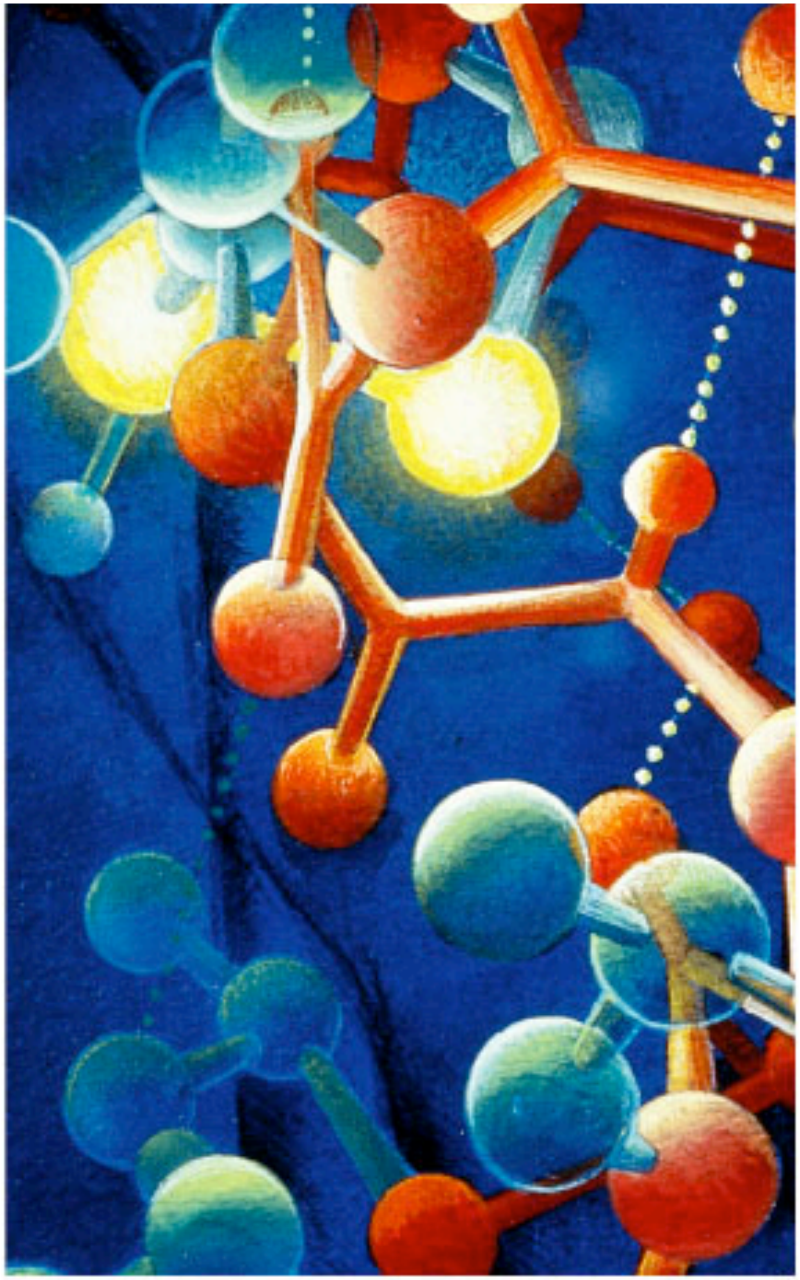
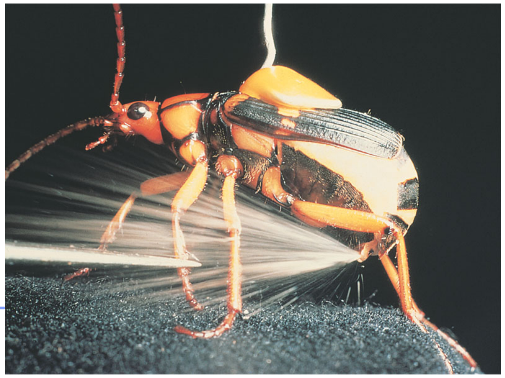
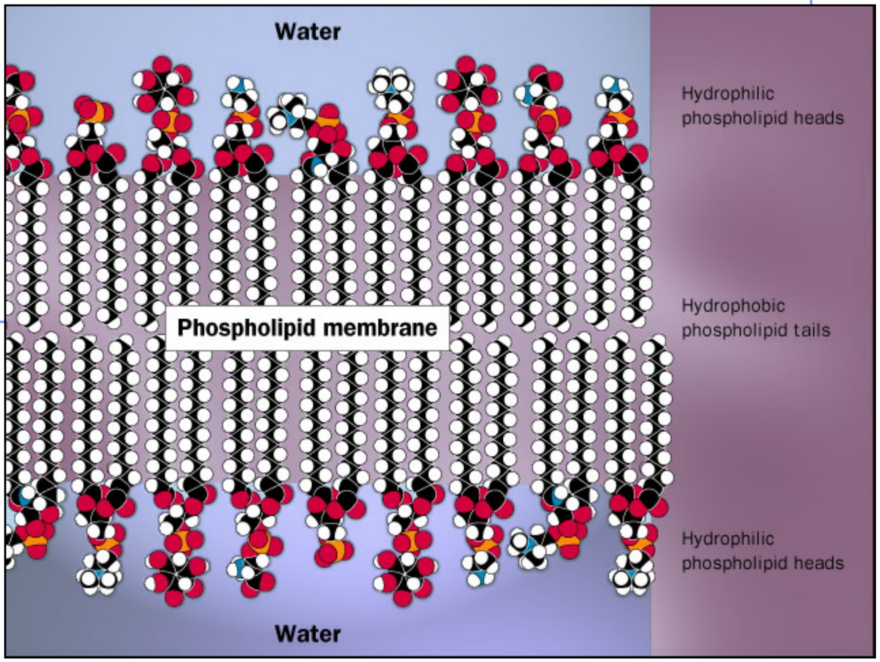


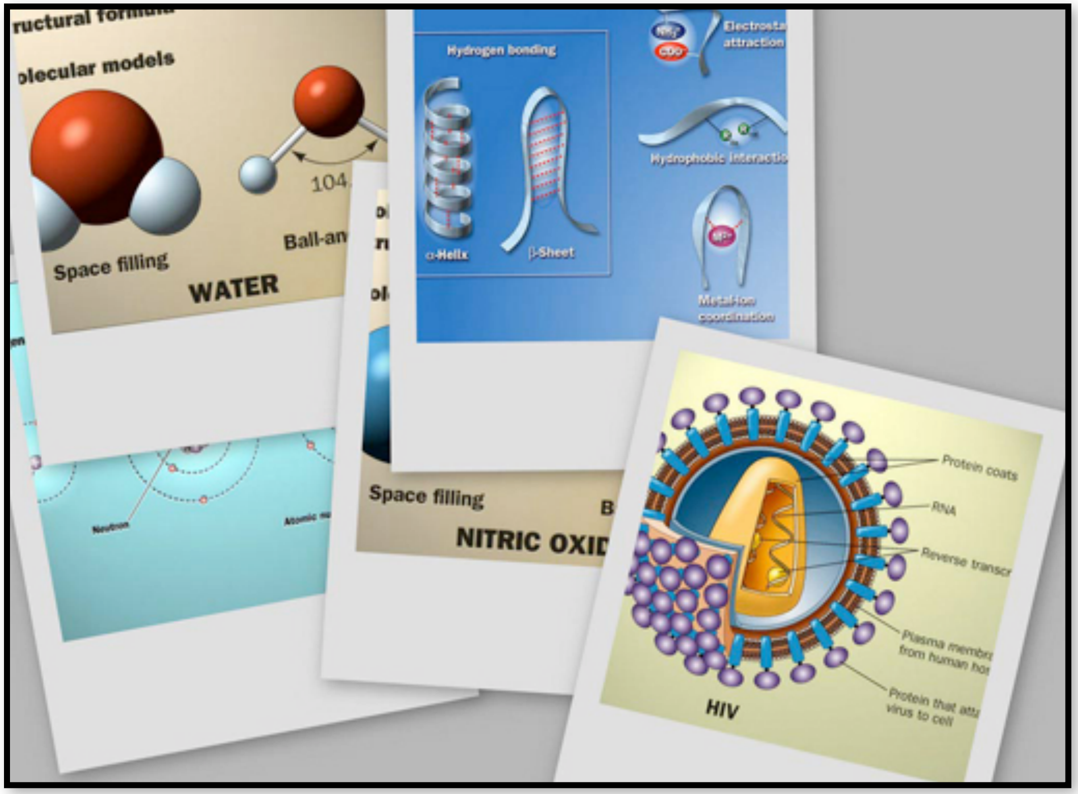


The Chemistry of Life



Why are we studying chemistry?

Chemistry is the foundation of Biology

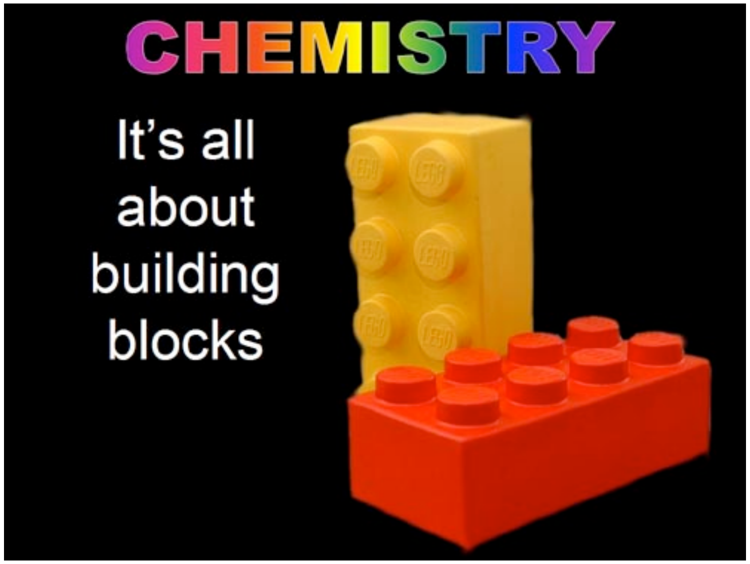


Life only happens because of the millions of chemical reactions taking place inside our bodies every second.

Matter is made of one or more elements

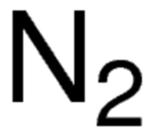
- An ELEMENT is a fundamental substance that cannot be chemically changed or broken down into a simpler substance by ordinary means.

  - Example: Table salt is made up of the elements sodium and chlorine.
  - Example: Glucose is made up of the elements hydrogen, carbons, and oxygen, and chlorine.



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?*

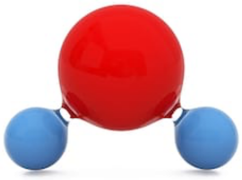


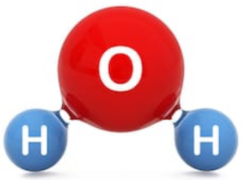
ANSWER: Oxygen and nitrogen are elements. They cannot be broken down into simpler substances.

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.

H_2O

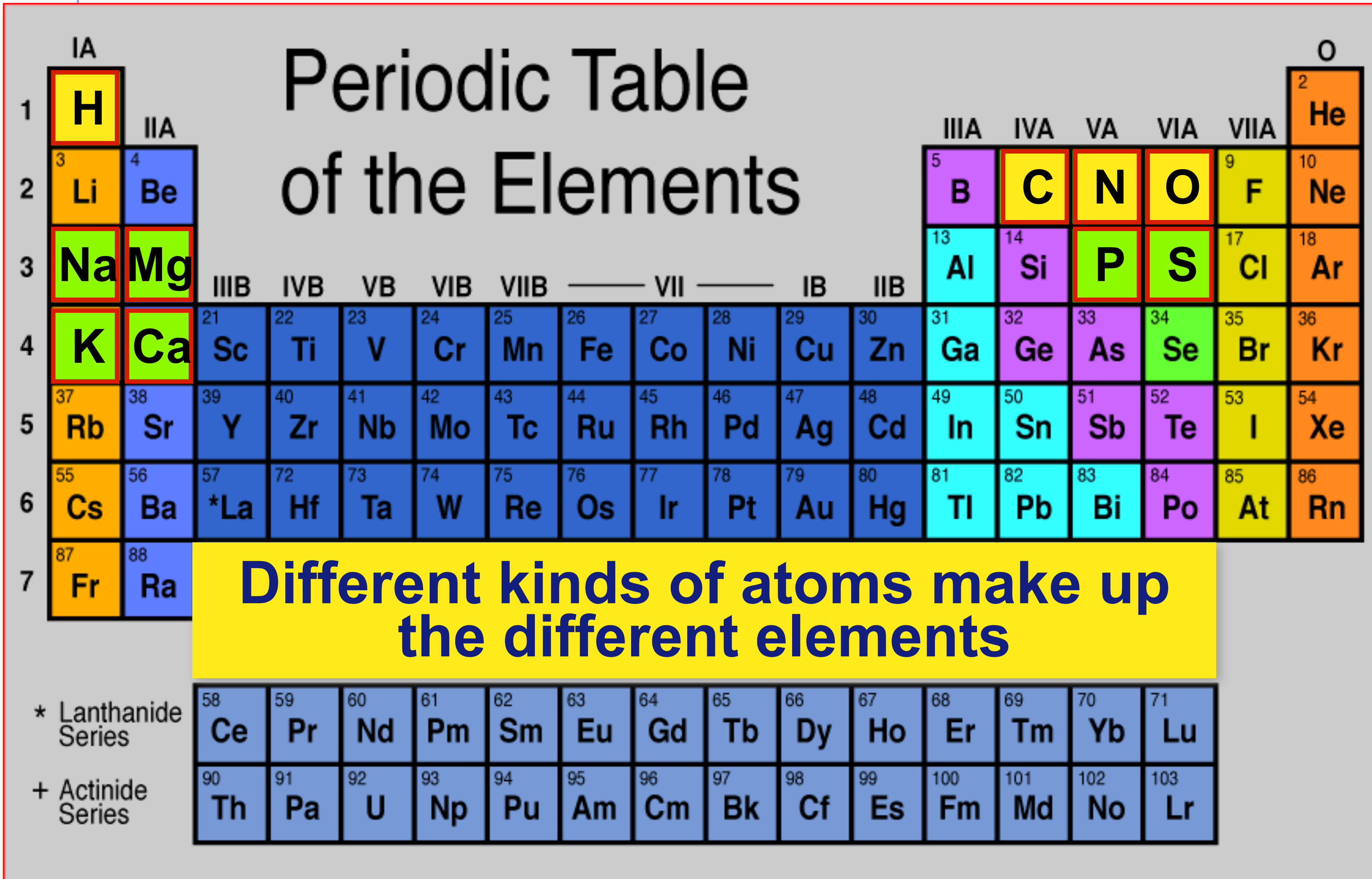
Water

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

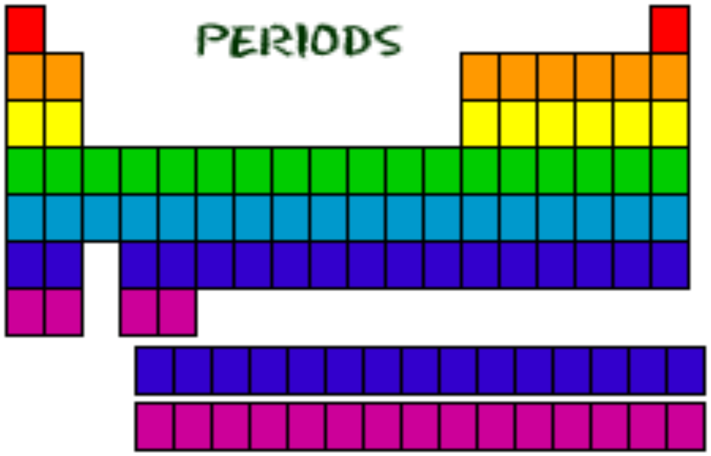
Element Symbols are Arranged Into the Periodic Table



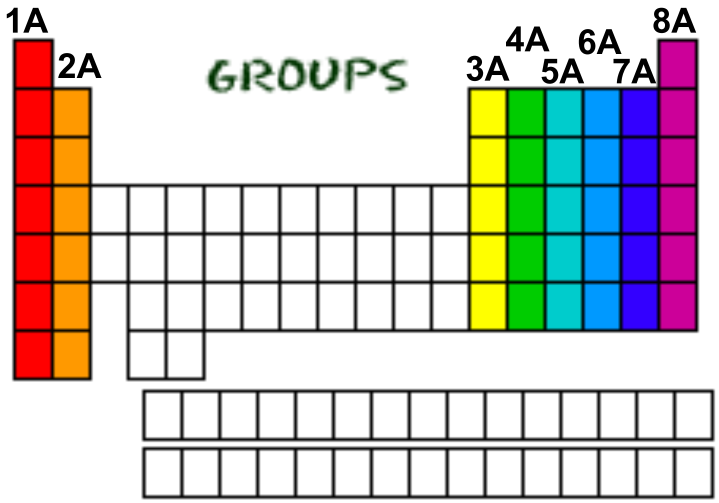
Different kinds of atoms make up the different elements

Matter is made of one or more elements

- Elements are placed on a grid with 7 horizontal rows called PERIODS.

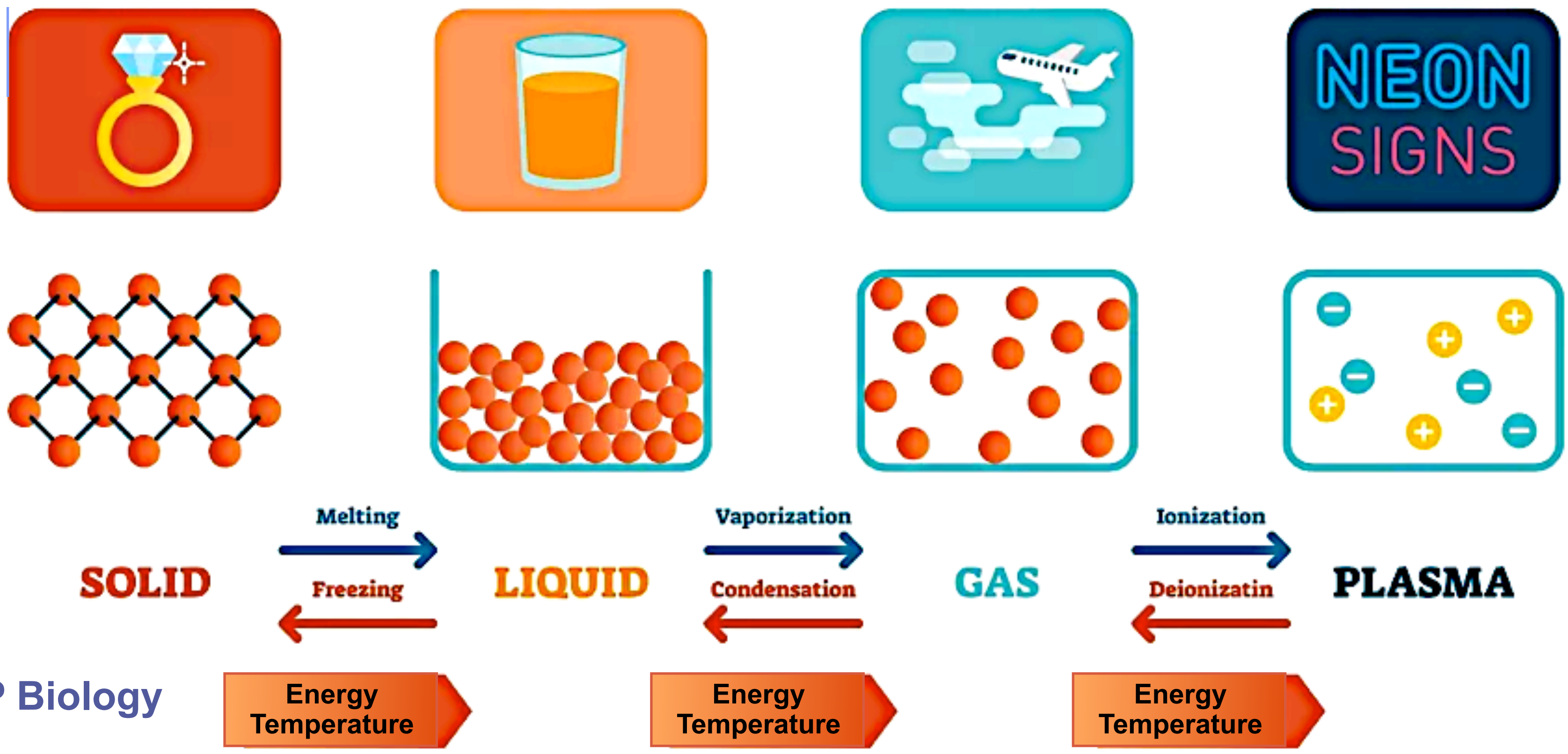


- There are also vertical columns called GROUPS.
  - The colored groups are groups 1A, 2A, 3A, 4A, 5A, 6A, 7A, and 8A and are referred to as the MAIN GROUPS.

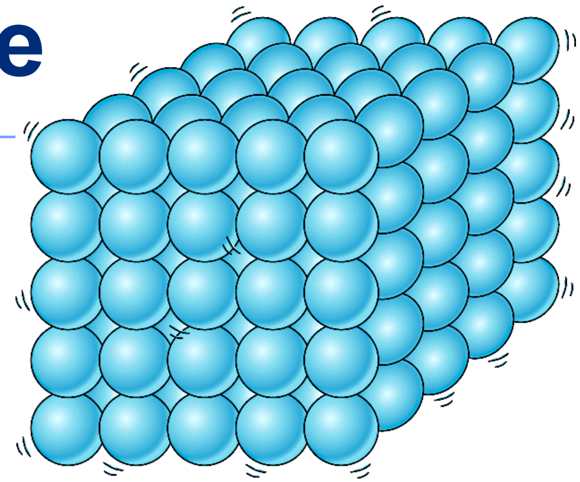


Matter is made of one or more elements

- **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



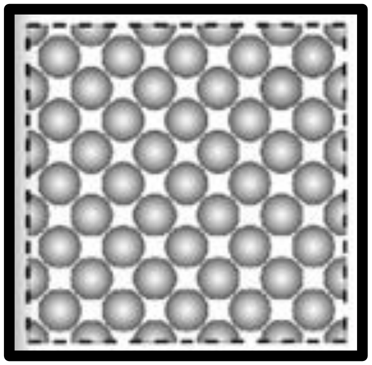
The Solid Phase



1. High density
2. Hard to expand or compress
3. Rigid shape
4. Fixed volume
5. Particles that make up a solid are often tightly packed <u>or</u> 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

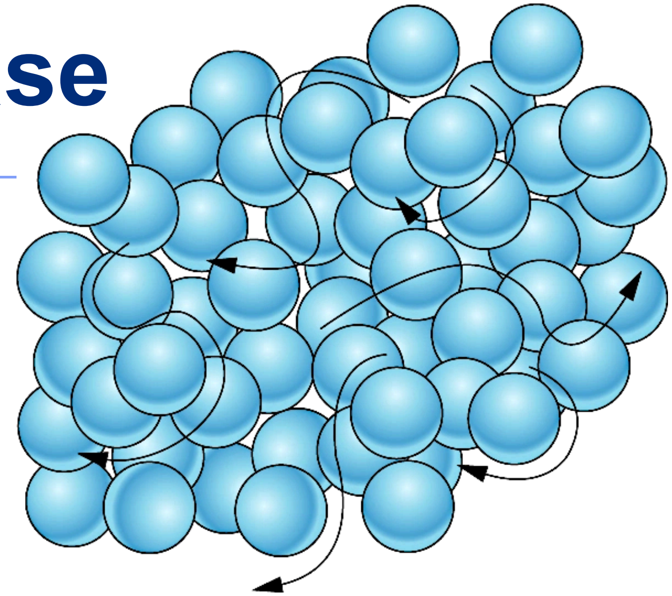
EXAMPLE: Sugar Cube ($C_{12}H_{22}O_{11}$)

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 slides 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)

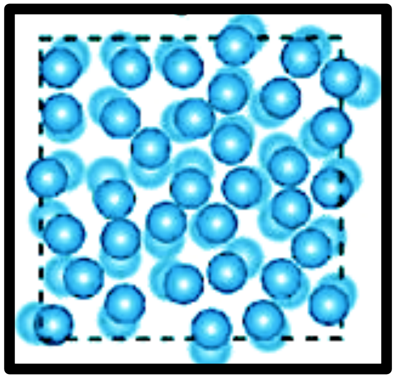
The Liquid Phase



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**

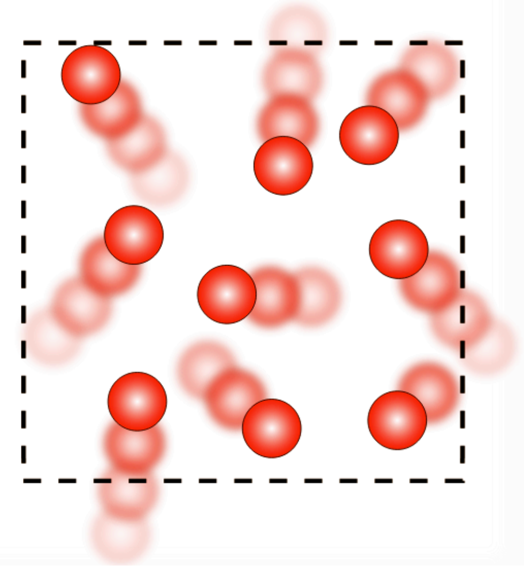
EXAMPLE: LIQUID WATER ($H_2$0)

The Liquid Phase



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

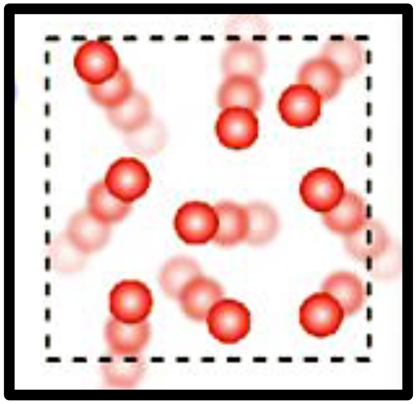
The Gas Phase



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.

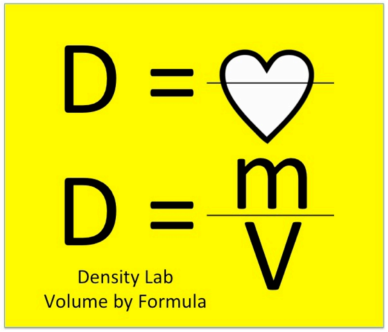
EXAMPLE: STEAM or WATER VAPOR (H_20)

The Gas Phase



- **Particles in a gas move <u>far away</u> from one another since the high amount of thermal energy in the system <u>prevents</u> the weak intermolecular attractions between particles from holding the particles close together.**
  1. **Because there is <u>a high amount of thermal energy (compared to the amount in the liquid version of this substance)</u>, there exists a lot of vigorous random motion of now fast moving particles in the system, allowing the particles to move far apart and <u>fully overcome the weak intermolecular forces</u> 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, <u>too far for weak intermolecular forces of attraction to have a significant effect</u>.**
  3. **Without the intermolecular forces being able to hold particles together in the presence of the high thermal energy, <u>particles spread apart into any empty space, filling the volume of the container they are in.</u>**

Density



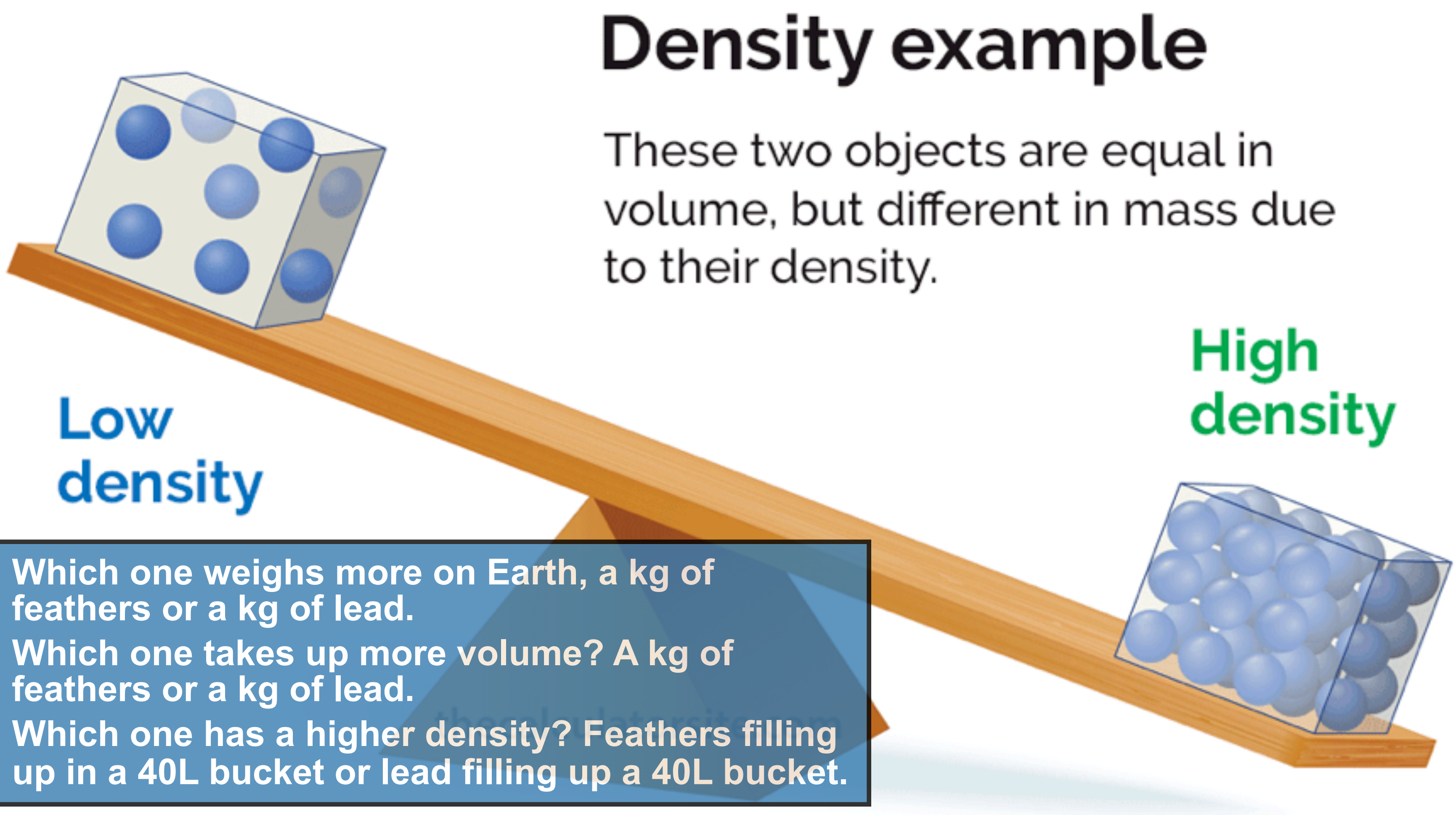
- The **density** of an object equals its total mass divided by its total volume.
  - Generally, solids of a substance are more dense than liquids of that substance and liquids of a substance are more dense than gases of that substance.
    - Units of density relate mass to volume such grams per cubic centimeter (g/cm^3) or grams per cubic milliliter (g/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.

density, mass, volume:

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

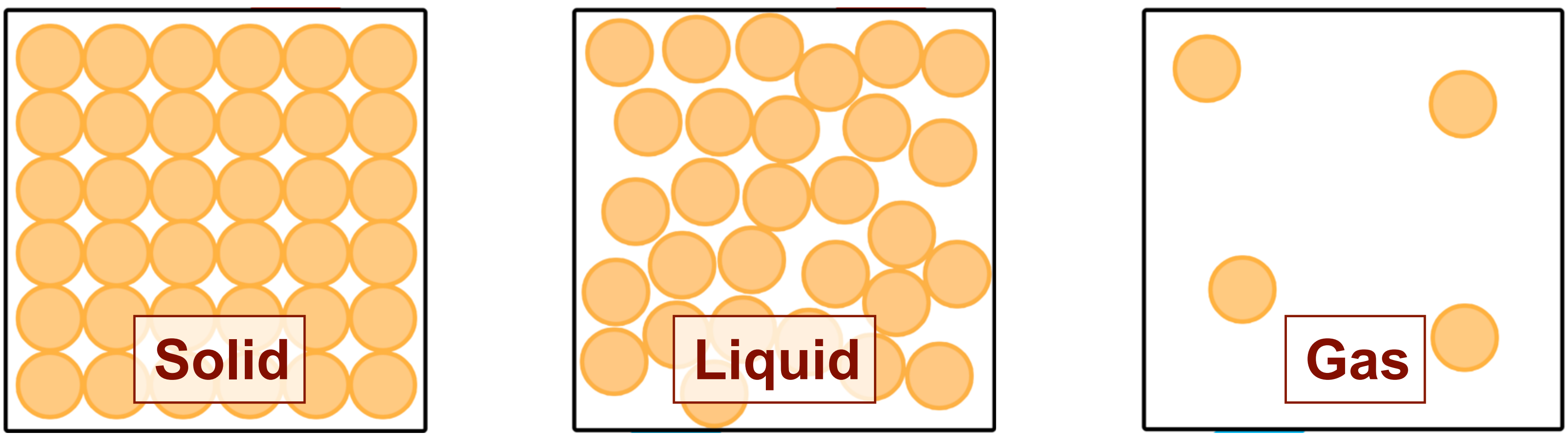
If volumes are equal, a more dense object will contain more mass than a less dense substance .



- Which one weighs more on Earth, a kg of feathers or a kg of lead.
- Which one takes up more volume? A kg of feathers or a kg of lead.
- Which one has a higher density? Feathers filling up in a 40L bucket or lead filling up a 40L bucket.

Changes in the Density of Solids, Liquids, & Gases

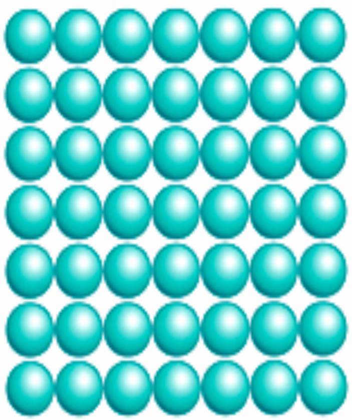
- **Let's say we have three cubes of equal volume filled with the same substance in three different phases of matter: solid, liquid, and gas.**
  - **In general, in solid form, more particles of a certain substance would fit into that cube's volume compared to what would fit if that substance was in 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

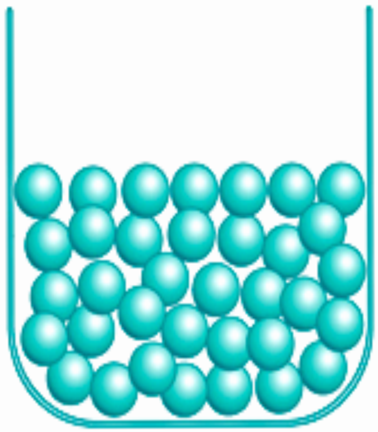
decreasing thermal energy ←

increasing thermal energy →



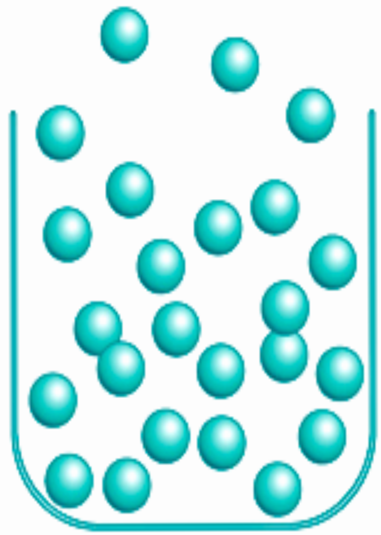
Solid

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.



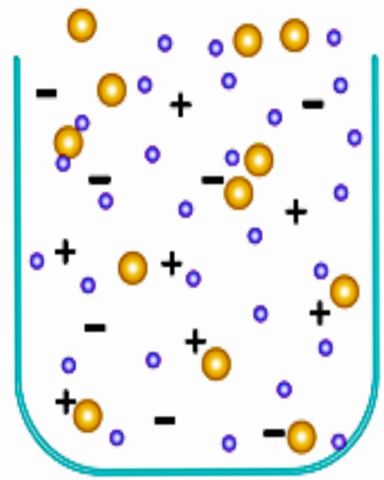
Liquid

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.

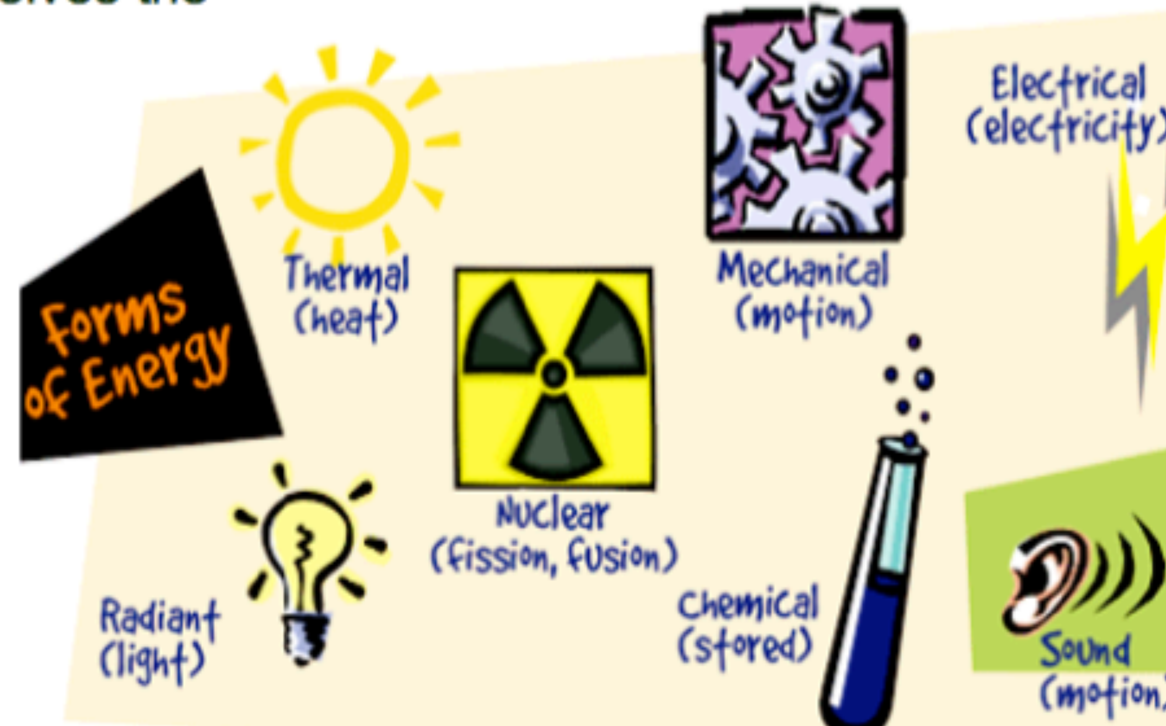
Energy is found and stored in different forms such as an object's position, light, heat, sound, motion etc...

Everything in the world involves the exchange of energy.

One form can be changed to another.

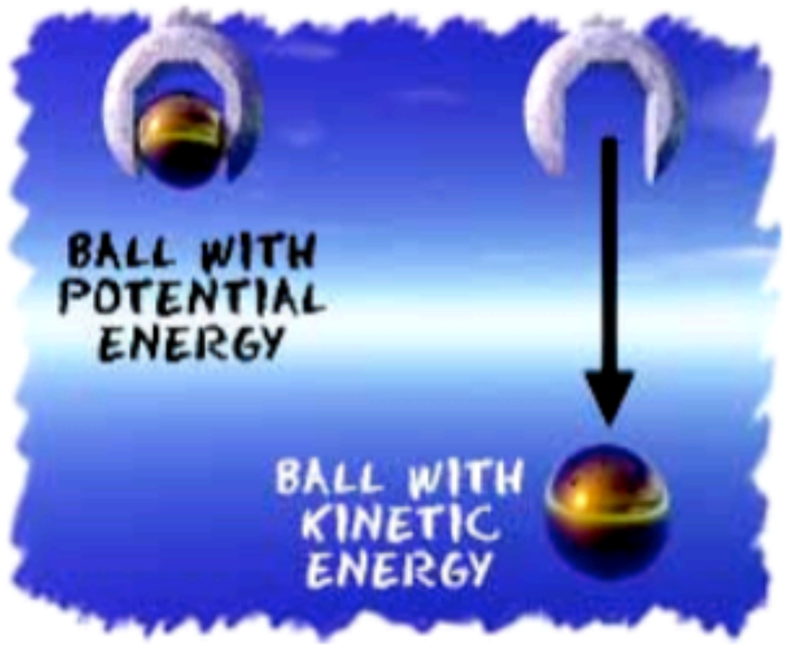
Forms of Energy:

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.

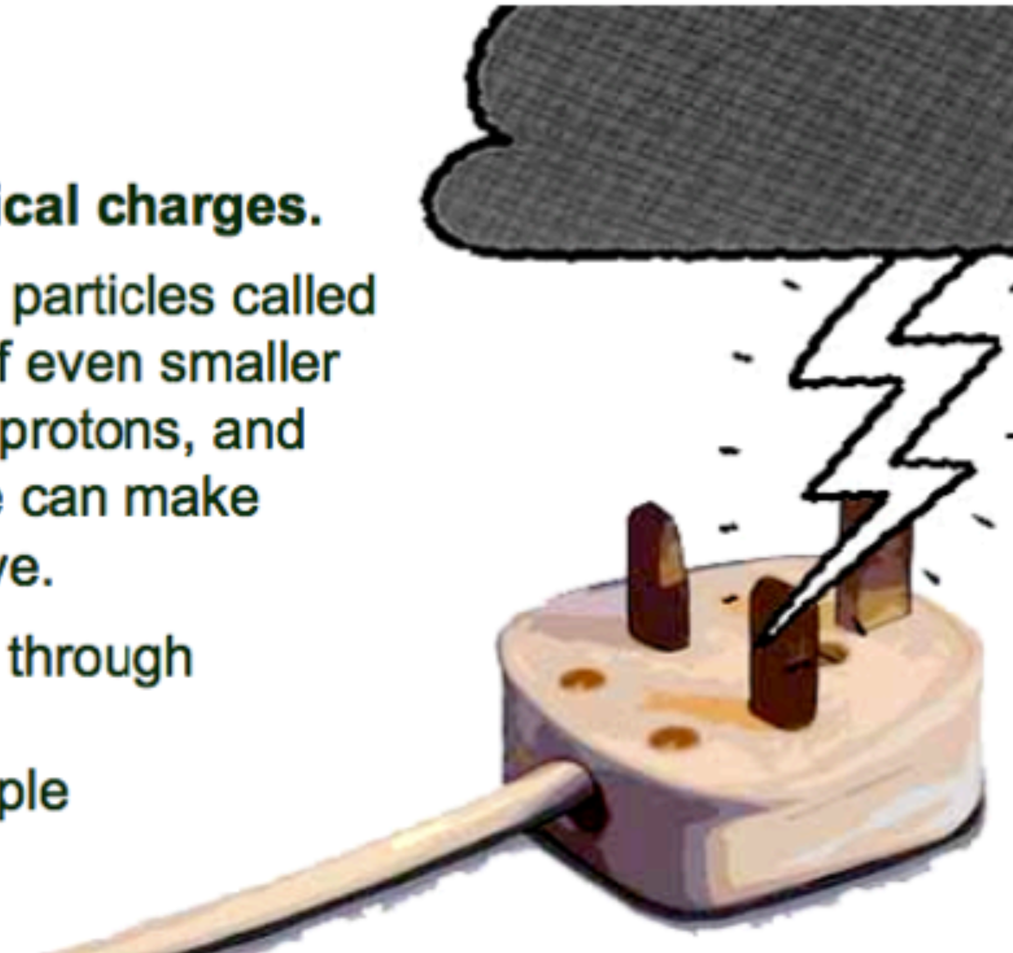
KINETIC ENERGY: Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.

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.



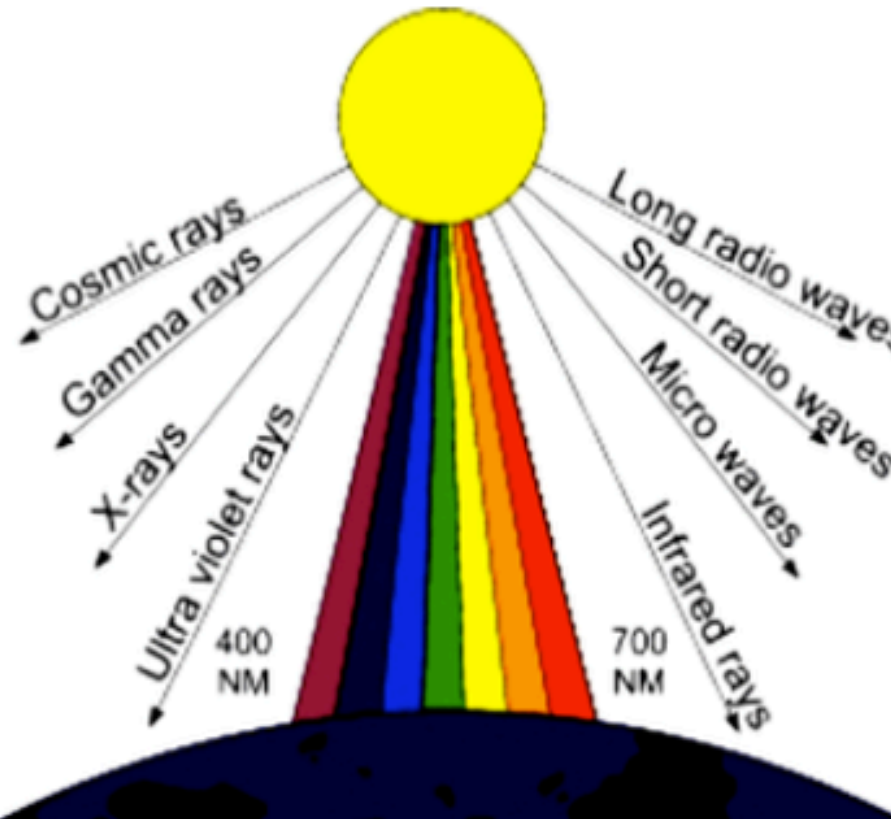
KINETIC ENERGY: Energy of Motion — Motion of waves, electrons, atoms, molecules, substances, and objects.

2. Radiant Energy:

Electromagnetic energy that travels in transverse waves

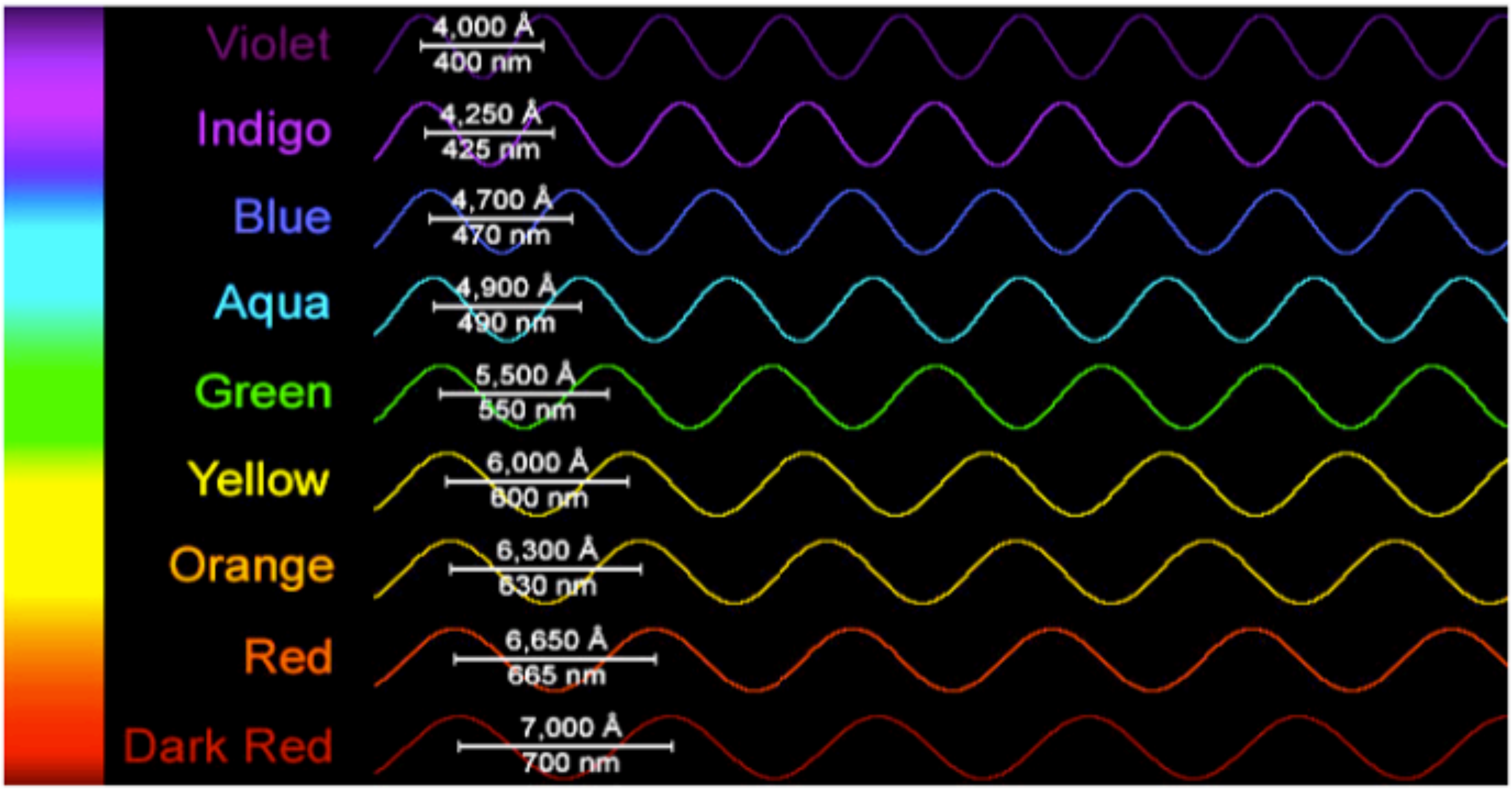
Radiant energy includes visible light, x-rays, gamma rays and radio waves.

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

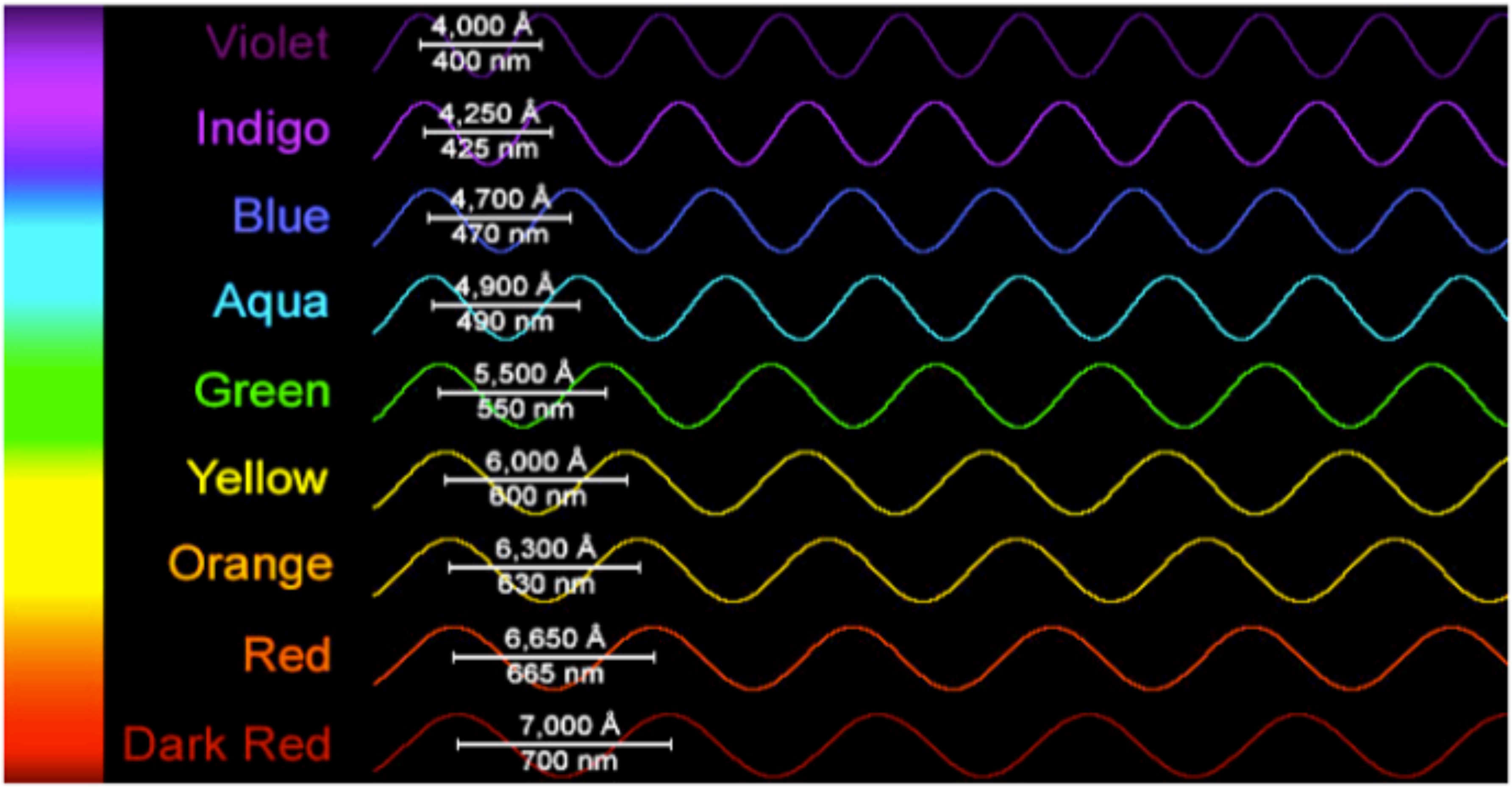


Light travels as waves of energy!

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



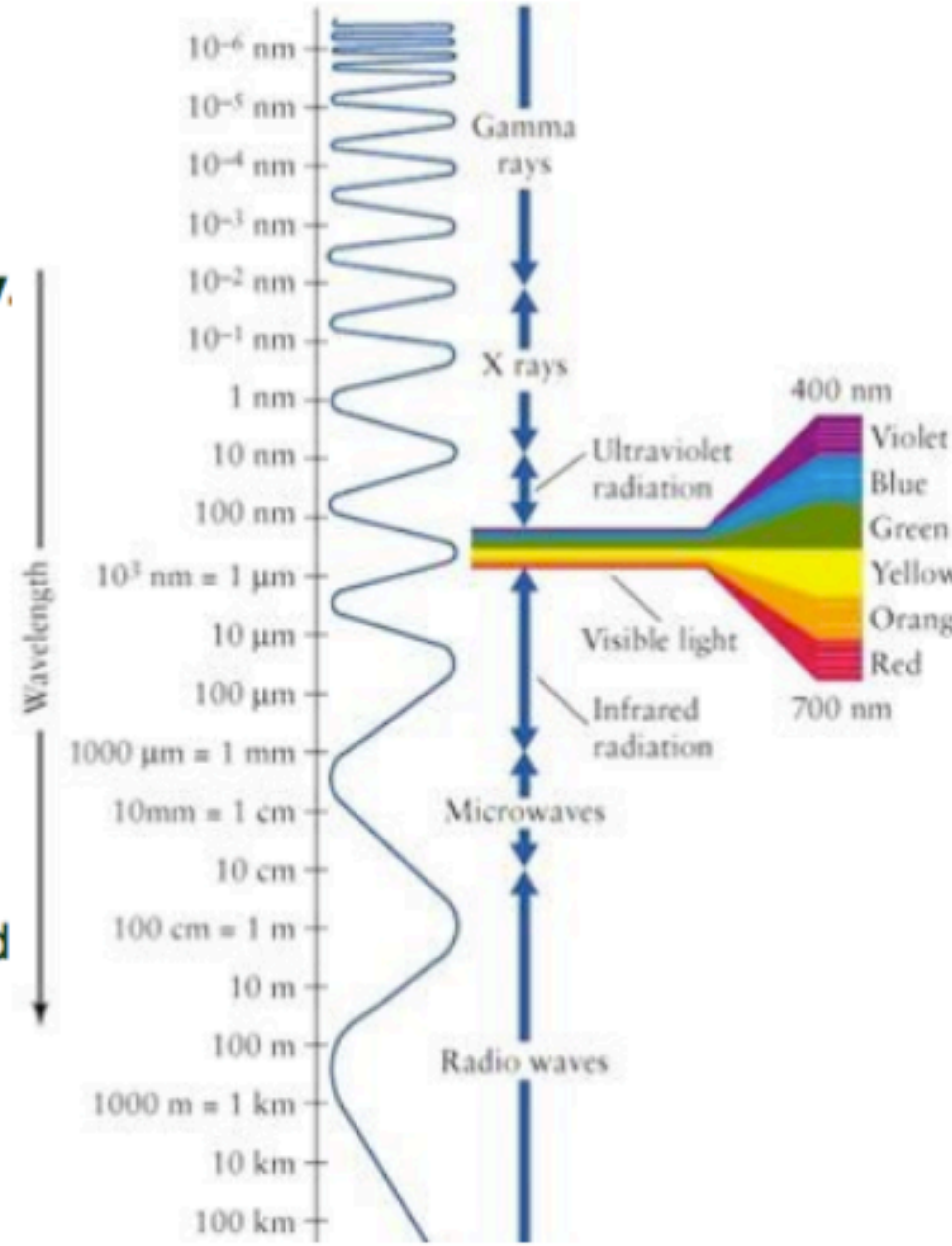
FREQUENCY: A measure of the number of occurrences of a repeating event per unit time. Here, it refers to how often the wave moves up in or down in a set period. Frequency increases as we move toward purple light and decreases as we move toward red light.



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

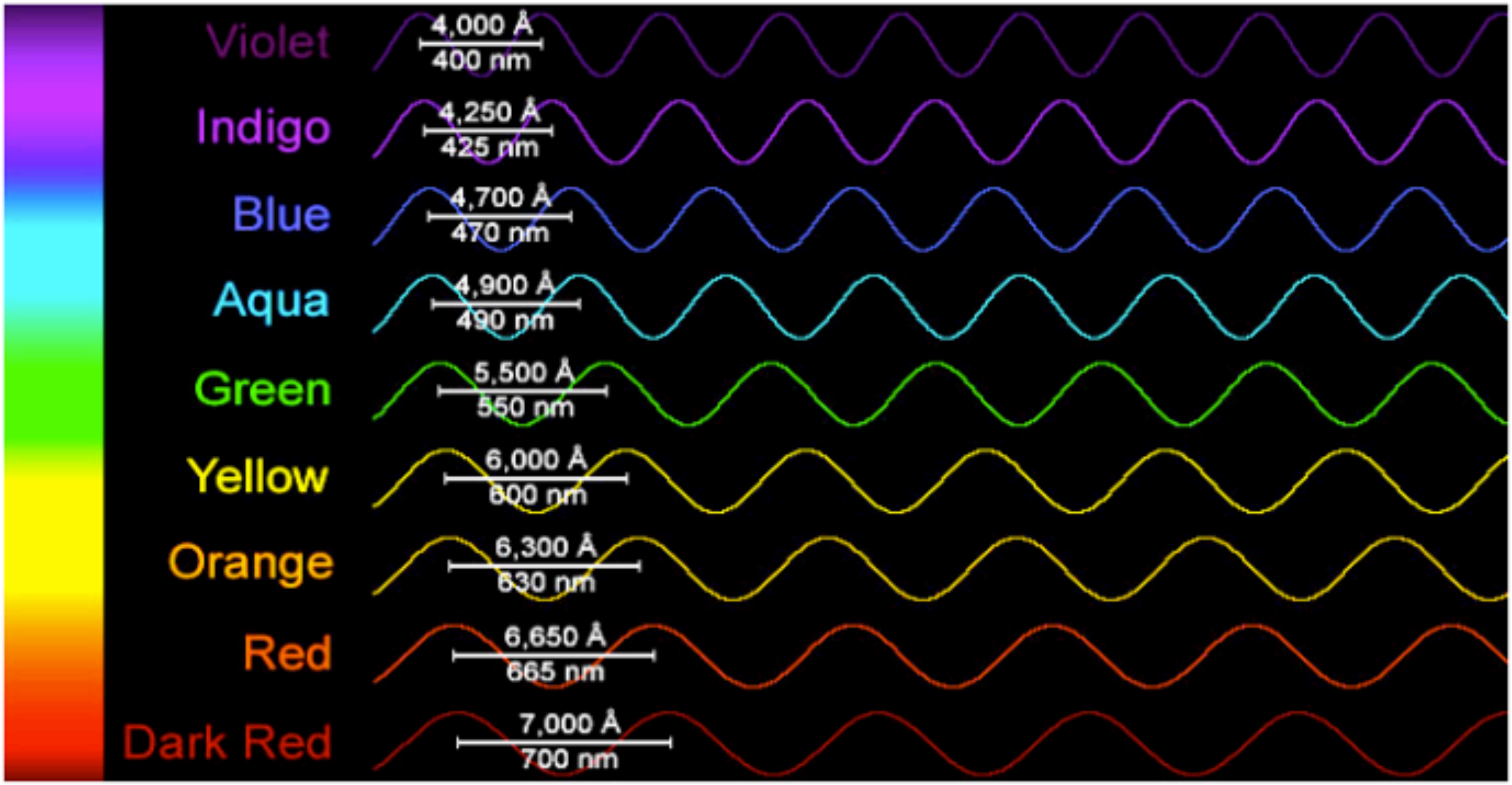
The EM extends from below the frequencies used for modern radio (at the long-wavelength end) through gamma radiation (at the short-wavelength end).

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.



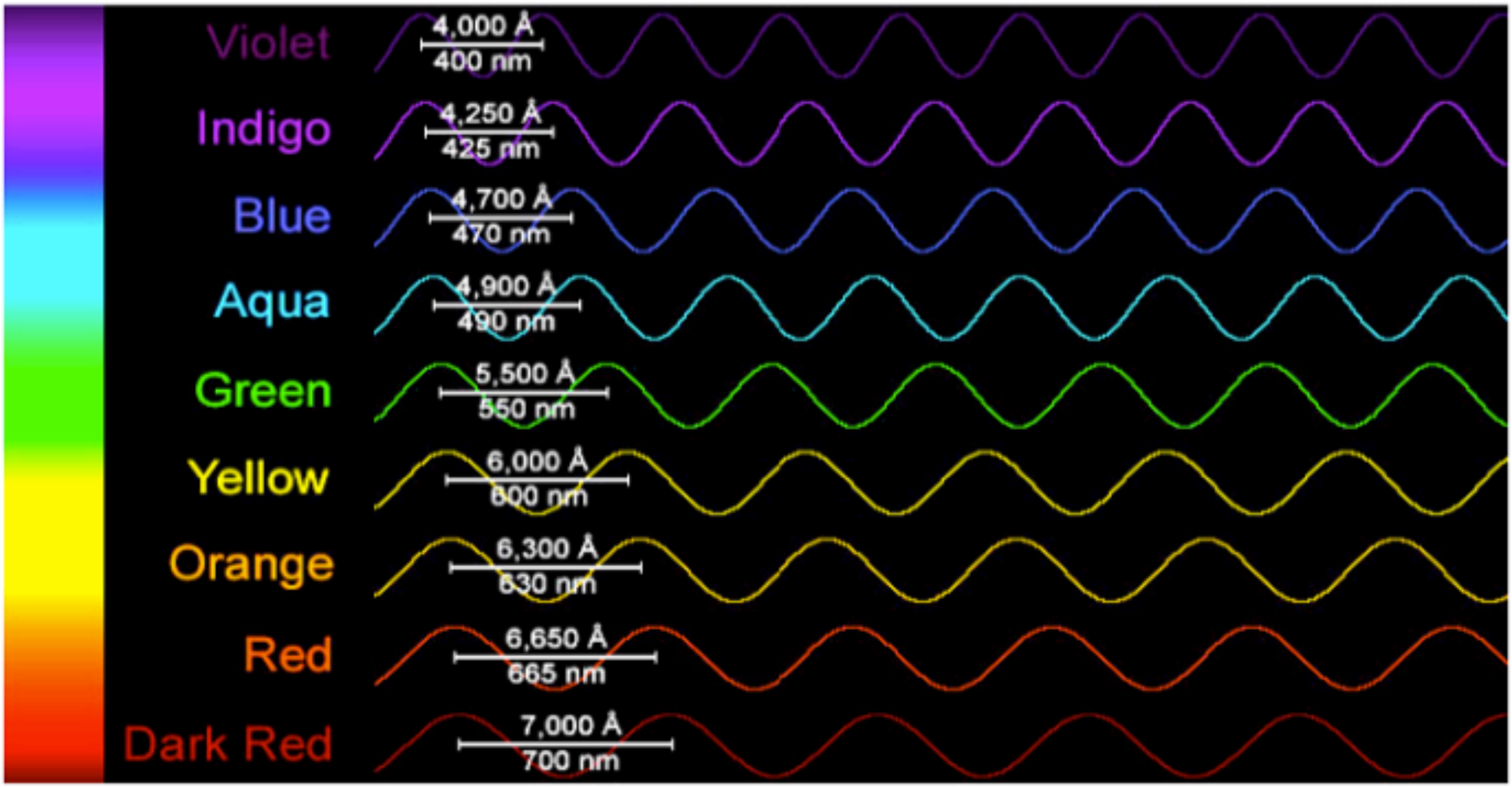
Different colors of light have different wavelengths and frequencies!

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.

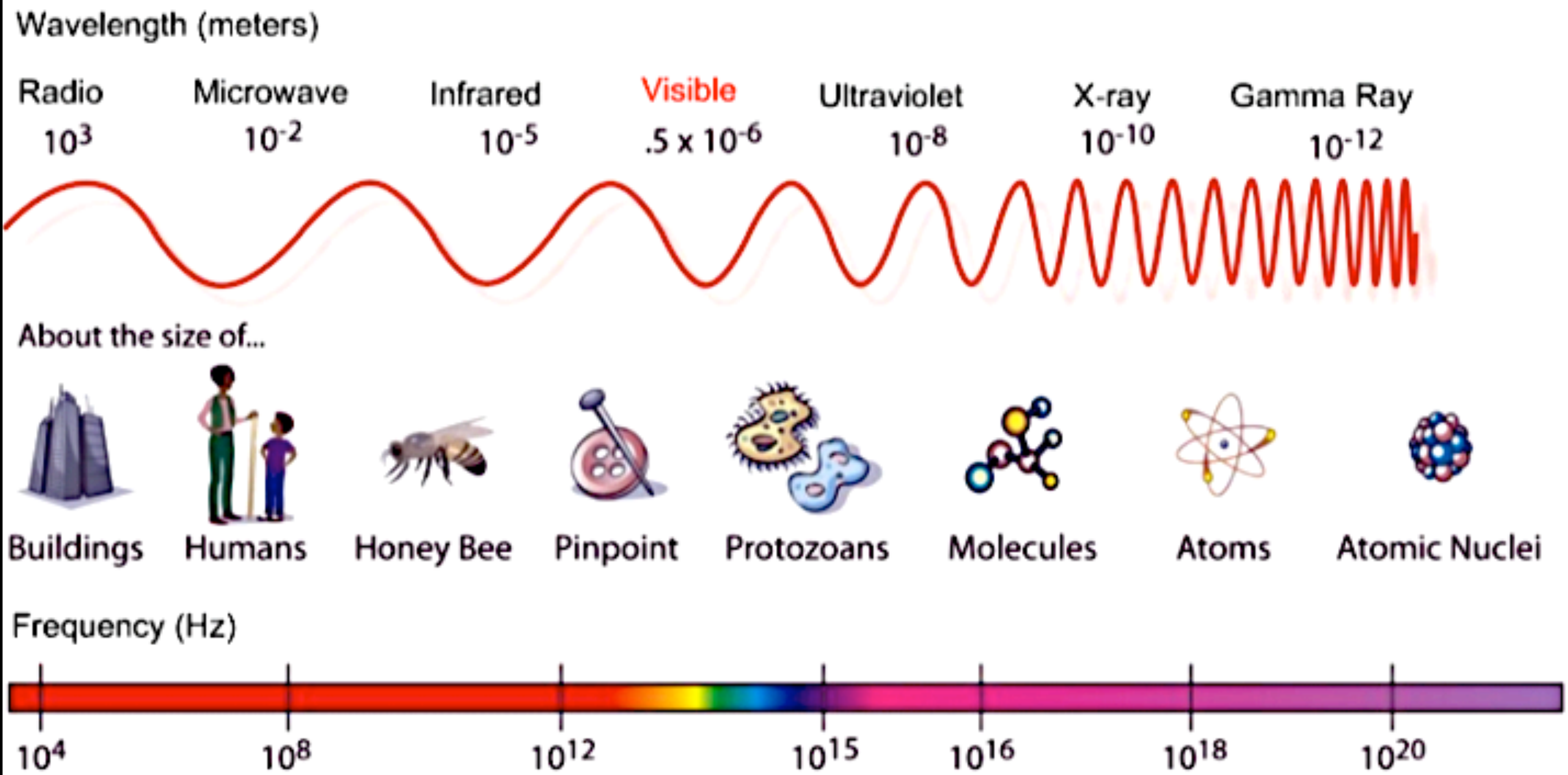


Different colors of light have different wavelengths and frequencies!

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.

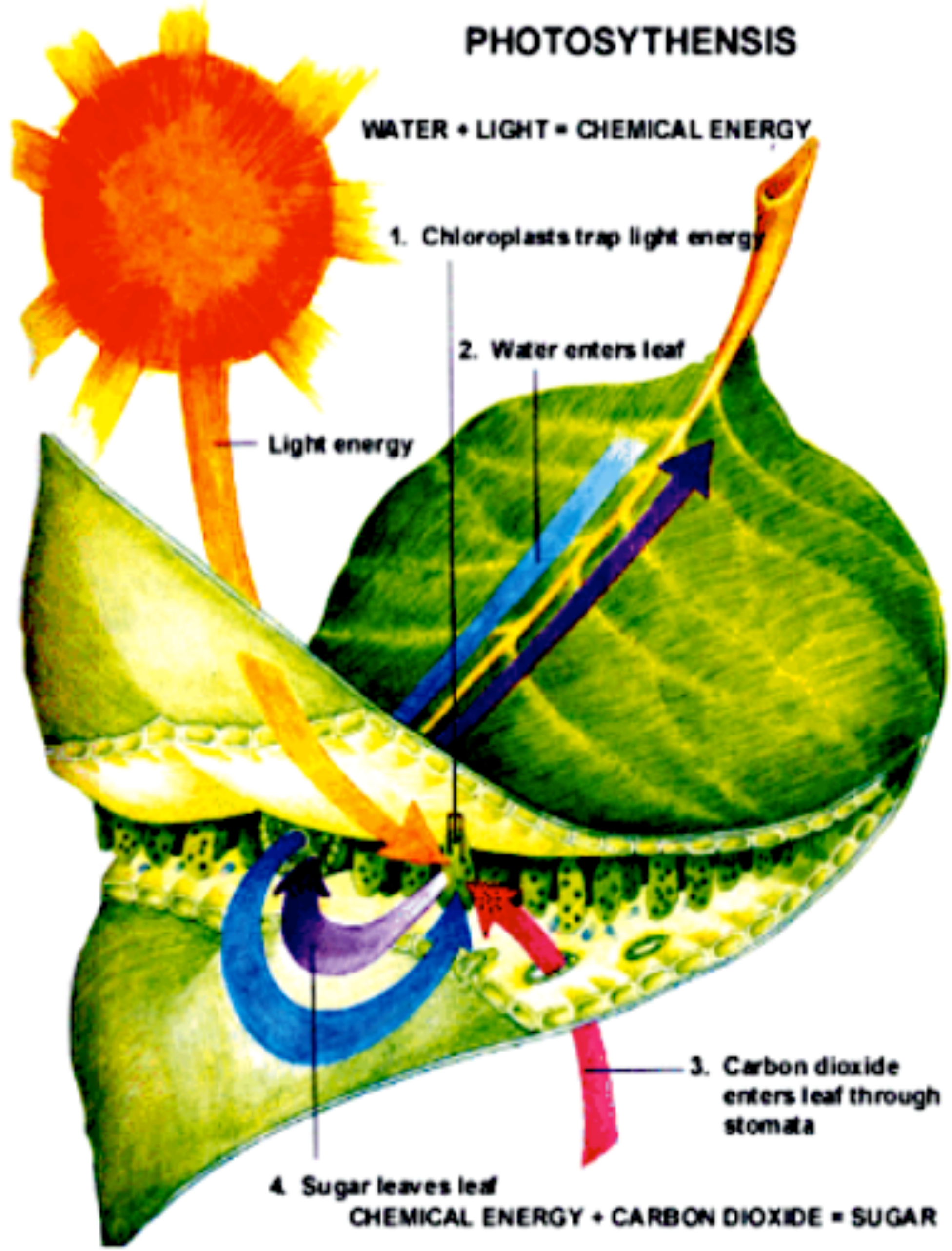


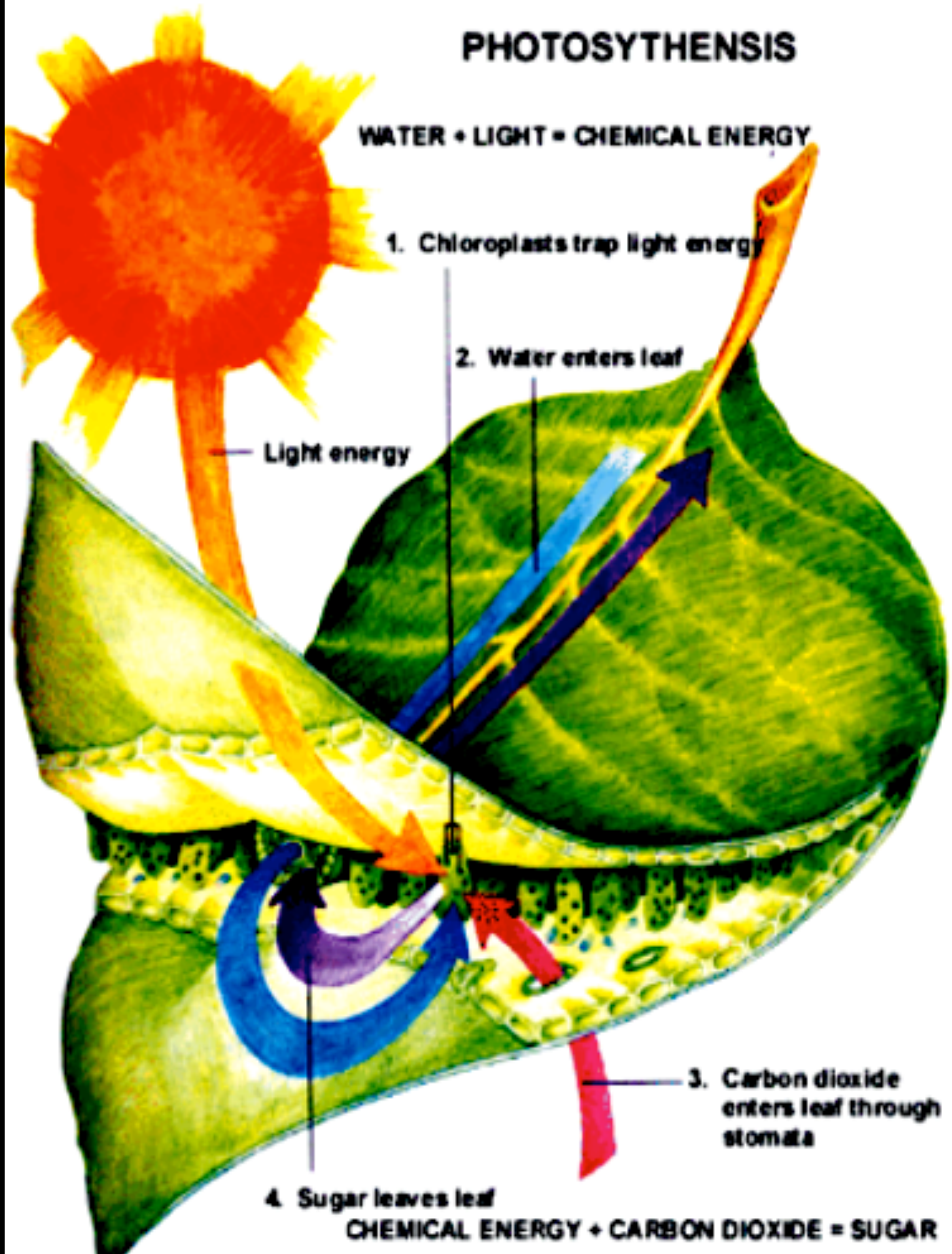
Electromagnetic waves with wavelengths below 400 nm are in the ultraviolet (UV) portion of the electromagnetic spectrum, while waves longer than 700 nm are in the infrared (IR) region of the spectrum.



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

Using the radiant energy from the sun (EM radiation), certain plants, algea, and bacteria convert CO_2 and H_2O into Oxygen (O_2) and energy-containing carbohydrates such as sucrose, glucose, and starch.





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 (organims 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.

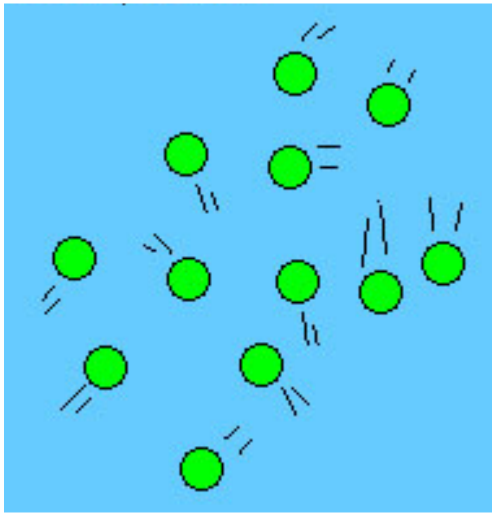
(Plants absorb light primarily using the pigment ***chlorophyll*** which does not absorb green light, reflecting it back to our eyes instead which is the reason that most plants have a green color.)

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.

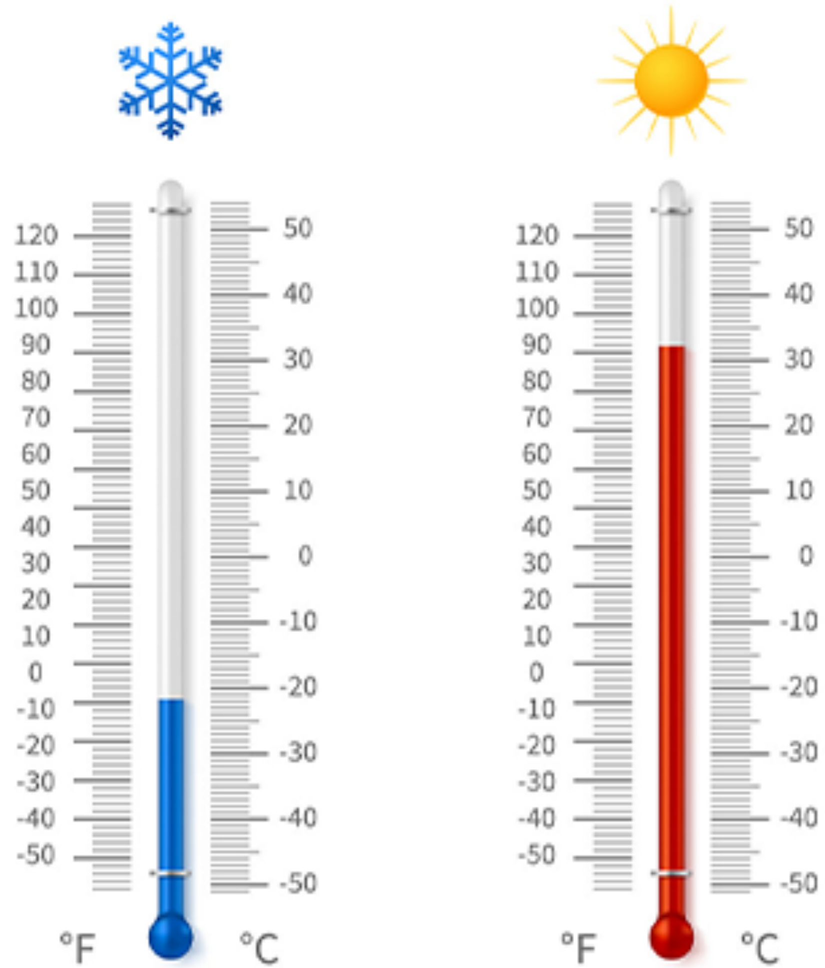


As thermal energy increases, atoms vibrate or move faster. This energy is needed to overcome the molecular interactions that hold matter together allowing matter to undergo a phase change into a more disorganized state.

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.

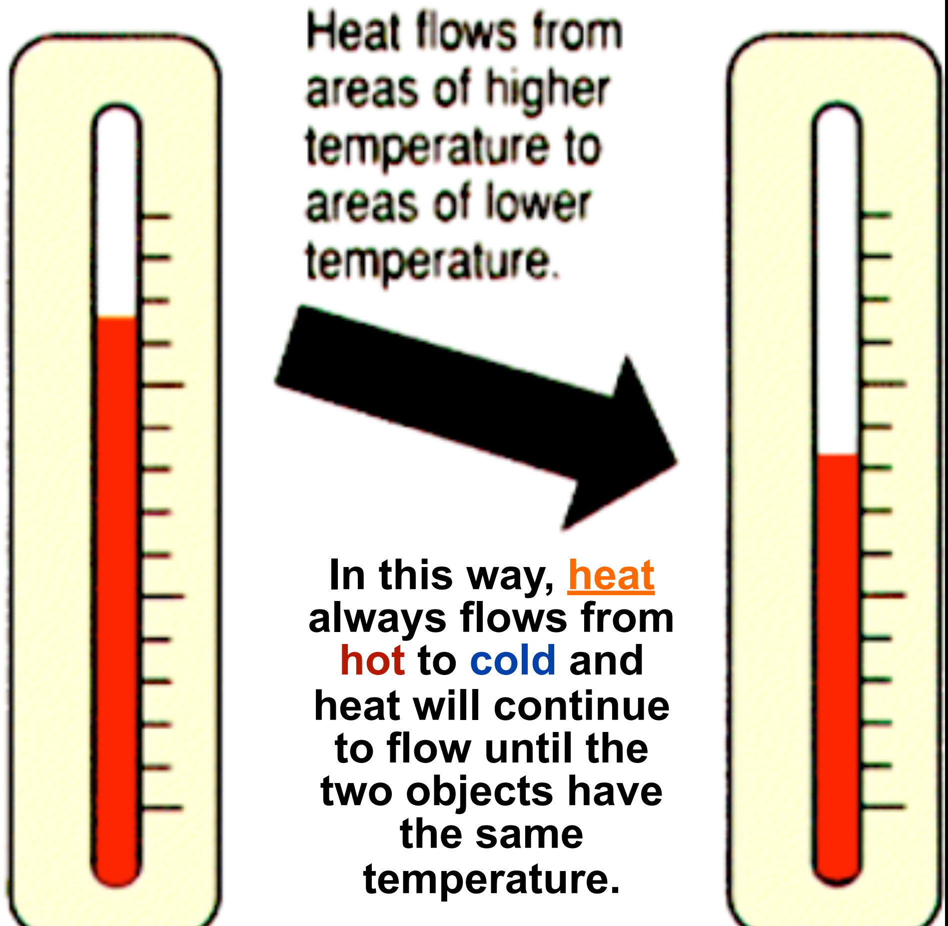
- If an object was composed of exactly three molecules and the kinetic energies of the three molecules are 50 J, 70 J, and 90 J, the total Thermal Energy would be 210 J and the temperature would be 70 J.



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.

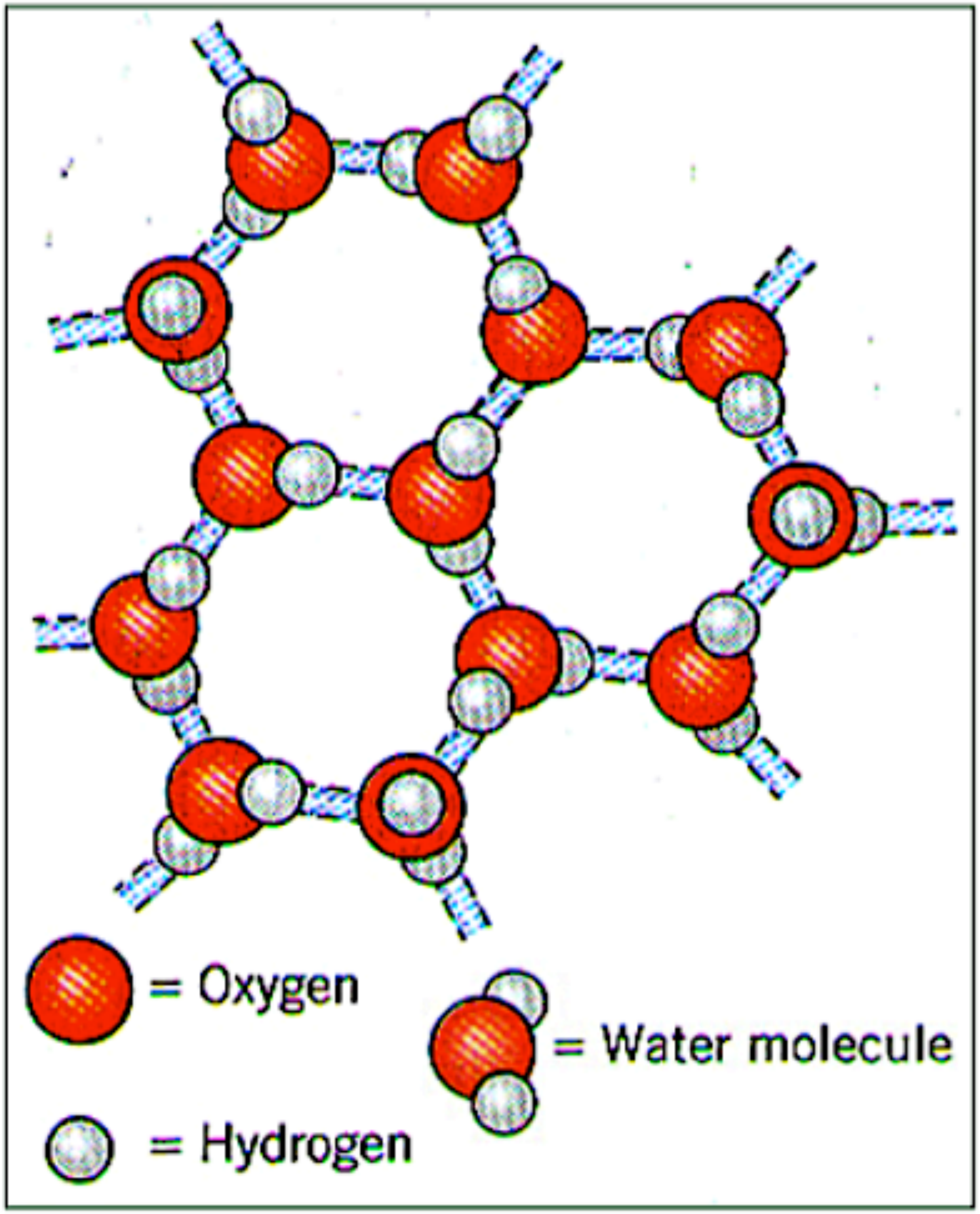
- When a hot substance and a cold substance touch, the molecules of the objects collide along the surface where they touch. When molecules with higher kinetic energy collide with molecules with lower kinetic energy, kinetic energy is passed from the molecules with more kinetic energy to those with less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



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.

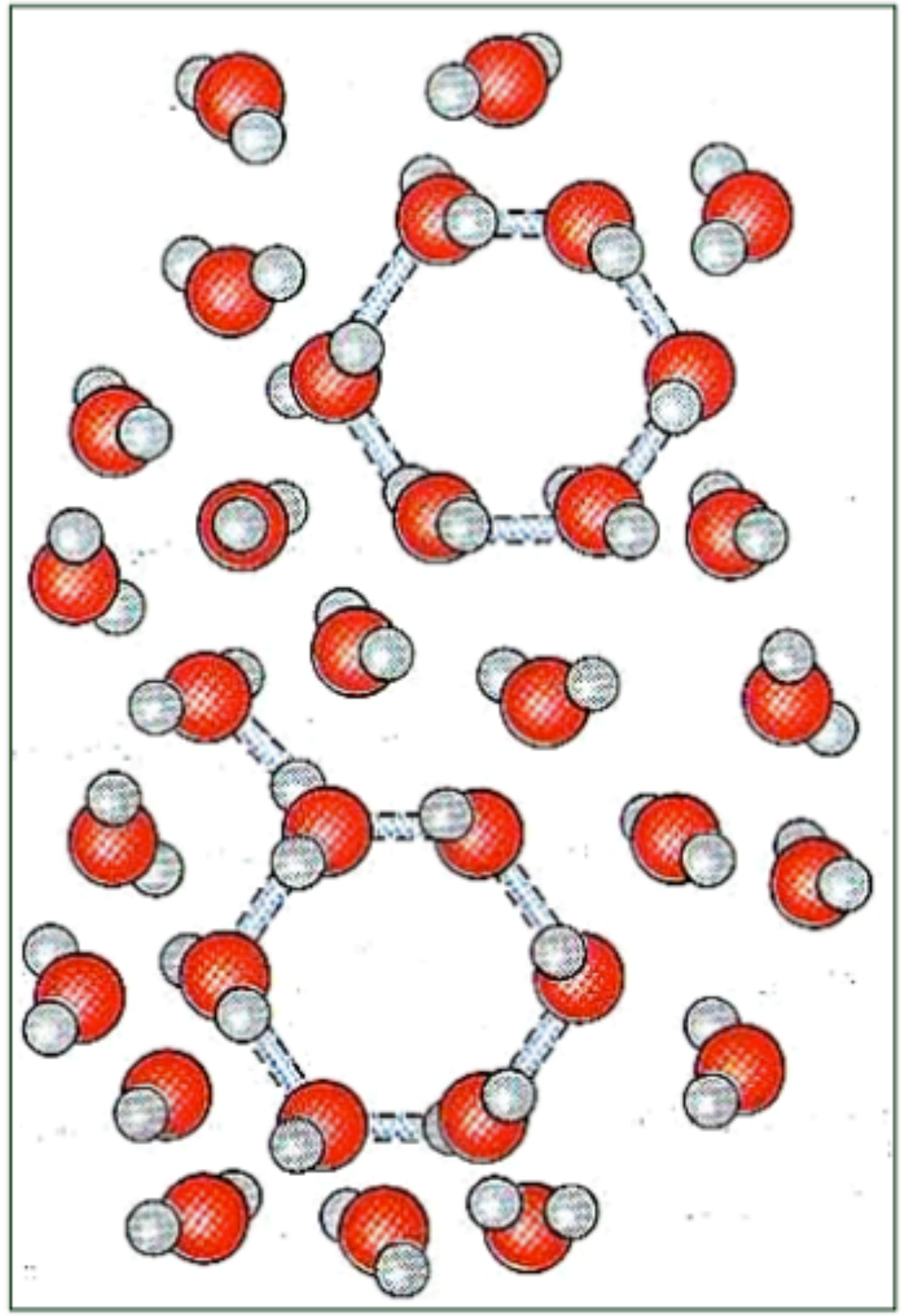
Consider a block of ice being warmed by an external heat source. Although the ice molecules contain some heat energy, their vibrations are not sufficiently energetic to overcome the interactions between neighboring H_2O molecules that hold them together in a solid structure made up of hexagonal crystals.



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

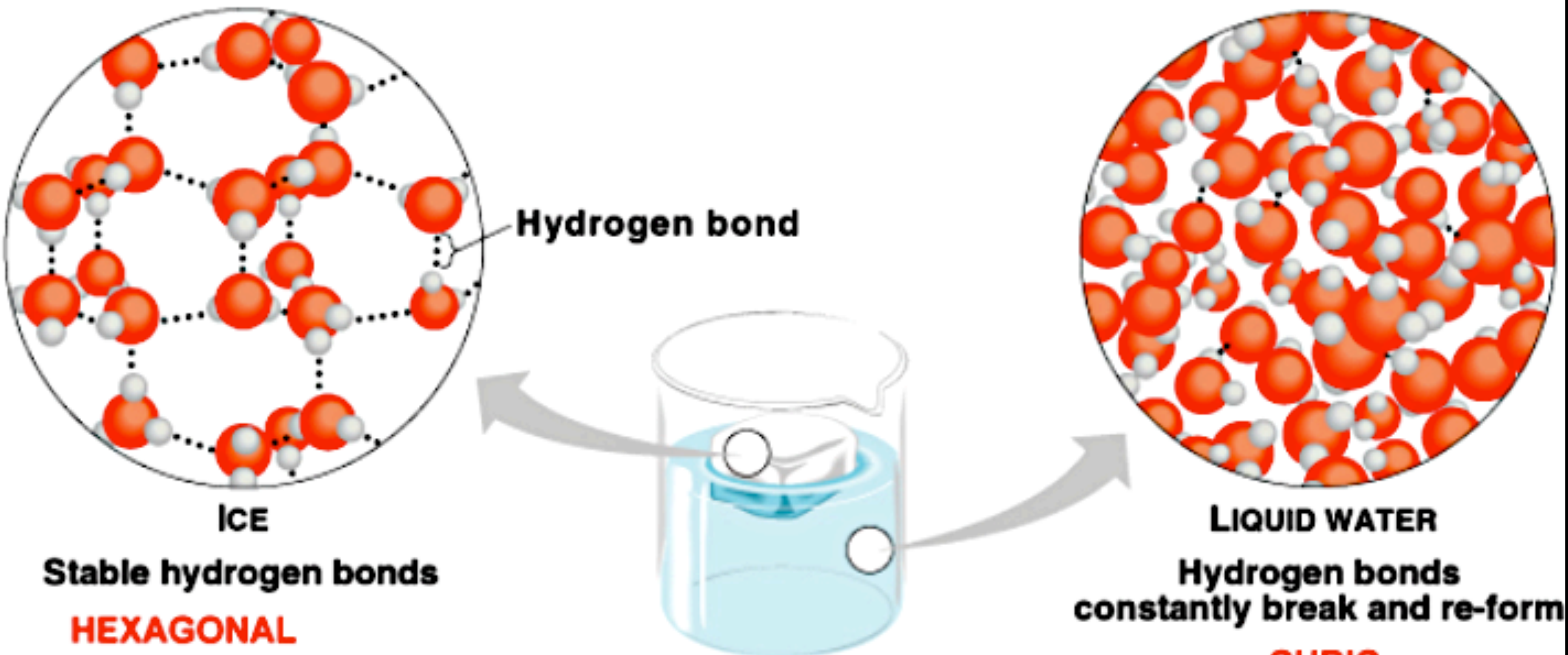
When its temperature reaches 0°C, the ice begins to melt because the molecules now have enough vibrational energy to overcome some of the forces holding together the atoms in a solid structure.

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



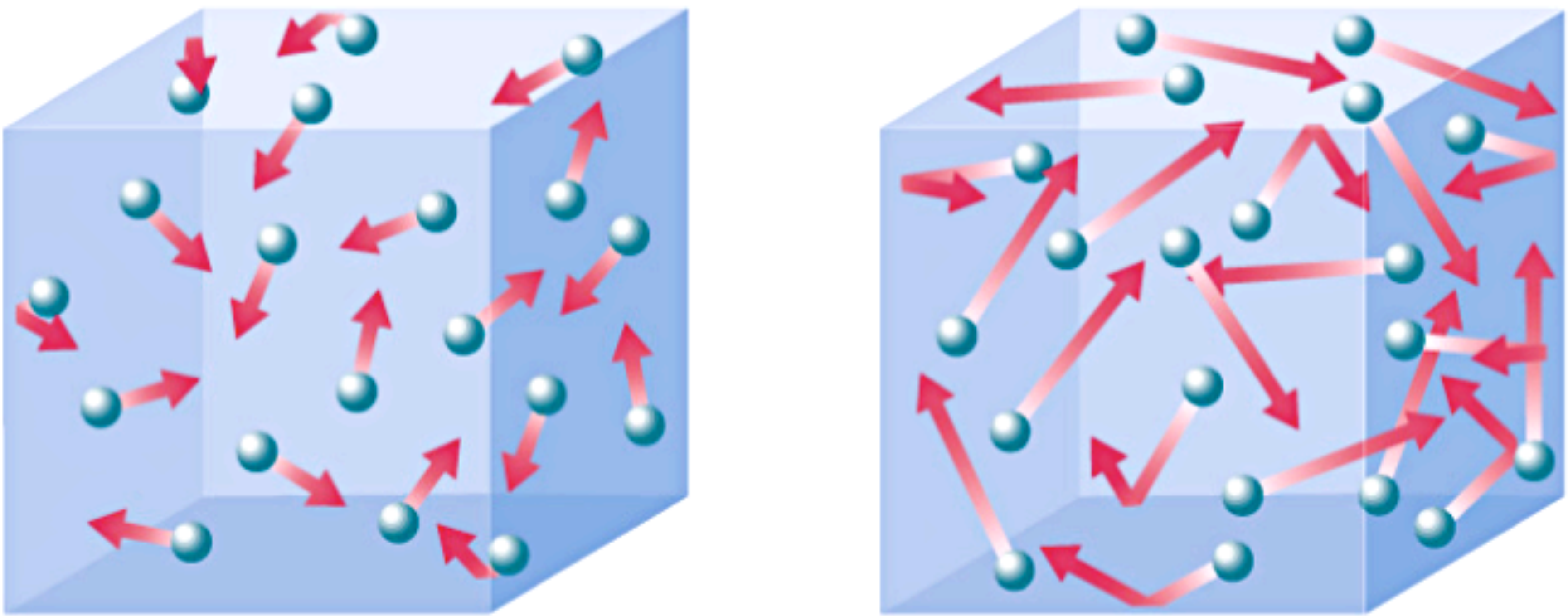
Finally the solid structure completely breaks down into a more loosely connected liquid state. This process is called **MELTING**.

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.

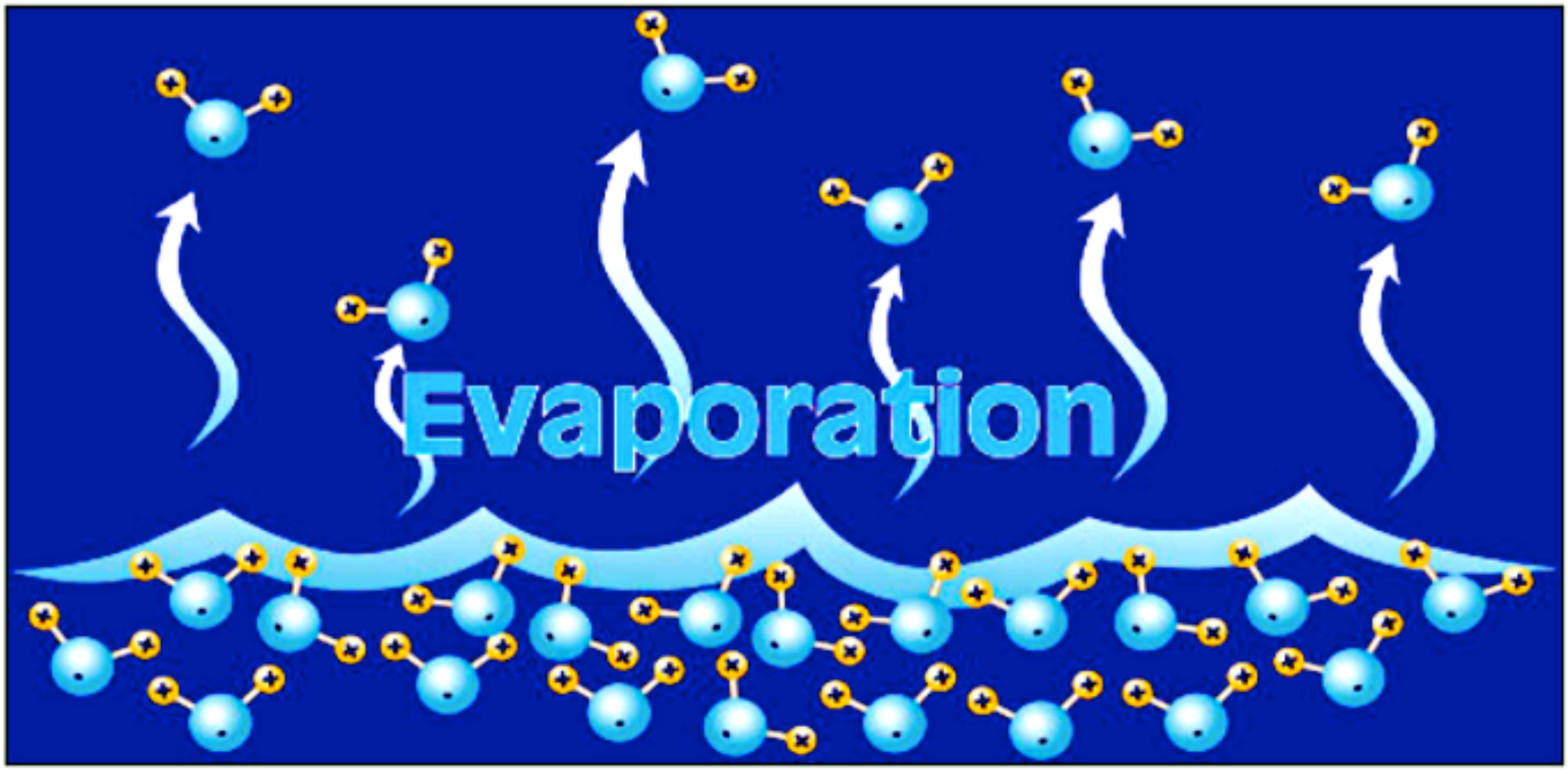
Note that the TEMPERATURE at any given time represents the average speed of random molecular motion; some individual molecules move faster and some move slower.



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.

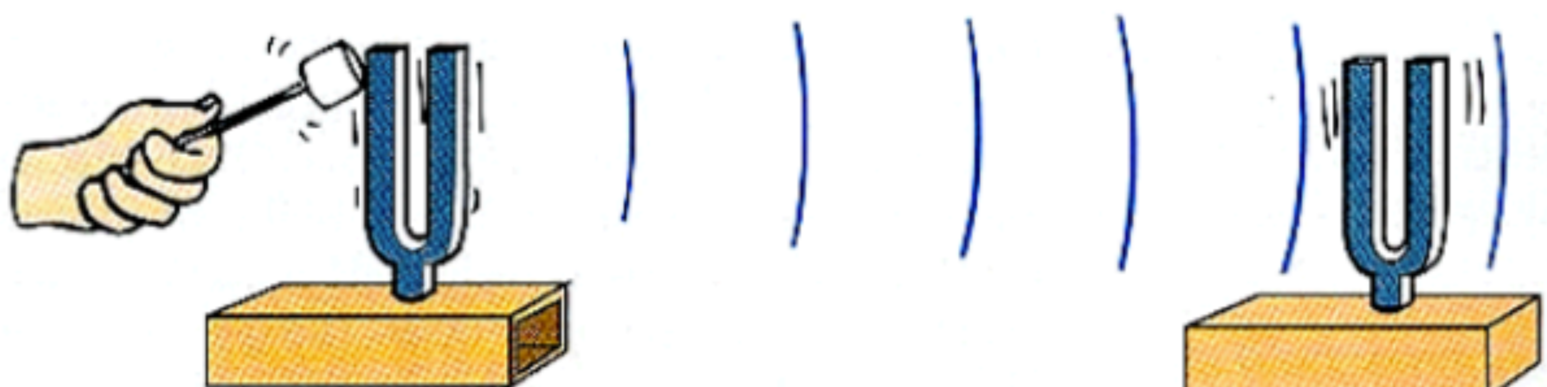
Wind is an example of motion energy.

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.

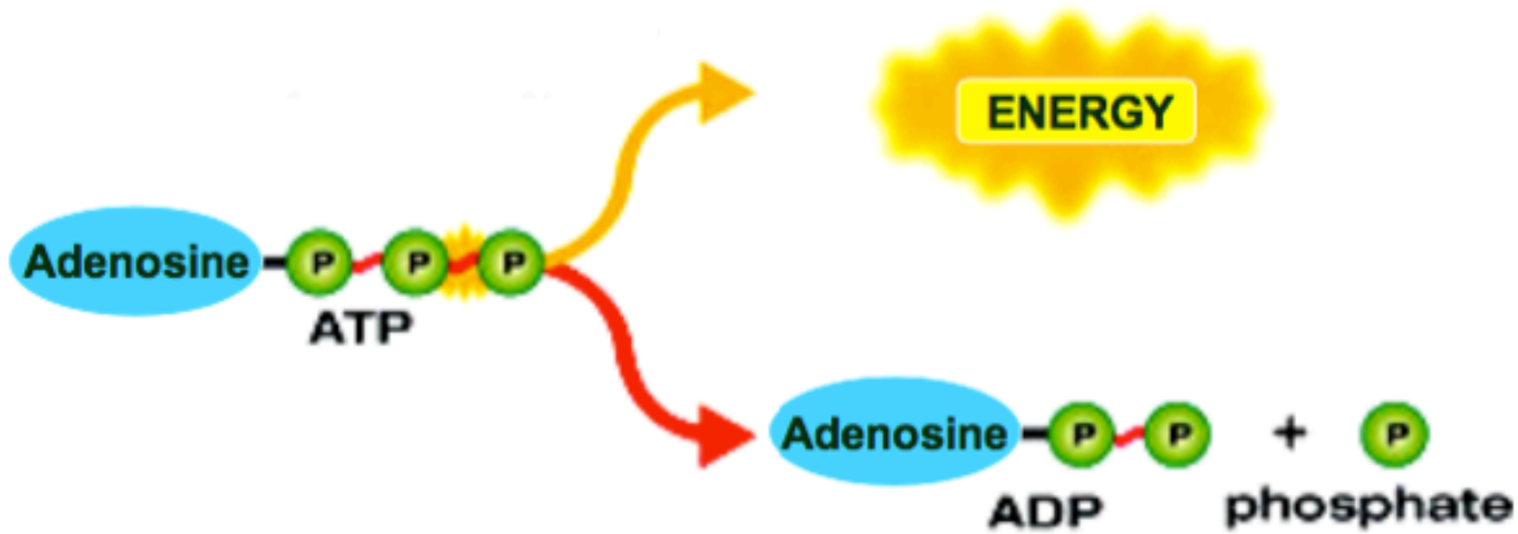


POTENTIAL ENERGY: stored energy and the energy of position

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

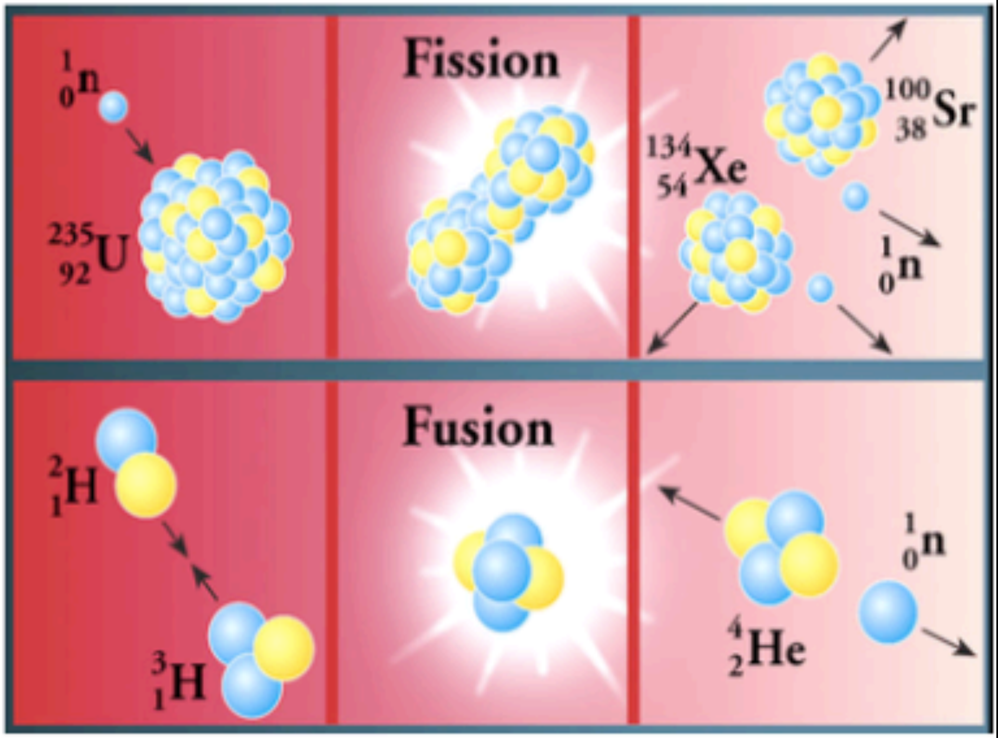
3. Nuclear Energy:

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**.



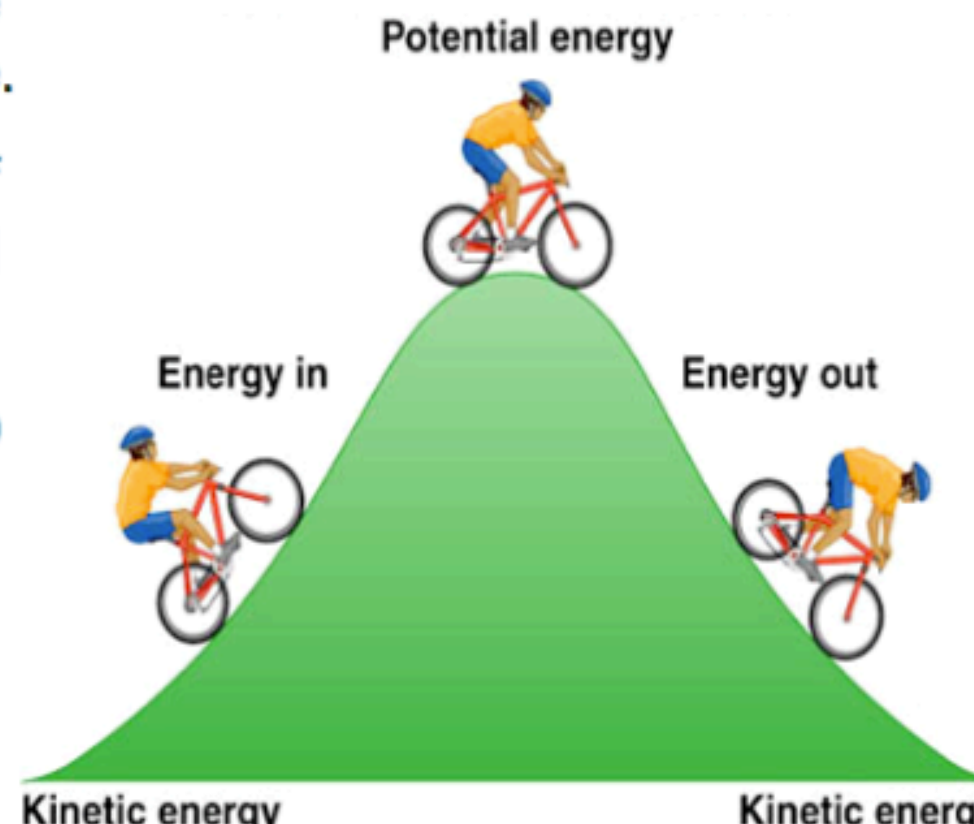
POTENTIAL ENERGY: stored energy and the energy of position

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.

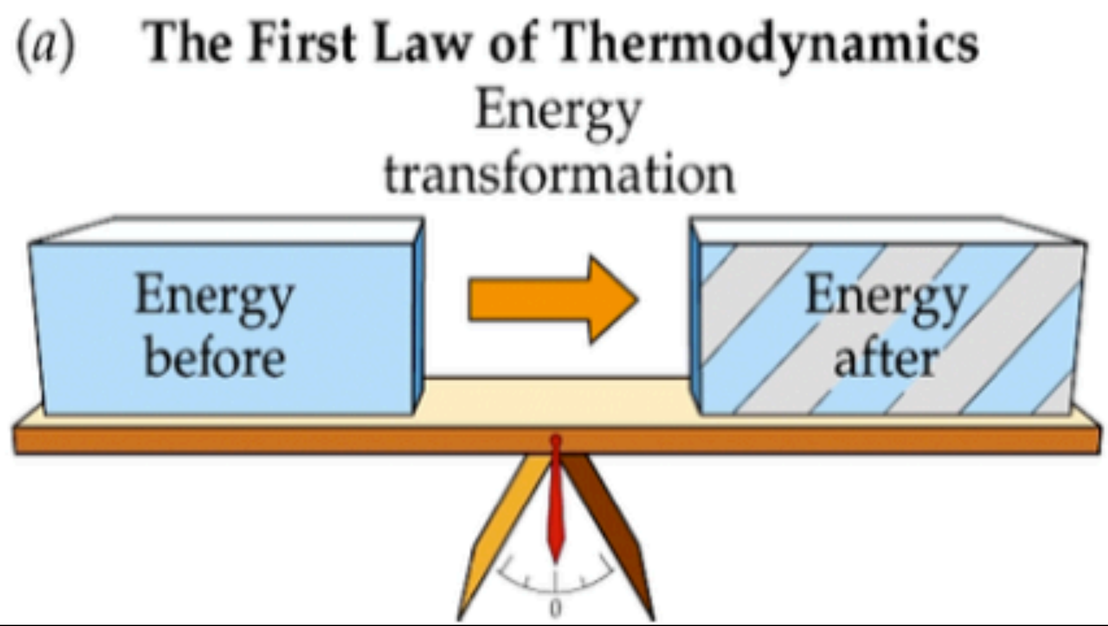


When we use energy we don't create it or use it up, we convert one form of energy to make another.

Often chemical reactions occur or are carried out for the sole purpose of producing energy in 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.

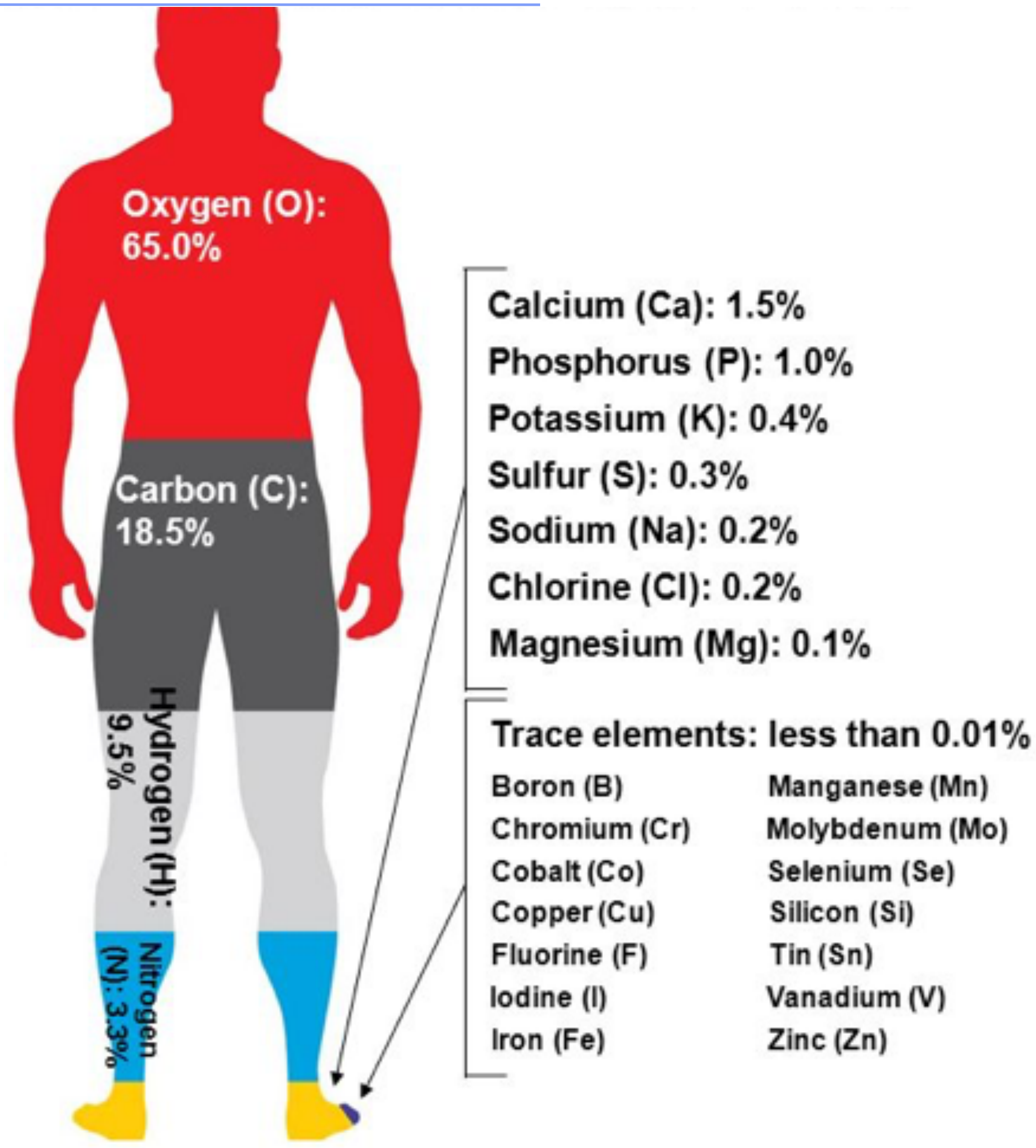


Let’s Return to our Discussion on Matter...

...and Atoms.

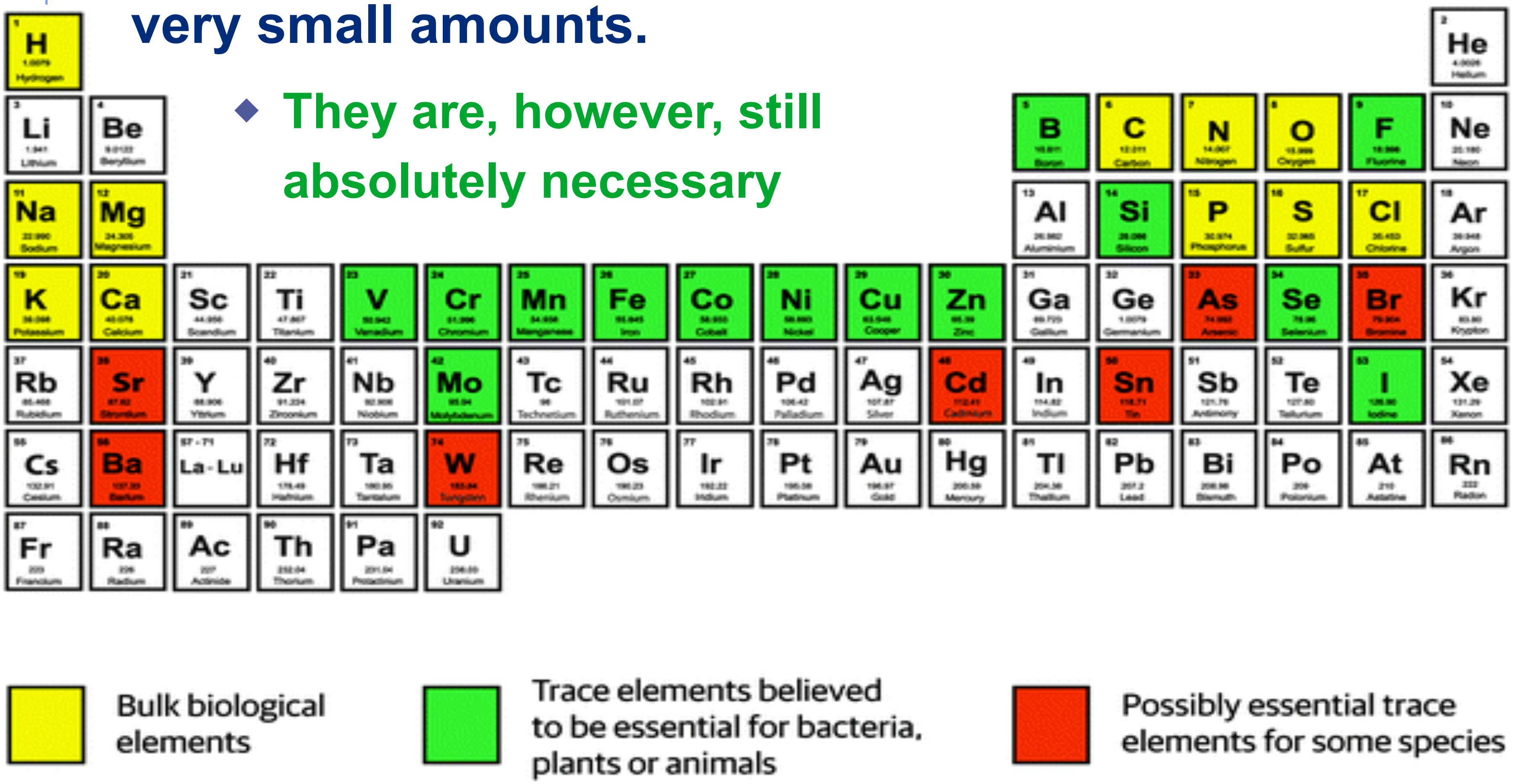
Life requires ~25 chemical elements

- **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)

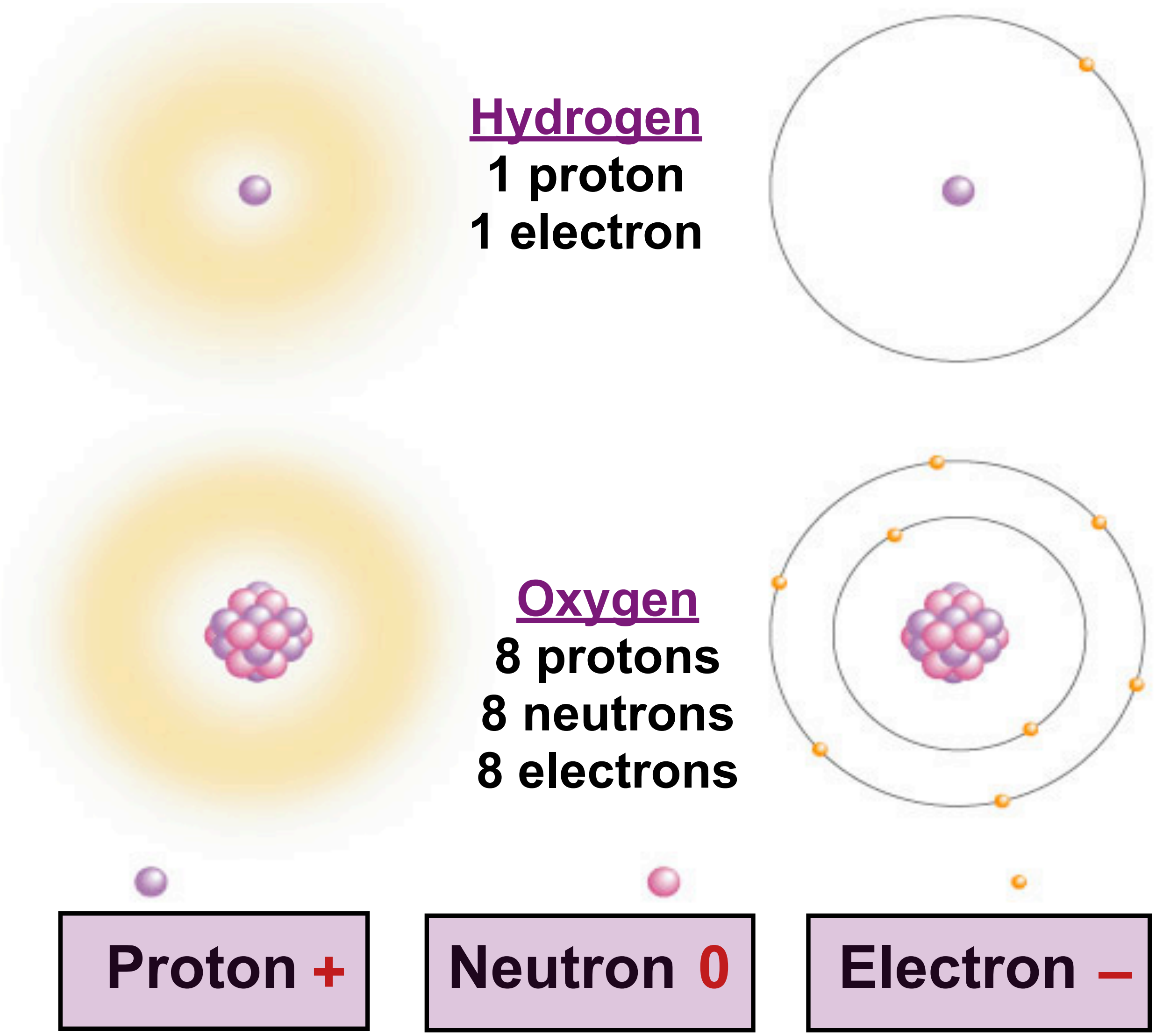


Life requires ~25 chemical elements

- **Less than 1% of elements required for life on earth are considered <u>trace elements</u>, elements required in very small amounts.**
  - **They are, however, still absolutely necessary**



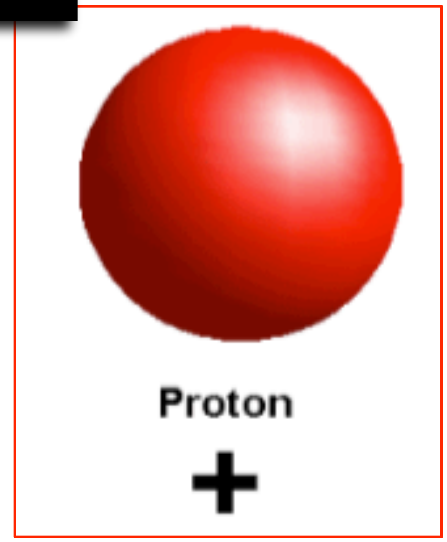
Matter is made of atoms

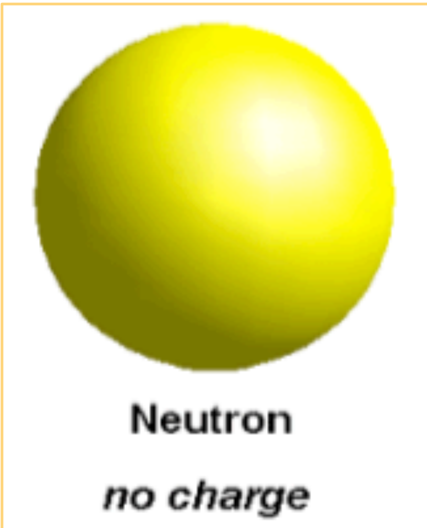


Matter is made of atoms

PROTONS

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



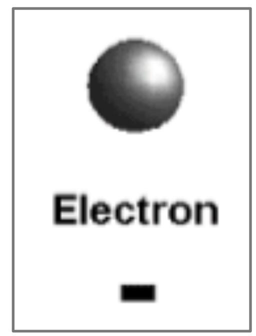


NEUTRONS

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

ELECTRONS

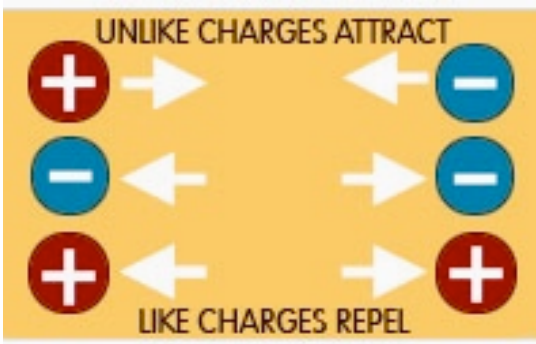
Symbol: **e-**
Mass: ~**0** dalton (d) or amu
(.0005 amu, 1/2000)
Charge: **-1**

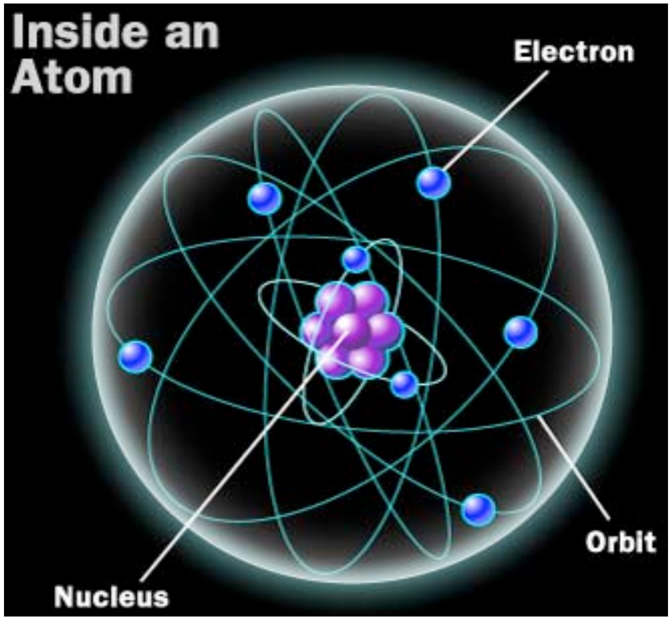


1 dalton or amu = 1.660539 x 10^{-24} g

The Atom

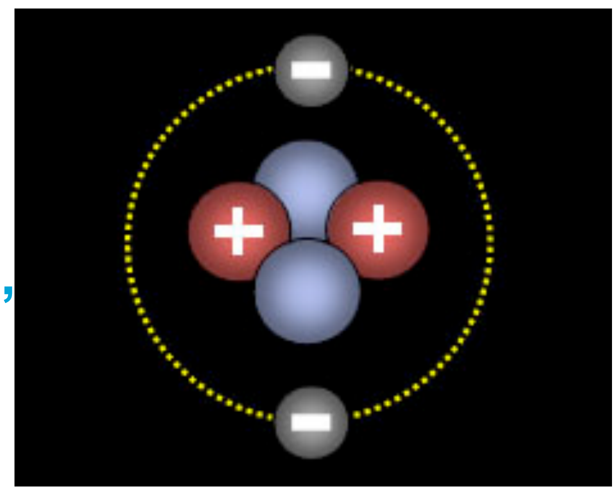
- In the nucleus, neutrons help keep positively charged protons close together through forces called <u>Strong Nuclear Forces</u>.
- The negatively charged electrons are held in orbit around the nucleus because they are <u>attracted</u> to positive protons while also being <u>repelled</u> by each other.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



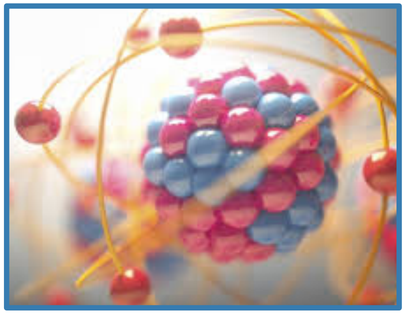


Though Atoms Contain Charged Particles, they can be Neutral.

- 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

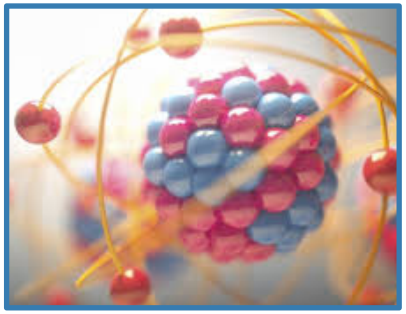


- Atoms are electrically neutral, only if the number of protons and electrons are equal and the charges have a SUM OF ZERO.
    - If the sum of atomic charges is NOT ZERO then the atom is said to carry a CHARGE or to be CHARGED.

- EXERCISE: If the atom is neutral. Will the atom contain?
    1. More protons than electrons?
    2. More electrons than protons?
    3. An equal number of protons & electrons?

- EXERCISE: How many electrons would a neutral atom have if the atom has 32 protons in the nucleus?

Neutral vs Charged Atom



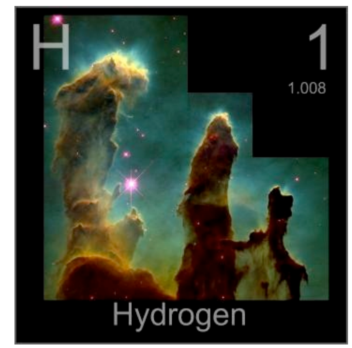
- Atoms are electrically neutral, only if the number of protons and electrons are equal and the charges have a SUM OF ZERO.
  - If the sum of atomic charges is NOT ZERO then the atom is said to carry a CHARGE or to be CHARGED.

- 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

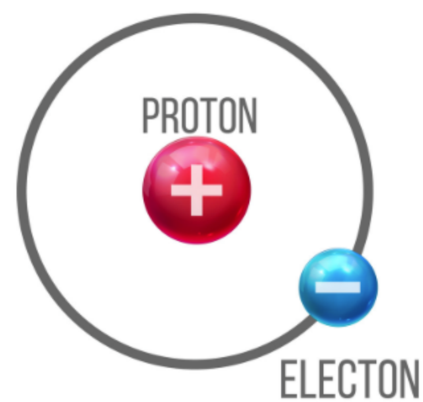
- EXERCISE: How many electrons would a neutral atom have if the atom has 32 protons in the nucleus?
  - $0 = (+32) + x$
  - $x = -32$
  - Therefore, this atom would have a total of 32 electrons.

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.**

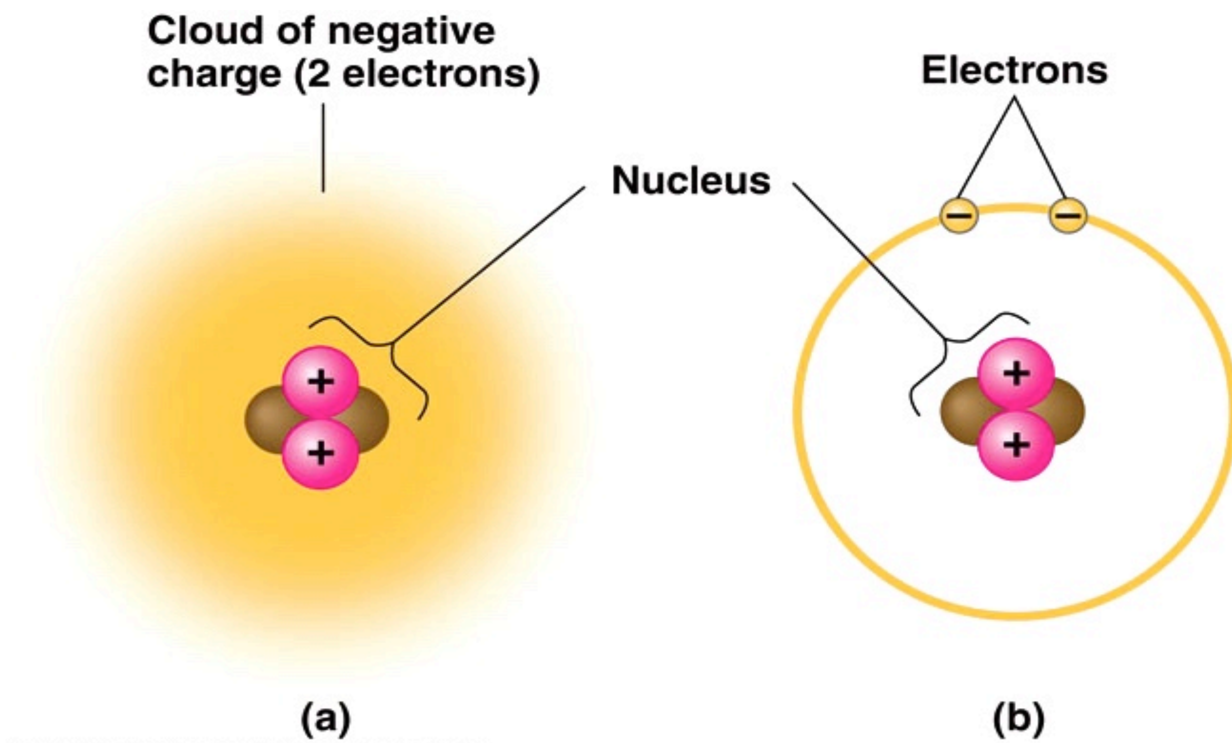


- **HYDROGEN is the simplest atomic structure.**
  - **It has only 1 proton and 1 electron.**
    - **The most common type of hydrogen atom, protium, *(making up 99.985% of naturally occurring hydrogen atoms)* has NO neutron.**
  - **On the periodic table, hydrogen is the 1st element in group 1A.**
    - **Notice that Hydrogen has a #1 above its symbol H which indicates the number of protons that atom contains.**



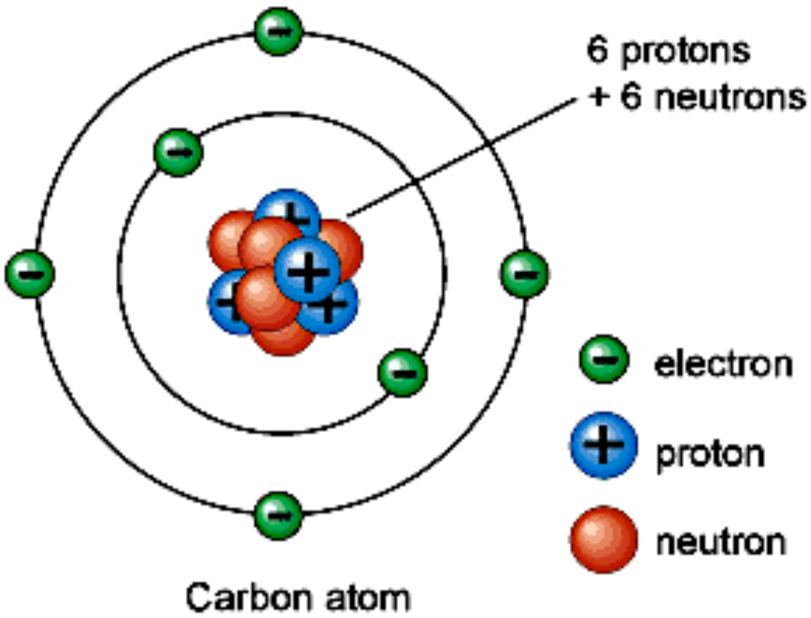
The Number of Protons Matters

- 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

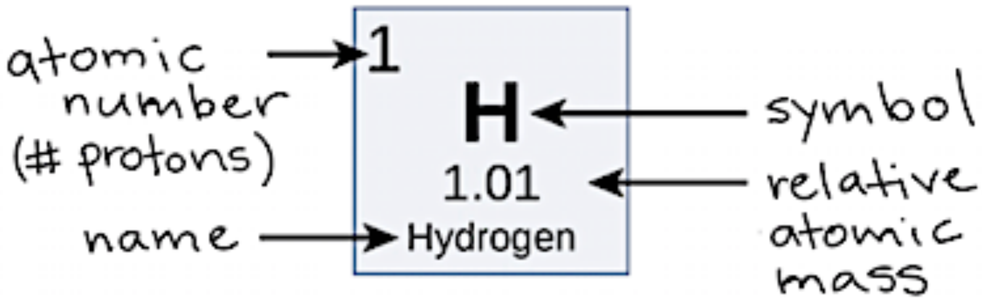
- The element <u>CARBON</u> has a number 6 above its symbol in the periodic table
  - The neutral Carbon atom, therefore, has 6 protons and, therefore, 6 electrons.



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

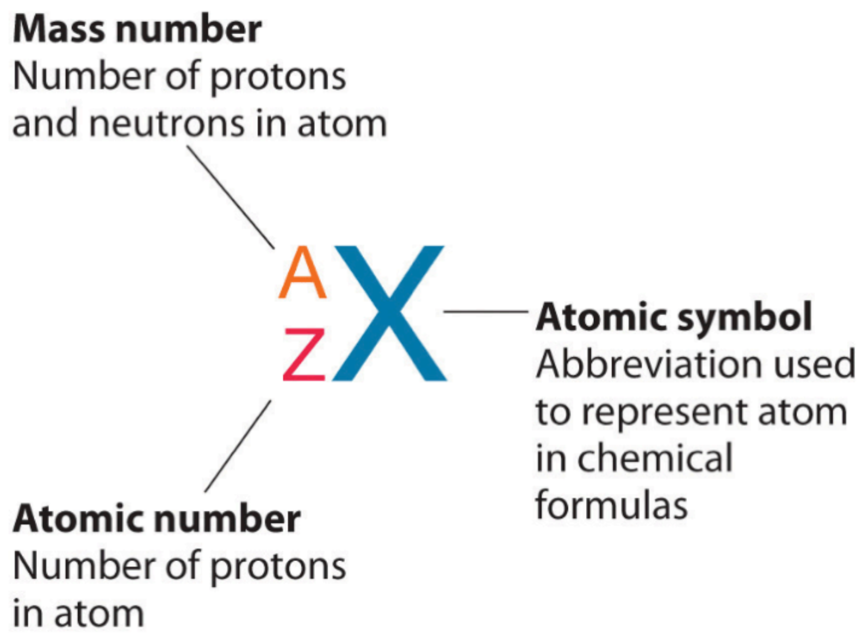
Atomic Number (# of Protons)

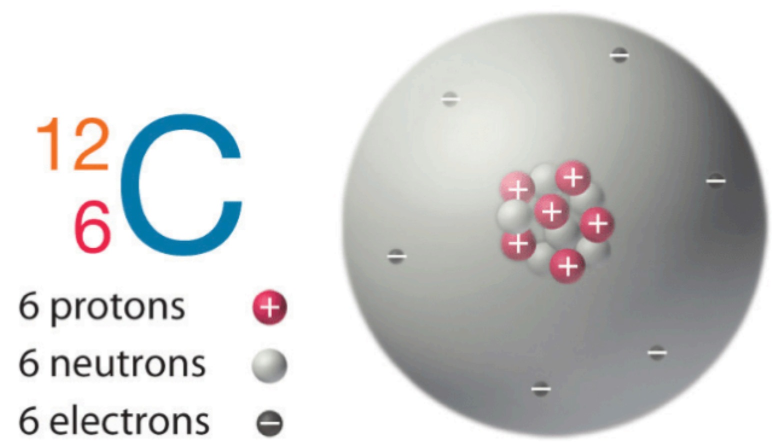
1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H Hydrogen 1.00794																	2 He Helium 4.00260
3 Li Lithium 6.941	4 Be Beryllium 9.01218											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.998403	10 Ne Neon 20.1797
11 Na Sodium 22.98977	12 Mg Magnesium 24.305											13 Al Aluminum 26.98154	14 Si Silicon 28.0855	15 P Phosphorus 30.97376	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 47.88	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.9380	26 Fe Iron 55.847	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.9216	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.9059	40 Zr Zirconium 91.224	41 Nb Niobium 92.9064	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.82	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.60	53 I Iodine 126.9045	54 Xe Xenon 131.29
55 Cs Cesium 132.9054	56 Ba Barium 137.327	57 *La	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.2	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.9665	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radiu 226.02	Ac Actinium 227.0278	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (268)	110 (269)	111 (272)	112 (277)						

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





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

- **<u>EXERCISE</u>: 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:

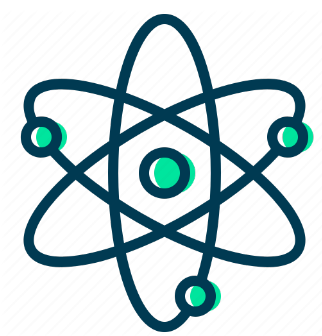
Mass # = 210 so #p + #n = 210
#n = 125

Now perform the necessary calculations:

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

Recall that # of protons determines the element.

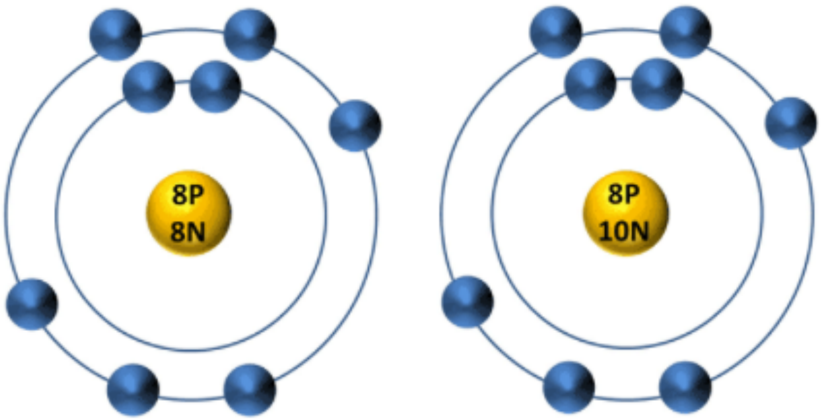
Element with Atomic # 85 on the Periodic Table, is Astetine (At)



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)

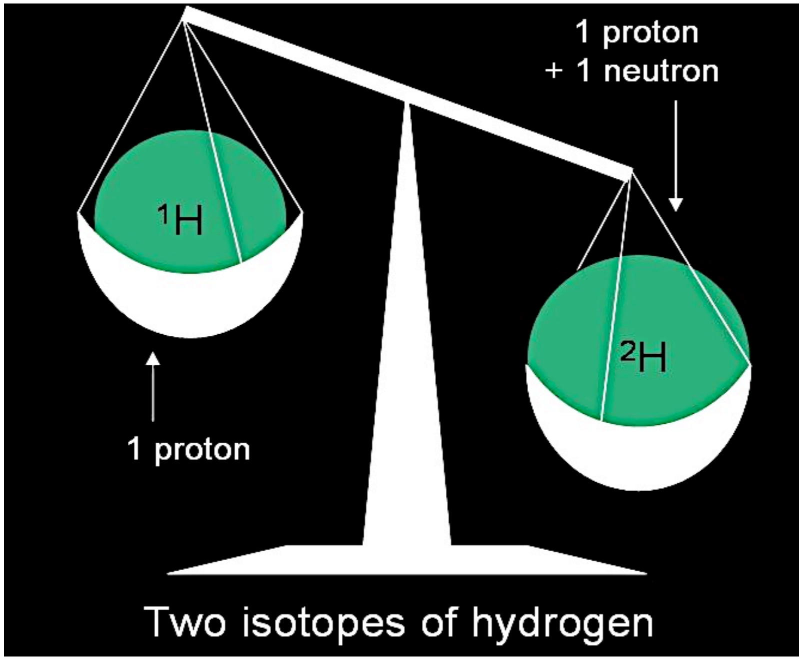


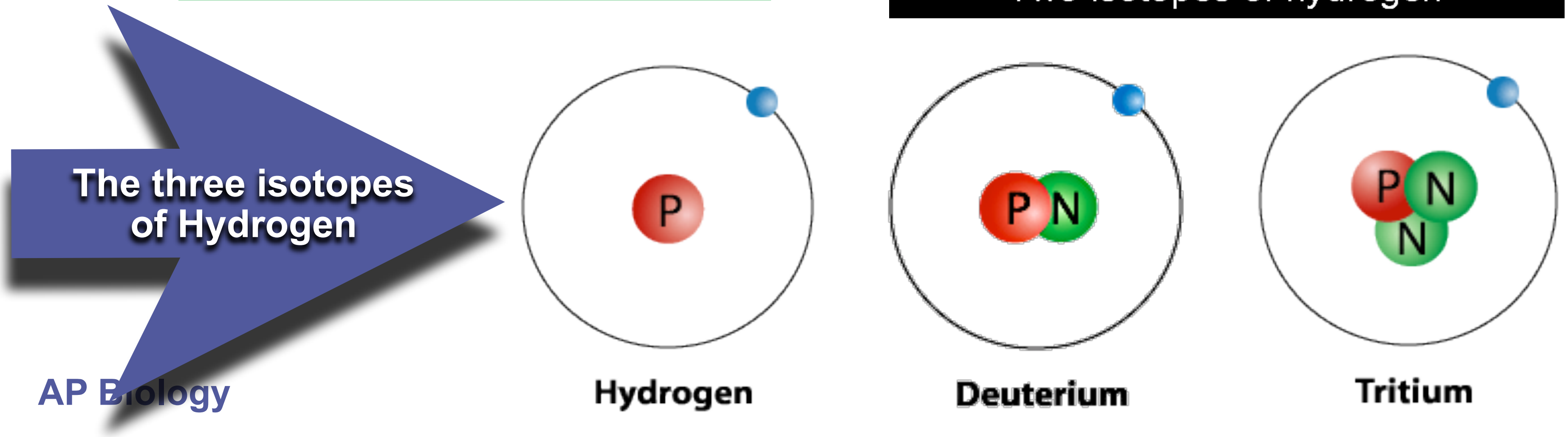
^{16}O Isotope

^{18}O Isotope

Isotopes

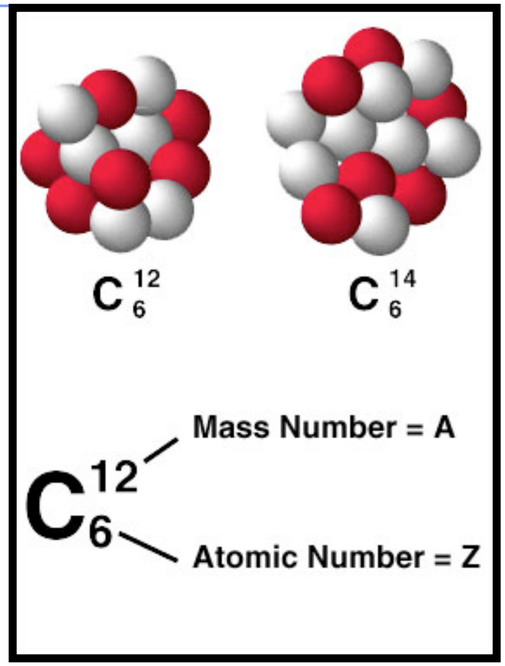
- Isotopic variants of an element generally have the **same chemical behavior**, because they have the same number of electrons (since the number of protons is the same), though they **differ in their number of neutrons**.

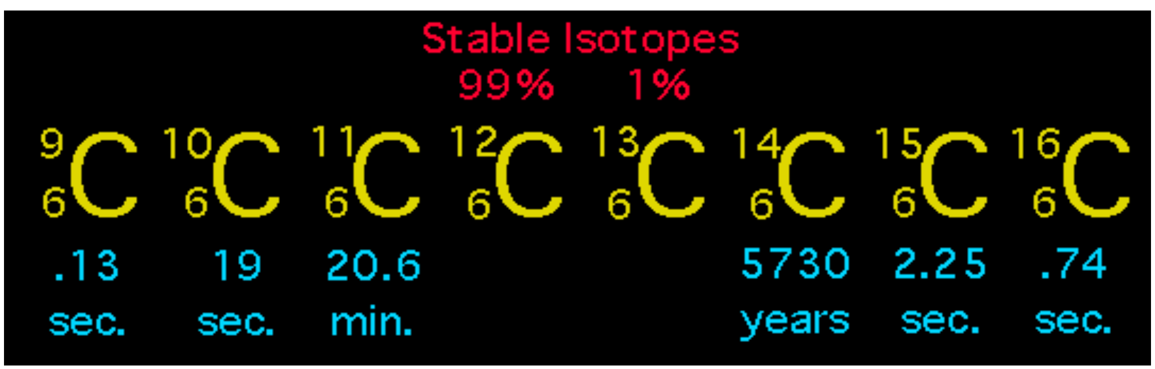


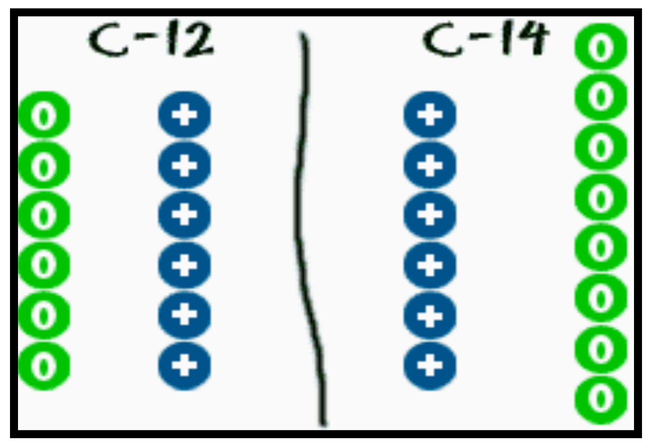


All Atoms Exist as an Isotopic Variant

- **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).*

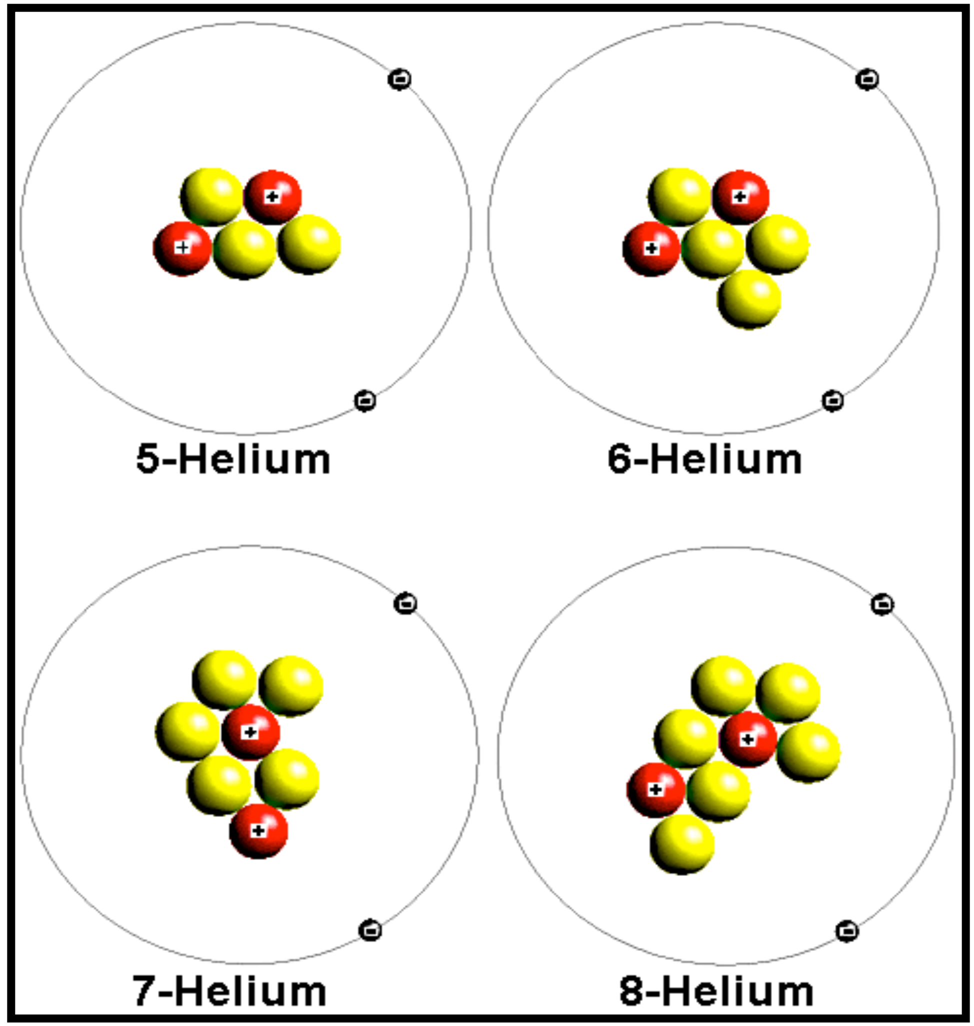






All Atoms Exist as an Isotopic Variant

- 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?

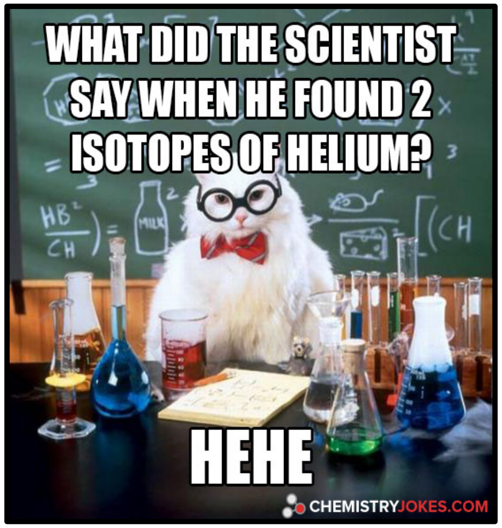
$$^{20}_{10}X$$

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

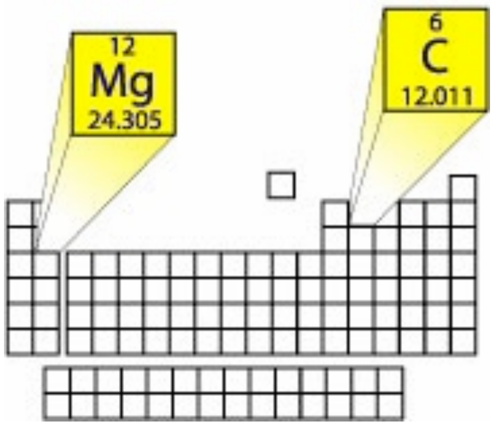
$$^{21}_{10}X$$

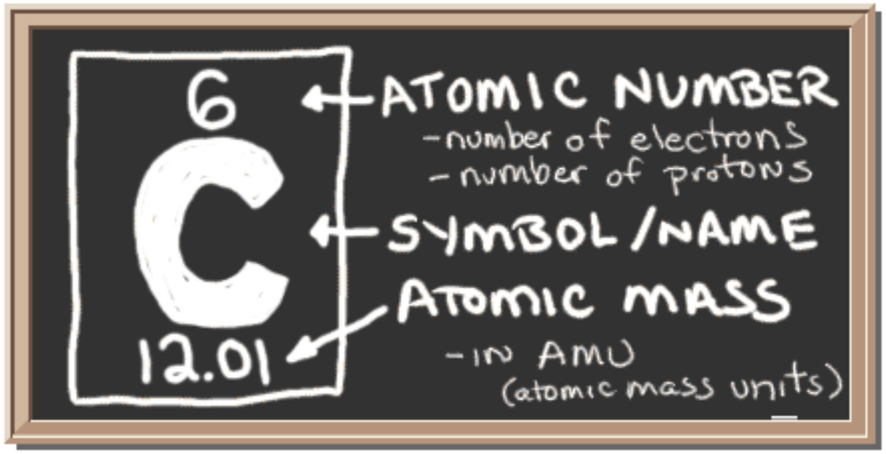
3. Can element X have more or fewer protons????

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



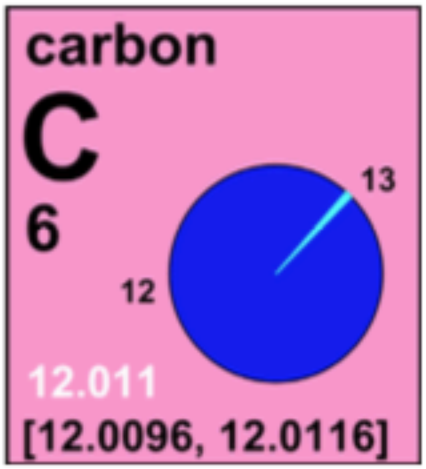
MOST ELEMENTS OCCUR NATURALLY AS A MIXTURE OF DIFFERENT ISOTOPES!





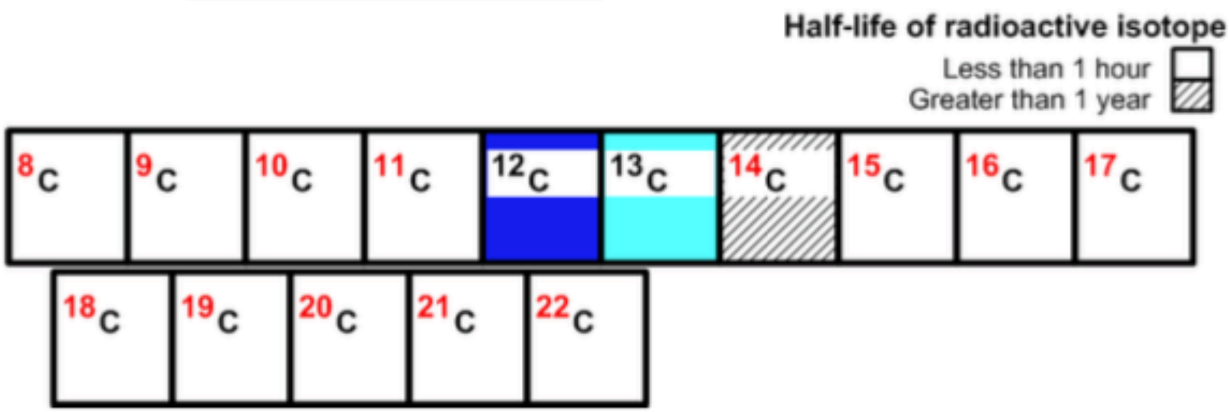
- **The mass of one atom of an element (of one type of isotope of an element) in amu is called the atom's <u>ISOTOPIC MASS</u>.**
  - **The mass of that one atom's total protons and neutrons in amu.**
- **The element's <u>ATOMIC MASS</u> or <u>ATOMIC WEIGHT</u> is the <u>weighted</u> average of the element's 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,
0.0000000010% as C-14.



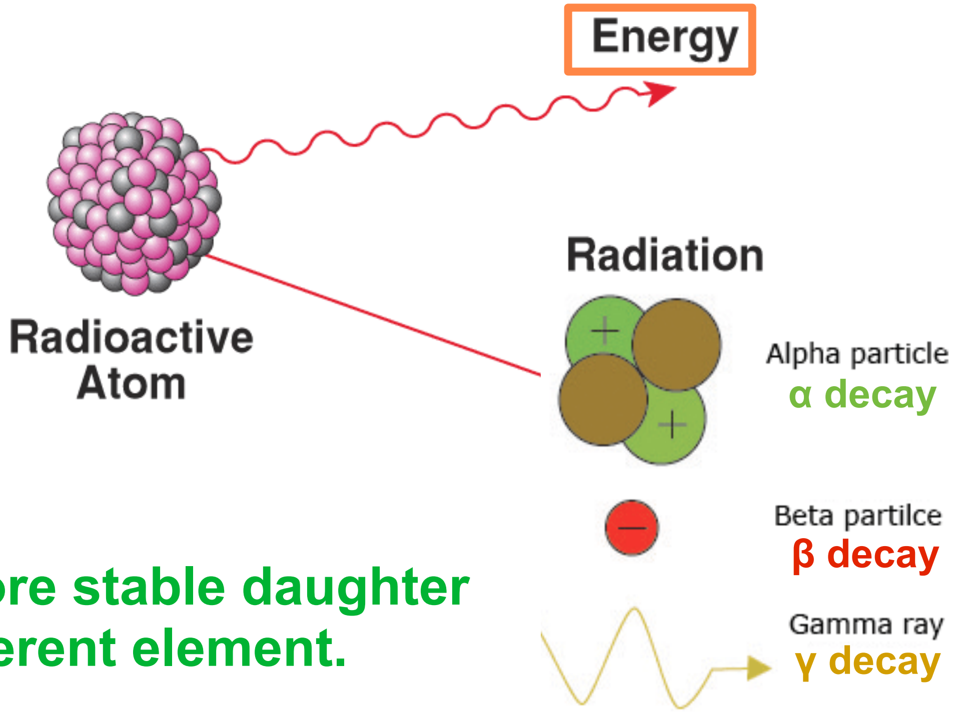
When you average out all of the masses, you get a value that is a bit larger than 12 amu (the isotopic mass of a c-12 single C-12 atom).

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

Some isotopes are stable and others NOT.

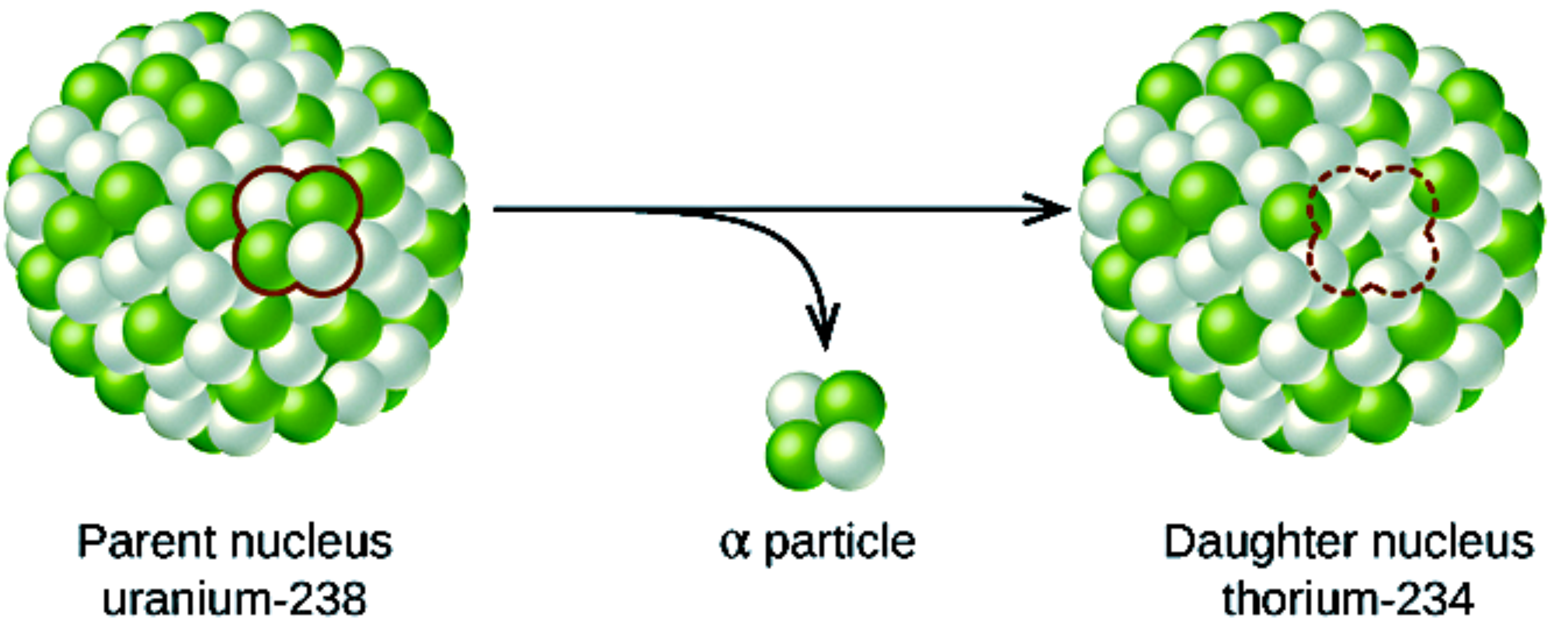
- When an isotope has an unstable nucleus is RADIOACTIVE: They spontaneously emit energy to become more stable.
  - The energy emitted from the nucleus is called RADIATION.

- During RADIOACTIVE DECAY, an unstable nucleus spits out ENERGY and either alpha (α) particles (these isotopes are known as Alpha Emitters), beta (β) particles (these isotopes are known as Beta Emitters, or gamma (γ) 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.



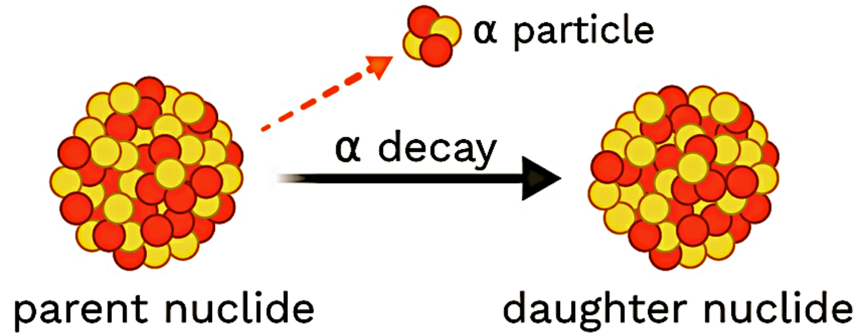
Radioactive Decay

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



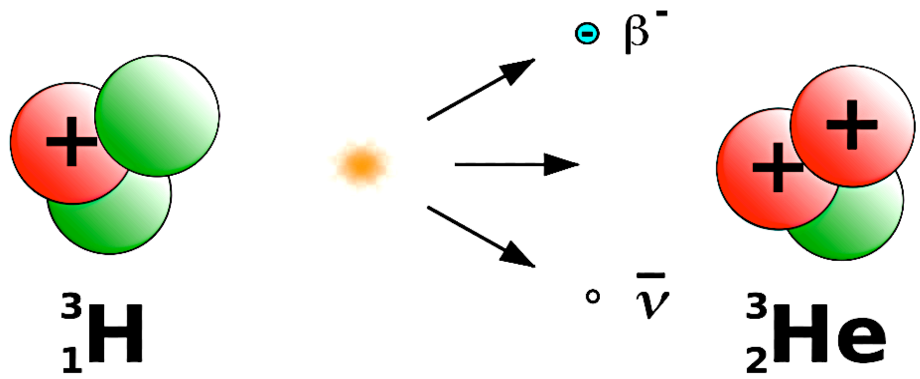
Example: A nucleus of uranium-238 (the parent isotope) undergoes α decay to form thorium-234 (the daughter isotope). The alpha particle removes two protons (green) and two neutrons (white) from the uranium-238 nucleus, *all while energy is also released from the parent nucleus.*

Alpha Decay & Alpha Radiation



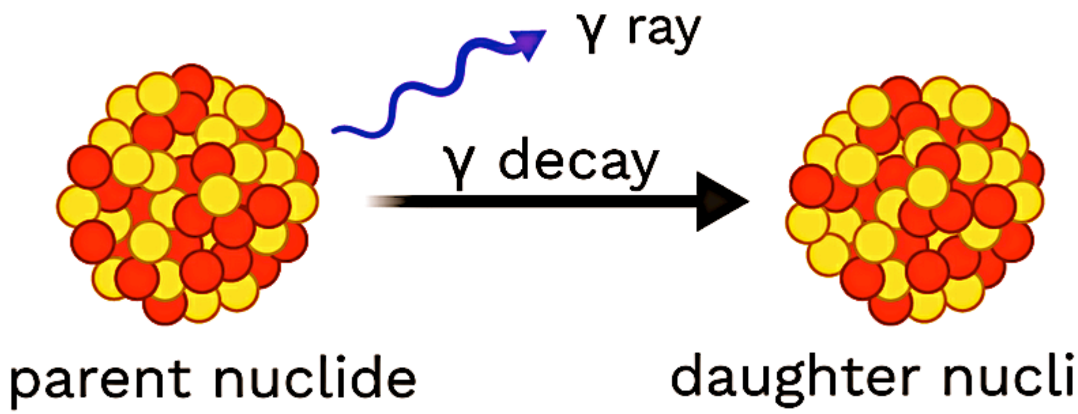
- **During alpha decay, a pair of protons bound to a pair of neutrons (a helium nucleus) called an alpha particle is emitted from the nucleus of the parent isotope.**
  - **The atom changes in atomic #, becoming a different element**
    - **Ex: The radium nucleus (Ra, atomic number 88) emits a helium 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 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.

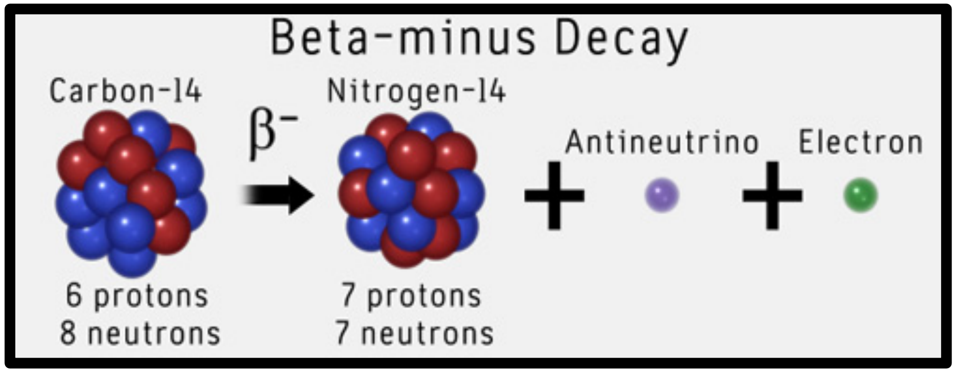
Gamma Decay & Gamma Radiation

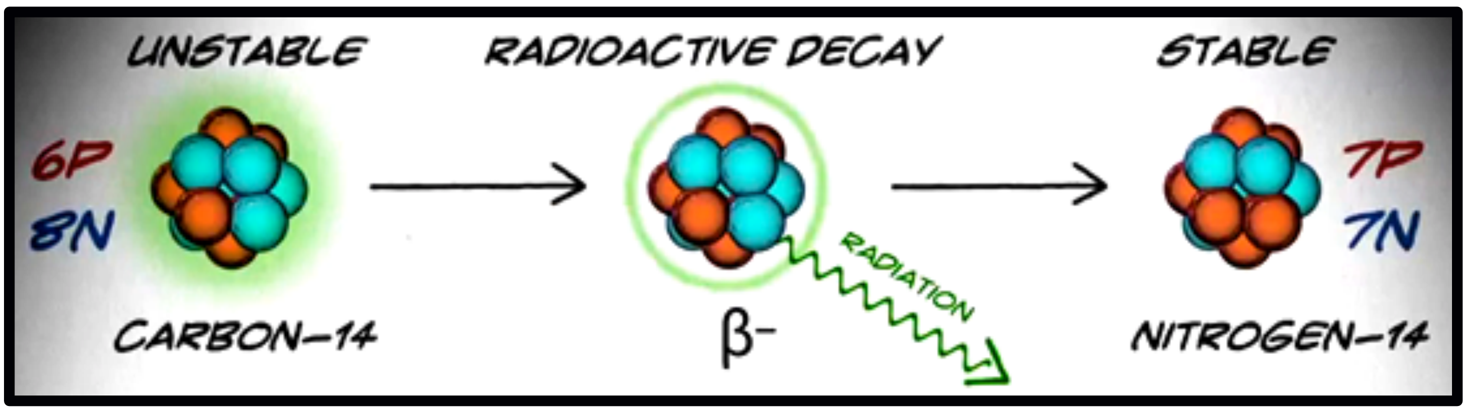


- During gamma decay, the nucleus emits radiation (energy) <u>without</u> actually changing its composition
  - The arrangement of protons and neutrons in the nucleus changes to a lower total energy state/configuration, releasing a high-energy photon called a <u>gamma ray</u>.
    - For Ex: Uranium-239m, 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 <u>most dangerous sources of radiation</u> 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.**

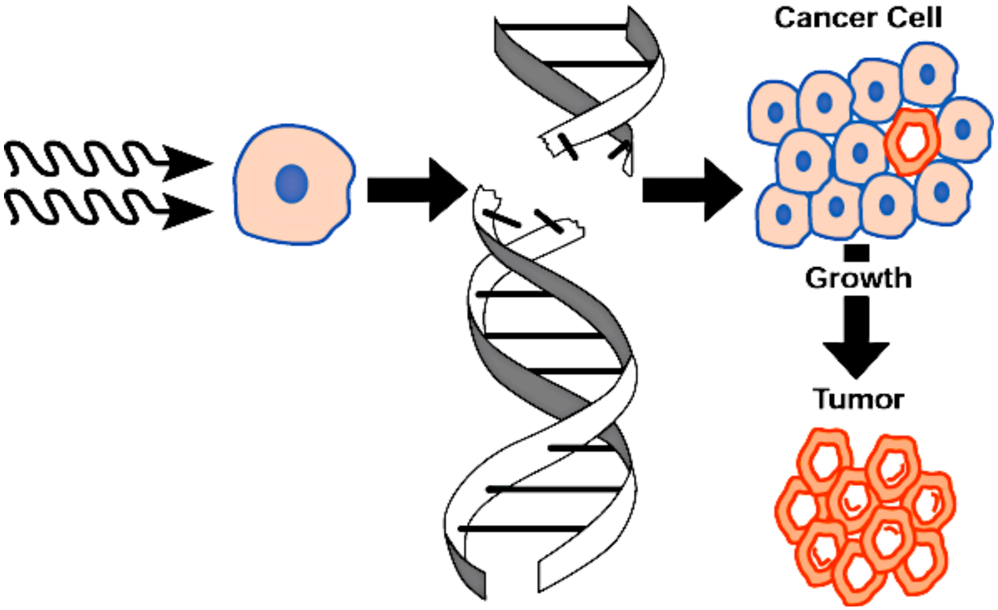




Carbon-14 (6 protons & 8 neutrons) decays into Nitrogen-14 (7 protons & 7 neutrons)

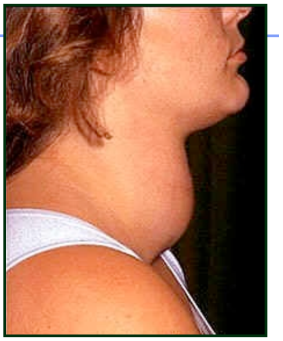
Radiation can be Harmful

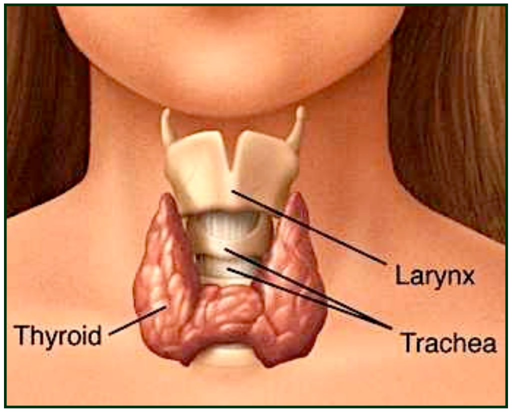
- High doses of radioactivity can be very toxic, because the high energies released damages essential molecules in our body's cells by disrupting covalent bonds.
- High energy radiation can knock electrons out of atoms or molecules resulting in the formation of unstable ions or radicals.
  - A FREE RADICAL 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…

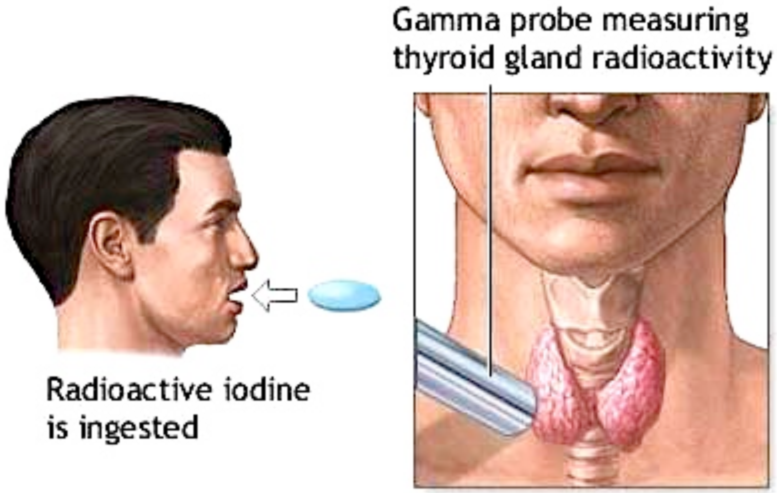


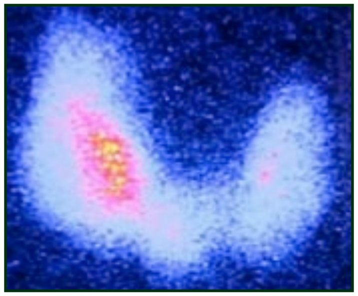
Radiation can be Useful too!

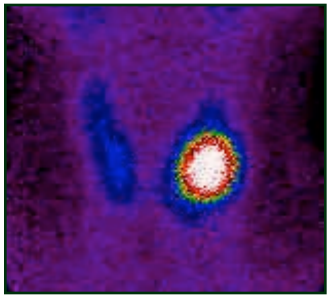
- Radioisotopes can be used to <u>trace certain molecules</u> in scientific research and through the body, and to treat and diagnose certain diseases such as cancers or thyroid conditions.
  - Cells of the body <u>CANNOT</u> distinguish generally between non-radioactive atoms and radioactive ones of the same element
    - Chemical reactions occur with <u>any</u> 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.





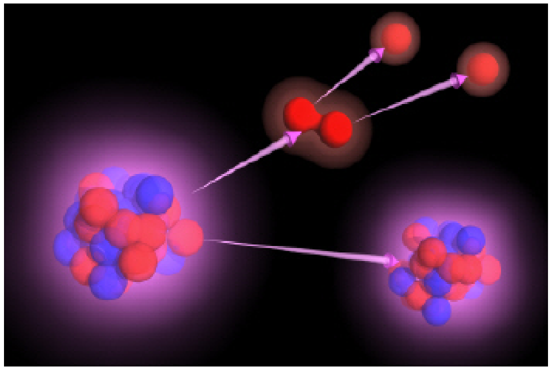






Radioactive Isotopes Can Be Used To Date Matter

- Because radioisotopes are unstable and decay over time, the number of radioactive atoms in a certain portion of matter decreases with time.
  - All radioisotopes of elements have a specific "half life."
    - The half-life is the interval of time required for an initial quantity of that radioisotope to decay to half of its initial quantity.
      - A half-life is the time necessary for one half of a particular radioactive material's nuclei to complete the release of radiation necessary for the nuclei to stabilize
- The knowledge of how long it takes a certain radio-isotope to decay is used to date material in a process called radiometric dating.

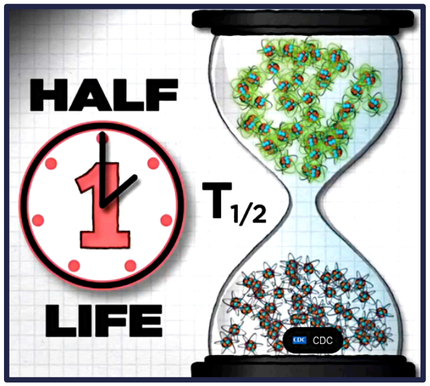


RADIOMETRIC DATING

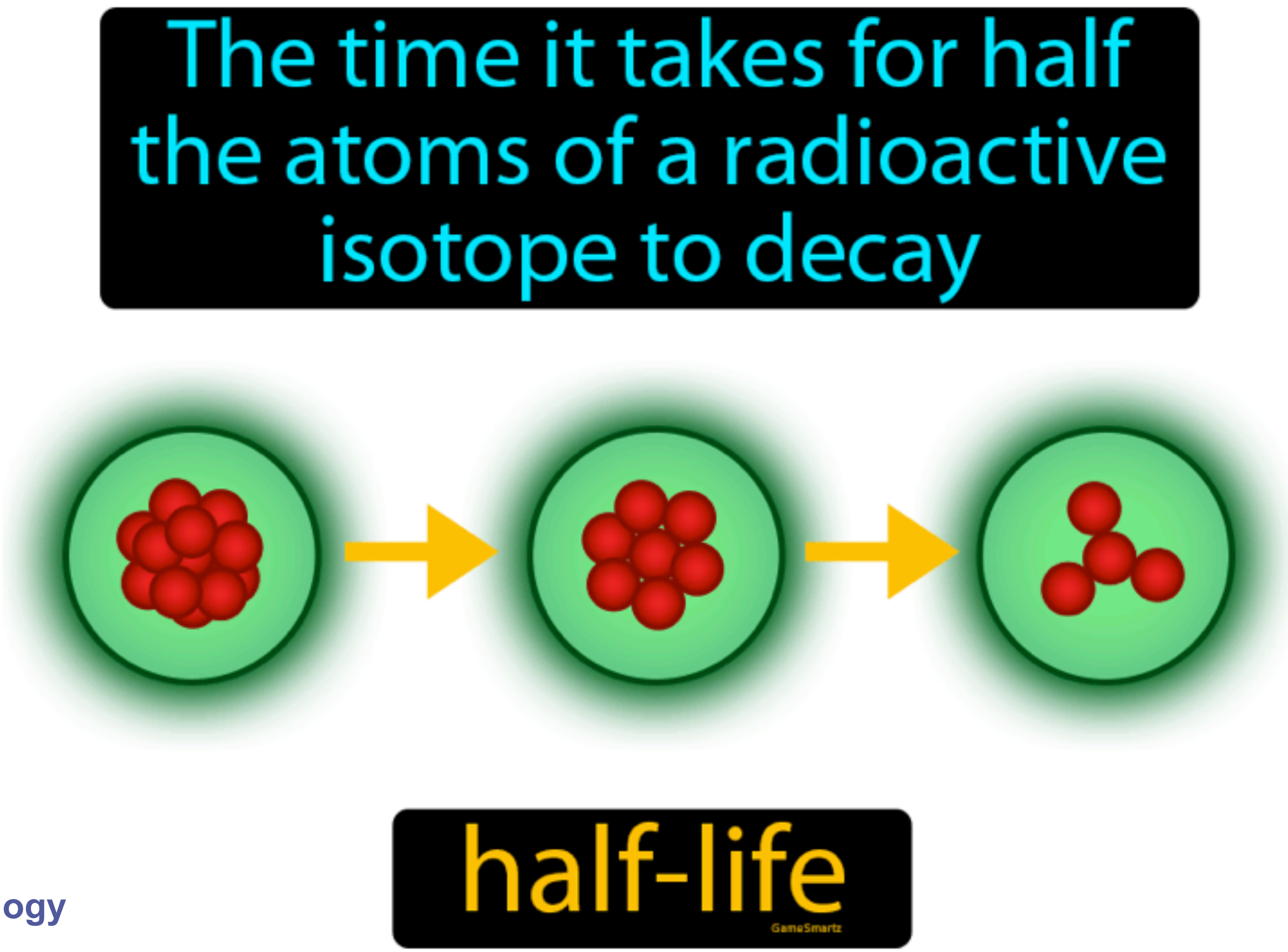
- Radiometric dating relies on the use of radioactive elements as "geological clocks."
  - Since each element decays at its own characteristic rate, geologists can estimate the length of time over which the decays have occurred by measuring the amount of the radioactive parent isotope (original radioactive isotope) present in a sample relative to the amount of the stable daughter isotope (stable atom that forms from the unstable radioactive isotope).

RADIOMETRIC DATING

- We do not know the exact moment one radioactive atom will decay; we just know that it *will* spontaneously decay into a more stable daughter isotopes at a certain point in time.
  - When using the rates of decay of radioactive isotopes to try to measure how old a substance containing such radioisotopes is, a useful aspect of radioactive decay is a radioactive isotopes' half-life = the amount of time it takes for one-half of the radioactive isotopes in a substance to decay.
    - The half-life of a specific radioactive isotope is constant
    - It is unaffected by conditions
    - It is independent of the initial amount of that isotope.
      - As time passes, less and less of the radioactive isotope will be present, and the level of radioactivity decreases.
        - Ex: We have 100.0 g of radioactive H-3 (tritium). It has a half-life of 12.3 years. After 12.3 y, half of the sample will have decayed to He-3 by emitting a beta particle, so that only 50.0 g of the original H-3 remains. After another 12.3 years —making a total of 24.6 y—another half of the remaining H-3 will have decayed, leaving 25.0 g of H-3. 11.2.1

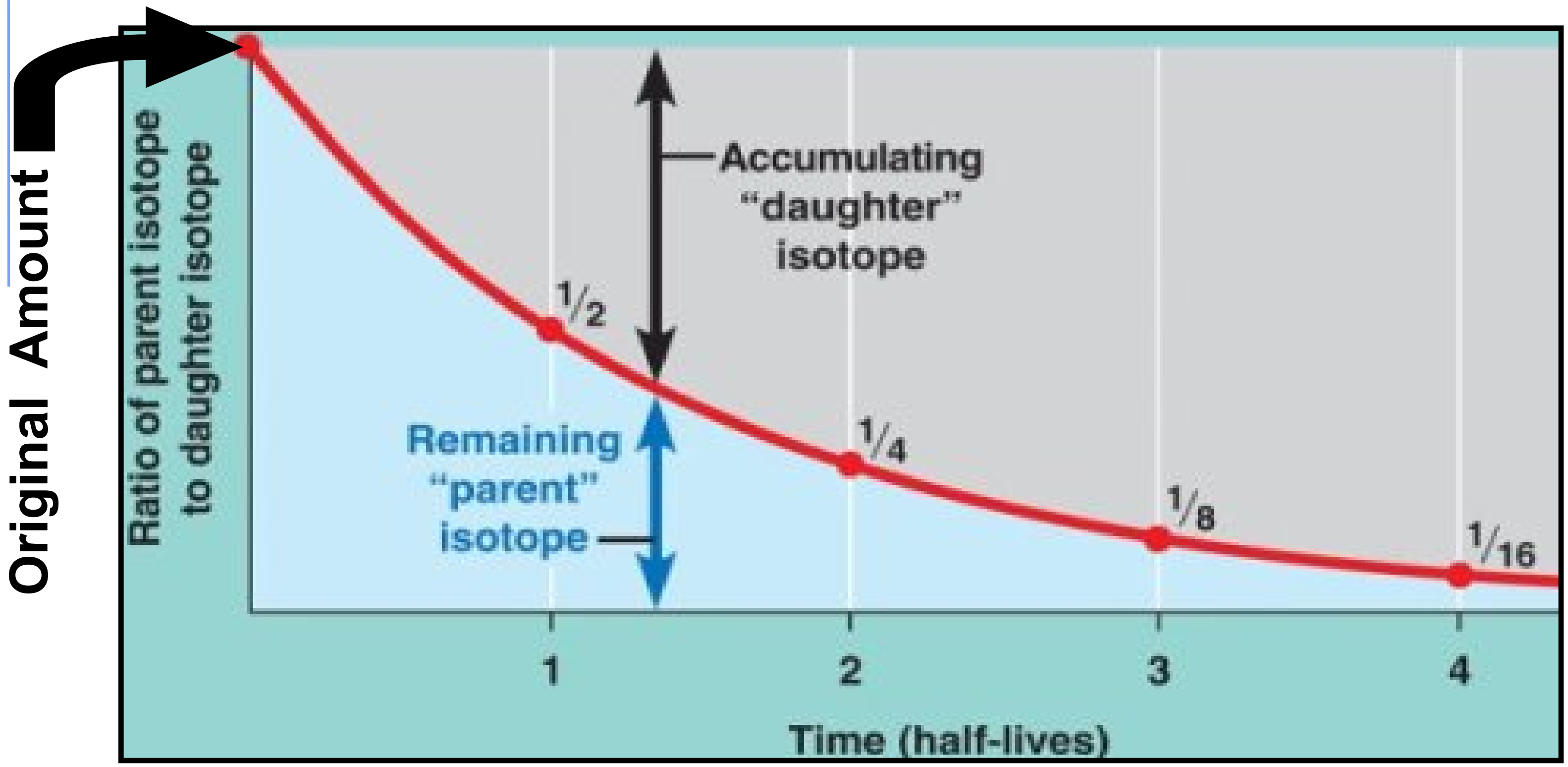


Half-Life of a Radioactive Isotope



RADIOMETRIC DATING

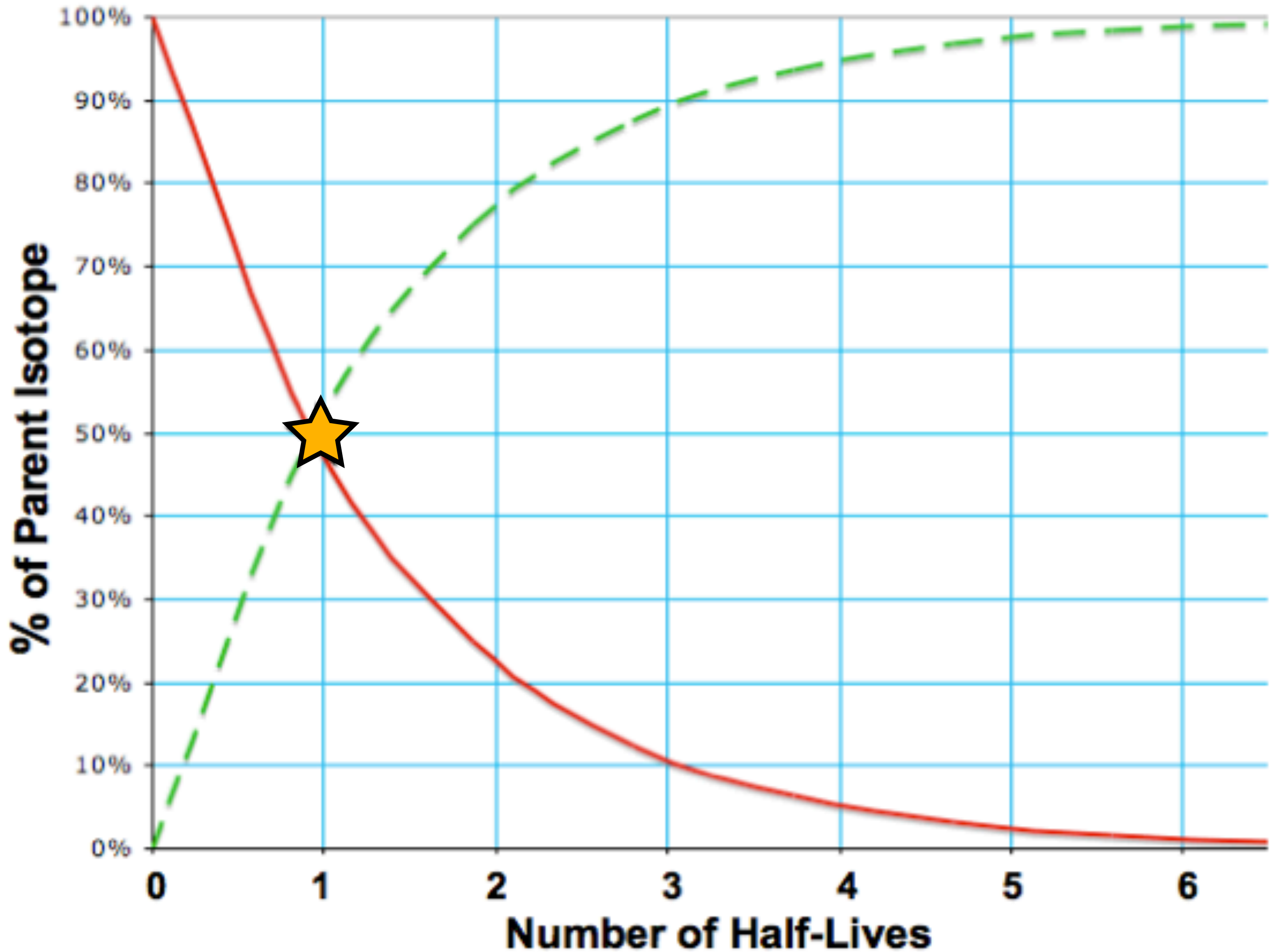
- **From Past to Present:** Every time **ONE** half-life passes, half of the parent isotopes in the sample has disappeared.



- **From Present to Past:** For every half-life we go back in time, there would have been 2x as much parent isotope in the sample.

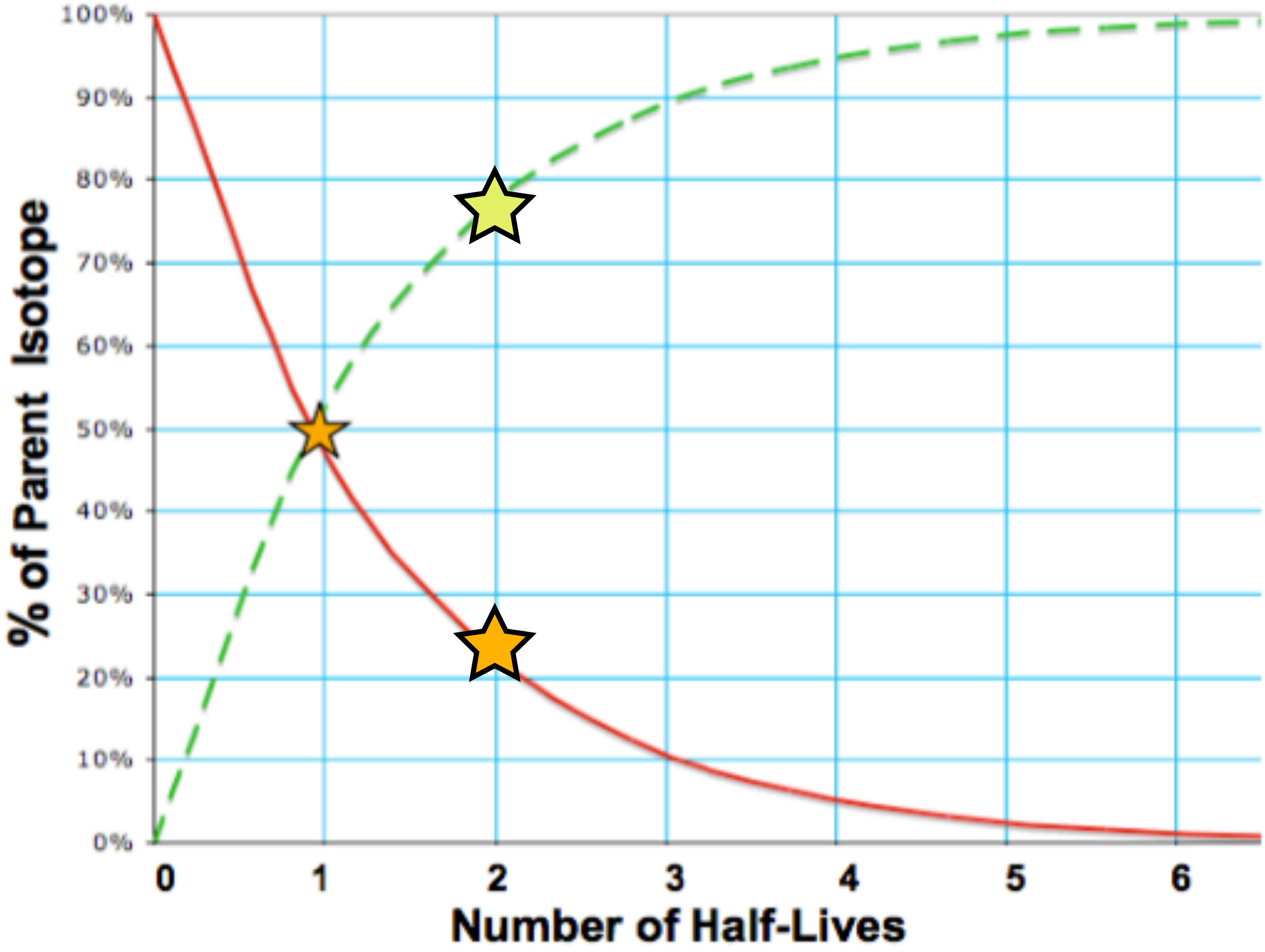
When a sample is 1 half-life old, 50% of the parent Isotope has decayed or turned into daughter atoms.

(The sample is made up now of 50% parent and 50% daughter atoms).

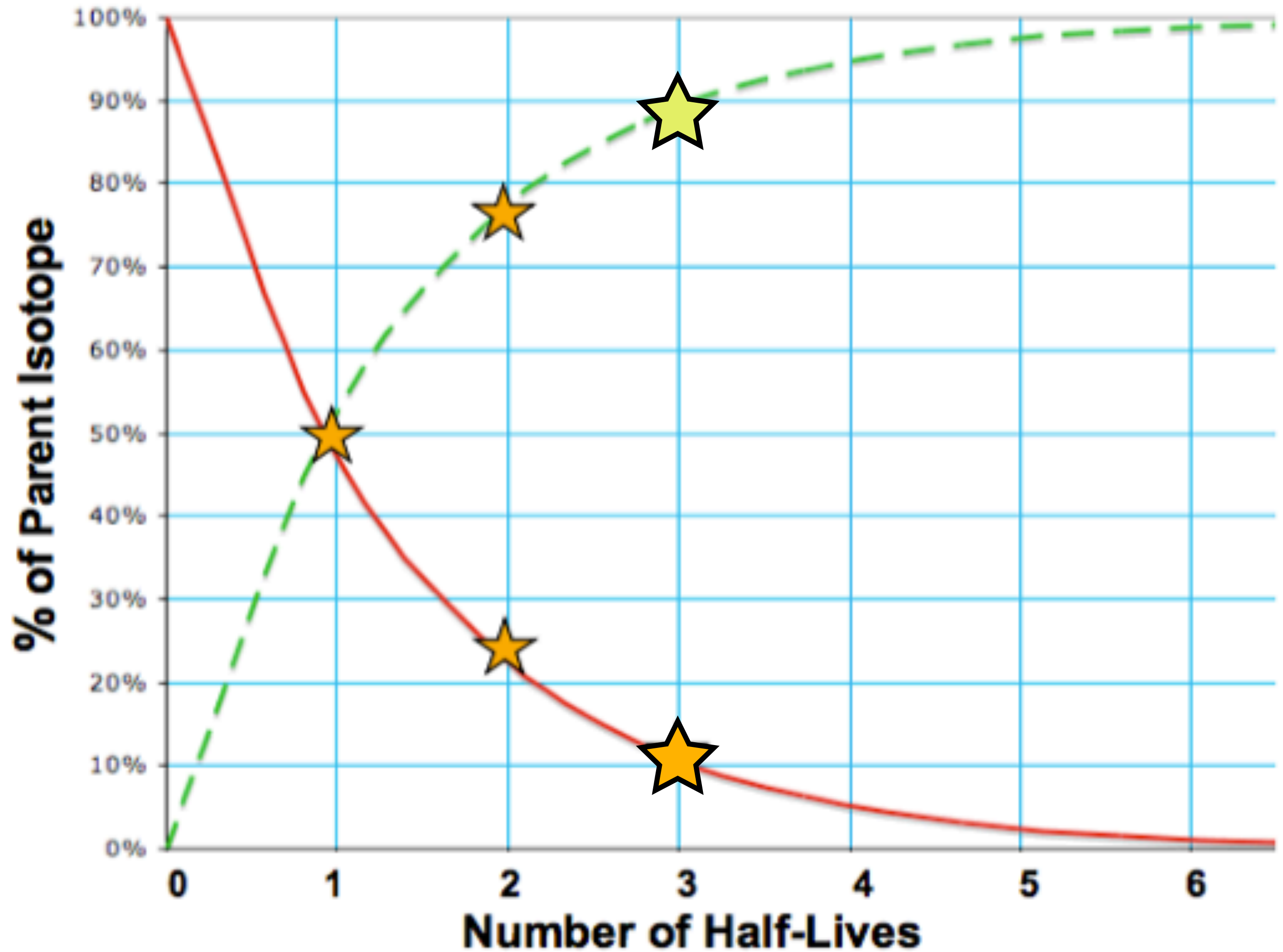


When the sample is 2 half-lives old, 25% of the parent isotope has decayed into daughter atoms (75%).

(The amount of parent isotope left after 1 half life decayed by another 50% after the 2nd half life)



The amount of parent isotope <u>after 2 half-lives have passed decreases again by half</u> when yet another half life passes and the <u>sample reaches 3 half lives old</u>. (Now the sample is made up of only 12.5% parent but 87.5% daughter atoms)



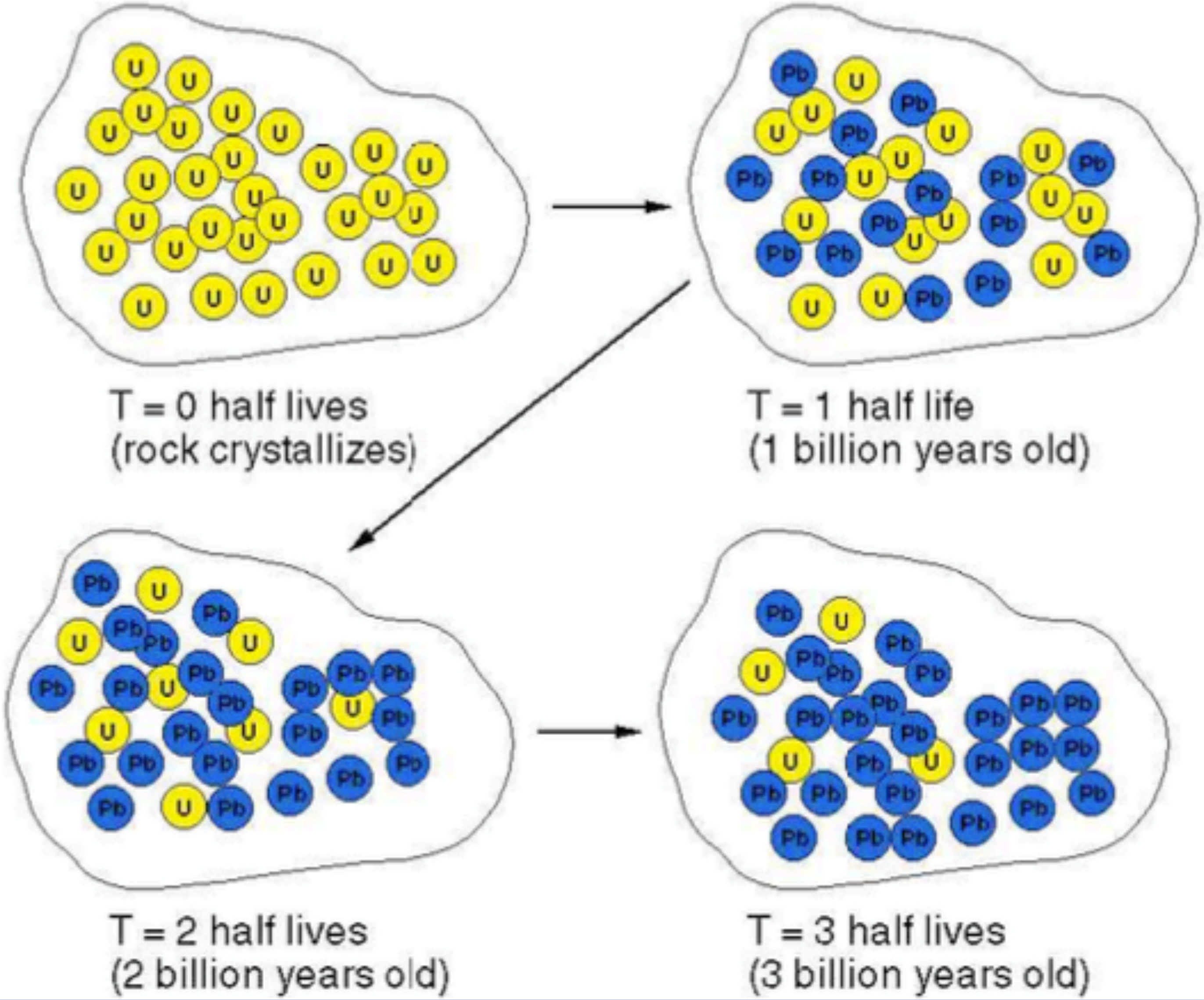
RADIOMETRIC DATING USING URANIUM

<u>Assume</u> this radioactive uranium has a half-life of 1 billion yrs.

In time, the radioactive parent U atoms decay to non-radio-active daughter lead atoms (Pb).

The rate of the decay is constant.

Over time, more and more U turns to Pb



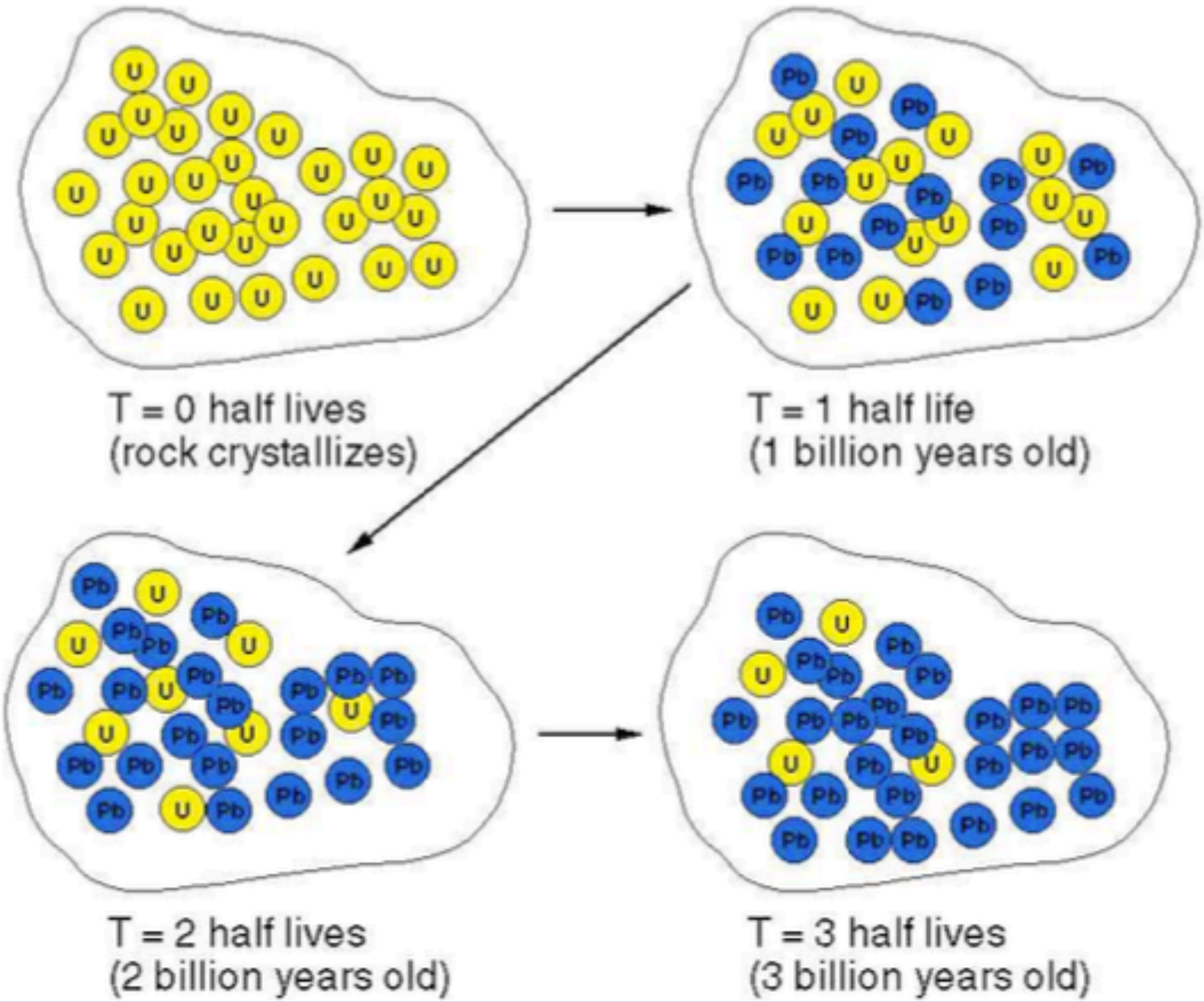
RADIOMETRIC DATING USING URANIUM

Assume this radioactive uranium has a half-life of 1 billion yrs.

When the rock formed, 0 half lives had passed.

Every atom was U.

After 1 billion years (1 half life) 50% of the U converted to Pb.



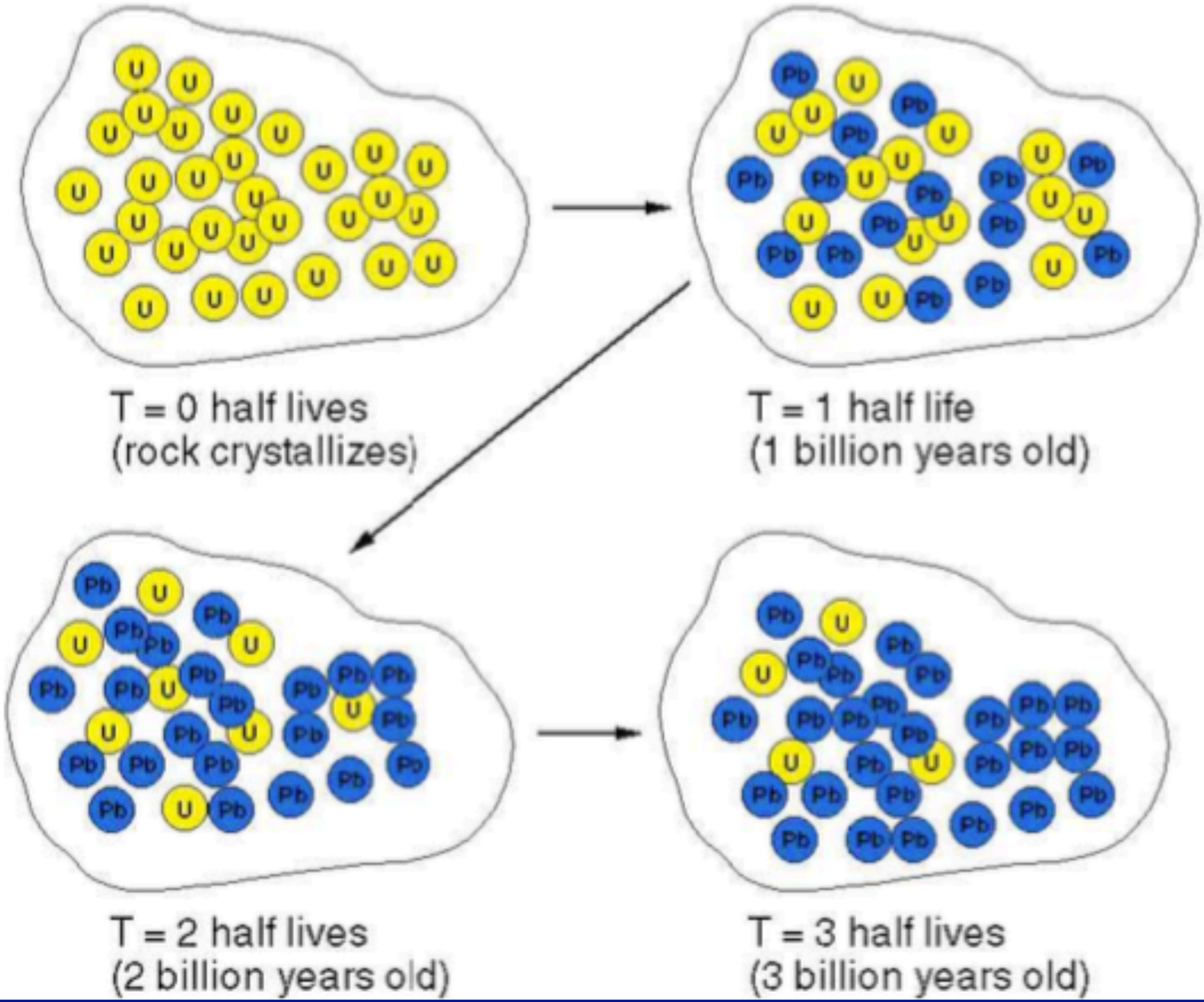
RADIOMETRIC DATING USING URANIUM

<u>Assume</u> this radioactive uranium has a half-life of 1 billion yrs.

After 2 billion years, 2 half lives passed.

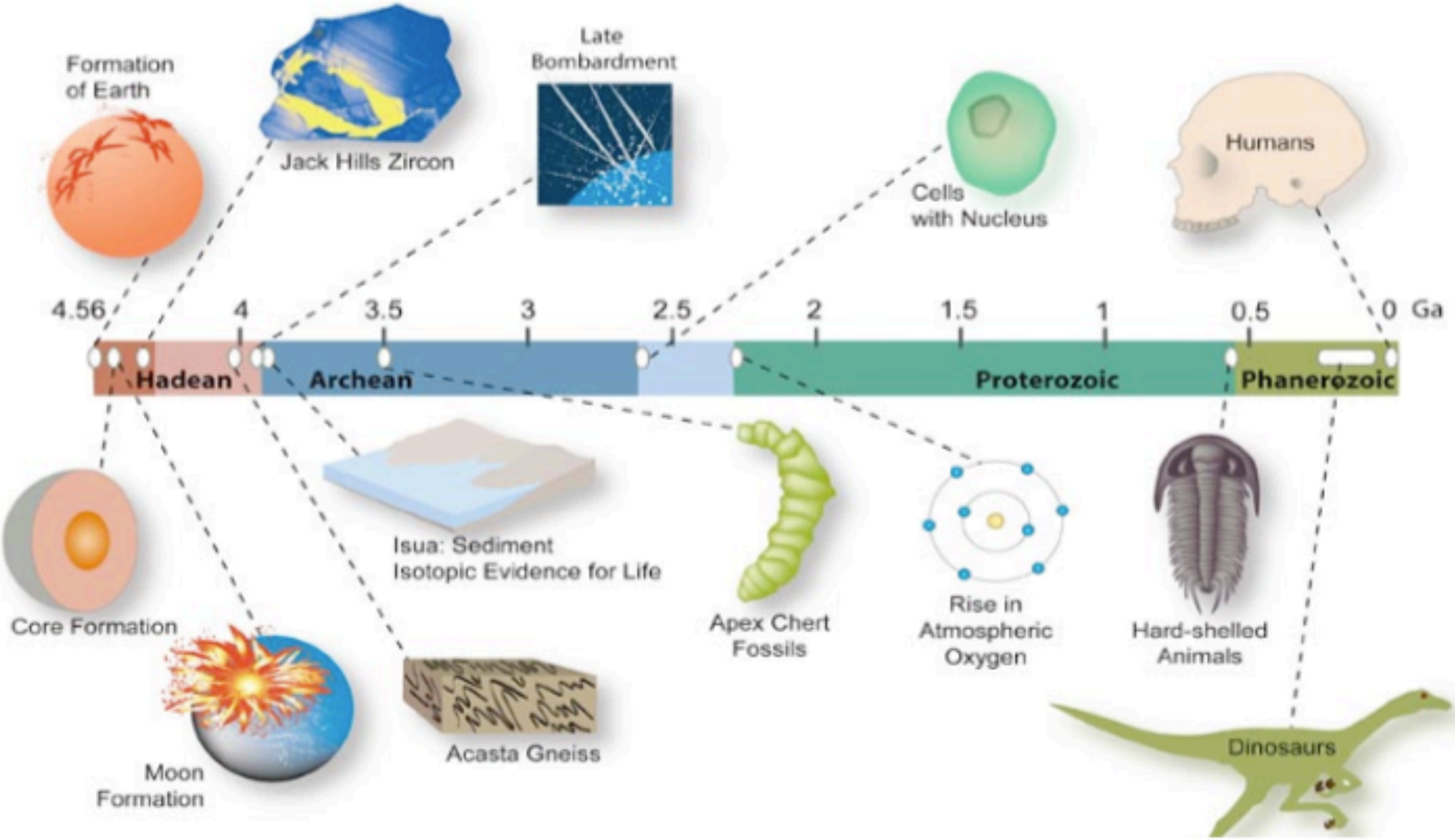
Only 25% of the U remains.

75% of atoms are now Pb.



If the length of the half-life is multiplied by the number of elapsed half-lives, then the age of the rock is obtained.

In our example, U's half life is 1 billion years. So if a sample is 3 half-lives old, then it is 3 x 1 billion = 3 billions years old.



RADIOCARBON DATING

- In reality, the element uranium contains multiple unstable isotopic variants, several of which are radioactive.
  - The half-life of U-235 decaying to Pb-207 is 713 million years, U-232 is 72 years, U-237 is 6.75 days, U-238 is 4.47×10^9 years, U-240 is 14.1 hours.
- Half-lives can range from mere fractions of a second to billions of years and are unique to each radioisotope.

  Fluorine: * F-18 = 109.74 minutes

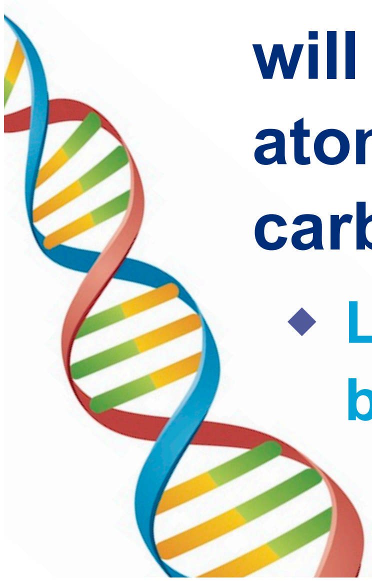
  Polonium: * Po-210 = 138.38 days + * Po-211 = 0.516 seconds
- Remember, a radioactive parent atom is unstable and will spontaneously decay into a more stable daughter atom.

Radioactive Parent Isotopes	Stable Daughter Products	Half-Lives
Potassium 40	Argon 40	1.25 billion yrs
Rubidium 87	Strontium 87	48.8 billion yrs
Thorium 232	Lead 208	14 billion year
Carbon 14	Nitrogen 14	5730 years

RADIOCARBON DATING

- Recall that this decaying Carbon-14 atoms results in the release of energy and one particle of beta radiation, transforming a neutron into a proton inside the c-14 nucleus.
  - In the process this unstable carbon atom changes into an atom of nitrogen.

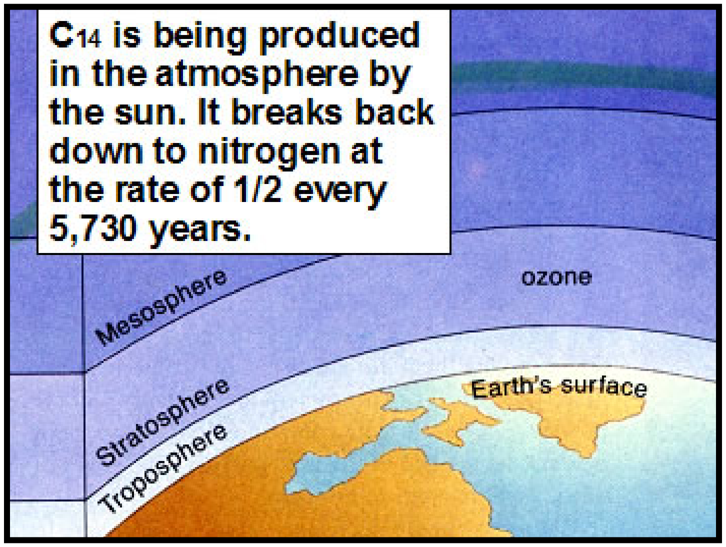
- Remember that a carbon-14 atom will chemically react with other atoms just like any isotope of carbon would.
  - Living organisms incorporate C-14 into their carbon based molecules just like they do C-12 and C-13.



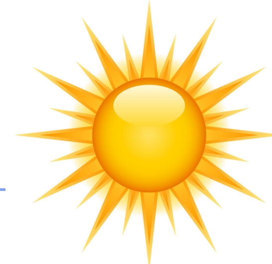
- The half-life of Carbon-14 is ~5730 years

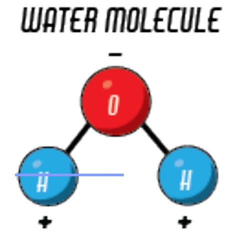
RADIOCARBON DATING

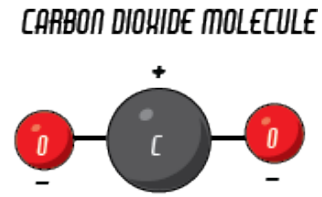
- Radiocarbon = a common name of Carbon-14, the only radioactive isotope of carbon.
  - Two main properties that differ between Carbon-14 atoms and the more abundant Carbon-12 atoms are:
    - 1. mass 2. radioactivity
- Though in very low abundance, radiocarbon is widely distributed on the Earth.
  - Radiocarbon is widely used for dating geological and archaeological carbon-based materials as well as in studies of past and present environment.
    - Atoms of radioactive Carbon-14 decay spontaneously!



The Carbon Cycle





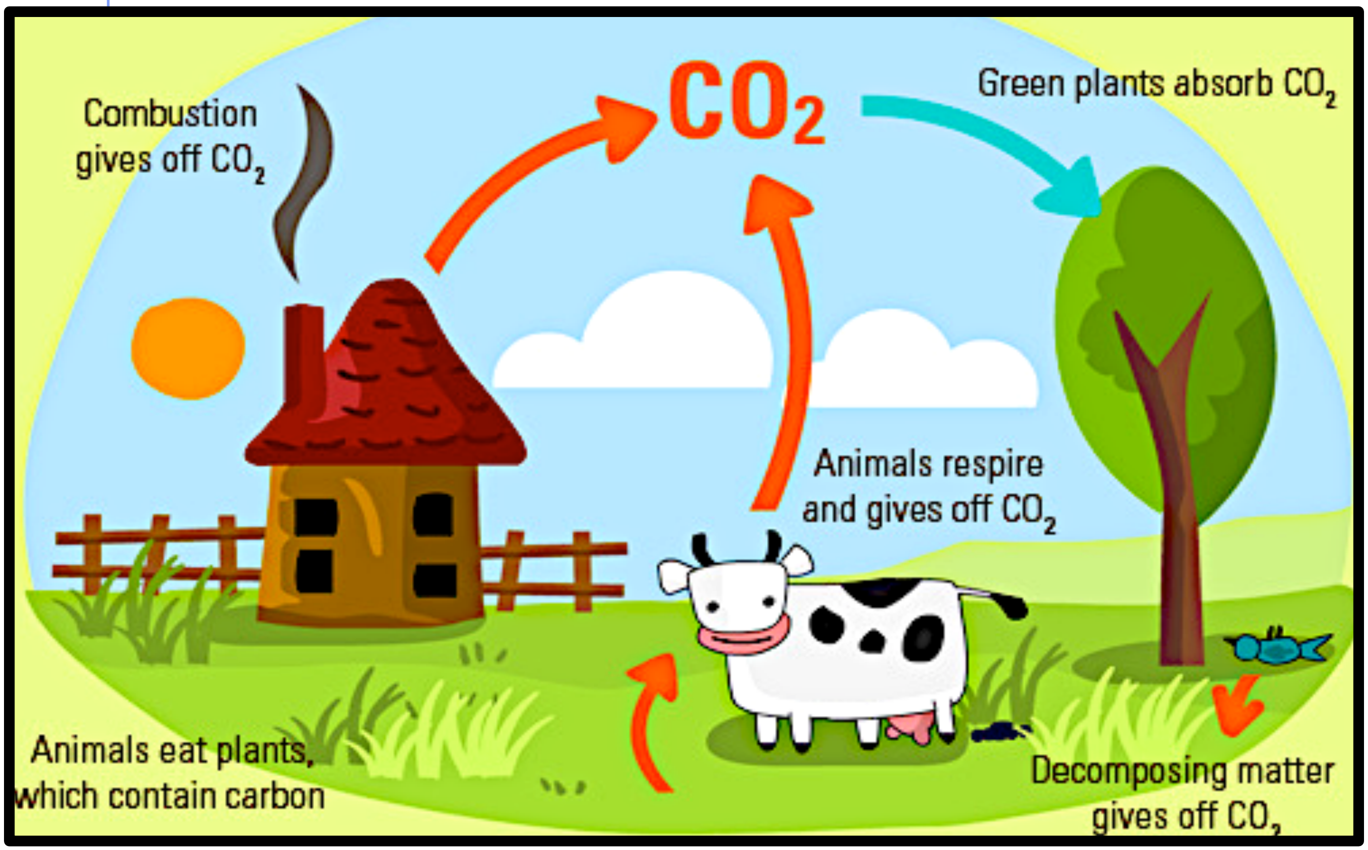


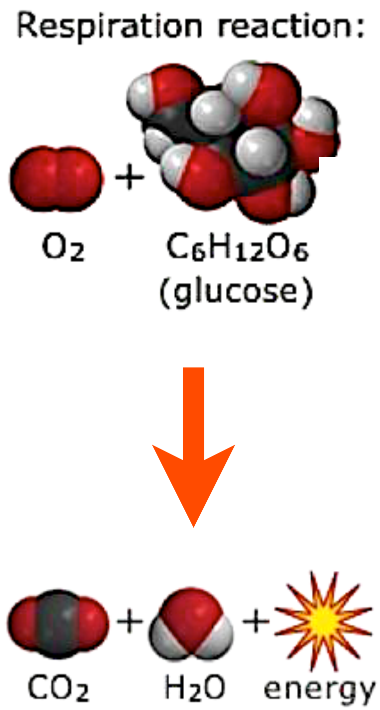
- Unlike energy, which flows THROUGH the environment (in from sun, out to space), carbon, as matter, is continuously cycled through and reused within the environment as part of one type of a biogeochemical cycle.
  - The Earth only has a fixed amount of carbon.
    - The movement of carbon from reservoir to reservoir is known as the carbon cycle.
- Producers *(plants, and certain protists and bacteria)* engage in photosynthesis that allows them to capture the carbon in carbon dioxide in our atmosphere and, using energy of the sun and the electrons from water, combine these carbon atoms into high energy, organic sugars (carbohydrates) and later other organic molecules like lipids, nucleic acids, and proteins.

(Organic molecules = molecules made with C & H atoms)

The Carbon Cycle

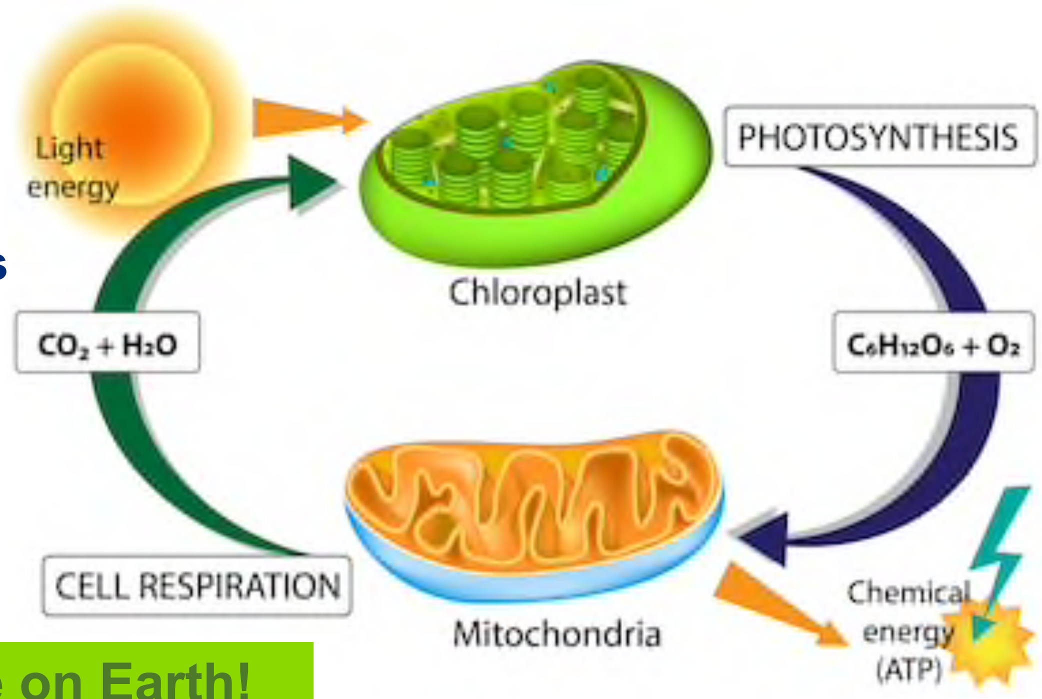
- Many non-photosynthetic organisms *(consumers and decomposers)* on the planet use the oxygen, and a process known as cellular respiration, to extract the energy stored in the covalent bonds of these carbon-based carbohydrates, releasing water and carbon in the form of low energy, inorganic carbon dioxide back to the atmosphere.





The Carbon Cycle

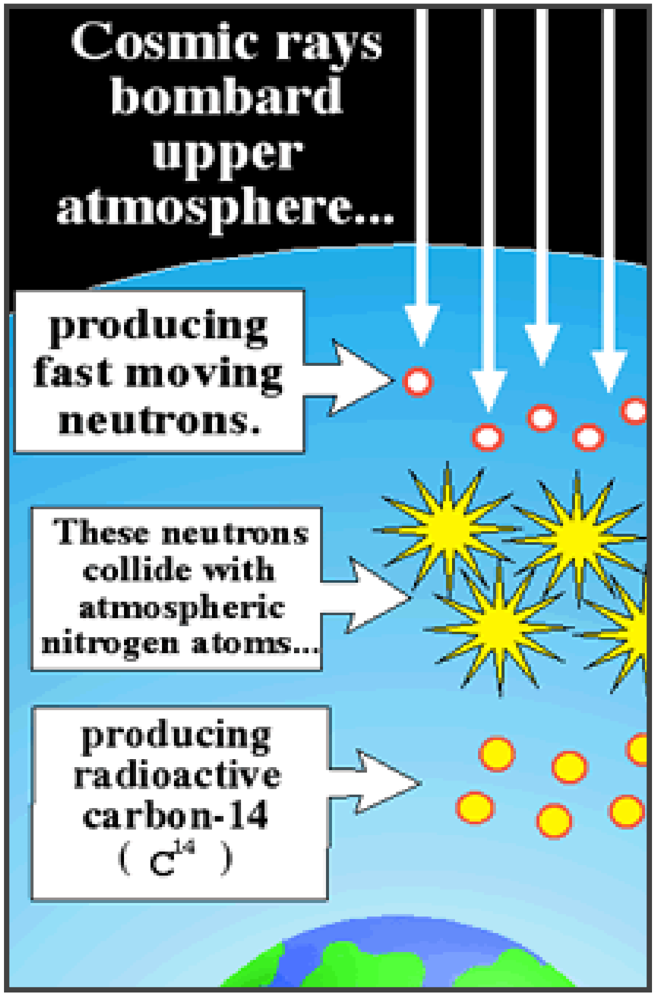
- The amount of carbon on Earth doesn't changes. However, the amount of carbon in a specific reservoir can change over time as carbon moves from one reservoir to another.
  - Besides the bodies of living organisms and the air, carbon is also found dissolved in ocean water or as part of aquatic organisms' shells or skeletons, such as seen in clams and coral.
  - Most of the carbon on the planet is contained within rocks, minerals, and other sediment buried beneath Earth's surface.
    - Fossil fuels *(coal, oil, natural gas etc)* extracted from the Earth represents organic carbon that was not decomposed, though when these are burnt, the C is returned through combustion reactions to the atmosphere as CO_2.

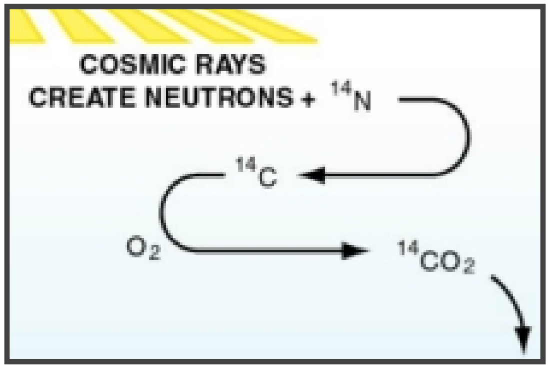


The carbon cycle is vital to life on Earth!

How does C-14 Become Part of the Carbon Cycle?

- Radiocarbon (Carbon-14) is continuously present on the Earth.
  - Cosmic rays from the sun bombard our atmosphere causing neutrons to collide with a nitrogen-14 atom which has 7 protons + 7 neutrons.
    - The neutron knocks a proton free and takes its place, creating a carbon-14 atom with 6 protons + 8 neutrons.
      - This process is called cosmogenic production.
- Once produced, Carbon -14 atom enters the carbon cycle.



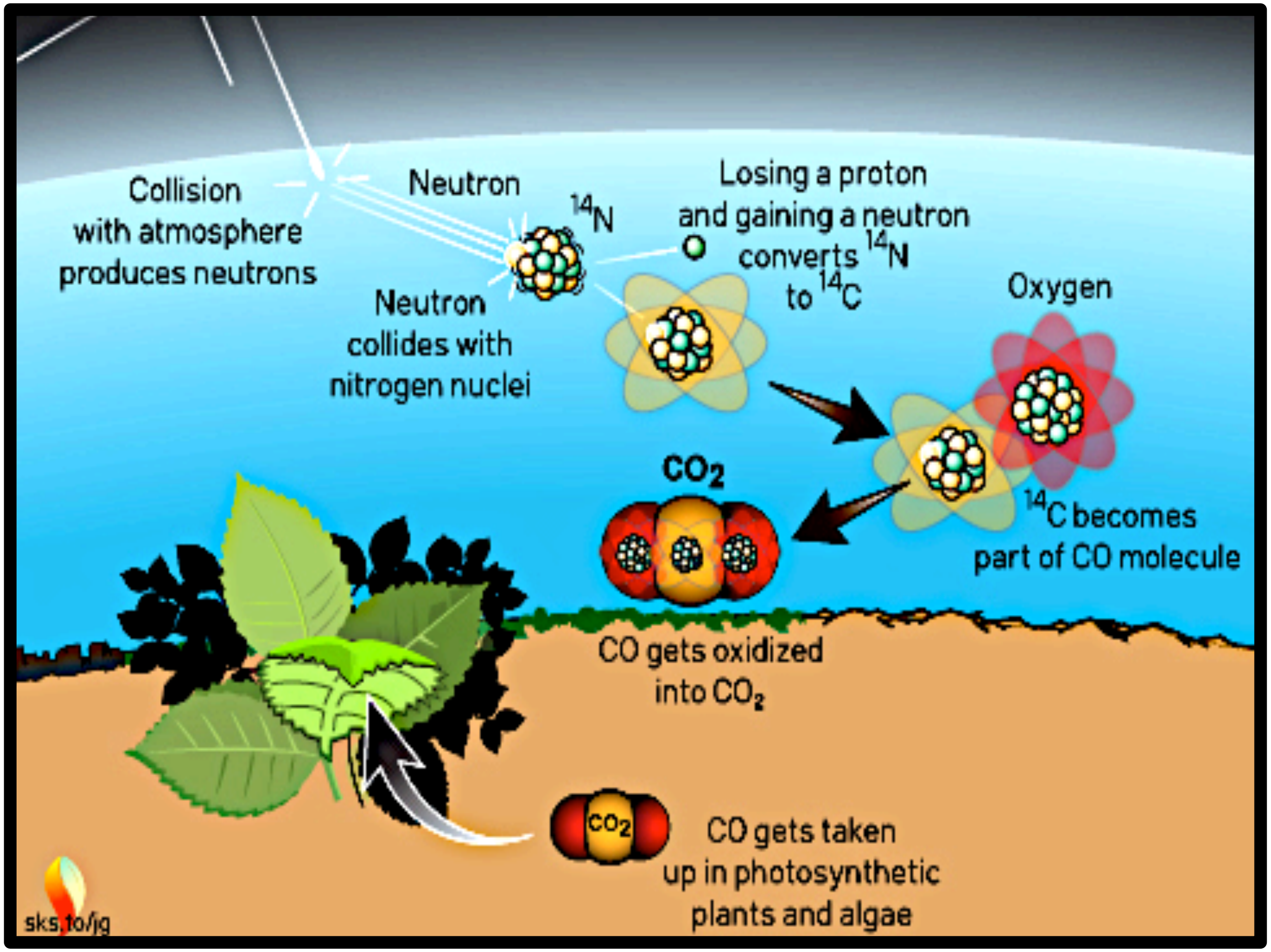


C-14 circulates in the atmosphere mainly in form of carbon dioxide ($^{14}CO_2$).

How does Carbon-14 enter the Food Chain?

$^{14}CO_2$ gets assimilated into organic matter by producers.

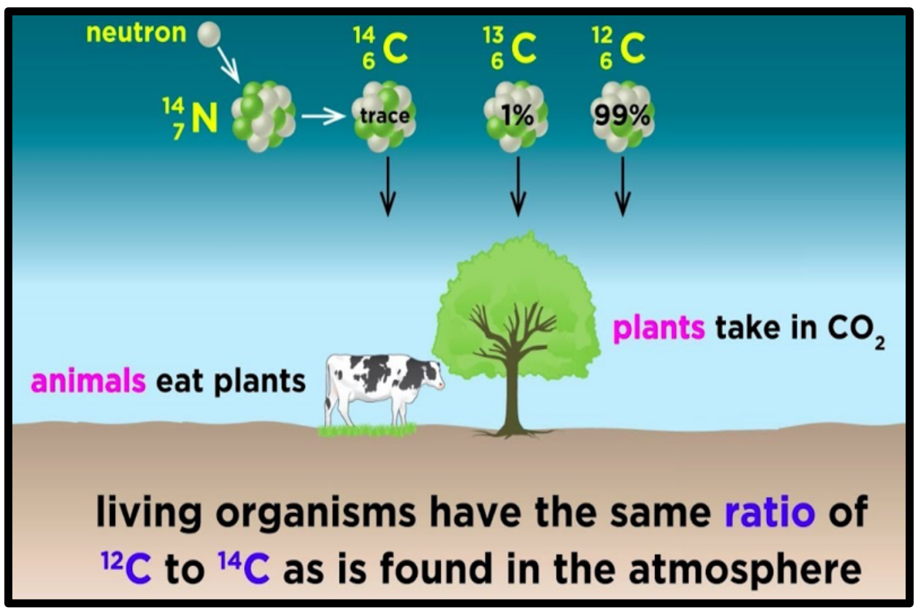
- Through photo-synthesis, producers absorb the C-14 (as part of CO_2) from the atmosphere, converting it into molecules of sugar:

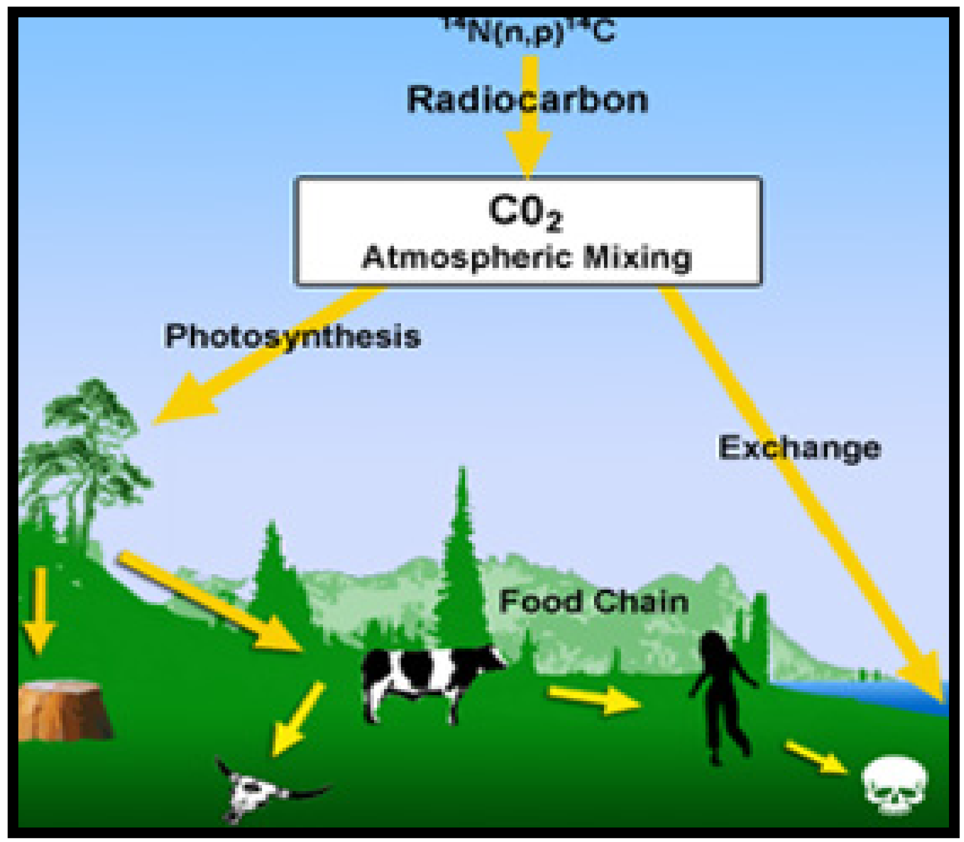


$CO_2 + H_2O$
(+ Radiant Energy)
$\Rightarrow C_6H_{12}O_6 + O_2$

How does Carbon-14 enter the Food Chain?

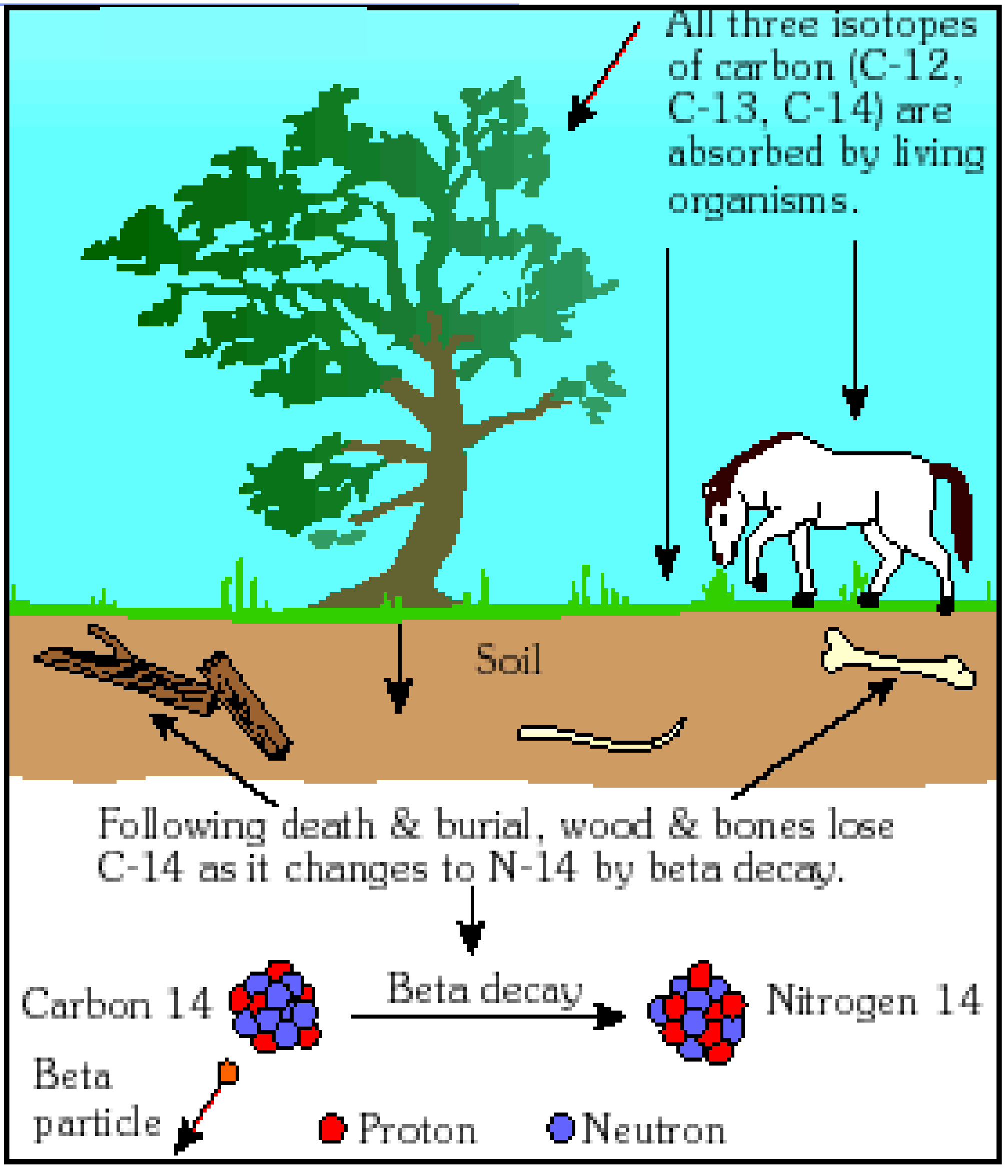
- **Carbon-14 is circulated when consumers feed off producers and consumers eat other consumers.**
  - **It may also be dissolved and circulate with oceanic water where it becomes incorporated living aquatic organisms as well.**
  - **In living organisms, the concentration of C-14 remains constant.**





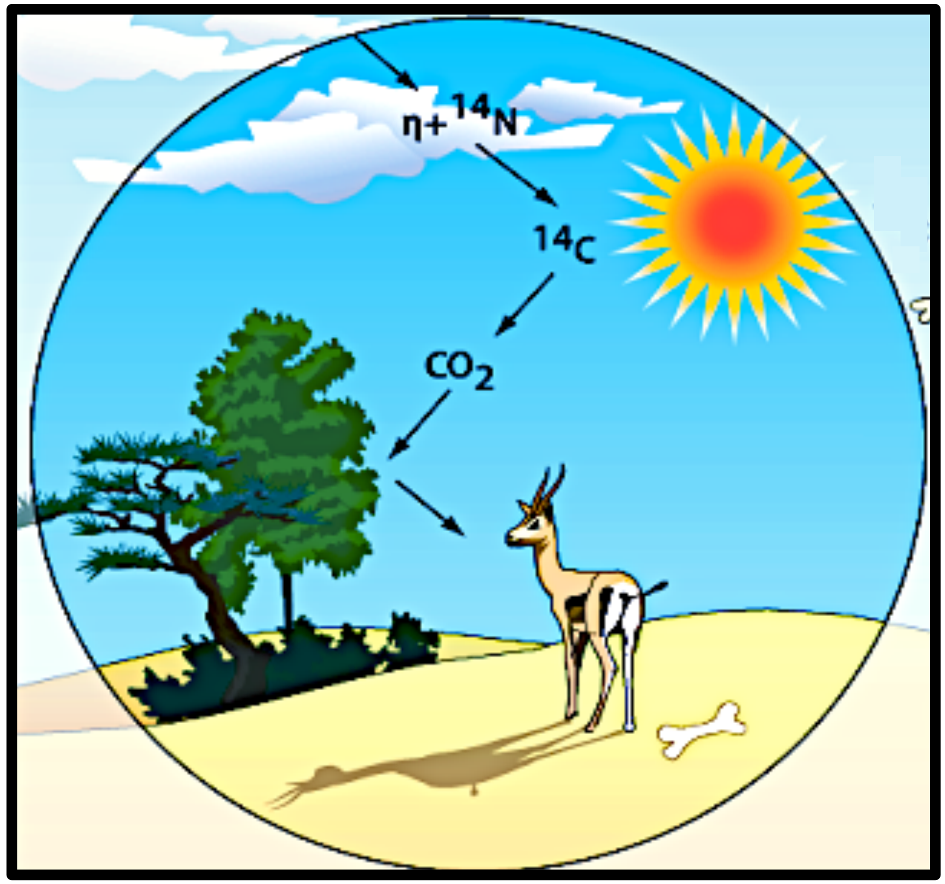
RADIOCARBON DATING

- ONLY AFTER DEATH, WILL THE LEVELS OF C-14 BEGIN TO DECREASE IN THE ORGANISM'S REMAINS OR RESULTING FOSSILS BECAUSE C-14 LOSS IS NO LONGER BEING REPLACED
  - On average, total radiocarbon production rate on the Earth is in equilibrium with (equal to) the decay rate.
    - The concentration of C-14 remains CONSTANT in the atmosphere.



CARBON DATING - Looking at ^{14}C / ^{12}C

- **Due to assimilation from atmosphere, concentration of ^{14}C in living terrestrial organisms remains constant.**
  - The ratio of carbon-12 to carbon-14 in the air (R_{atm}) and in all living things (R_o) at any given time is nearly constant.



The carbon-14 atoms are always decaying, but they are being replaced by new carbon-14 atoms at a constant rate in living organisms.

CARBON DATING - Looking at ^{14}C / ^{12}C

- Remember, only unstable isotopes decay over time.
  - After death, the amount of C-12 will remain constant, but the amount of C-14 will decrease over time.
    - The smaller the ratio, the longer the organism has been dead.
- Radiocarbon dating can't be used to directly date rocks, but can only be used to date organic material made by <u>once living</u> organisms.
  - When an organism dies, the C-14 decays into N-14, with a half-life of 5,730 years.
    - Measuring the amount of 14C in dead material, and comparing that amount to the atmospheric amounts, which it once equaled when the organism was living, allows us to determine the time elapsed since death.

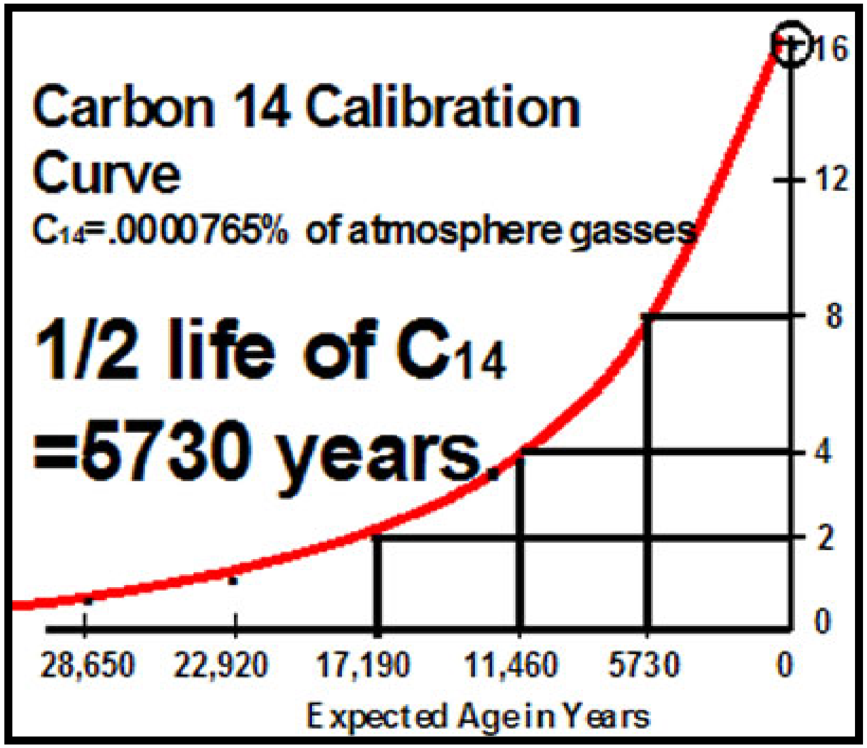
CARBON DATING - Looking at ^{14}C / ^{12}C

% 14C Remaining	%12C Remaining	# of Half-Lives	Years Dead
100	100	0	0
50	100	1	5,730
25	100	2	11,460
12.5	100	3	17,190
6.25	100	4	22,920
3.125	100	5	28,650

- Because of the short half-life of C-14, it is only used to date materials younger than about 60,000-80,000 years.
    - After this, the levels of become too small to detect.

RADIOCARBON DATING

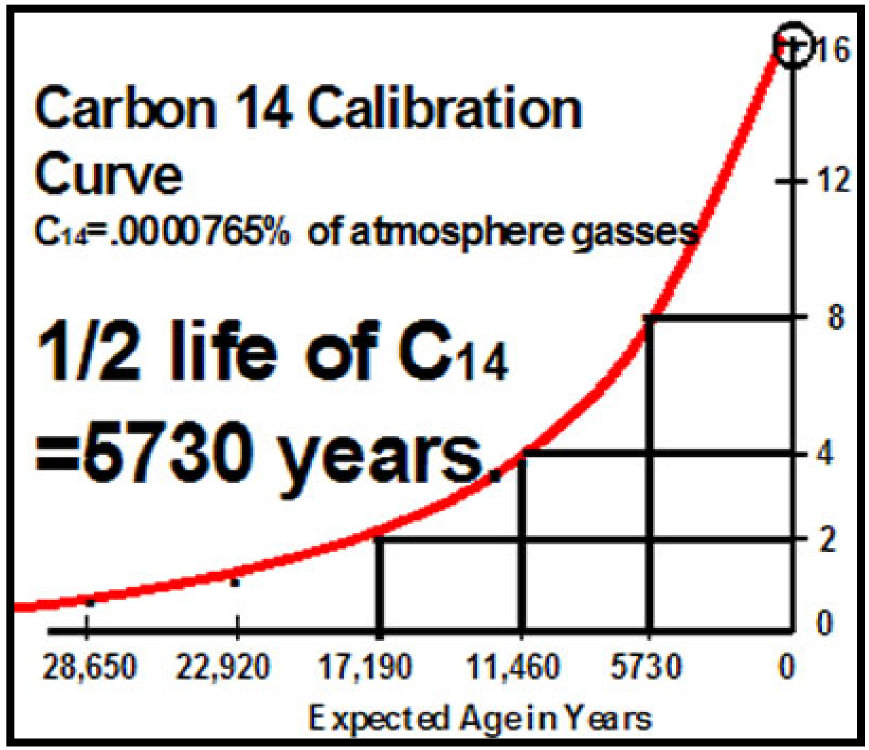
- It takes **5730 yrs** for half of a sample's C-14 to decay into N.
  - After 5730 years, 1/2 of the radioactive C atoms have not decayed.
  - After 11460 years (2 x 5730) half of 1/2 remains or 1/4 of the original amount of C-14is left.
  - After 17190 years (3 x 5730), only 1/8 of the original amount of C-14 remains.
- Similarly, going back in time 5,730 years, lets say from when a sample is 17,190 years old to when it was only 11,460 years old, means that the level of C atoms doubles.
  - EXAMPLE: If there are only 2 grams of radio-active isotope in a sample today, there would have been 2 grams x 2 = 4 grams one half-life ago



RADIOCARBON DATING

- If instead we go back in time 11,460 years, lets say from when a sample is 17190 years old to when it was only 5,730 years old, means that the level of C atoms quadrupled.

  - EXAMPLE: If there is only 2 grams of radio-active isotope in a sample today, there would have been (2 g x 2) x 2 = 8 grams two half-lives ago.



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RADIOCARBON DATING

SAMPLE PROBLEM:

Let's assume a fossil is found to contain 4 grams of radioactive isotope. It is also known that originally there were 16 grams of radioactive isotope. This particular isotope has a half-life of 25 years. How old is this fossil?

SOLUTION:

If 2 half lives passed, then the age of the fossil is 2 x 25 (the length of one half-life) = 50 years

This fossil is 50 years old.

RADIOCARBON DATING

SAMPLE PROBLEM:

Lets assume a fossil is found to contain 4 grams of radioactive isotope. It is also known that 3 half-lives have passed since the fossil was created. How much radioisotope was there at the time of death of the organism?

SOLUTION:

$$4 \times 2 \times 2 \times 2 = 4 \cdot 2^3 = 4 \cdot 8 = 32 \text{ grams}$$

Originally, there were 32 grams of radioisotope.