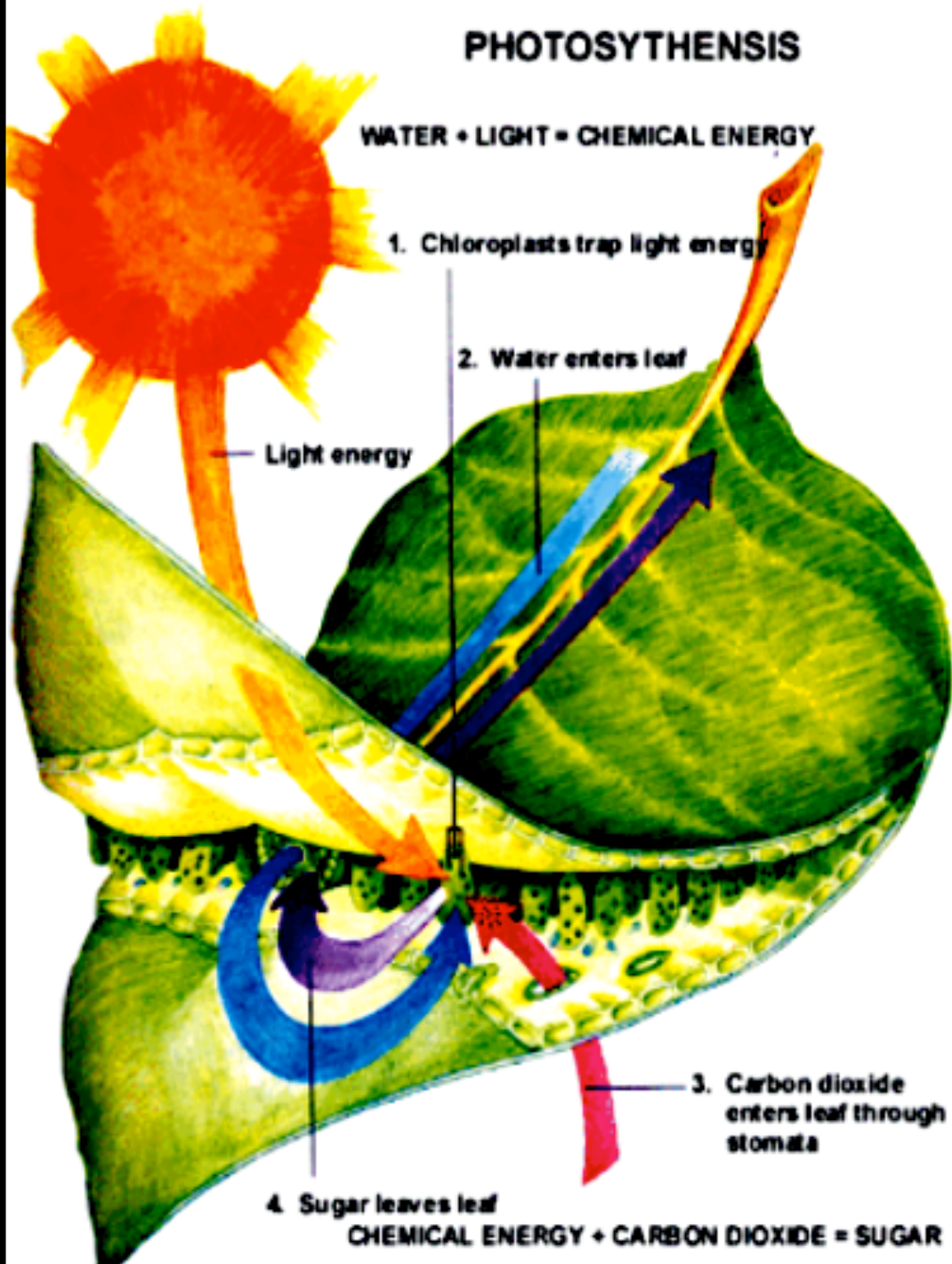
**PHOTOSYNTHESIS: A metabolic pathway that converts light energy into chemical energy.**

Using the radiant energy from the sun (EM radiation), certain plants, algae, and bacteria convert  $\text{CO}_2$  and  $\text{H}_2\text{O}$  into Oxygen ( $\text{O}_2$ ) and energy-containing carbohydrates such as sucrose, glucose, and starch.



## PHOTOSYTHENSIS

WATER + LIGHT = CHEMICAL ENERGY



Photosynthesis is one of the most important biochemical pathways since nearly all life depends on it as a source of energy.

The carbohydrates made by plants are passed through the food chain to other organisms (organisms that eat plants or animals that eat plants or animals that eat animals that eat plants). Organisms can break carbohydrates down, releasing the chemical energy stored in these molecules to do work and complete the functions needed to stay alive.

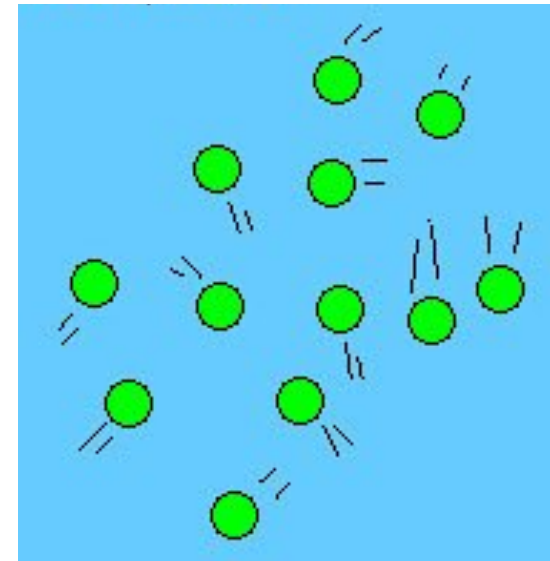
(Plants absorb light primarily using the pigment **chlorophyll** which does not absorb green light, reflecting it back to our eyes instead which is the reason that most plants have a green color.)

**KINETIC ENERGY: Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.**

**3. Thermal Energy:**

All substances in any phase of matter are made up of particles that vibrate and/or move and, thus, have kinetic energy.

- Adding up the **TOTAL** amount of kinetic energy of all the molecules in an object yields the thermal energy of the object.

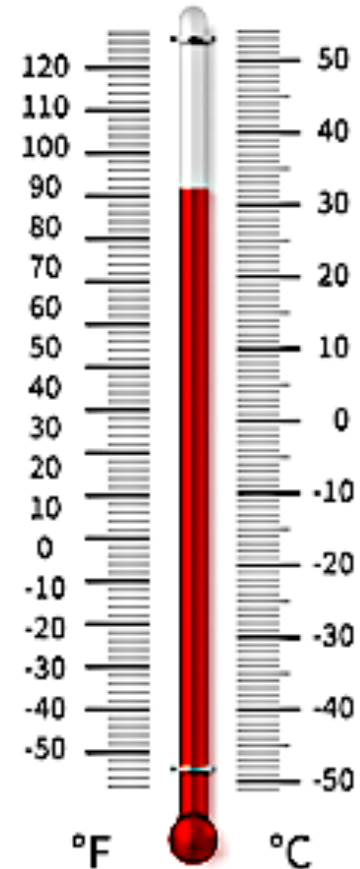
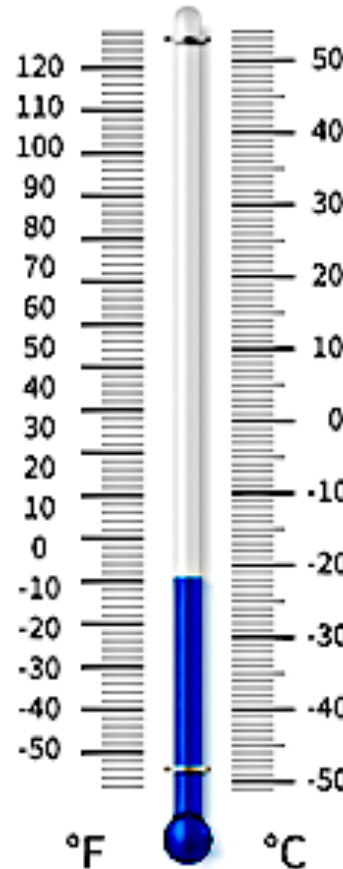


As thermal energy increases, atoms vibrate or move faster. This energy is needed to overcome the molecular interactions that hold matter together allowing matter to undergo a phase change into a more disorganized state.

# KINETIC ENERGY: Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and

The temperature of an object is a measurement of the AVERAGE kinetic energy of all the molecules of the object.

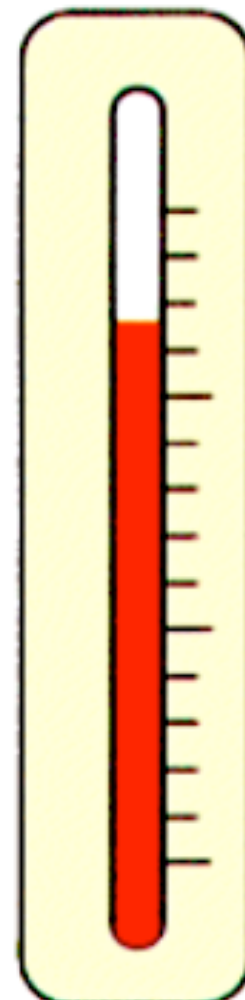
- If an object was composed of exactly three molecules and the kinetic energies of the three molecules are 50 J, 70 J, and 90 J, the total Thermal Energy would be 210 J and the temperature would be 70 J.



# KINETIC ENERGY: Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.

The thermal energy that TRANSFERS from area of higher temperature to an area of lower temperature is referred to as HEAT.

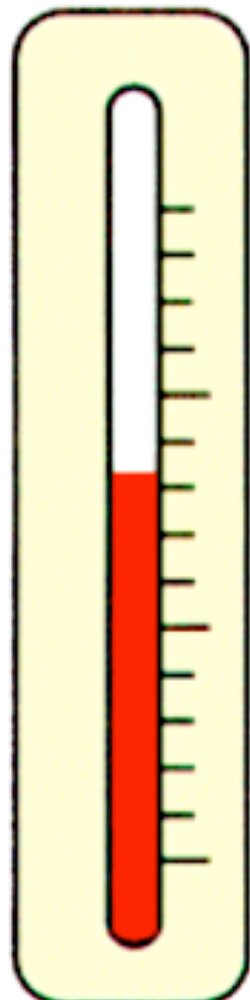
- When a hot substance and a cold substance touch, the molecules of the objects collide along the surface where they touch. When molecules with higher kinetic energy collide with molecules with lower kinetic energy, kinetic energy is passed from the molecules with more kinetic energy to those with less kinetic energy.



Heat flows from areas of higher temperature to areas of lower temperature.

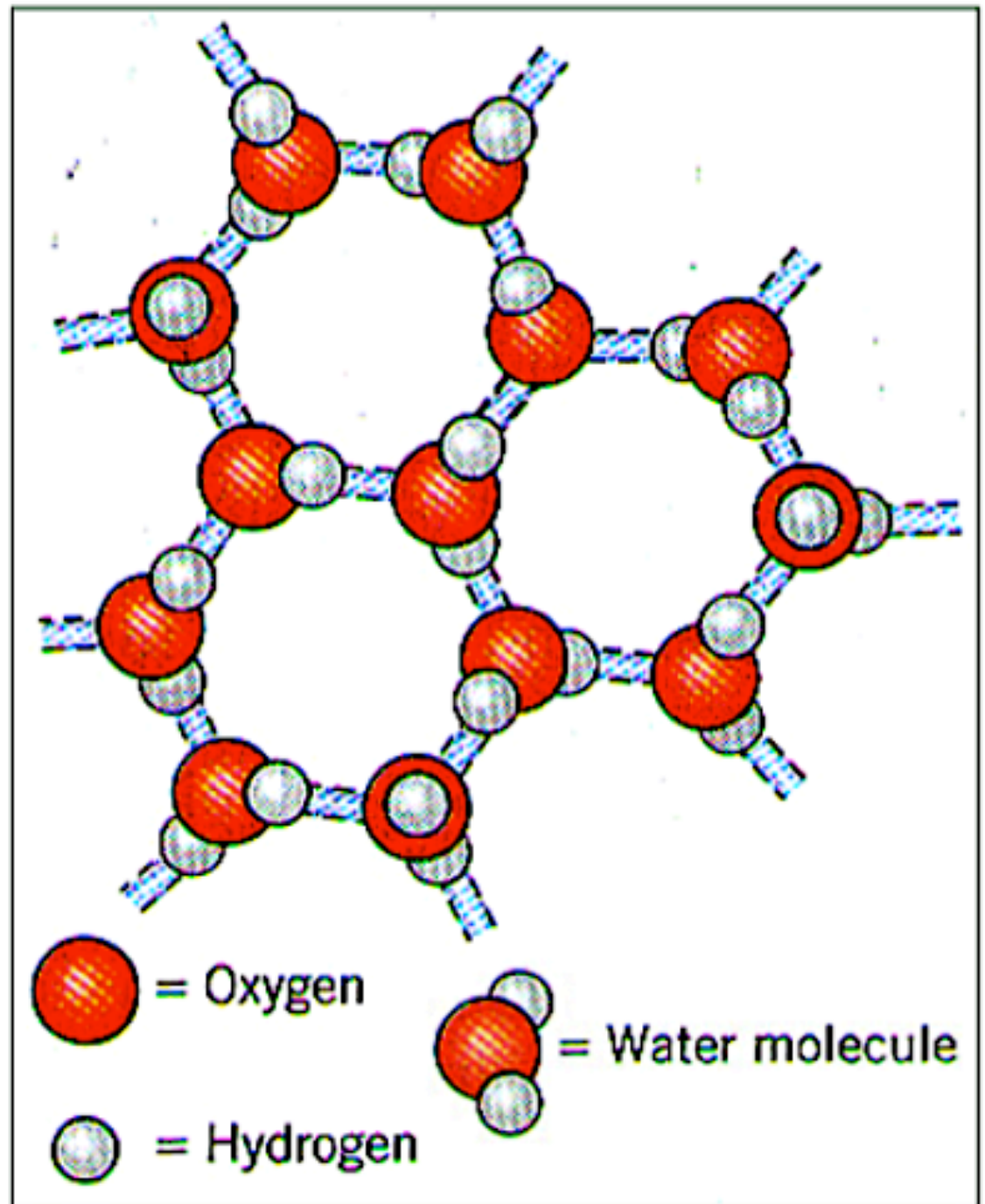


In this way, heat always flows from **hot** to **cold** and heat will continue to flow until the two objects have the same temperature.



Solids are more atomically organized than liquids, which in turn are more organized than gases.

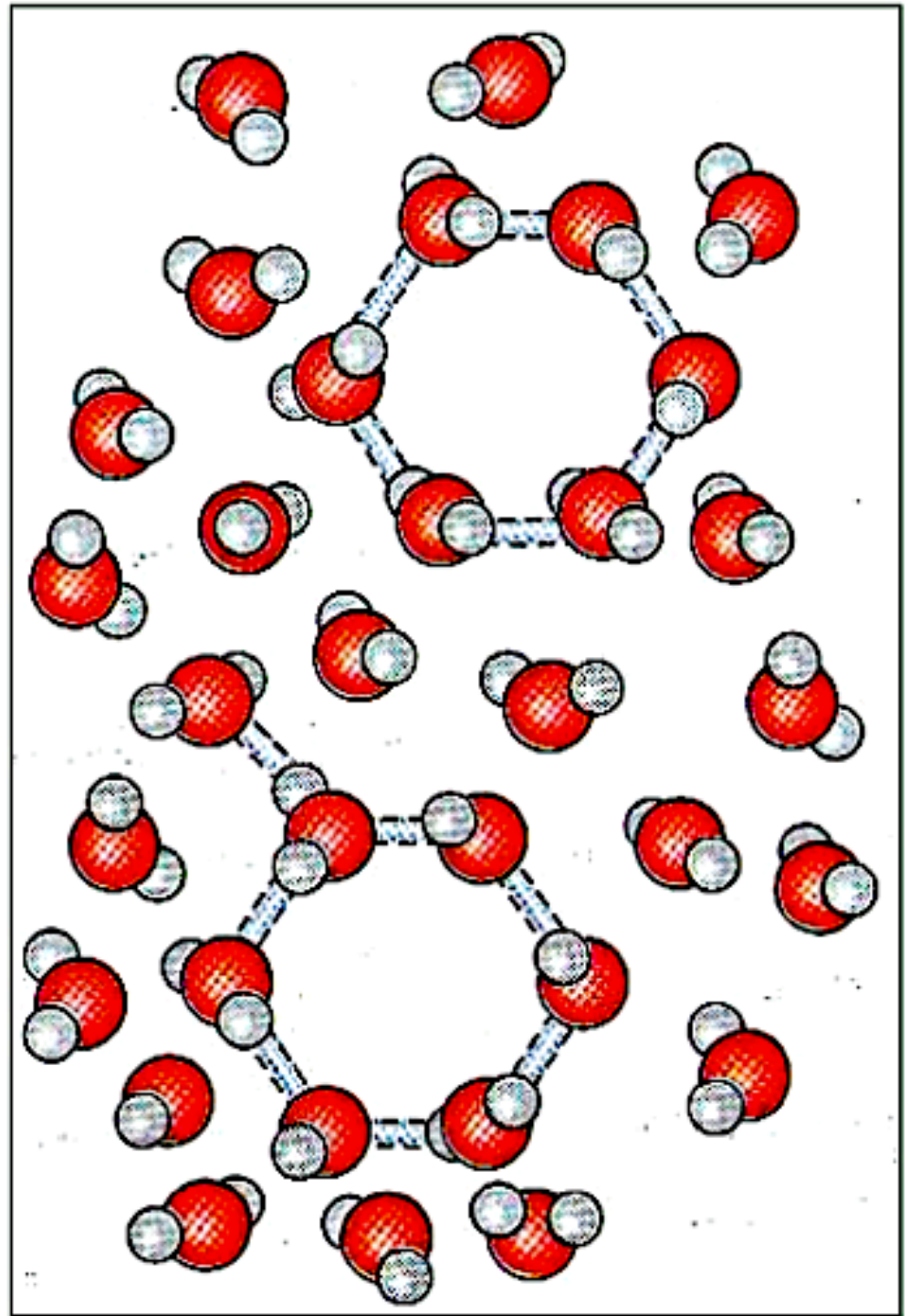
Consider a block of ice being warmed by an external heat source. Although the ice molecules contain some heat energy, their vibrations are not sufficiently energetic to overcome the interactions between neighboring  $\text{H}_2\text{O}$  molecules that hold them together in a solid structure made up of hexagonal crystals.



As heat energy is absorbed by the ice, its molecules vibrate faster within the solid structure, and its temperature rises.

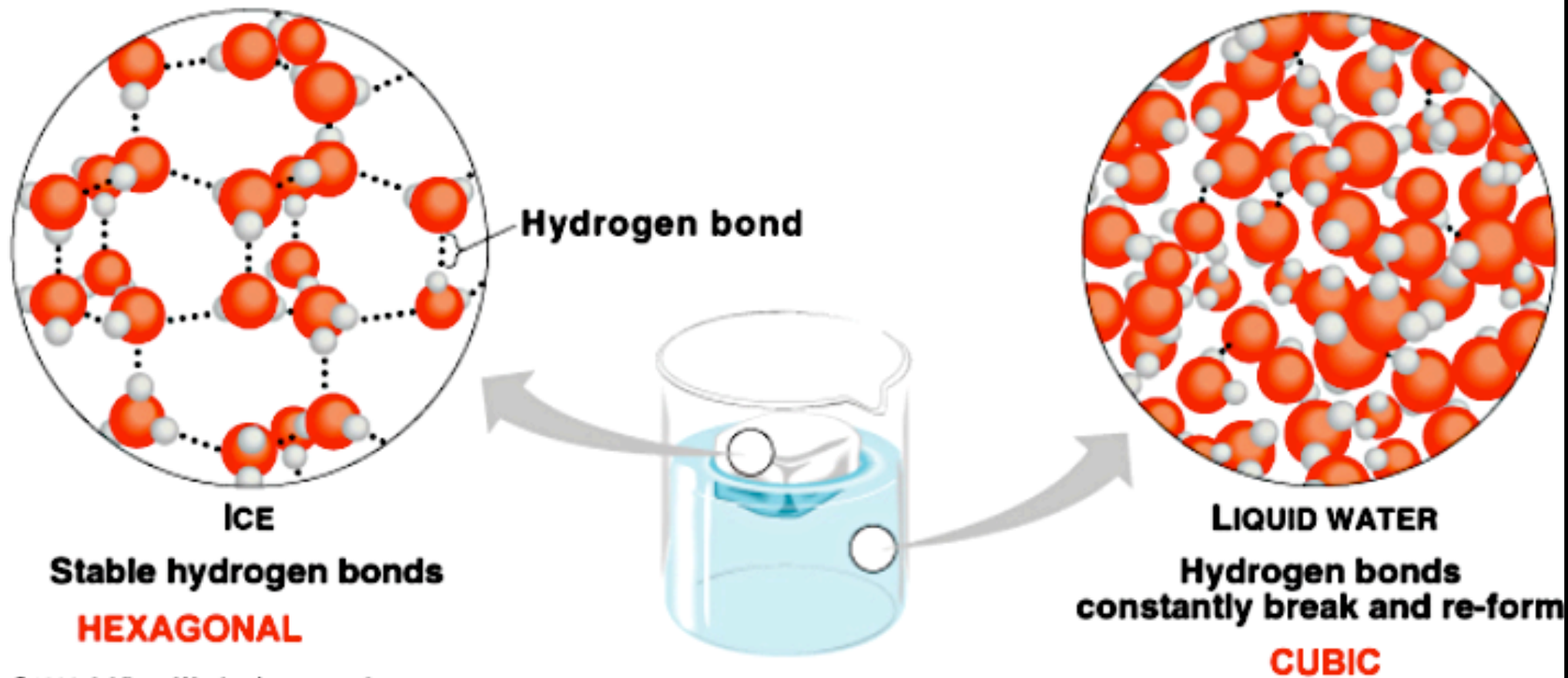
When its temperature reaches  $0^{\circ}\text{C}$ , the ice begins to melt because the molecules now have enough vibrational energy to overcome some of the forces holding together the atoms in a solid structure.

(The forces holding adjacent water molecules together are called Hydrogen Bonds and will be discussed in more detail later).



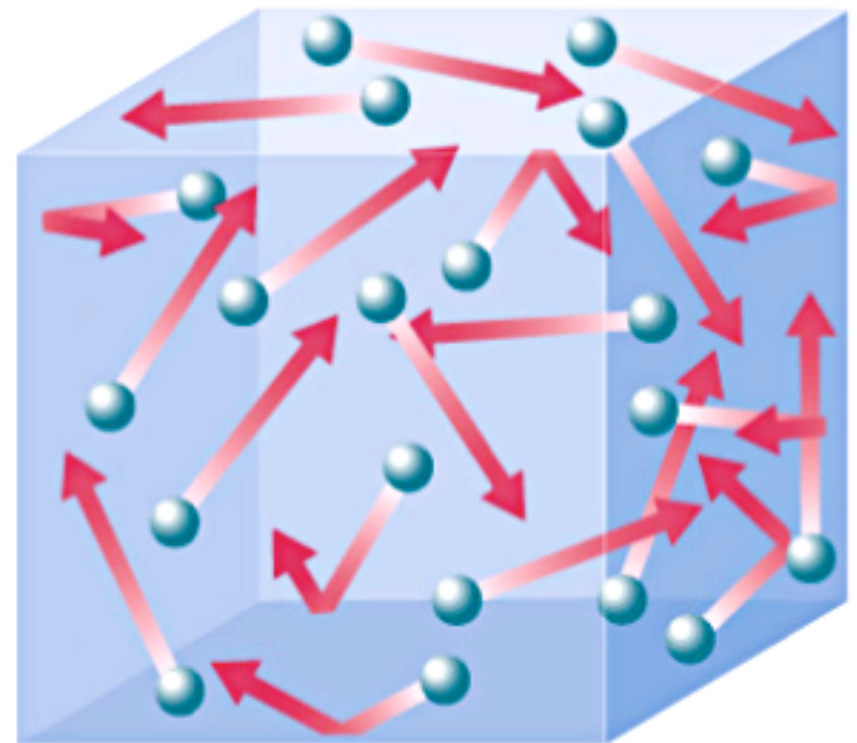
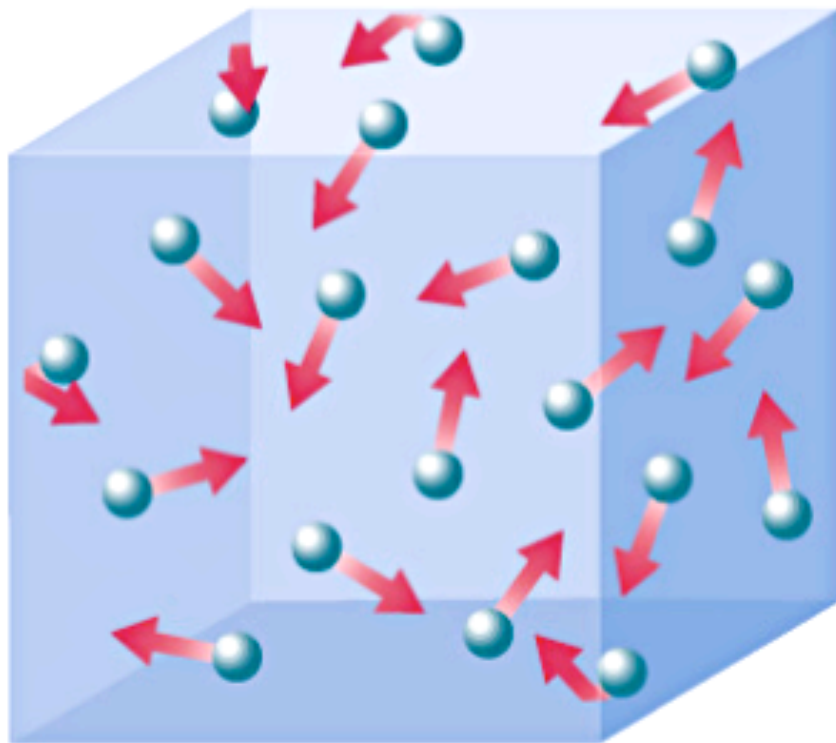
Finally the solid structure completely breaks down into a more loosely connected liquid state. This process is called **MELTING**.

The molecules in water are now free to move past one another and vibrate faster. The molecules move too fast to remain as crystals but slow enough to remain attached on and off.



If more heat energy is absorbed after all the ice has melted can again create faster molecular motions, but now within a liquid structure, and the water temperature begins to rise.

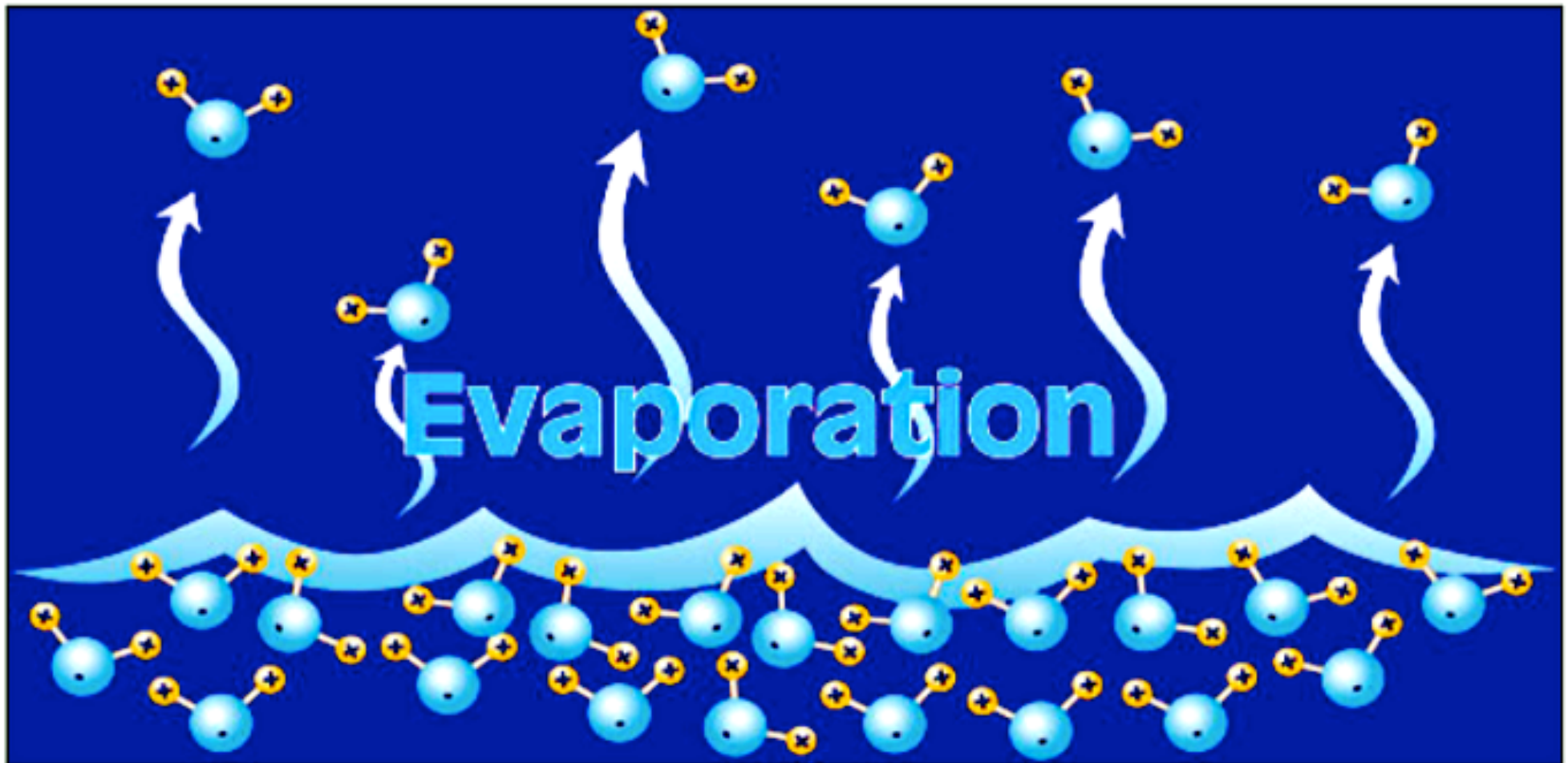
Note that the **TEMPERATURE** at any given time represents the average speed of random molecular motion; some individual molecules move faster and some move slower.



**Longer arrows mean higher average speed.**

When the faster-moving molecules at the water's surface have enough energy to break free of the cohesive forces that hold them in the liquid structure (the temporary Hydrogen Bonds), they escape into the gas phase. This is the process of **EVAPORATION**.

The molecules now move fast enough to remain detached.



**KINETIC ENERGY:** Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.

4. **Motion Energy:**

Motion Energy is the movement of objects and substances from one place to another. Objects and substances move when a force is applied according to Newton's Laws of Motion.

Wind is an example of motion energy.

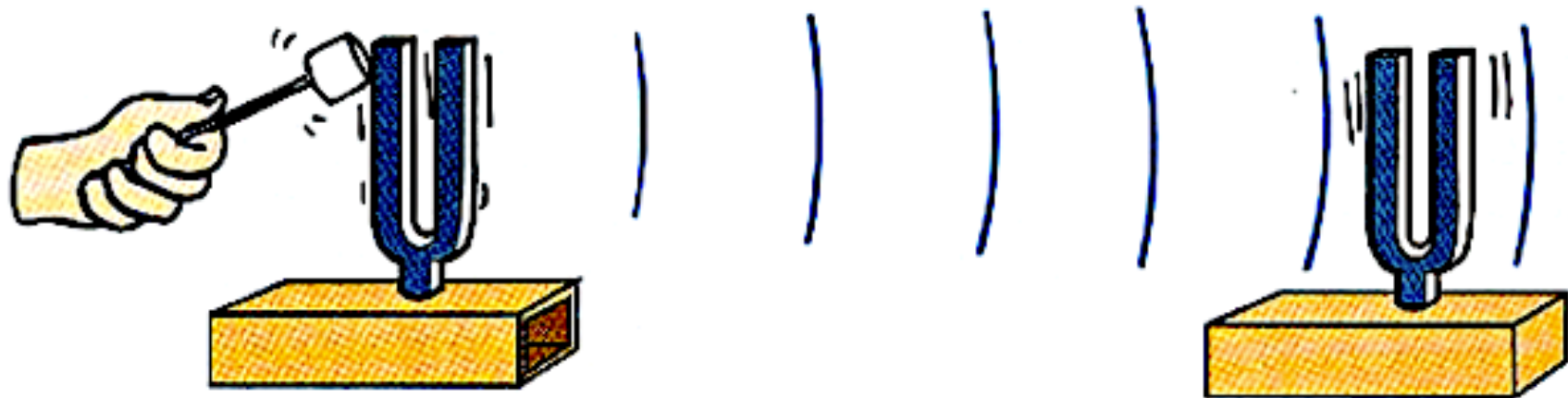


**KINETIC ENERGY:** Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.

5. **Sound Energy:**

Sound is the movement of energy through substances in longitudinal waves.

Sound is produced when a force causes an object or substance to vibrate—the energy is transferred through the substance in a wave.

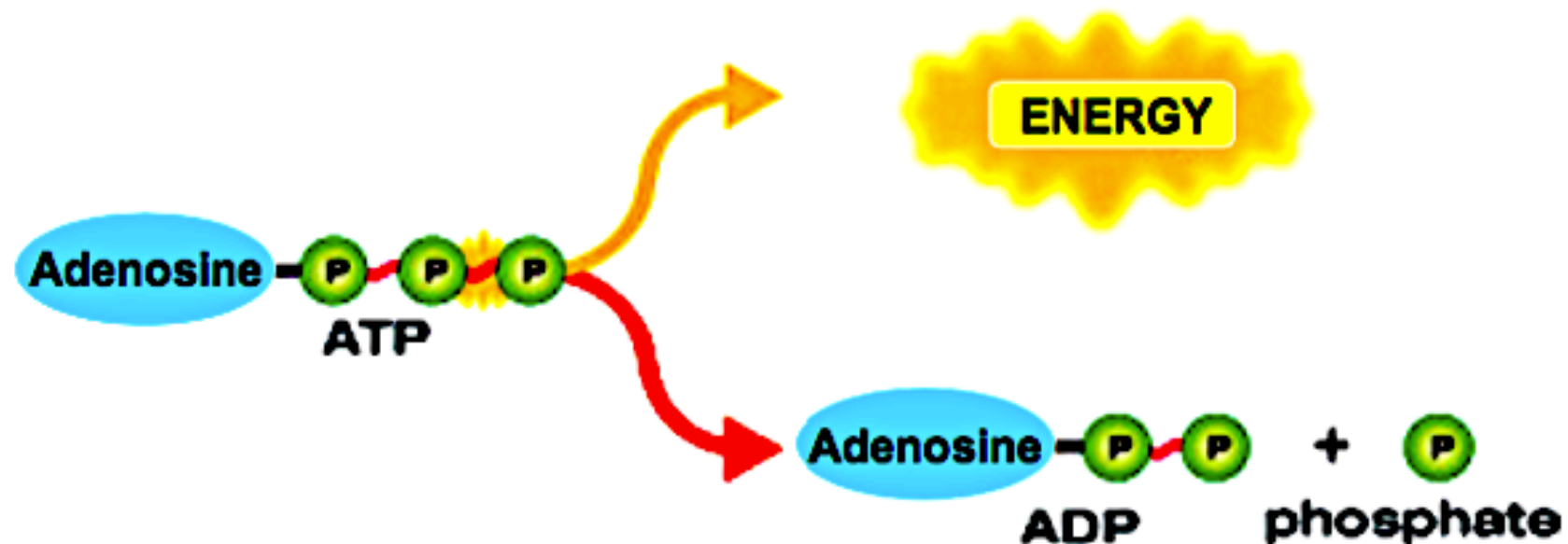


**POTENTIAL ENERGY:** stored energy and the energy of position

1. **Chemical Energy:**

Chemical Energy is energy stored in the bonds of atoms and molecules. It is the energy that holds these particles together. When these bonds between atoms are broken, the energy is released.

Petroleum, propane, ATP are examples of stored chemical energy.



**POTENTIAL ENERGY:** stored energy and the energy of position

2. **Stored Mechanical Energy:**

Stored Mechanical Energy is energy stored in objects by the application of a force.

Compressed springs and stretched rubber bands are examples of stored mechanical energy.



**POTENTIAL ENERGY:** stored energy and the energy of position

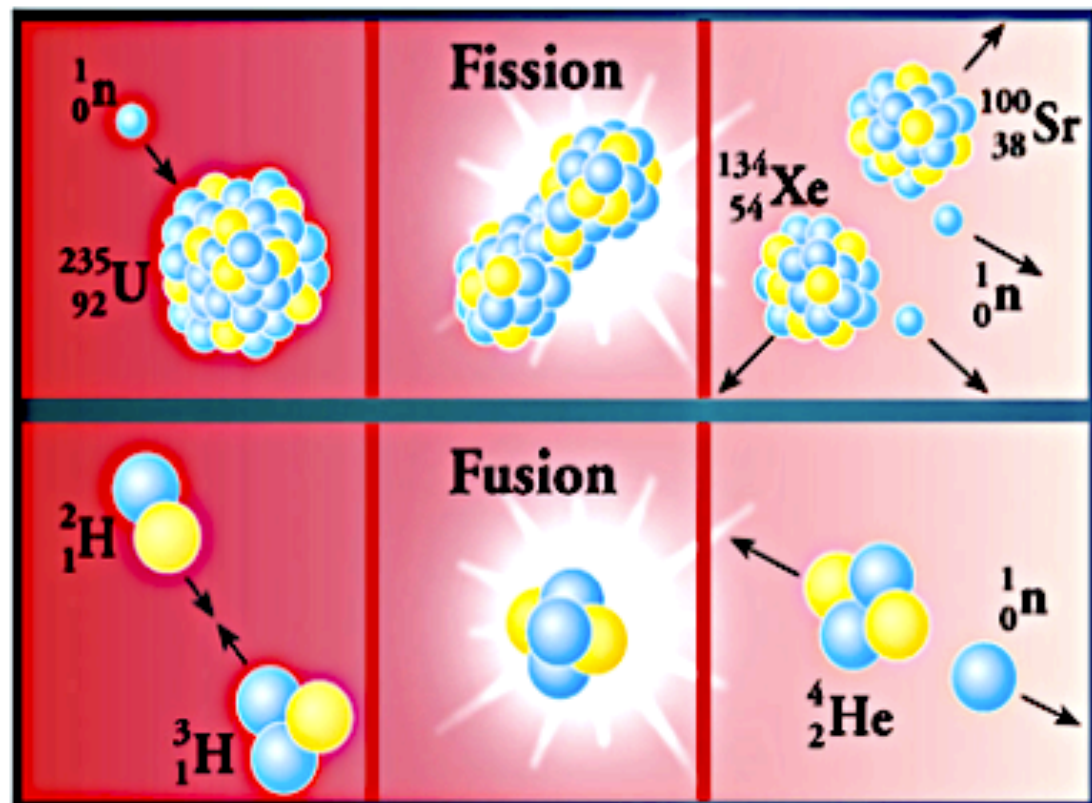
### 3. Nuclear Energy:

Nuclear Energy is energy stored in the nucleus of an atom—the energy that holds the nucleus together.

Energy is released when the nuclei are combined or split apart.

Nuclear power plants split the nuclei of uranium atoms in a process called **fission**.

The sun combines the nuclei of hydrogen atoms in a process called **fusion**.



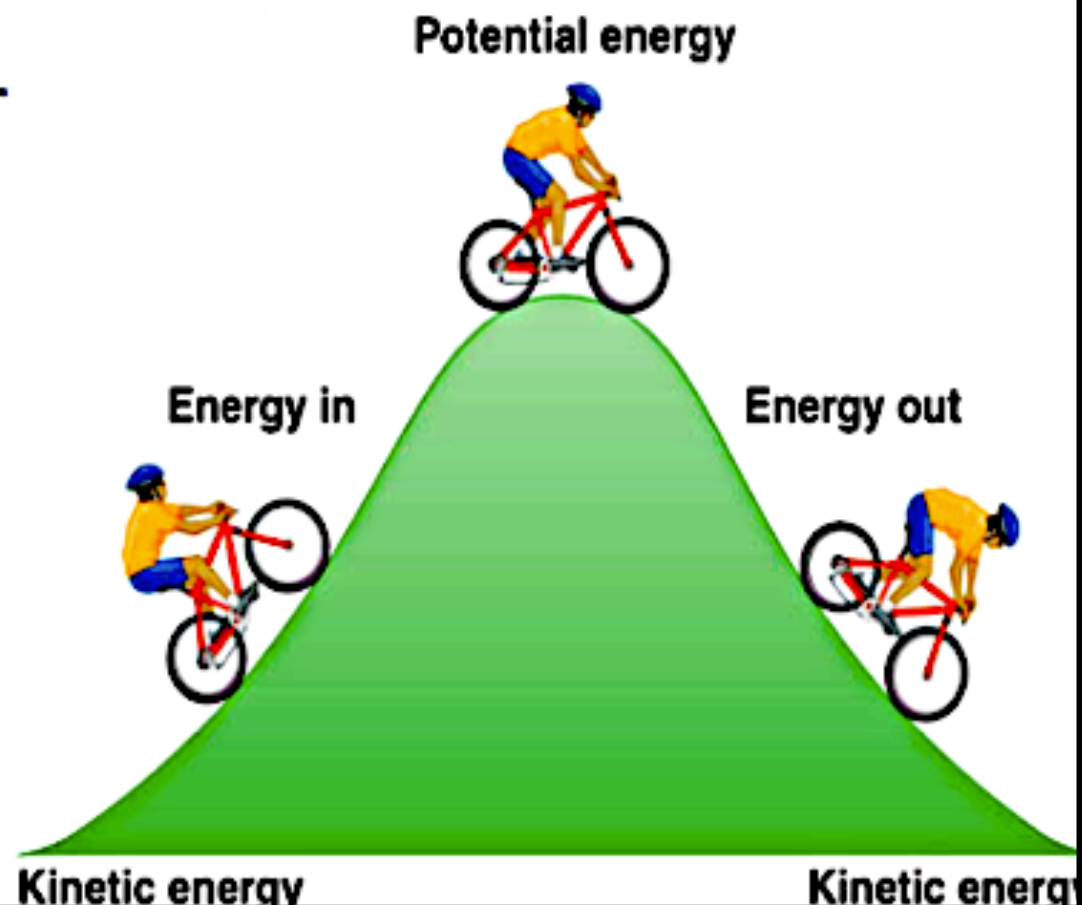
**POTENTIAL ENERGY:** stored energy and the energy of position

#### 4. Gravitational Energy:

Gravitational Energy is the energy of position or place.

A rock resting at the top of a hill contains gravitational potential energy.

Hydropower, such as  $H_2O$  in a reservoir behind a dam is an example of gravitational potential energy.



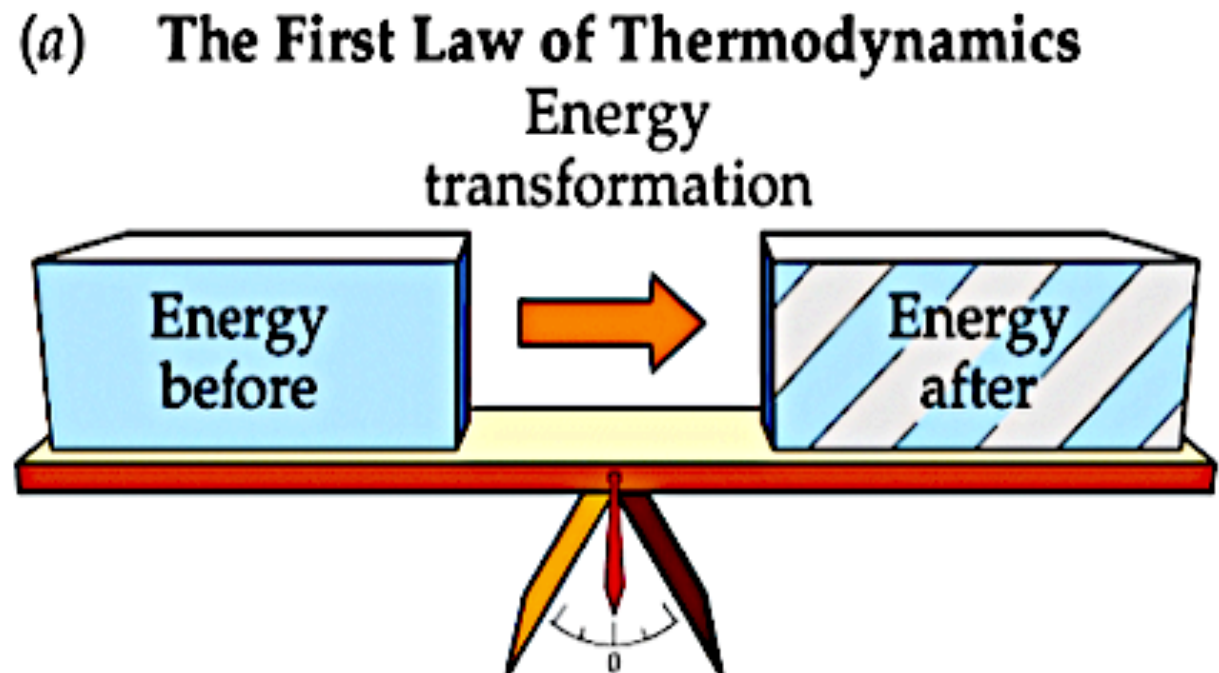
When we use energy we don't create it or use it up, we convert one form of energy to make another. ←

Often chemical reactions occur or are carried out for the sole purpose of converting energy to a desired form. For example, chemical energy stored in fuel can be converted by burning the fuel in automobiles to mechanical energy of motion.

Energy changes form but the total amount of energy in the universe stays the same.

### FIRST LAW OF THERMODYNAMICS:

(a.k.a. Conservation of Energy). Energy can be transferred and transformed but it can't be created or destroyed.



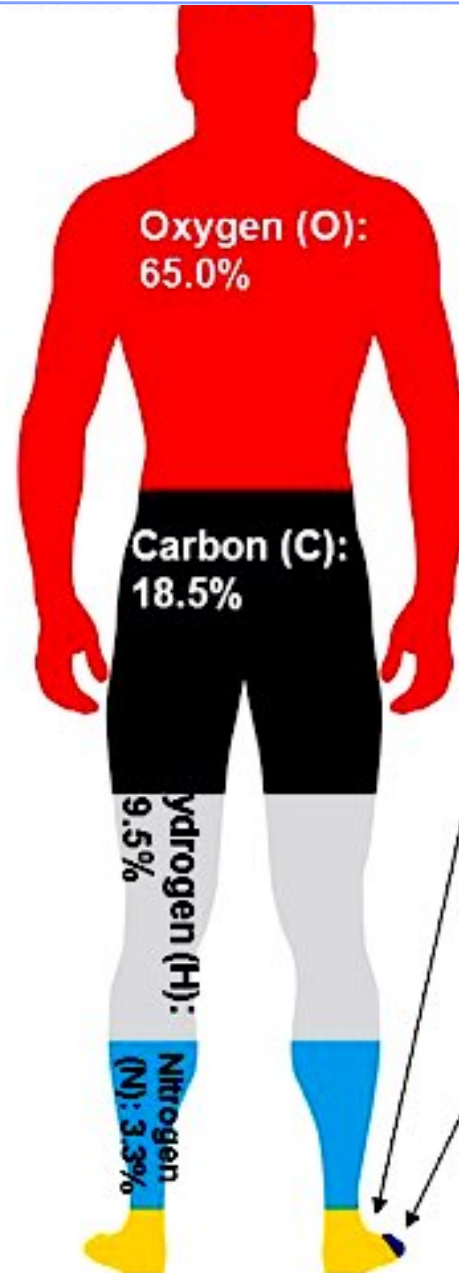
Let's Return to our Discussion on Matter...

...and Atoms.



# Life requires ~25 chemical elements

- **Around 25 elements are essential for life**
- ◆ Four elements make up **~96%** of living matter:
  - ◆ carbon (C)
  - ◆ hydrogen (H)
  - ◆ oxygen (O)
  - ◆ nitrogen (N)
- ◆ Four elements make up most of remaining **~4%**:
  - ◆ phosphorus (P)
  - ◆ calcium (Ca)
  - ◆ sulfur (S)
  - ◆ potassium (K)



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)	Manganese (Mn)
Chromium (Cr)	Molybdenum (Mo)
Cobalt (Co)	Selenium (Se)
Copper (Cu)	Silicon (Si)
Fluorine (F)	Tin (Sn)
Iodine (I)	Vanadium (V)
Iron (Fe)	Zinc (Zn)


# Life requires ~25 chemical elements


- ◆ Less than 1% of elements required for life on earth are considered trace elements, elements required in very small amounts.

◆ They are, however, still absolutely necessary

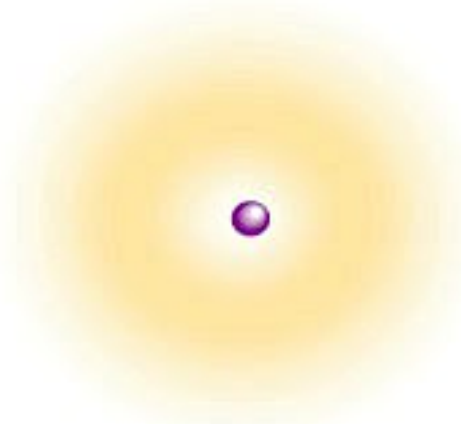
1 H 1.008 Hydrogen																	2 He 4.0026 Helium
3 Li 6.941 Lithium	4 Be 9.0122 Beryllium											5 B 10.811 Boron	6 C 12.011 Carbon	7 N 14.007 Nitrogen	8 O 15.999 Oxygen	9 F 18.998 Fluorine	10 Ne 20.180 Neon
11 Na 22.990 Sodium	12 Mg 24.305 Magnesium											13 Al 26.982 Aluminum	14 Si 28.086 Silicon	15 P 30.974 Phosphorus	16 S 32.065 Sulfur	17 Cl 35.453 Chlorine	18 Ar 39.948 Argon
19 K 39.098 Potassium	20 Ca 40.078 Calcium	21 Sc 44.956 Scandium	22 Ti 47.867 Titanium	23 V 50.942 Vanadium	24 Cr 51.996 Chromium	25 Mn 54.938 Manganese	26 Fe 55.845 Iron	27 Co 58.933 Cobalt	28 Ni 58.693 Nickel	29 Cu 63.546 Copper	30 Zn 65.38 Zinc	31 Ga 69.723 Gallium	32 Ge 72.630 Germanium	33 As 74.922 Arsenic	34 Se 78.96 Selenium	35 Br 79.904 Bromine	36 Kr 83.80 Krypton
37 Rb 85.468 Rubidium	38 Sr 87.62 Strontium	39 Y 88.906 Yttrium	40 Zr 91.224 Zirconium	41 Nb 92.906 Niobium	42 Mo 95.94 Molybdenum	43 Tc 98 Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.71 Tin	51 Sb 121.76 Antimony	52 Te 127.60 Tellurium	53 I 126.905 Iodine	54 Xe 131.29 Xenon
55 Cs 132.91 Cesium	56 Ba 137.33 Barium	57-71 La-Lu Lanthanides	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.84 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 186.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury	81 Tl 204.38 Thallium	82 Pb 207.2 Lead	83 Bi 208.98 Bismuth	84 Po 209 Polonium	85 At 210 Astatine	86 Rn 222 Radon
87 Fr 203 Francium	88 Ra 226 Radium	89 Ac 207 Actinides	90 Th 232.04 Thorium	91 Pa 231.04 Protactinium	92 U 238.03 Uranium												

 Bulk biological elements

 Trace elements believed to be essential for bacteria, plants or animals

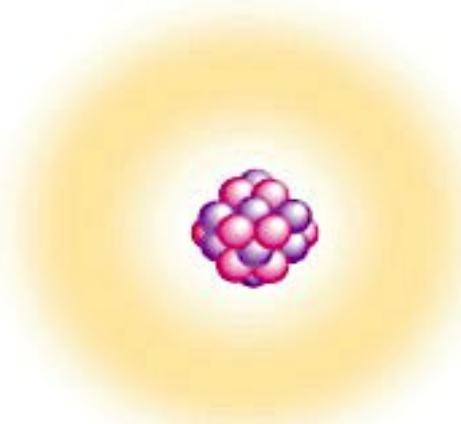
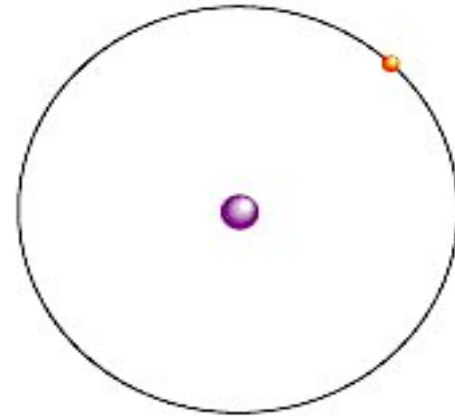
 Possibly essential trace elements for some species

# Matter is made of atoms



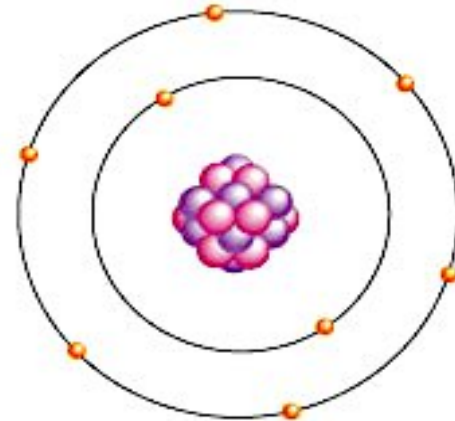
Hydrogen

1 proton  
1 electron



Oxygen

8 protons  
8 neutrons  
8 electrons



**Proton +**



**Neutron 0**



**Electron -**

# Matter is made of atoms

## PROTONS

Symbol: p  
Mass: 1 dalton (d) or amu  
Charge: +1



Proton



Neutron

*no charge*

## NEUTRONS

Symbol: n  
Mass: 1 dalton (d) or amu  
Charge: 0

## ELECTRONS

Symbol: e-  
Mass: ~0 dalton (d) or amu  
(.0005 amu, 1/2000)  
Charge: -1



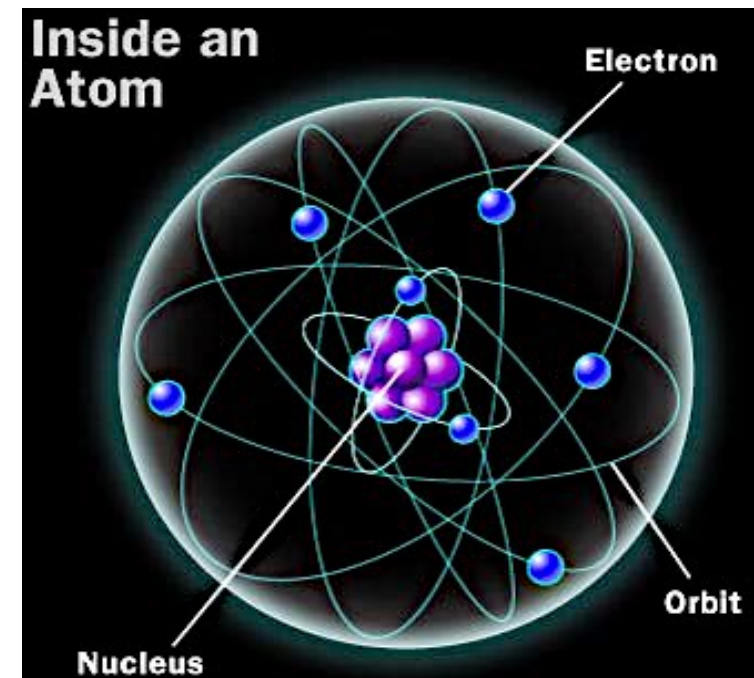
Electron



1 dalton or amu =  $1.660539 \times 10^{-24}$  g

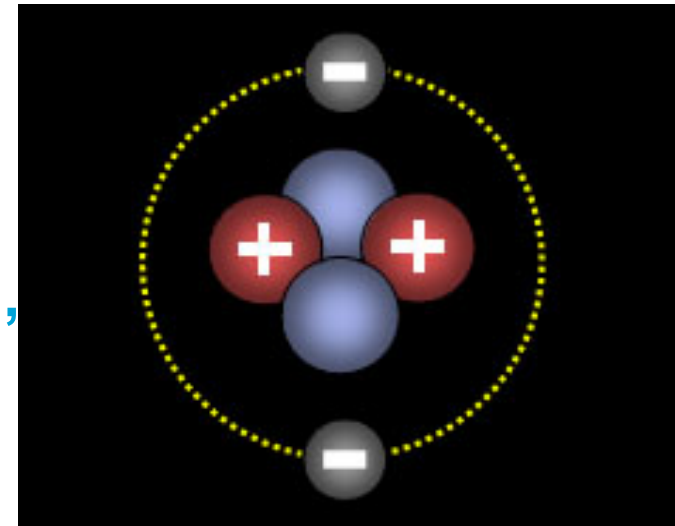
# The Atom

- In the nucleus, neutrons help keep positively charged protons close together through forces called Strong Nuclear Forces.
- The negatively charged electrons are held in orbit around the nucleus because they are attracted to positive protons while also being repelled by each other.
  - ◆ The entire outer region of the atom, which contains oscillating electrons is called the ELECTRON CLOUD.
    - The electron cloud has a negative electrical charge due to the negatively charged electrons.

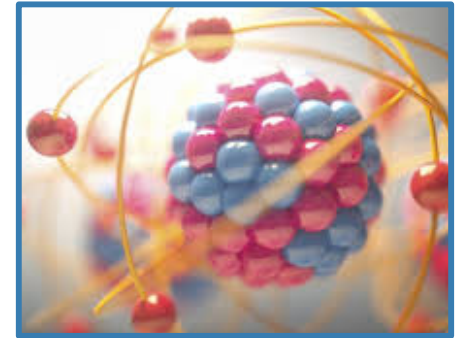


# Though Atoms Contain Charged Particles, they can be Neutral.

- The nucleus is always positively charged.
  - ◆ While neutrons do not carry a charge and are neutral, protons each carry a positive charge.
- When the electron cloud contains electrons it will always be negatively charged.
- In a neutral atom (one with NO net “overall” charge), the charge of the electron balances the charge on the proton!
  - ◆ Ex: An atom with one proton in its nucleus (a charge of +1) and one electron outside that nucleus (charge of -1), in the electron cloud, would have an overall NET charge of ZERO (0):  $(+1) + (-1) = 0$

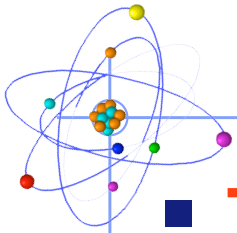


# Neutral vs Charged Atom

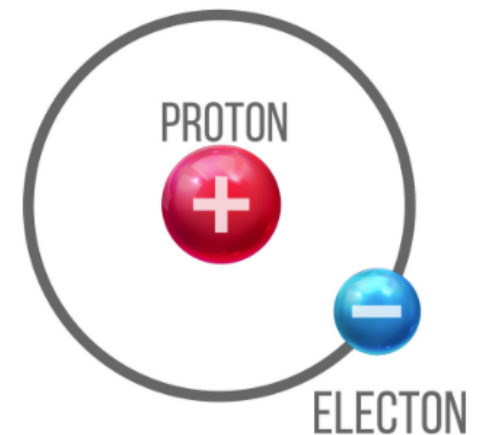
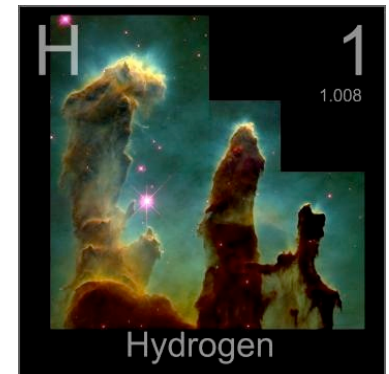


- Atoms are electrically neutral, only if the number of protons and electrons are equal and the charges have a SUM OF ZERO.
  - If the sum of atomic charges is NOT ZERO then the atom is said to carry a CHARGE or to be CHARGED.
- **EXERCISE:** If the atom is neutral. Will the atom contain?
  1. More protons than electrons? **NO**
  2. More electrons than protons? **NO**
  3. An equal number of protons & electrons? **YES**
- **EXERCISE:** How many electrons would a neutral atom have if the atom has 32 protons in the nucleus?
  - $0 = (+32) + x$
  - $x = -32$
  - Therefore, this atom would have a total of 32 electrons.

# The Number of Protons Matters

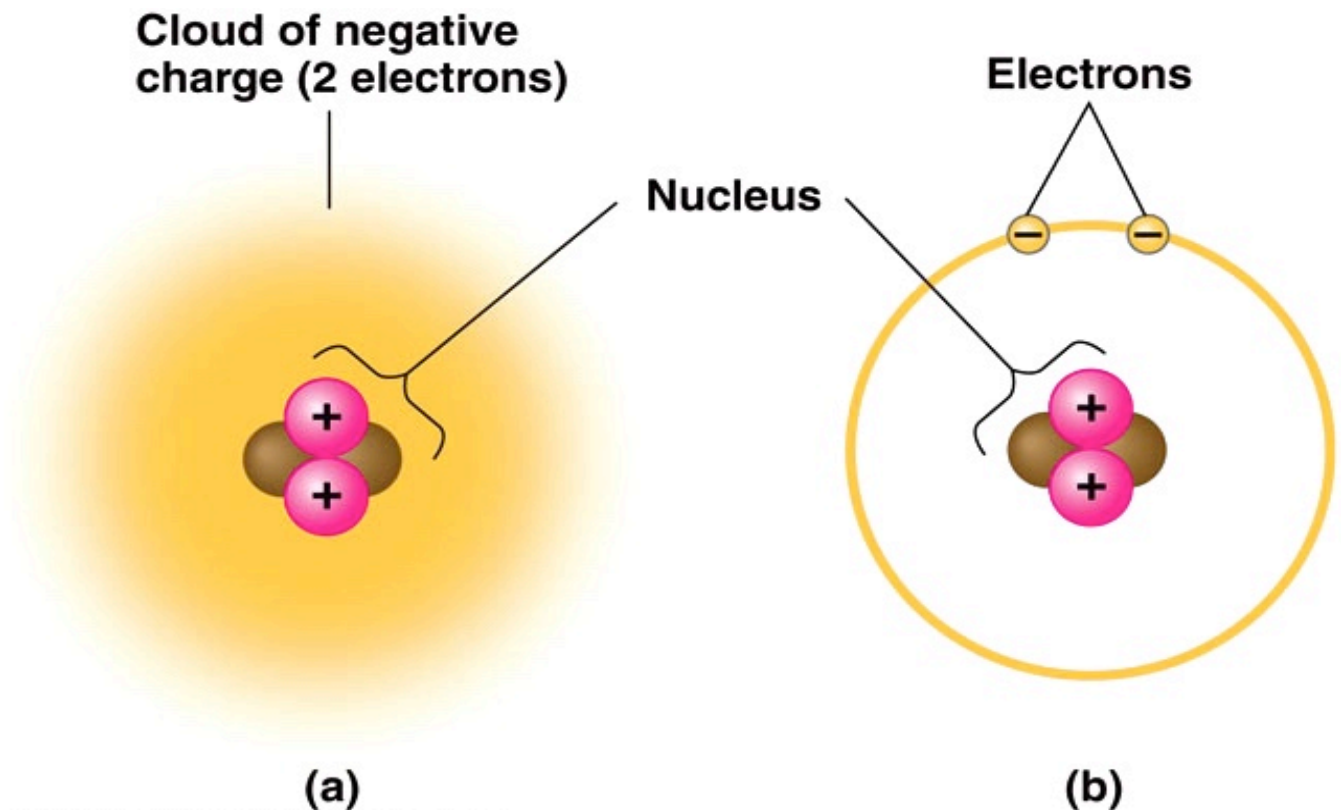
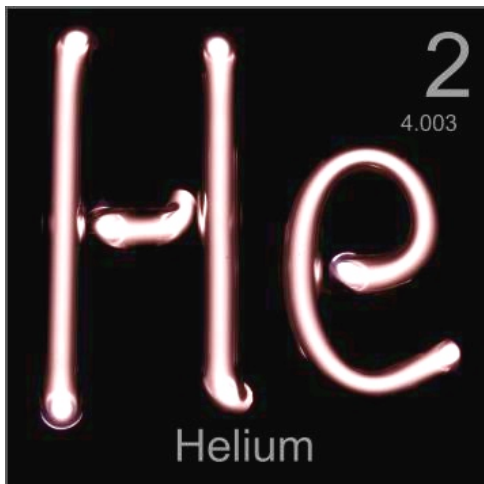


- **The number of protons determines the element!**
  - ◆ Remove or add a proton from or to an atom of one element and you now have a totally new element.
- **HYDROGEN** is the simplest atomic structure.
  - ◆ It has only 1 proton and 1 electron.
    - The most common type of hydrogen atom, protium, (*making up 99.985% of naturally occurring hydrogen atoms*) has **NO** neutron.
  - ◆ On the periodic table, hydrogen is the 1st element in group 1A.
    - Notice that Hydrogen has a #1 above its symbol H which indicates the number of protons that atom contains.



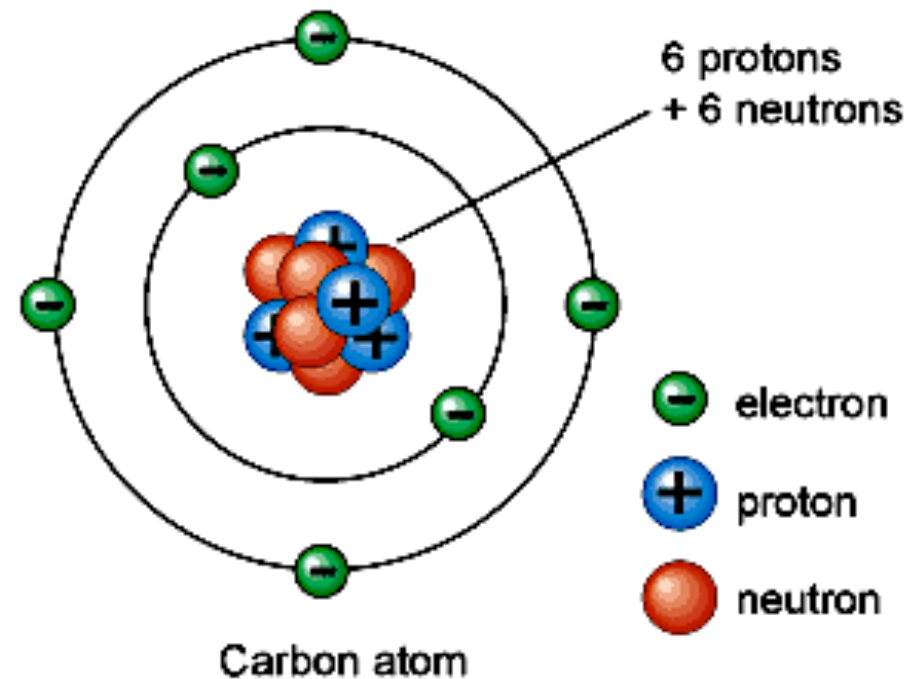
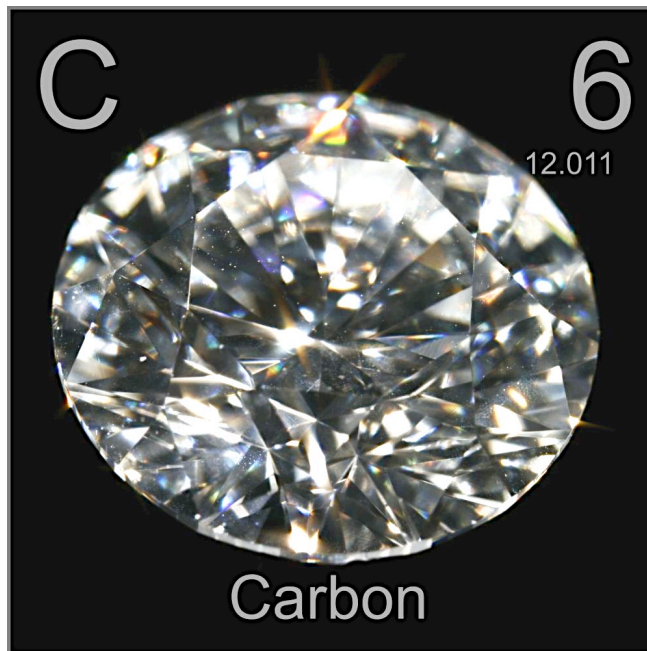
# The Number of Protons Matters

- **HELIUM** has a number 2 above its symbol in the periodic table
  - ◆ The neutral Helium atom (He) - top right in the periodic table - has 2 protons and, therefore, 2 electrons.



# The Number of Protons Matters

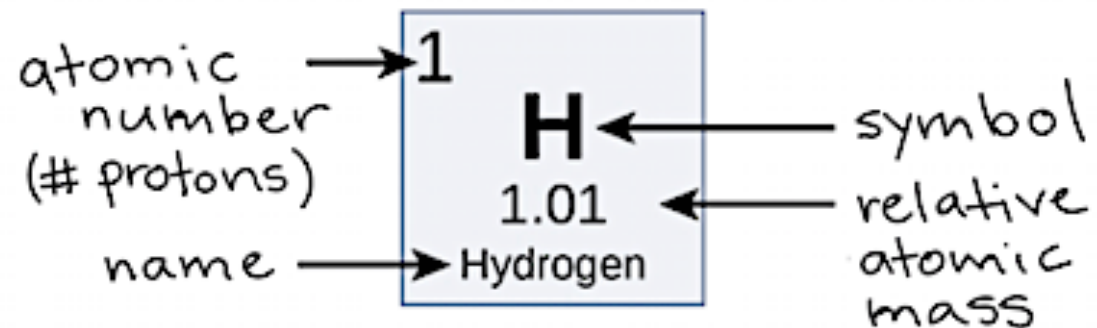
- The element **CARBON** has a number 6 above its symbol in the periodic table
  - ◆ The neutral Carbon atom, therefore, has 6 protons and, therefore, 6 electrons.



# Atomic Number & Mass Number

- Each atom has 2 numbers associated with it that tells us information about the element's atoms:
  1. The Atomic Number
  2. The Mass Number
- **ATOMIC NUMBER (Z)**: The number of protons in the nucleus of the atom (*and thus the number of electrons in a NEUTRAL atom of that element*)
  - ◆ Located above the element's symbol in the periodic table but written on the lower left of the atomic symbol.
  - ◆ Always a whole number.

- Every element has a different Atomic Number!



# PERIODIC TABLE OF THE ELEMENTS

1A 1 <b>1</b> <b>H</b> Hydrogen 1.00794																	2A 2 <b>2</b> <b>He</b> Helium 4.00260
<b>3</b> <b>Li</b> Lithium 6.941	<b>4</b> <b>Be</b> Beryllium 9.01218											<b>5</b> <b>B</b> Boron 10.811	<b>6</b> <b>C</b> Carbon 12.011	<b>7</b> <b>N</b> Nitrogen 14.0067	<b>8</b> <b>O</b> Oxygen 15.9994	<b>9</b> <b>F</b> Fluorine 18.998403	<b>10</b> <b>Ne</b> Neon 20.1797
<b>11</b> <b>Na</b> Sodium 22.98977	<b>12</b> <b>Mg</b> Magnesium 24.305	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8 9 10			1B 11	2B 12	<b>13</b> <b>Al</b> Aluminum 26.98154	<b>14</b> <b>Si</b> Silicon 28.0855	<b>15</b> <b>P</b> Phosphorus 30.97376	<b>16</b> <b>S</b> Sulfur 32.066	<b>17</b> <b>Cl</b> Chlorine 35.4527	<b>18</b> <b>Ar</b> Argon 39.948
<b>19</b> <b>K</b> Potassium 39.0983	<b>20</b> <b>Ca</b> Calcium 40.078	<b>21</b> <b>Sc</b> Scandium 44.9559	<b>22</b> <b>Ti</b> Titanium 47.88	<b>23</b> <b>V</b> Vanadium 50.9415	<b>24</b> <b>Cr</b> Chromium 51.9961	<b>25</b> <b>Mn</b> Manganese 54.9380	<b>26</b> <b>Fe</b> Iron 55.847	<b>27</b> <b>Co</b> Cobalt 58.9332	<b>28</b> <b>Ni</b> Nickel 58.6934	<b>29</b> <b>Cu</b> Copper 63.546	<b>30</b> <b>Zn</b> Zinc 65.39	<b>31</b> <b>Ga</b> Gallium 69.723	<b>32</b> <b>Ge</b> Germanium 72.61	<b>33</b> <b>As</b> Arsenic 74.9216	<b>34</b> <b>Se</b> Selenium 78.96	<b>35</b> <b>Br</b> Bromine 79.904	<b>36</b> <b>Kr</b> Krypton 83.80
<b>37</b> <b>Rb</b> Rubidium 85.4678	<b>38</b> <b>Sr</b> Strontium 87.62	<b>39</b> <b>Y</b> Yttrium 88.9059	<b>40</b> <b>Zr</b> Zirconium 91.224	<b>41</b> <b>Nb</b> Niobium 92.9064	<b>42</b> <b>Mo</b> Molybdenum 95.94	<b>43</b> <b>Tc</b> Technetium (98)	<b>44</b> <b>Ru</b> Ruthenium 101.07	<b>45</b> <b>Rh</b> Rhodium 102.9055	<b>46</b> <b>Pd</b> Palladium 106.42	<b>47</b> <b>Ag</b> Silver 107.8682	<b>48</b> <b>Cd</b> Cadmium 112.411	<b>49</b> <b>In</b> Indium 114.82	<b>50</b> <b>Sn</b> Tin 118.710	<b>51</b> <b>Sb</b> Antimony 121.757	<b>52</b> <b>Te</b> Tellurium 127.60	<b>53</b> <b>I</b> Iodine 126.9045	<b>54</b> <b>Xe</b> Xenon 131.29
<b>55</b> <b>Cs</b> Cesium 132.9054	<b>56</b> <b>Ba</b> Barium 137.327	<b>57</b> <b>*La</b> Lanthanum 138.9055	<b>72</b> <b>Hf</b> Hafnium 178.49	<b>73</b> <b>Ta</b> Tantalum 180.9479	<b>74</b> <b>W</b> Tungsten 183.85	<b>75</b> <b>Re</b> Rhenium 186.207	<b>76</b> <b>Os</b> Osmium 190.2	<b>77</b> <b>Ir</b> Iridium 192.22	<b>78</b> <b>Pt</b> Platinum 195.08	<b>79</b> <b>Au</b> Gold 196.9665	<b>80</b> <b>Hg</b> Mercury 200.59	<b>81</b> <b>Tl</b> Thallium 204.3833	<b>82</b> <b>Pb</b> Lead 207.2	<b>83</b> <b>Bi</b> Bismuth 208.9804	<b>84</b> <b>Po</b> Polonium (209)	<b>85</b> <b>At</b> Astatine (210)	<b>86</b> <b>Rn</b> Radon (222)
<b>87</b> <b>Fr</b> Francium (223)	<b>88</b> <b>Ra</b> Radium 226.0254	<b>89</b> <b>Ac</b> Actinium 227.0278	<b>104</b> <b>Rf</b> Rutherfordium (261)	<b>105</b> <b>Db</b> Dubnium (262)	<b>106</b> <b>Sg</b> Seaborgium (263)	<b>107</b> <b>Bh</b> Bohrium (262)	<b>108</b> <b>Hs</b> Hassium (265)	<b>109</b> <b>Mt</b> Meitnerium (268)	<b>110</b> (269)	<b>111</b> (272)	<b>112</b> (277)						

Atomic Number (# of Protons)

*Lanthanide Series	<b>58</b> <b>Ce</b> Cerium 140.115	<b>59</b> <b>Pr</b> Praseodymium 140.9077	<b>60</b> <b>Nd</b> Neodymium 144.24	<b>61</b> <b>Pm</b> Promethium (145)	<b>62</b> <b>Sm</b> Samarium 150.36	<b>63</b> <b>Eu</b> Europium 151.965	<b>64</b> <b>Gd</b> Gadolinium 157.25	<b>65</b> <b>Tb</b> Terbium 158.9254	<b>66</b> <b>Dy</b> Dysprosium 162.50	<b>67</b> <b>Ho</b> Holmium 164.9303	<b>68</b> <b>Er</b> Erbium 167.26	<b>69</b> <b>Tm</b> Thulium 168.9342	<b>70</b> <b>Yb</b> Ytterbium 173.04	<b>71</b> <b>Lu</b> Lutetium 174.967
† Actinide Series	<b>90</b> <b>Th</b> Thorium 232.0381	<b>91</b> <b>Pa</b> Protactinium 231.0359	<b>92</b> <b>U</b> Uranium 238.0289	<b>93</b> <b>Np</b> Neptunium 237.048	<b>94</b> <b>Pu</b> Plutonium (244)	<b>95</b> <b>Am</b> Americium (243)	<b>96</b> <b>Cm</b> Curium (247)	<b>97</b> <b>Bk</b> Berkelium (247)	<b>98</b> <b>Cf</b> Californium (251)	<b>99</b> <b>Es</b> Einsteinium (252)	<b>100</b> <b>Fm</b> Fermium (257)	<b>101</b> <b>Md</b> Mendelevium (258)	<b>102</b> <b>No</b> Nobelium (259)	<b>103</b> <b>Lr</b> Lawrencium (260)

# Atomic Number & Mass Number

- **MASS NUMBER (A)**: The sum of the masses of the particles in an atom (#p + #n).
  - ◆ Recall that a proton has a mass of 1 amu (or dalton)
  - ◆ Recall that a neutron has a mass of 1 amu (or dalton)
  - ◆ Recall that an electron is so small that its mass is almost 0 amu (or dalton)
    - Practically the entire mass of an atom is located in the **NUCLEUS!**




**Mass number**  
Number of protons  
and neutrons in atom

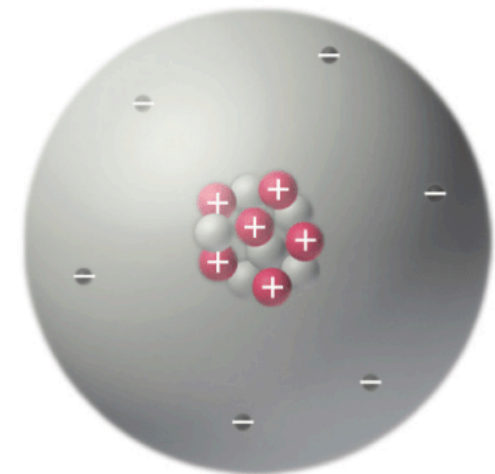


**Atomic symbol**  
Abbreviation used  
to represent atom  
in chemical  
formulas

**Atomic number**  
Number of protons  
in atom



6 protons   
6 neutrons   
6 electrons 



**EXERCISE:** Carbon-14 has a Mass Number of 14. What is C-14's Atomic Number? Number of neutrons? Number of Electrons? **6, 8, 6**

# Matter is made of one or more elements

- **EXERCISE:** An element has a Mass Number of 210 and is known to have 125 neutrons? Identify the element.

Begin by writing down the info given:

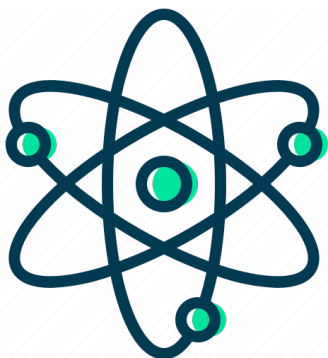
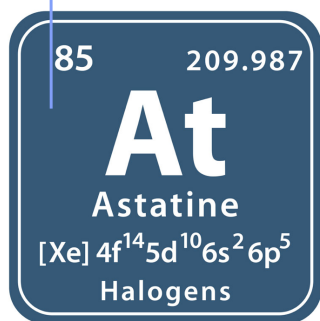
Mass # = 210 so #p + #n = 210  
#n = 125

Now perform the necessary calculations:

#p + 125 = 210 and #p = 85 = Atomic #

Recall that # of protons determines the element.

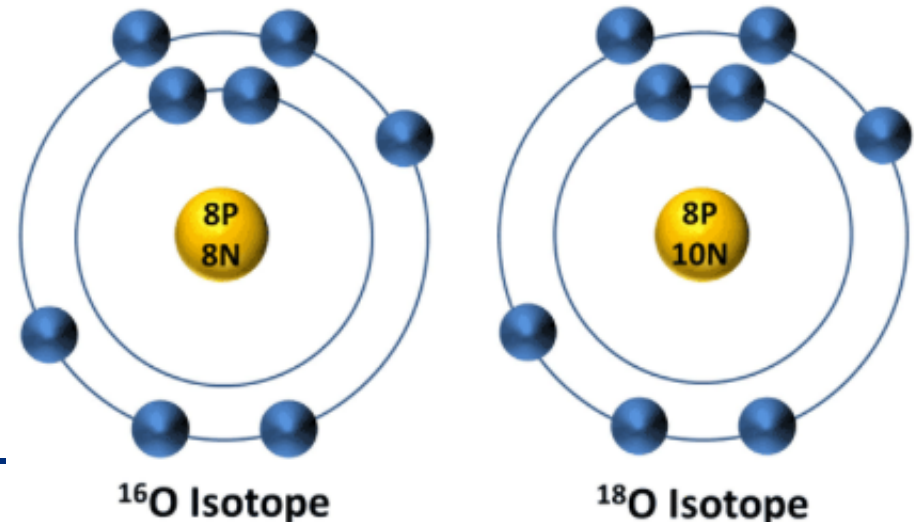
Element with Atomic # 85 on the Periodic Table, is **Astatine (At)**



# Not all Atoms of an Element are Identical

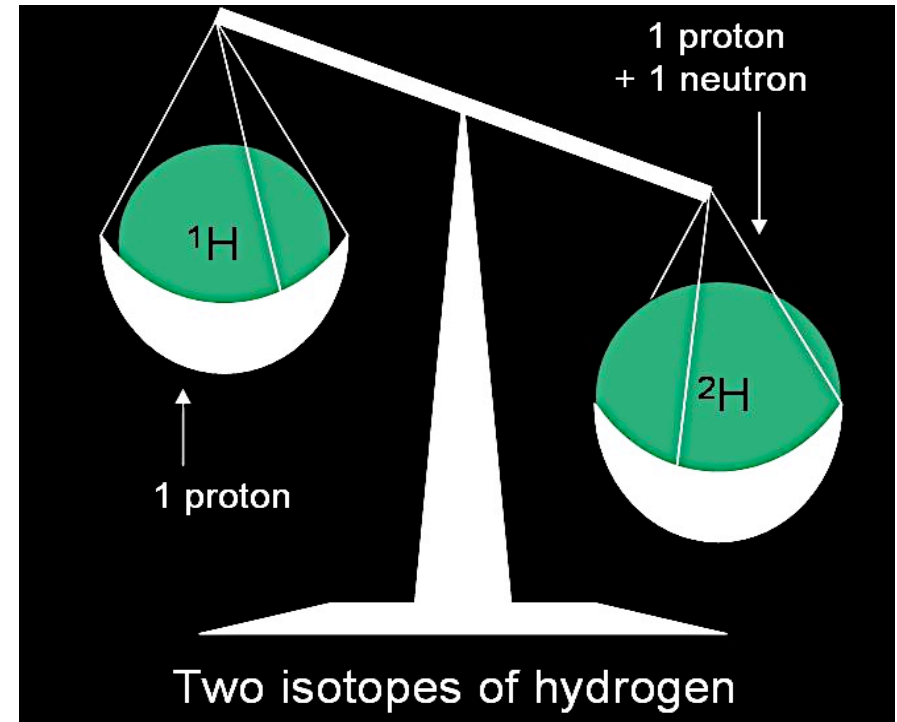
- Elements differ from one another according to the number of protons in their atoms.
  - ◆ All atoms of the same element contain the **SAME** number of protons.
- Still, atoms of one element are **not** always identical since **NEUTRONS CAN VARY** in number among the atoms of an element.

- **ISOTOPES** = Atoms with the same atomic number (same # of protons) but different mass numbers (differing # of neutrons)

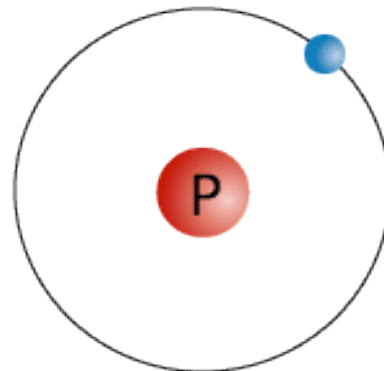


# Isotopes

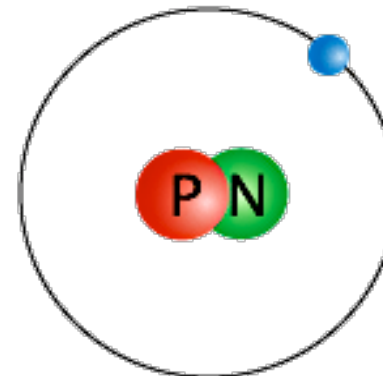
- Isotopic variants of an element generally have the **same chemical behavior**, because they have the same number of electrons (since the number of protons is the same), though they **differ in their number of neutrons**.



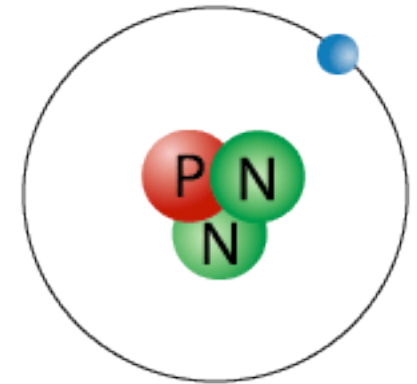
The three isotopes of Hydrogen



Hydrogen



Deuterium

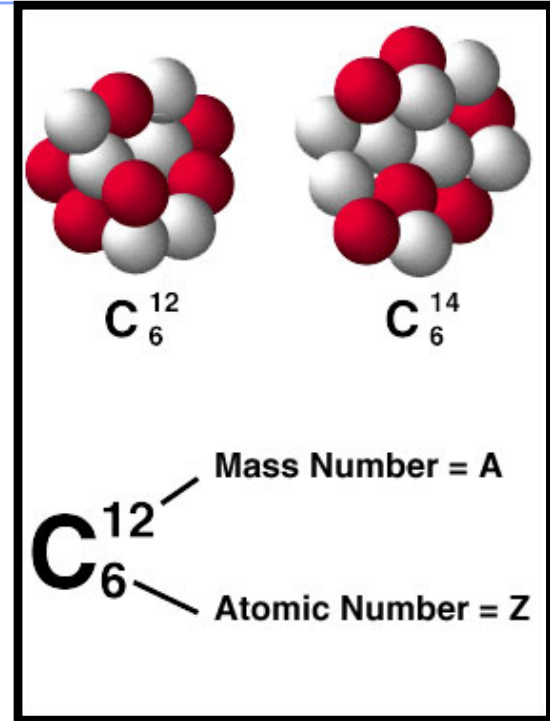


Tritium

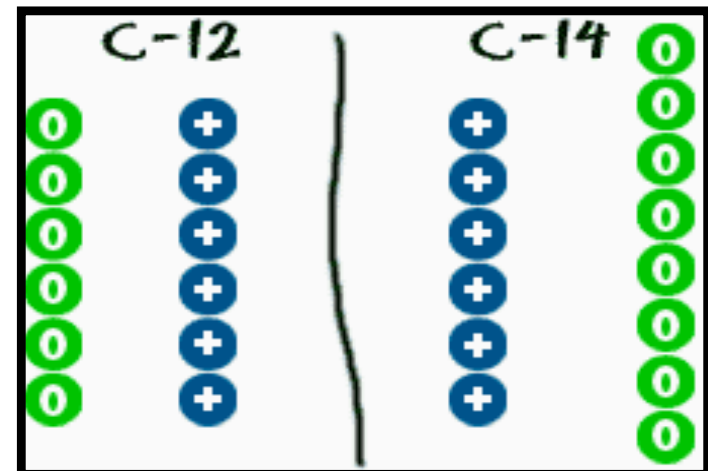
# All Atoms Exist as an Isotopic Variant

## EXAMPLE: CARBON (C)

- ◆ There are a lot of versions (isotopes) of carbon atoms in the universe.
- The most common one is carbon-12.
  - ◆ Those atoms have 6 protons and 6 neutrons.
- A few carbon atoms don't have 6.
  - ◆ Those odd ones may have 7 or even 8 neutrons.
    - The Carbon-14 isotopes has 8 neutrons (2 more than the isotope Carbon-12).

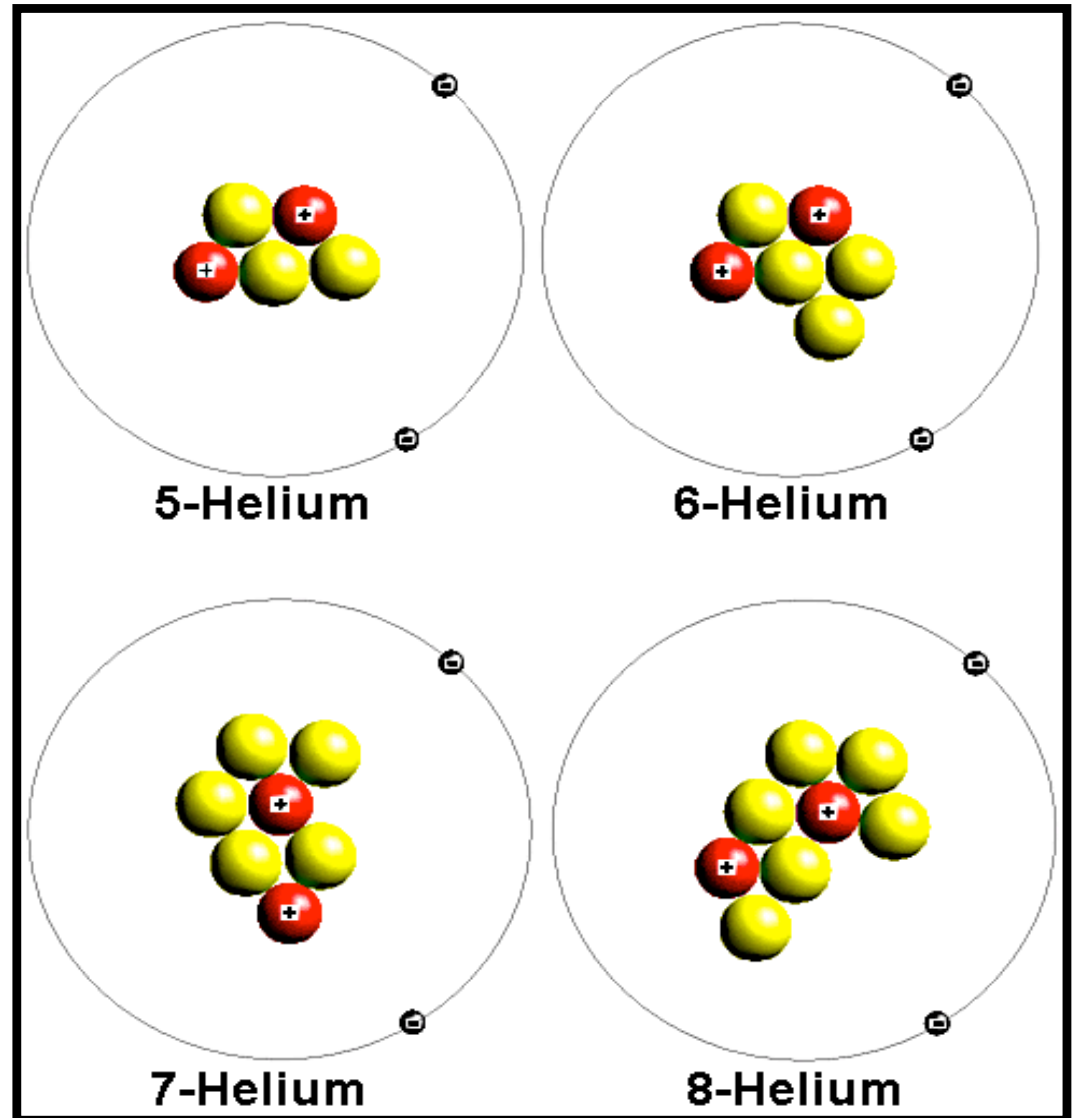


Stable Isotopes							
99%				1%			
${}^9_6\text{C}$	${}^{10}_6\text{C}$	${}^{11}_6\text{C}$	${}^{12}_6\text{C}$	${}^{13}_6\text{C}$	${}^{14}_6\text{C}$	${}^{15}_6\text{C}$	${}^{16}_6\text{C}$
.13	19	20.6		5730	2.25	.74	
sec.	sec.	min.		years	sec.	sec.	



# All Atoms Exist as an Isotopic Variant

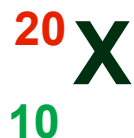
- Helium's isotopes vary in the number of neutrons, but always have 2 protons.



# All Atoms Exist as an Isotopic Variant

**Question:** A fictional element “X” has 2 isotopes. What is the chemical notation for each isotope?

1. Atom 1 has 10 electrons, 10 protons, and 10 neutrons?

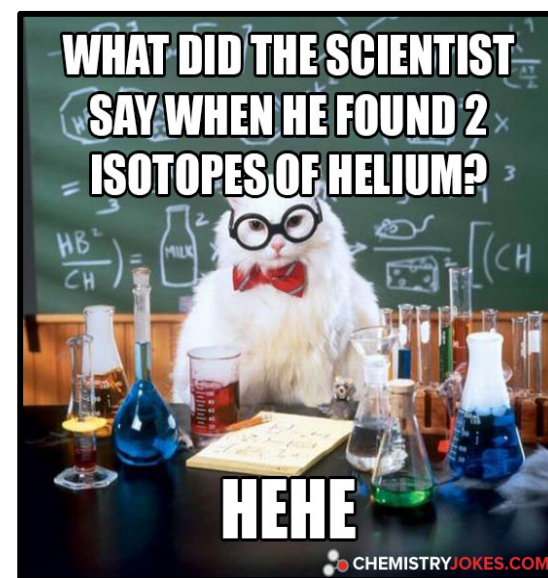


2 Atom 2 has 10 electrons, 10 protons, and 11 neutrons?

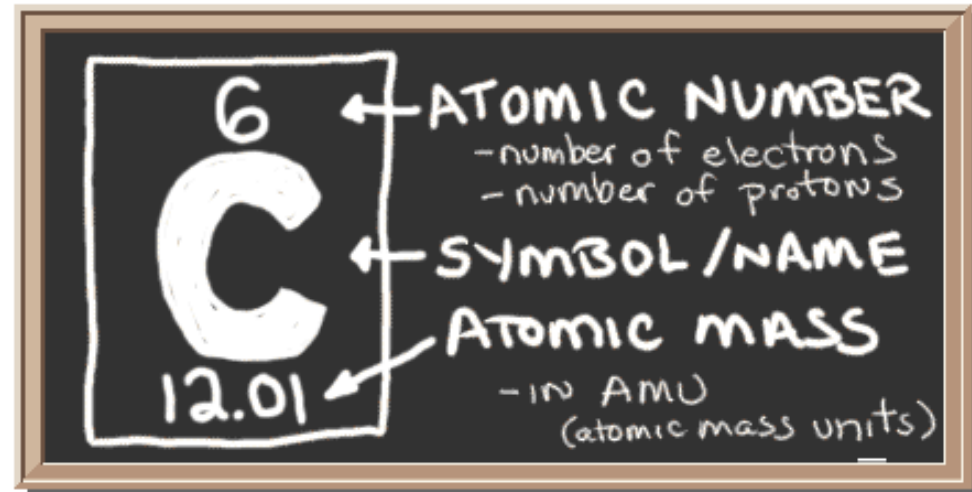
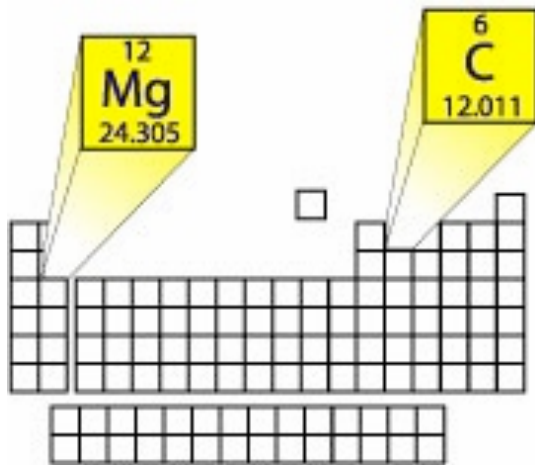


3. Can element X have more or fewer protons????

**NO!** If the proton number changes, the atom would be an atom of a different element!

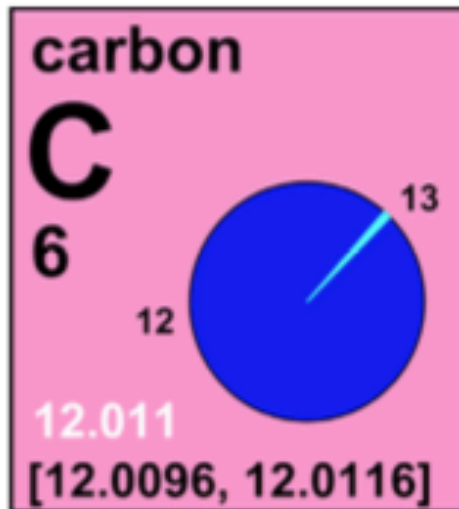


# MOST ELEMENTS OCCUR NATURALLY AS A MIXTURE OF DIFFERENT ISOTOPES!





- The mass of one atom of an element (of one type of isotope of an element) in amu is called the atom's **ISOTOPIC MASS**.
  - ◆ The mass of that one atom's total protons and neutrons in amu.
- The element's **ATOMIC MASS** or **ATOMIC WEIGHT** is the **weighted** average of the element's isotopic masses
  - ◆ This value (in amu) is located under the element's symbol in the periodic table.

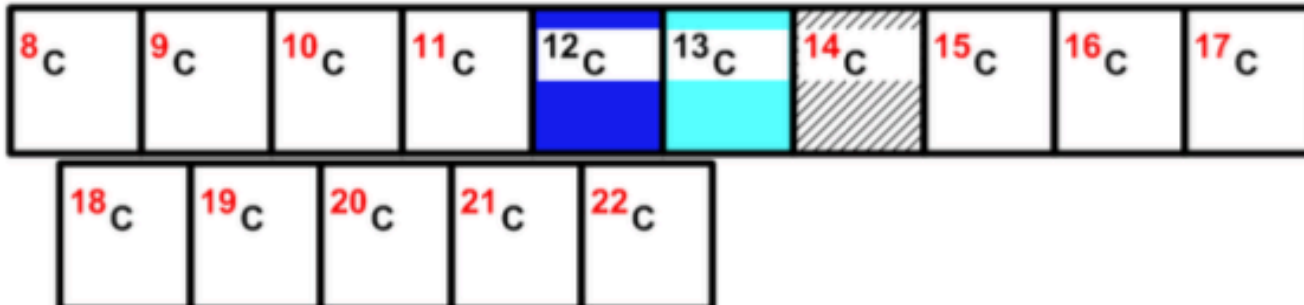
# Atomic Mass / Atomic Weight



← In the periodic table, atomic mass of an element is rarely an even number.

For carbon, **98.89%** occurs as **C-12**,  
**1.11%** occurs as **C-13**,  
**0.00000000010%** as **C-14**.

Half-life of radioactive isotope  
Less than 1 hour   
Greater than 1 year 

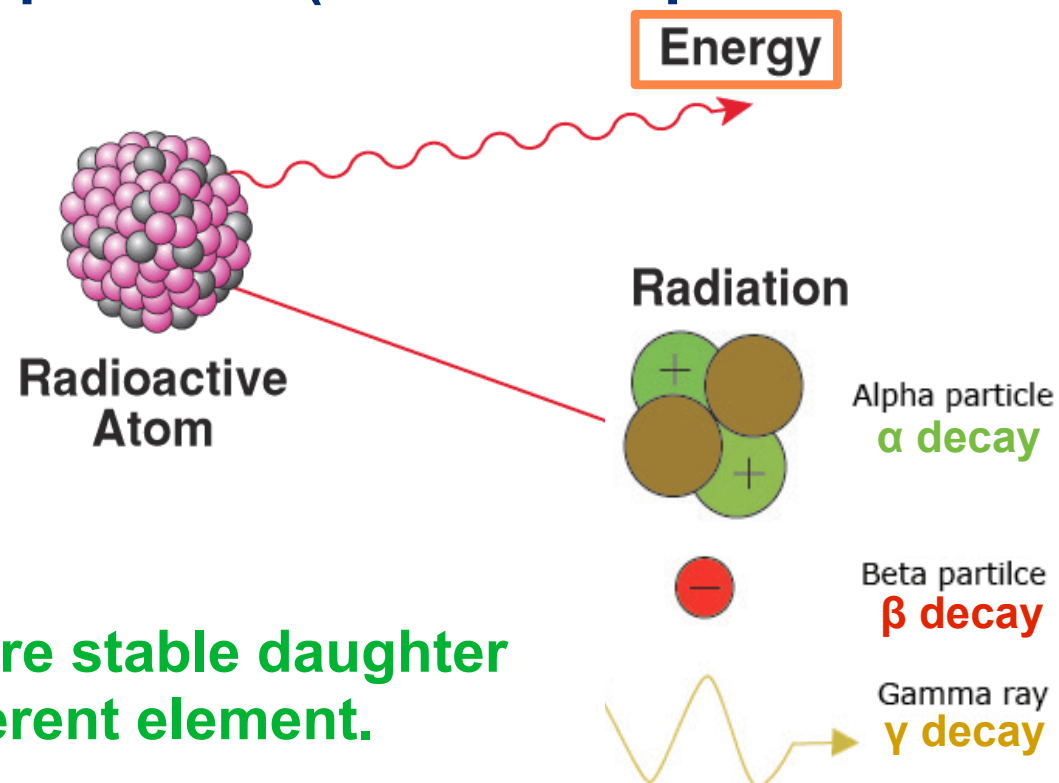


When you average out all of the masses, you get a value that is a bit larger than 12 amu (the isotopic mass of a c-12 single C-12 atom).

The atomic mass (atomic weight) for element C is 12.011 amu.

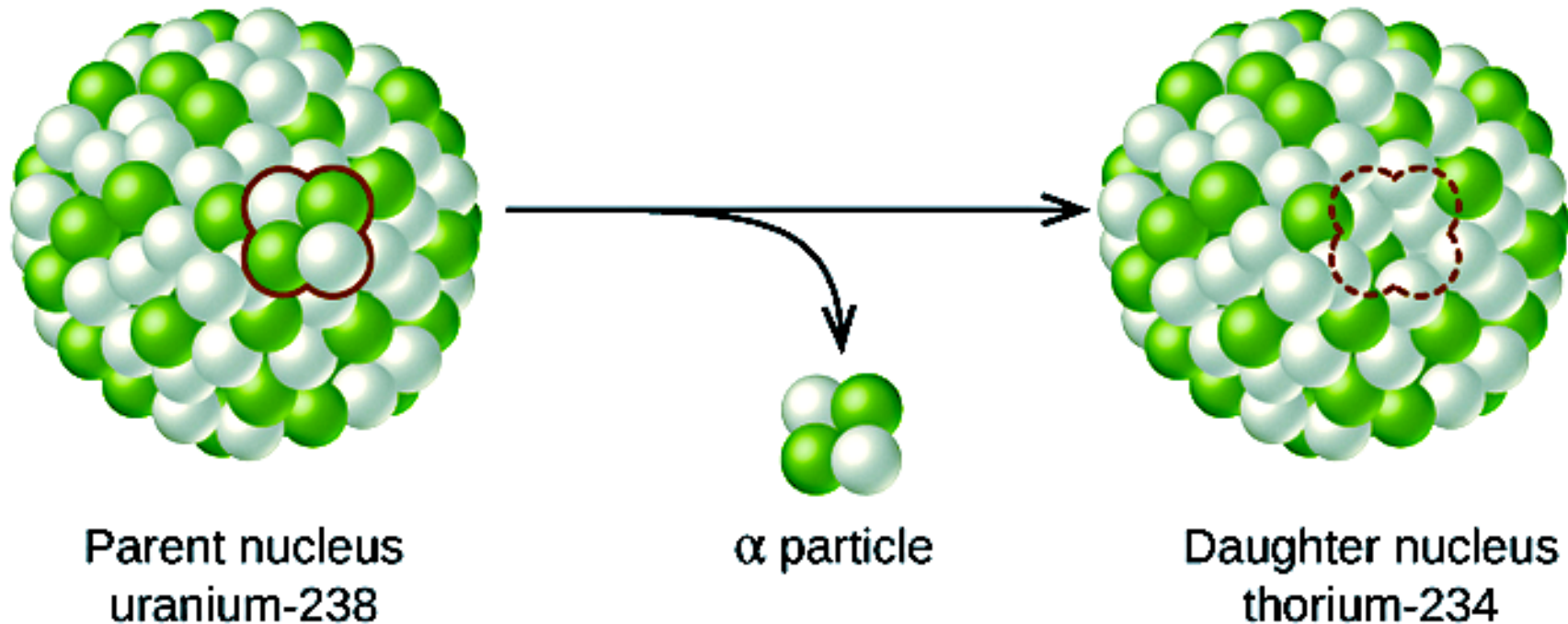
# Some isotopes are stable and others NOT.

- When an isotope has an unstable nucleus is RADIOACTIVE: They spontaneously emit energy to become more stable.
  - ◆ The energy emitted from the nucleus is called RADIATION.
- During RADIOACTIVE DECAY, an unstable nucleus spits out ENERGY and either alpha ( $\alpha$ ) particles (these isotopes are known as Alpha Emitters), beta ( $\beta$ ) particles (these isotopes are known as Beta Emitters), or gamma ( $\gamma$ ) rays (these isotopes are known as Gamma Emitters).
  - ◆ Radioisotopes as these isotopes are called decay at a constant rate to form a more stable daughter isotopes of the same or different element.



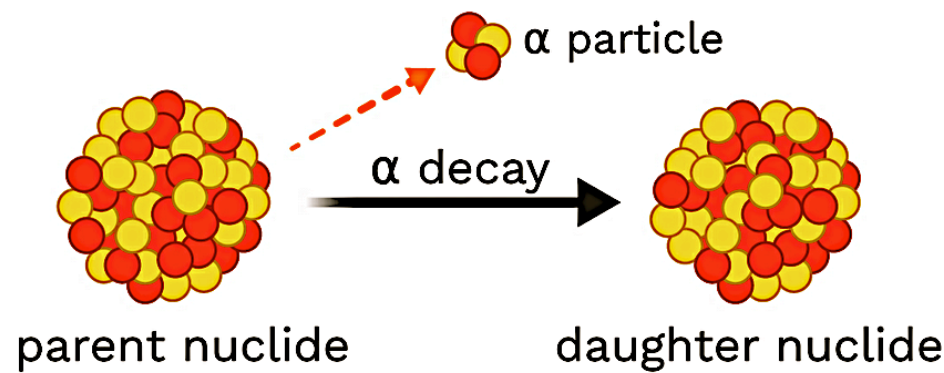
# Radioactive Decay

- During radioactive decay, a parent (radioactive) isotope with an unstable nucleus decays into a daughter isotope with a more stable nucleus.



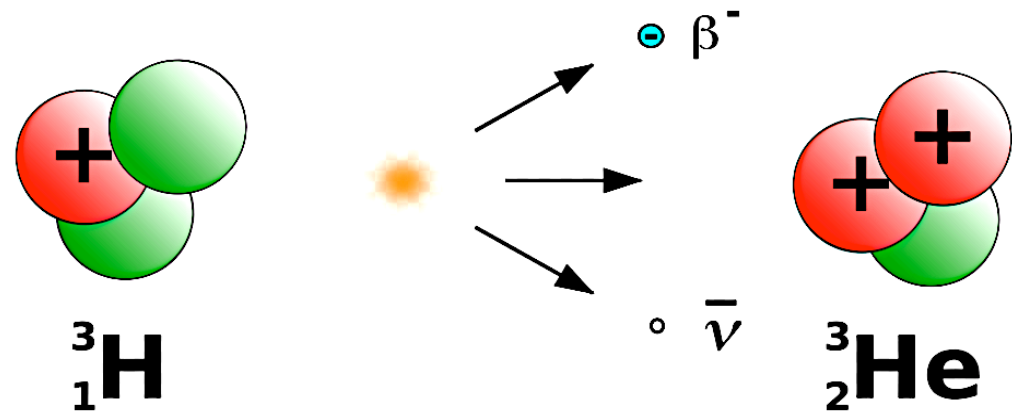
**Example:** A nucleus of uranium-238 (the parent isotope) undergoes  $\alpha$  decay to form thorium-234 (the daughter isotope). The alpha particle removes two protons (green) and two neutrons (white) from the uranium-238 nucleus, *all while energy is also released from the parent nucleus.*

# Alpha Decay & Alpha Radiation



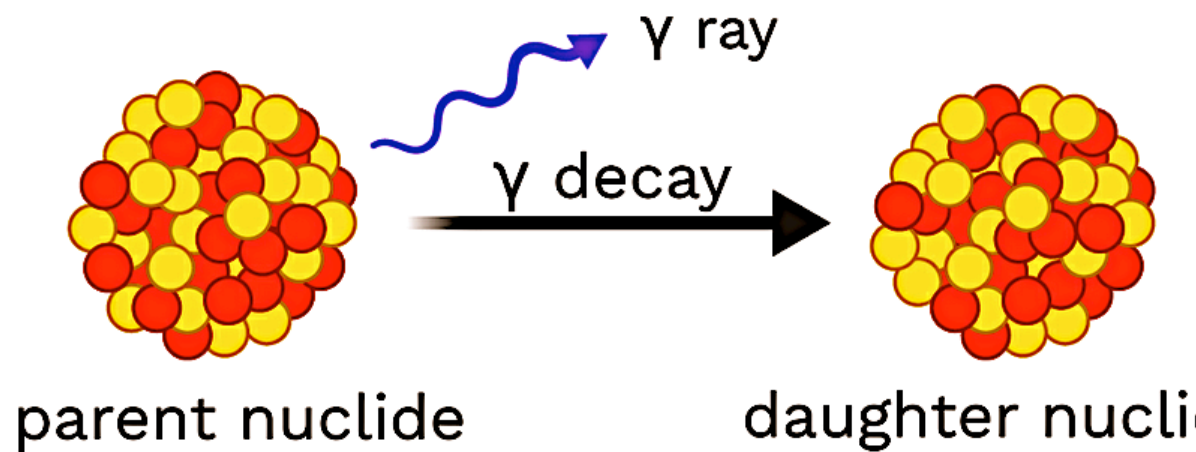
- During alpha decay, a pair of protons bound to a pair of neutrons (a helium nucleus) called an alpha particle is emitted from the nucleus of the parent isotope.
  - ◆ The atom changes in atomic #, becoming a different element
    - **Ex:** The radium nucleus (Ra, atomic number 88) emits a helium nucleus forming the daughter isotope radon (Rn, atomic number 86).
  - ◆ The medical risks from this radiation usually involve the fast speeds at which the radiation particle moves.
    - Think of the alpha particle released by this reaction as a tiny “bullet,” which can puncture soft tissues like the lining of the stomach and lungs.
      - ◆ Radon Poisoning in homes = Radioactive isotopes of radium can be found deep underground. When it undergoes alpha decay it turns into radon, a gas. The radon then seeps out of the ground and into the basements of people’s homes, where it can enter their lungs. Daughter isotopes of radon can themselves have unstable nuclei so the radon formed can decay again, releasing more alpha particles (or other types of radiation) directly into the unprotected tissues becoming a major lung cancer risk factor. *Do you have a radon detector at home?*

# Beta Negative or Positive Decay & Beta Radiation



- In **beta-minus decay**, one of the **neutrons** in the nucleus **changes into a proton**, causing an increase in the atomic number and thus a change in element.
  - ◆ This decay releases from the nucleus a charged beta particle (an electron but from the nucleus, not the electron cloud!!!)
    - Ex: The other two isotopes of hydrogen, protium and deuterium, are **not** radioactive. Their nuclei are stable. Tritium (with 1 proton and 2 neutrons), however, has an **unstable** nucleus and so is a **radioisotope**. Tritium undergoes beta decay, forming the daughter isotope helium-3.
- In **beta-plus decay**, one of the **proton** in the nucleus suddenly **changes into a neutron**, causing an decrease in the atomic number and thus a change in element.
  - ◆ This decay releases from the nucleus a charged a positron particle, which is similar to an electron but with a positive charge.
    - Because this particle's interactions with other tissues are easily identifiable, some medical imaging techniques involve purposefully injecting a patient with an element that beta decays into positrons, and then monitoring where the positrons are emitted.

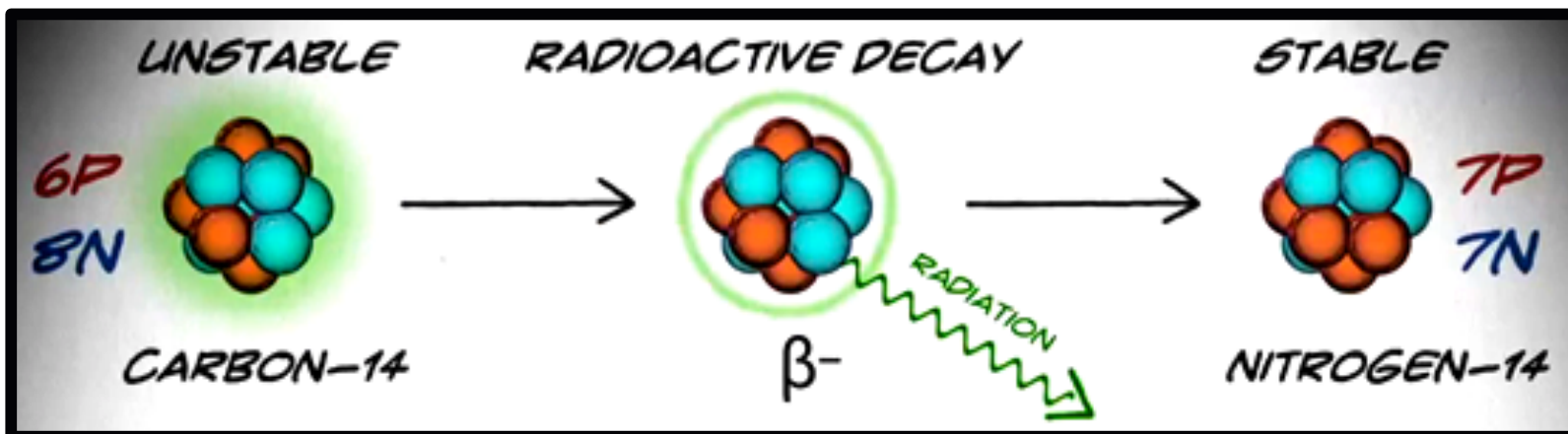
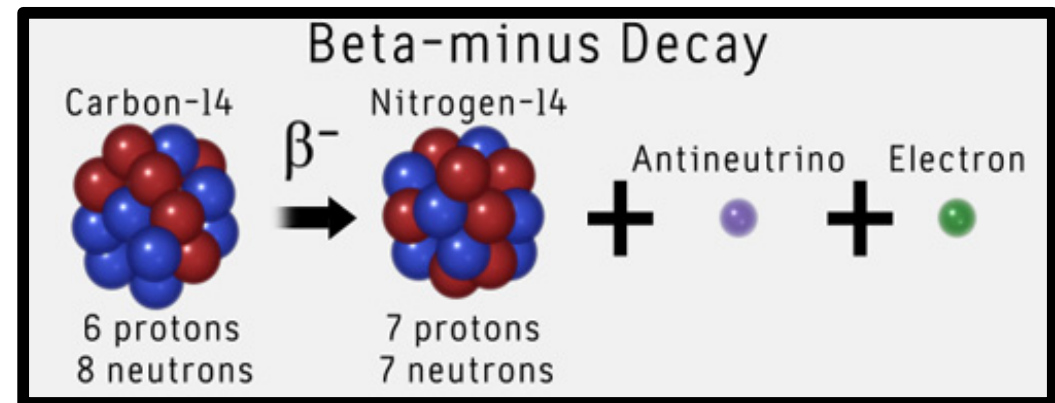
# Gamma Decay & Gamma Radiation



- During gamma decay, the nucleus emits radiation (energy) **without** actually changing its composition
  - ◆ The arrangement of protons and neutrons in the nucleus changes to a lower total energy state/configuration, releasing a high-energy photon called a **gamma ray**.
    - For Ex: Uranium-239m, a parent nuclide, would decay via gamma emission into uranium-239 and a gamma-ray.
  - ◆ Gamma rays are very high energy and are one of the **most dangerous sources of radiation** because photons can pass through most common shielding materials and cause DNA damage in living tissues.
    - **But gamma radiation also has practical uses:**
      - ◆ The element technetium emits relatively low-energy gamma decays that can be detected using a specialized scanner so it is used as a tracer element for imaging the inside of patients' bodies.
      - ◆ Airport security use them to look inside our luggage
      - ◆ Doctors use them to sterilize their equipment

# Carbon-14 is a Radioactive Isotope of the Element Carbon

- Beta(-minus) emitters, like Carbon-14, decay by emitting beta particles which results in a neutron changing into a proton inside the nucleus, resulting in the formation of a new element.
  - ◆ Carbon-14 decays into nitrogen atom.
    - Its Mass Number remains same, but its Atomic Number increases by +1.

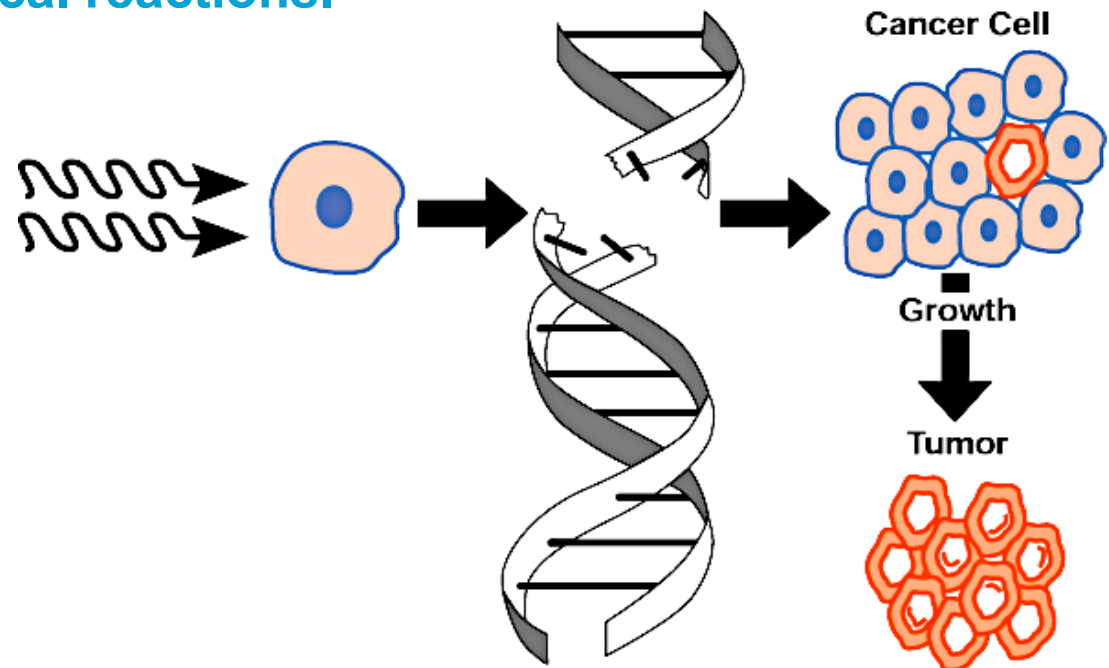


Carbon-14  
(6 protons &  
8 neutrons)  
decays into  
Nitrogen-14  
(7 protons &  
7 neutrons)

# Radiation can be Harmful

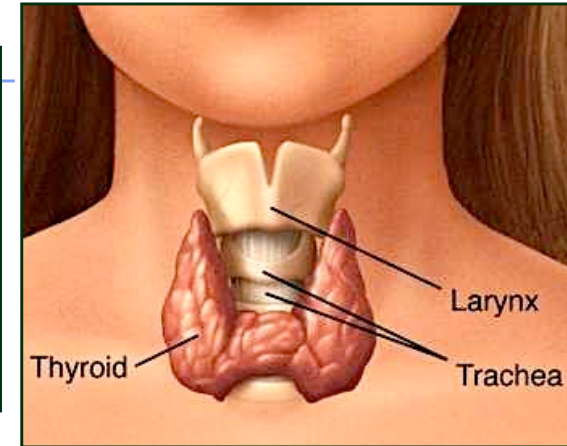


- High doses of radioactivity can be very toxic, because the high energies released **damages essential molecules** in our body's cells by disrupting covalent bonds.
- High energy radiation can knock electrons out of atoms or molecules resulting in the **formation of unstable ions or radicals**.
  - ◆ A **FREE RADICAL** is an atom that has an unpaired electron and so might be able to pull electrons off of other atoms within molecules or engage in dangerous chemical reactions.
- Radiation can damage cells in the bone marrow, for example, stopping the production of red blood cells, damage cells resulting in birth defects, result in shortened life spans, tumors, anemia, genetic mutations, etc...



# Radiation can be Useful too!

- Radioisotopes can be used to **trace certain molecules** in scientific research and through the body, and to treat and diagnose certain diseases such as cancers or thyroid conditions.
  - ◆ Cells of the body **CANNOT** distinguish generally between non-radioactive atoms and radioactive ones of the same element
    - Chemical reactions occur with **any** atom a particular element, regardless of how many neutrons are in its nucleus or if the nucleus is stable.
- **Example:** Hyperthyroidism is a condition in which the thyroid gland is overactive producing too many thyroid hormones resulting in muscle weakness, brittle hair, perspiration, nervousness, and irritability. Doctors give the person radioactive iodine to drink. **A scan shows a higher than normal rate of uptake of the radioactive iodine allowing the condition to be diagnosed.** Treatment can also include the use of these radioisotopes that destroy thyroid cells with the radiation they release.



Gamma probe measuring thyroid gland radioactivity



Radioactive iodine is ingested

