Matter and Energy

"The sun, with all those planets revolving around it and dependent on it, can still ripen a bunch of grapes as if it had nothing else in the universe to do."

- Galileo Galilei

Lessons From Thin Air

- In 1995, filmmakers from the Harvard Smithsonian Center for Astrophysics approached some new graduates from Harvard and the Massachusetts Institute of Technology.
- One of the questions they posed:

"Here's a seed. Imagine I planted that seed in the ground, and a tree grew. …Where did all that weight come from?"

"The President," a giant 3,200 year-old sequoia in California with a height of 247 feet.

A private universe ; Minds of our own. Dir. Lindsay Crouse. Harvard-Smithsonian Center for Astrophysics.

The Willow Tree Experiment

- The basic knowledge that plants need water, sunlight, and soil has been around since ancient times.
- The working hypothesis was that plants grew by "eating" soil through their roots.
- Jean Baptiste von Helmont wanted to verify this – to isolate the exact source of the increased mass of trees as they grew.

The Willow Tree Experiment

- Van Helmont planted a 5-pound willow tree in 200 pounds of dry, potted soil.
- He massed the tree, grew it for 5 years, then massed it and the soil again.
- The tree gained over 160 pounds of mass.
  - The soil only decreased in mass by about 2 ounces!
- The old hypothesis was rejected in favor of a new one – the mass came from water!

Matter and Energy

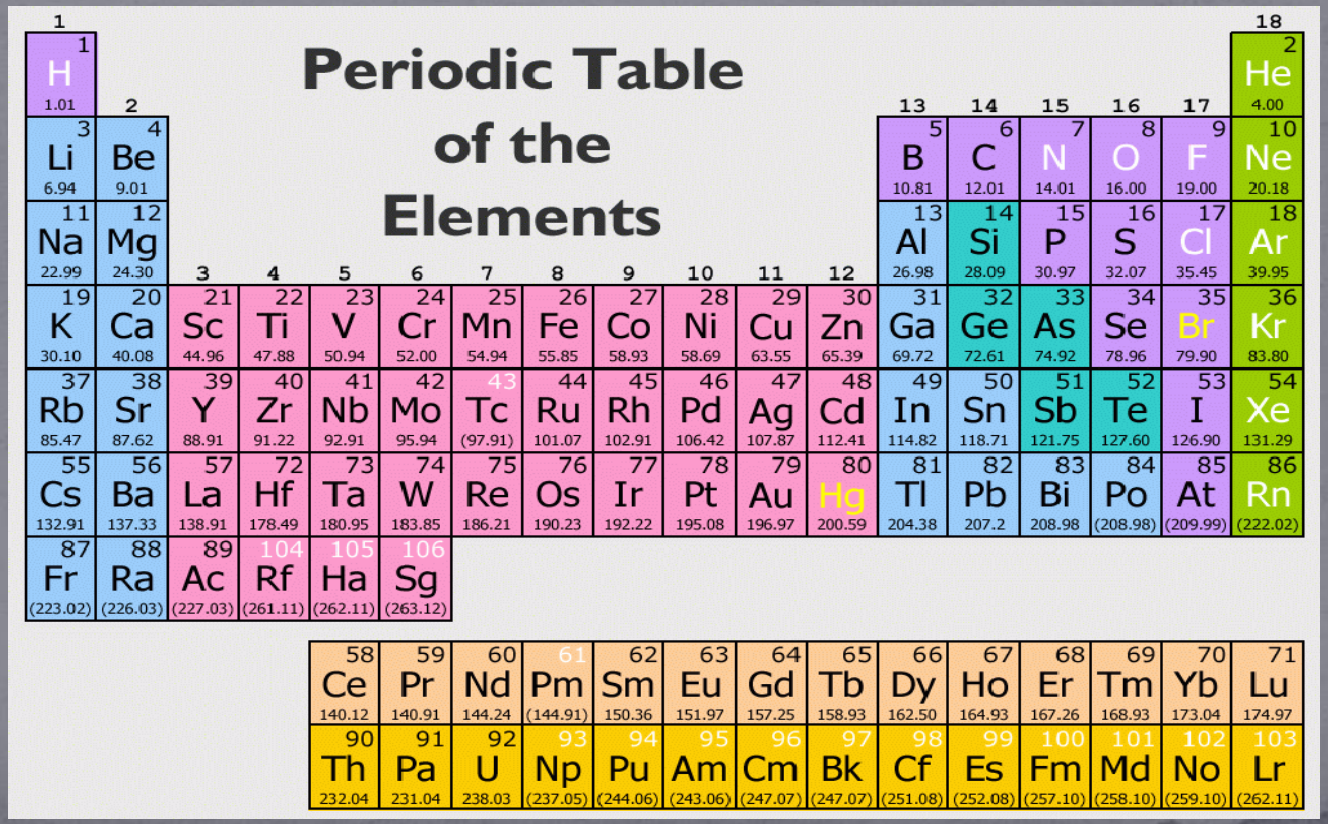
- Life cannot exist without two basic inputs: MATTER and ENERGY.

MATTER is any physical substance that has mass and occupies space (volume). The Earth is basically a closed system to matter.

ENERGY is the ability to do work. Most life on Earth could not survive without a constant input of energy from the sun.

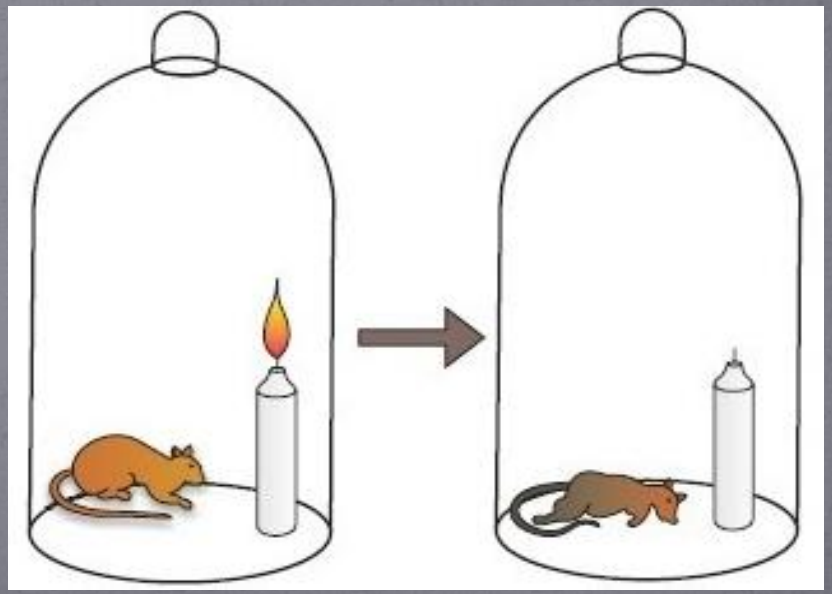
Elements

- All matter in the universe is made of elements –the periodic table represents all the known types of elements in the universe.



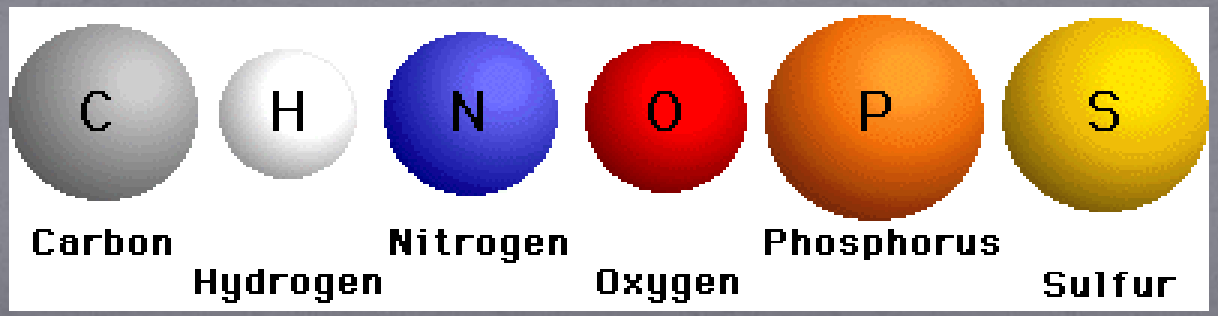
Priestley's Experiment

- Joseph Priestley, a British chemist, believed that air was not a single "elementary substance", but a "composition" of gases.
- During one experiment, he discovered that a candle placed in a sealed jar would extinguish very quickly.
  - He called the air "injured."
- Placing a mouse in the jar would have a similar effect, and it would die.
- Priestley had discovered the ELEMENT oxygen.



Elements of Life

- Carbon, hydrogen, oxygen, and nitrogen make up 96% of all living things.
- The remaining 4% is mostly calcium, phosphorous, potassium, and sulfur.
- These actually correspond to the most abundant elements in the universe……



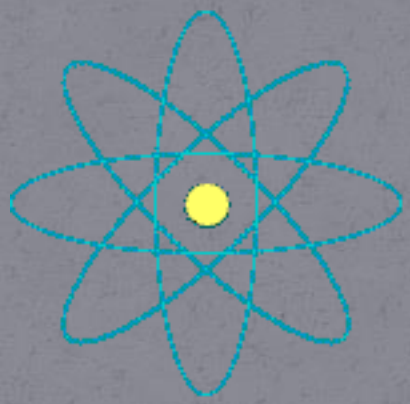
Elements by Amounts

- In your Body-
  C, O, H, N
- In the Universe-
  H, He, C, N, O

http://www.youtube.com/watch?v=JQMuNImYzjc

Atoms

- The smallest part of an element is an ATOM. It is the smallest particle that still exhibits the characteristics of it's element.

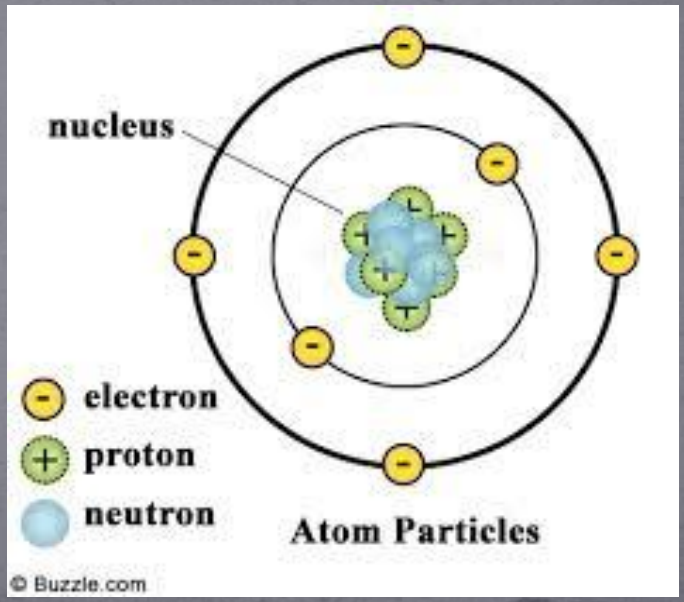


"Like everyone you are made of atoms. Atoms are RECYCLED through the universe in innumerable forms, both living and nonliving… so you don't "own" the atoms that make up your body – you are simply the present caretaker. There will be many more!!!

Atomic Structure

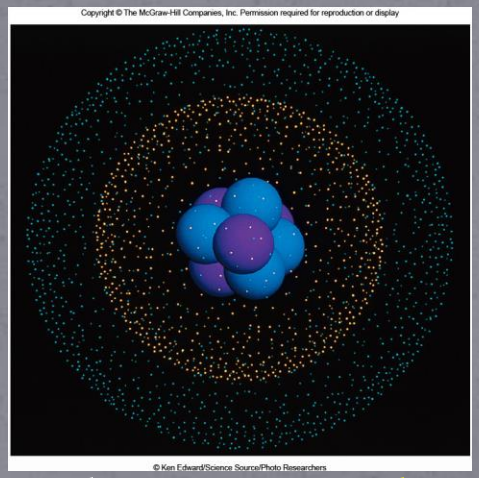
- All atoms are made of a combination of the same three particles:
  - Protons - Positively charged, located in the nucleus.
  - Electrons - Negatively charged, orbits the nucleus.
  - Neutrons – Neutral, located in the nucleus.

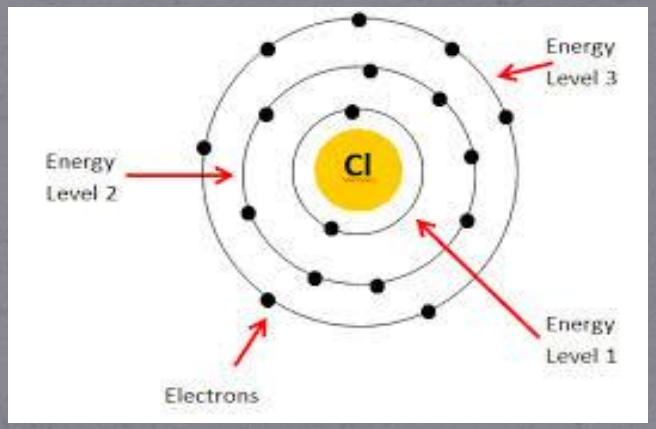
Incredibly strong forces bind protons and neutrons together to form the NUCLEUS of the atom.



Electrons

- Electrons have only 1/1840 the mass of a proton.
- Electrons are in constant motion around the nucleus.
  - This area is known as the ELECTRON CLOUD.
- But they are actually in various "energy levels" or "shells".

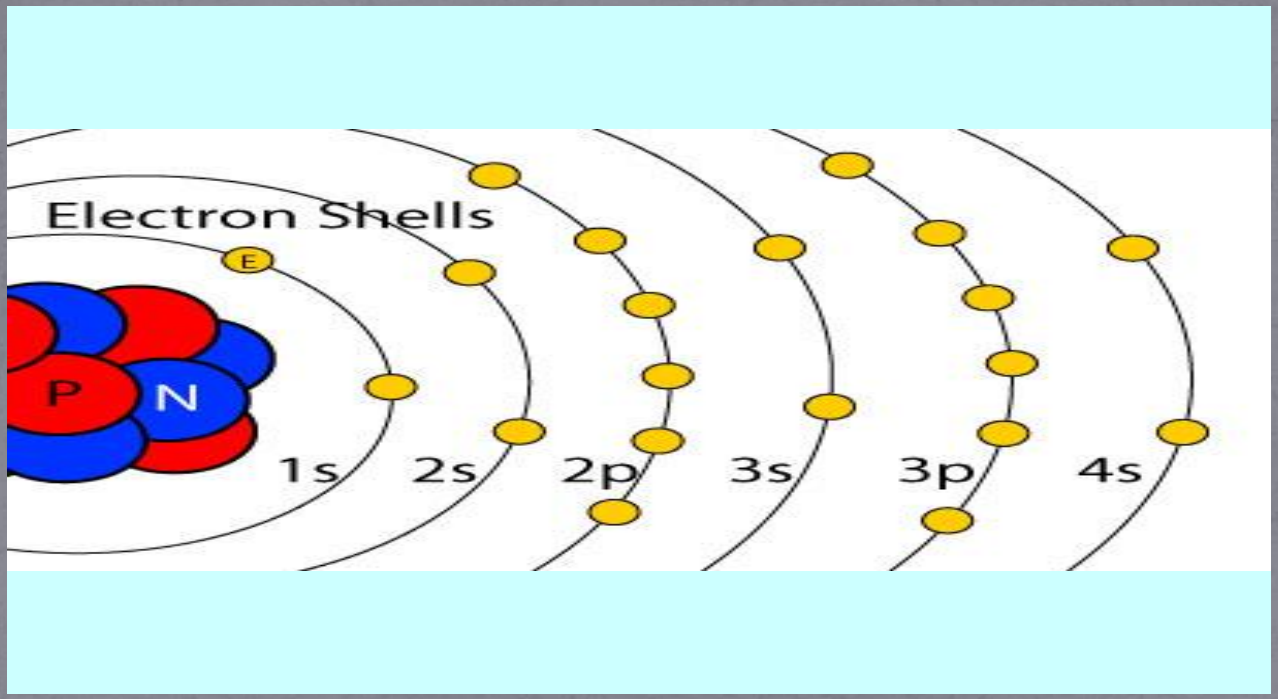




- Electrons determine *how reactive* an atom will be with other atoms!

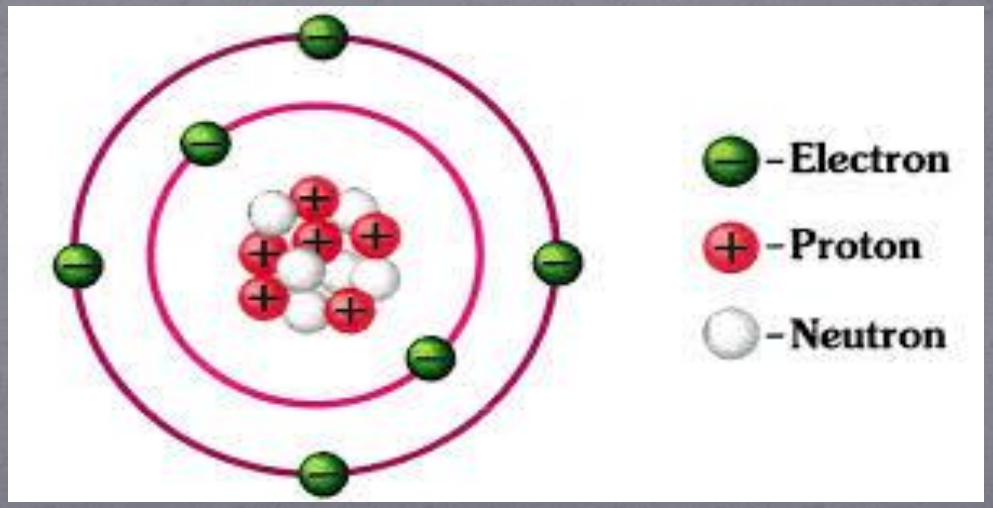
Electron Orbitals

- Electron orbitals or "shells" are related to their energy
- Higher energy electrons are further from the nucleus.



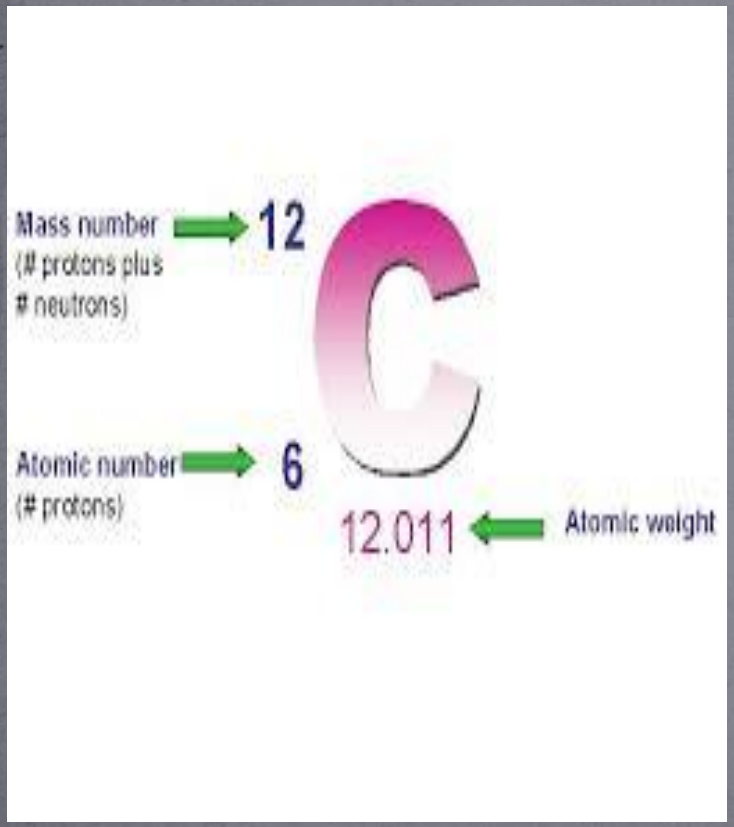
Protons & Neutrons

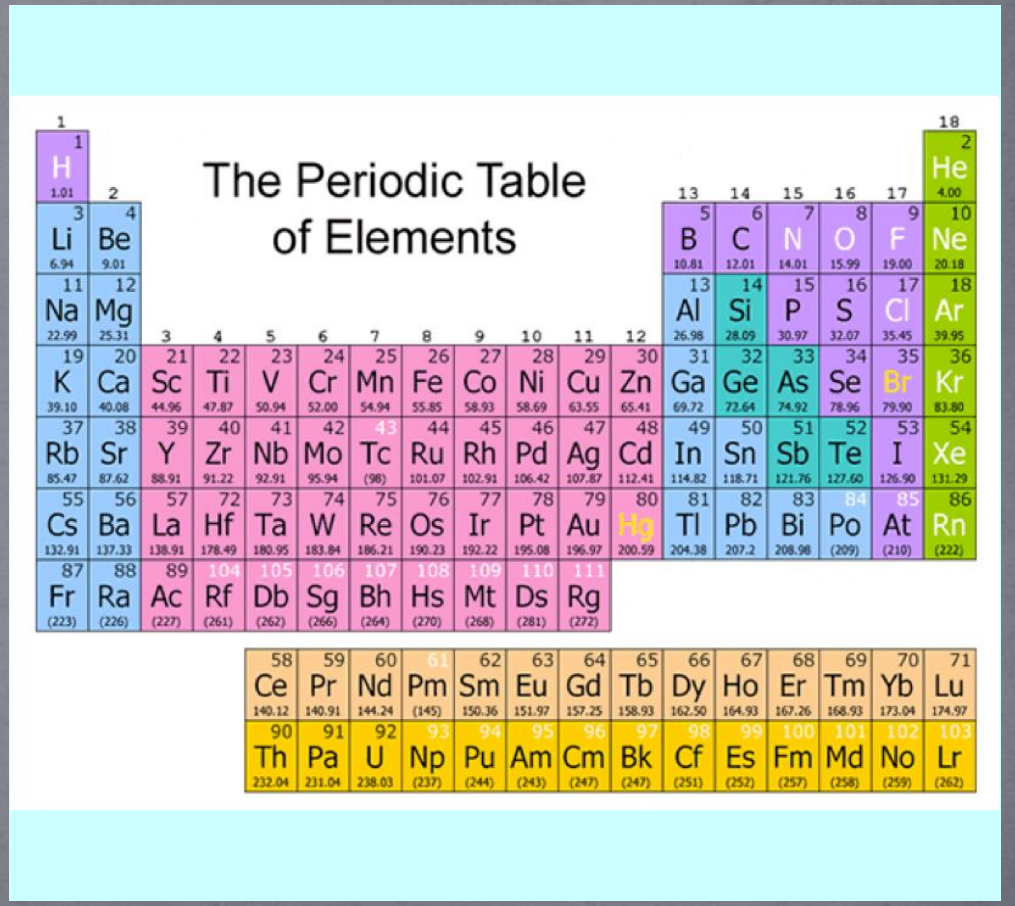
- The number of protons determines which element the atom is… Carbon ALWAYS has 6 protons.
- This is called the ATOMIC NUMBER.
- The number of protons + neutrons is how massive the atom is … Carbon has a total of 12 protons + neutrons.
- This is called the ATOMIC MASS Or WEIGHT.



Periodic Table

- All this information is on a chart: The Periodic Table.





Atomic Symbols

- Each element has a unique symbol.
- Symbols are 1 or 2 letters.
- Based on the name of the element:

  Carbon = C

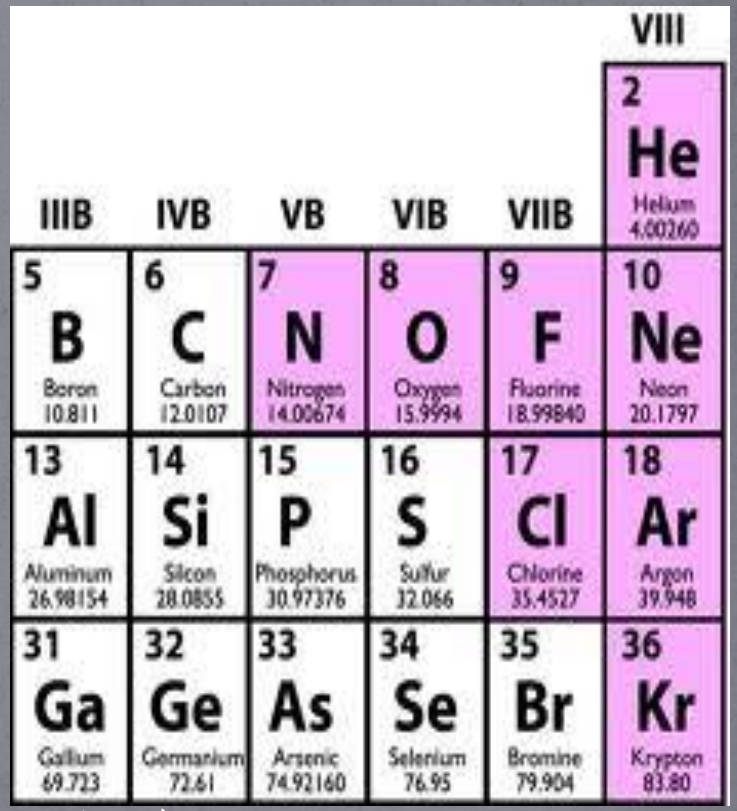
  Oxygen = O

  Chlorine = Cl

  Sodium = Na

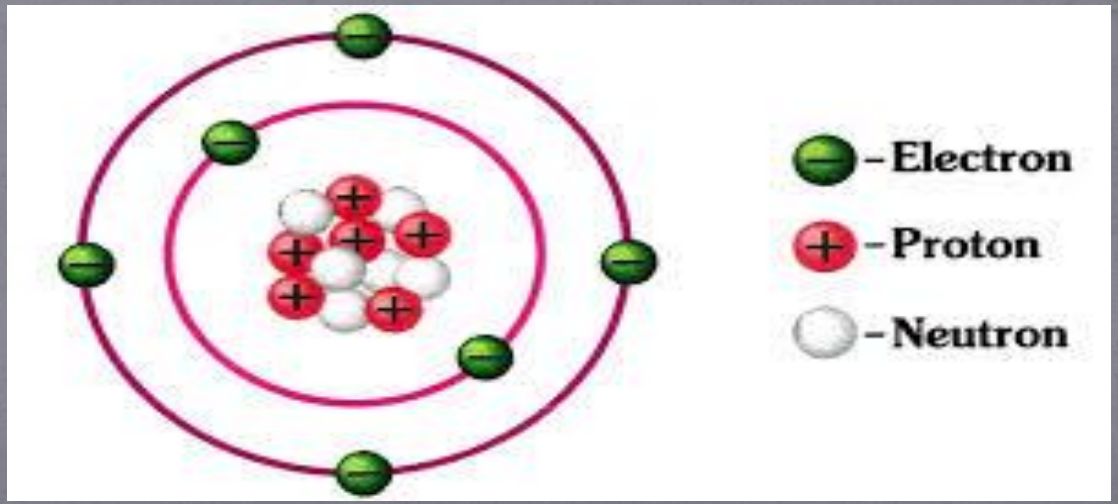
  Iron = Fe

(Latin names are sometimes used…)



Neutral Atoms

- Neutral atoms have equal numbers of protons and electrons.
- The positive and negative charges cancel each other out leaving no NET charge across the atom.
- The carbon atom shown is neutral with 6 protons and 6 electrons.

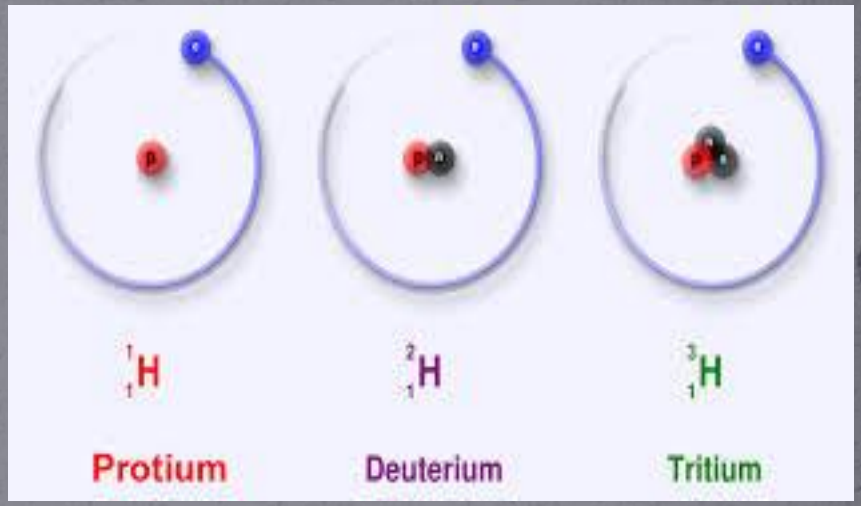


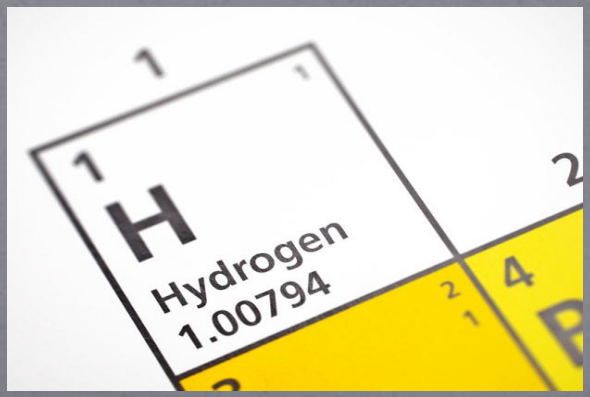
Using the Periodic Chart

Element	Symbol	Atomic Number	Atomic Mass	Number of Protons	Number of Neutron	Number of Electron
Carbon						
				11		
		8				
Chlorine						
	Cu					

Isotopes

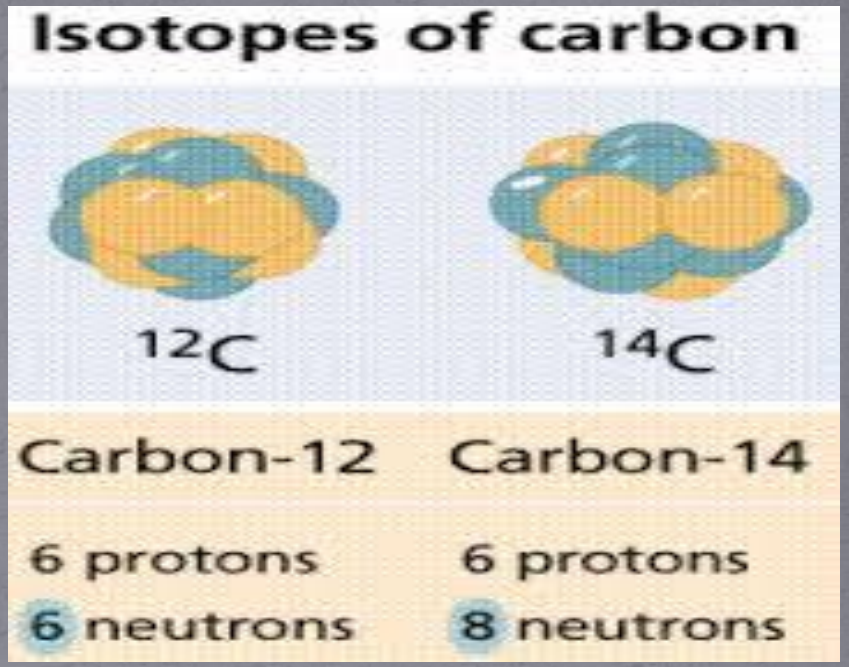
- Isotopes are atoms of the SAME elements that have a DIFFERENT number of neutrons.
- This gives them different masses.
- So this means the ATOMIC MASS of the element is an AVERAGE of all the isotope masses!





Carbon 14

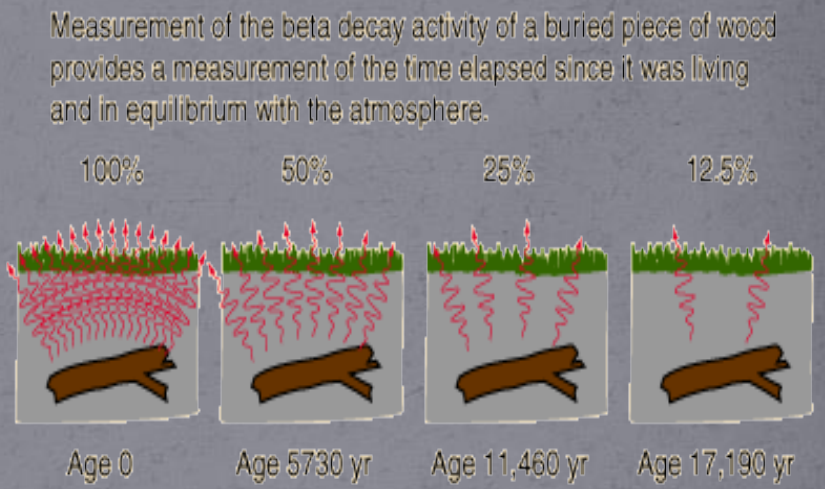
- Carbon has 3 isotopes:
  - Carbon 12
  - Carbon 13
  - Carbon 14



- Carbon 14 is a RADIOACTIVE isotope.
- Radioactive isotopes breakdown over time.
- This makes them very useful in science & medicine.

Carbon 14 Dating

- The half-life of an isotope is the amount of time it takes for half of a sample to breakdown or "decay".
- The half-life of C14 is 5,700 years.
- All living things contain the element carbon, so this can be used to determine the age of fossils.



http://www.youtube.com/watch?v=phZeE7Att_s

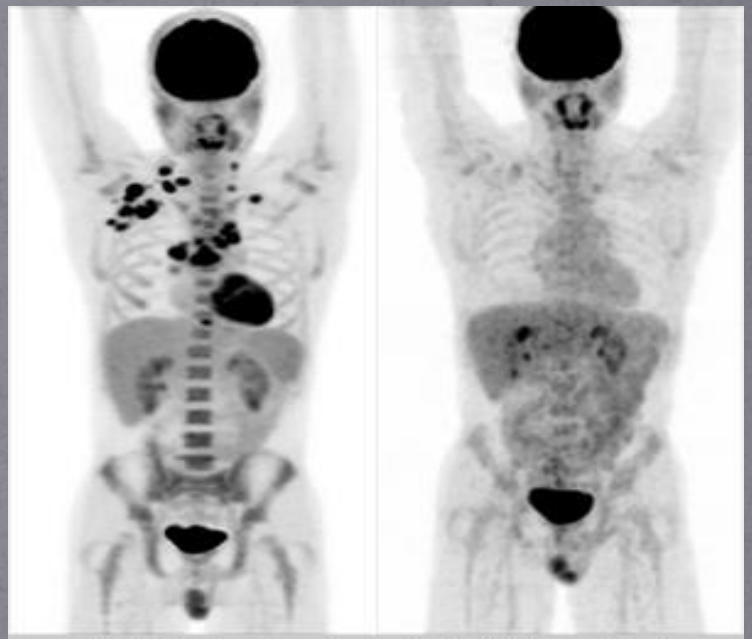
Carbon Dating Example

- An archeologist discovers a piece of pottery.
- Inside that pottery are some seeds.
- Chemical analysis reveals the seeds only have about 25% of the the original C14 remaining.
- How old is the piece of pottery?

- Think:
  - 100% -> 50% -> 25%

Radioactive Tracer Isotopes

- Tracer isotopes can be used to identify tumors or blockages in the body.



FDG PET study of a patient with large B cell lymphoma at baseline (left) and after 4 cycles of systemic chemotherapy. There is complete metabolicresponse of initial hypermetabolic lymphadenopathy (right).

Ions

- Atoms that have gained or lost an electron are no longer neutral…they now have a (+) or a (–) charge.
- These charged atoms are called IONS.
- Some common IONS in your body:

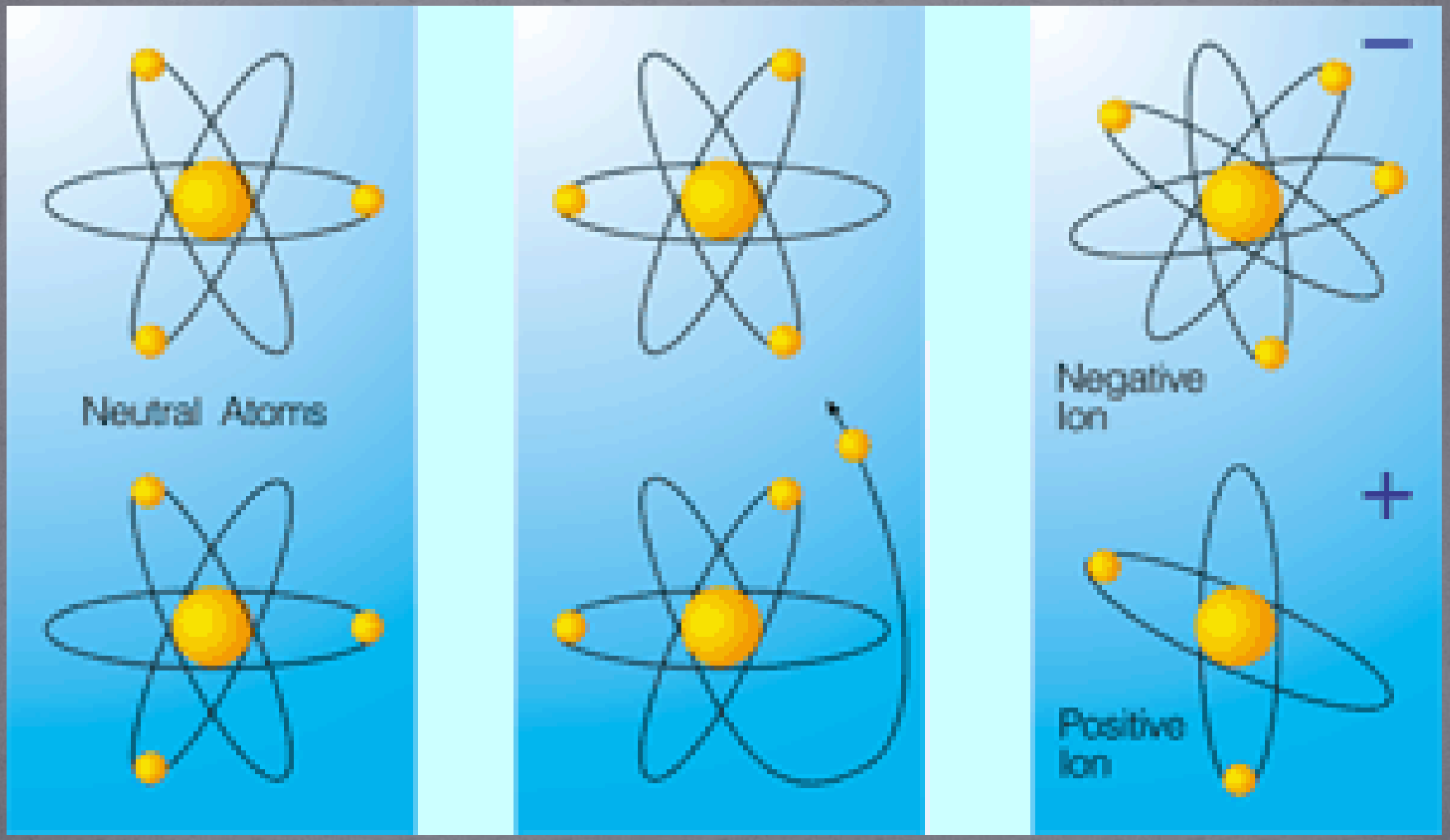
  Na+ (sodium), in tears and sweat.

  K+ (potassium) in nerves and blood.

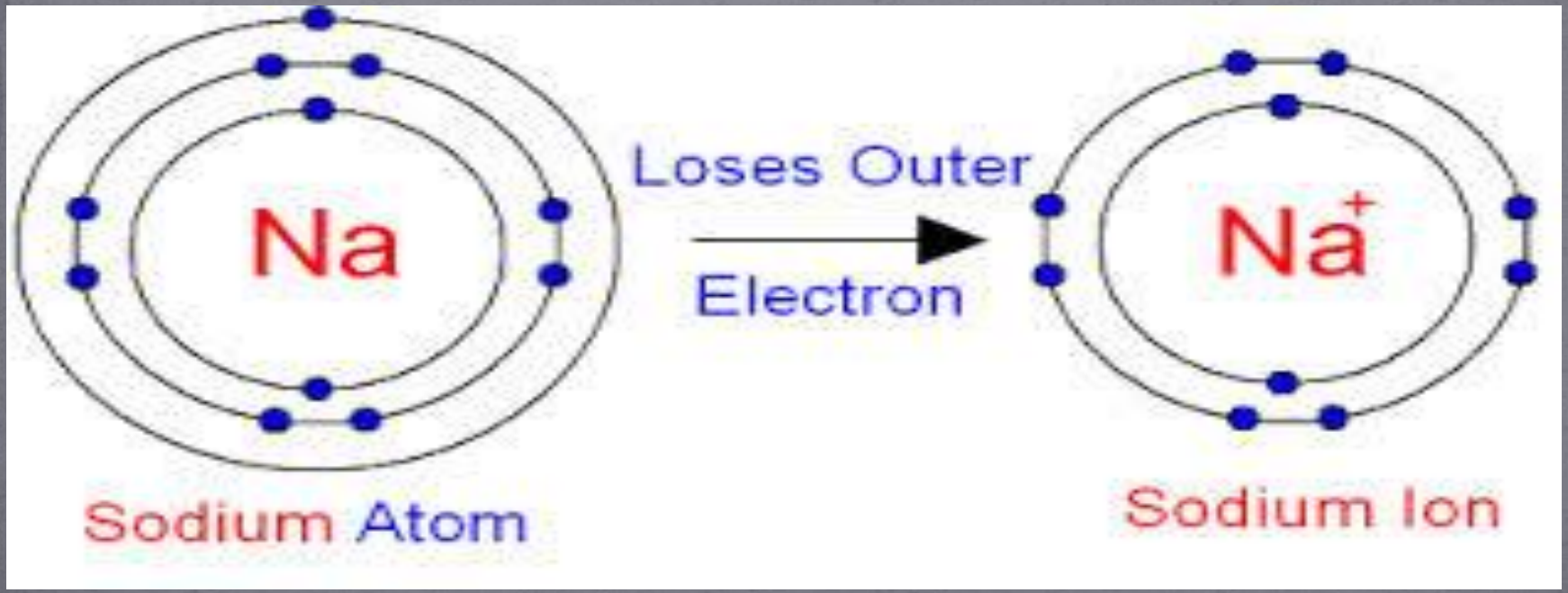
  Ca+ (calcium) in bones, muscles and nerves.

  Cl- (chlorine) in stomach acid

How Ions Form

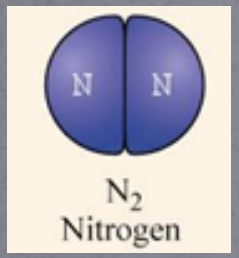


Examples of Ions

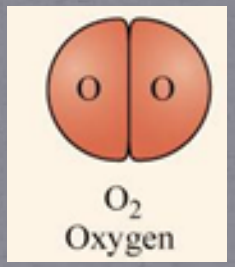


Air

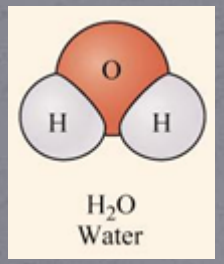
- Priestley's hypothesis about the composition of air was correct.
- Air is primarily made of:



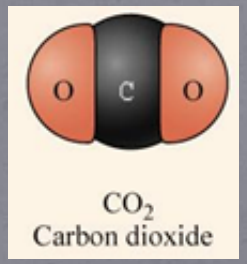
78%



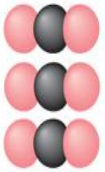
21%



0.02%



0.03%

C	means		One atom of carbon
O	means		One atom of oxygen
O_2	means		One molecule of oxygen consisting of two atoms of oxygen
CO	means		One molecule of carbon monoxide consisting of one atom of carbon attached to one atom of oxygen
CO_2	means		One molecule of carbon dioxide consisting of one atom of carbon attached to two atoms of oxygen
3 CO_2	means		Three molecules of carbon dioxide, each consisting of one atom of carbon attached to two atoms of oxygen

Ingenhousz's Experiment

- A Dutch physician, Jan Ingenhousz, repeated Priestley's experiment, with a few changes:
  - The sealed containers had a plant exposed to sunlight!
- When exposed to sunlight the candle would continue to burn and the mouse would stay alive!

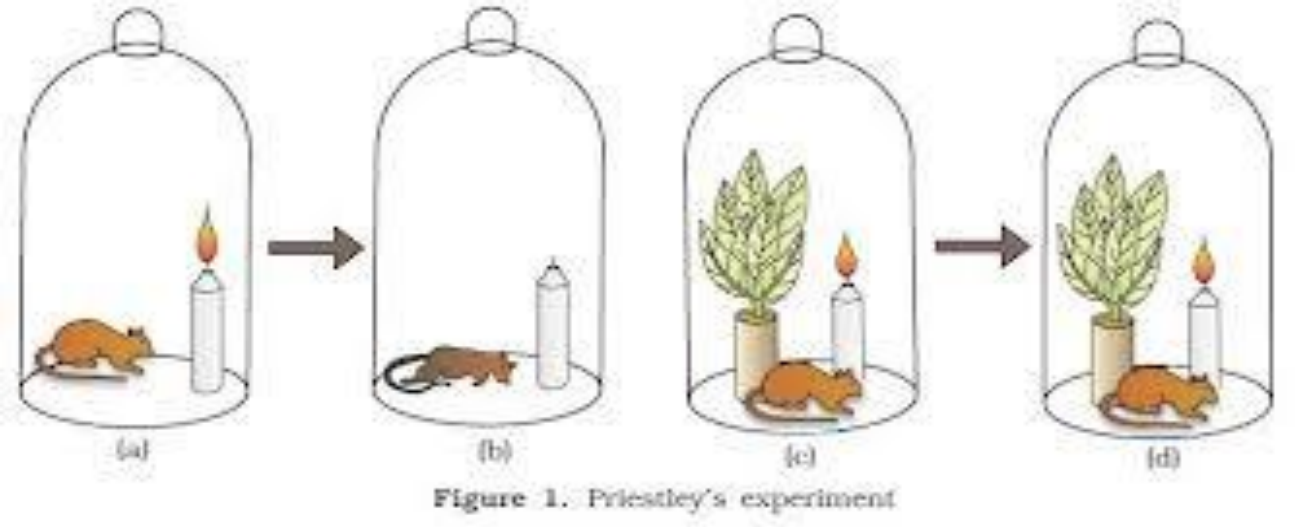
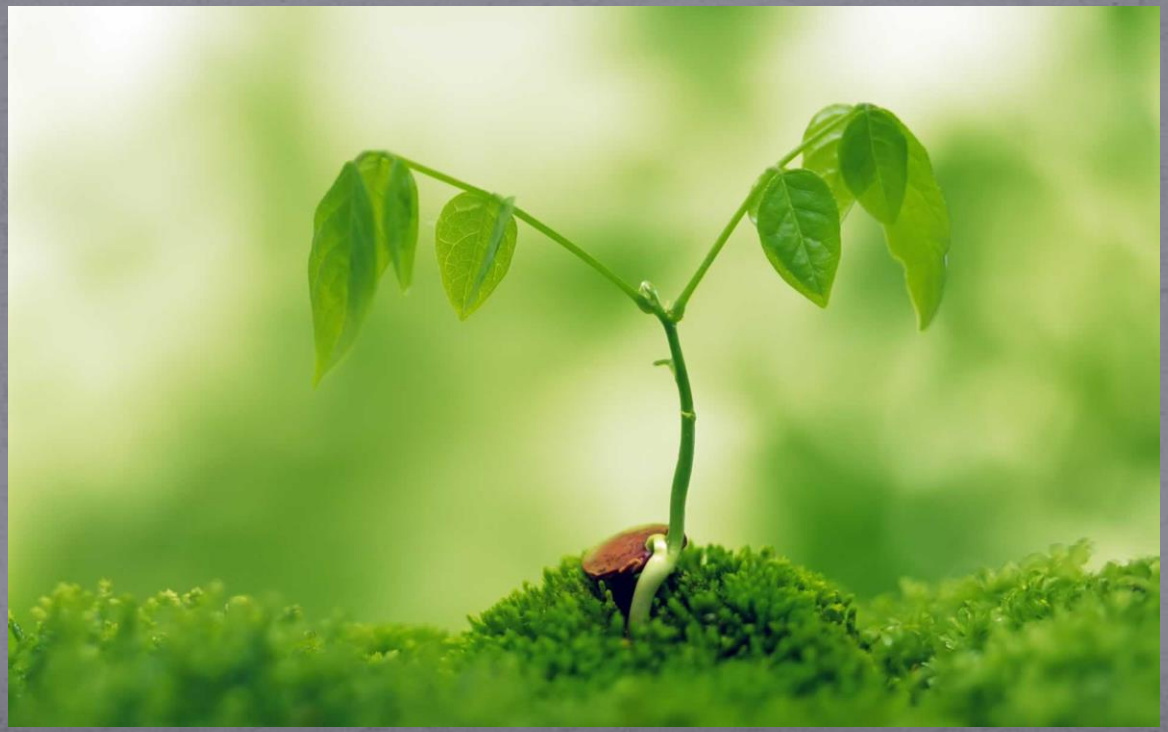


Figure 1. Priestley's experiment

Energy and Life

- Most of the energy that supports life on Earth originates from the sun.
- Solar radiation actually contains three wavelengths of energy:
  - Ultraviolet
    - Able to penetrate living tissue; causes skin damage.
  - Visible
    - Range of wavelengths we can detect with our eyes.
  - Infrared
    - Heat energy.

- Plants are able to use wavelengths of VISIBLE light as a source of energy to make food (sugar).
- What does this process have to do with the mass plants gain as they grow?



Photosynthesis

- The final piece of the puzzle was solved by a Swiss botanist named Nicolas de Saussure.
  - He enclosed plants in a sealed container of carbon dioxide: CO_2
  - By weighing the plant and the carbon dioxide before and after growth, he was able to show that the increased mass was a combination of:
    - Water from the soil.
    - Carbon from the air.
- The process was called photosynthesis. The overall equation was eventually discovered to be:

$$H_2O + CO_2 + \text{solar energy} \rightarrow C_6H_{12}O_6 + O_2$$

Cell Respiration

- Other organisms, such as animals and fungi, cannot directly absorb sunlight.
- They rely on a process called cell respiration, which breaks down molecules in food to provide them with energy.

$$C_6H_{12}O_6 + O_2 \rightarrow H_2O + CO_2 + \text{energy}$$

- Photosynthesis and cell respiration complement each other, forming the basis of the flow of energy and cycling of matter that makes up living ecosystems.

Energy Flows

- As energy flows through an ecosystem, it obeys two Laws of Thermodynamics.

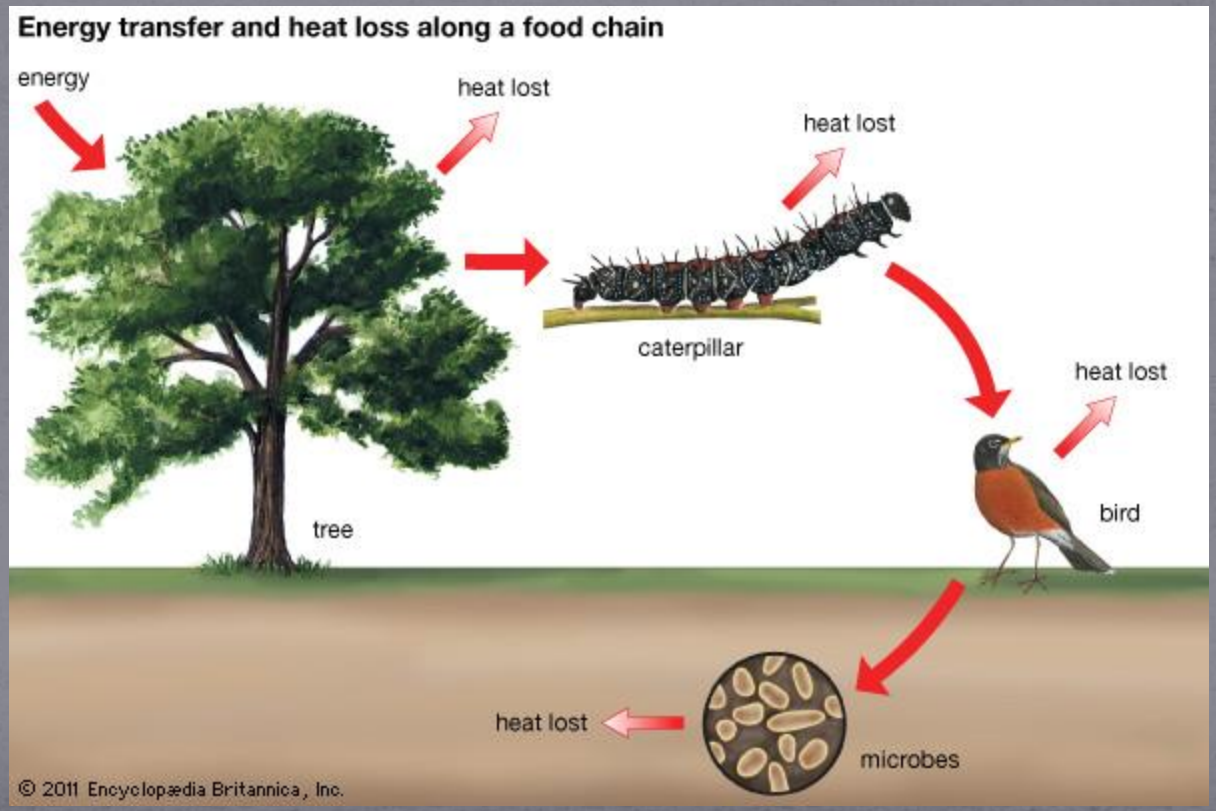
1. Energy cannot be created or destroyed, it only changes form.

   (This is also known as the *Law of Conservation of Energy*)

2. During each transformation, some energy is given off in the form of heat.

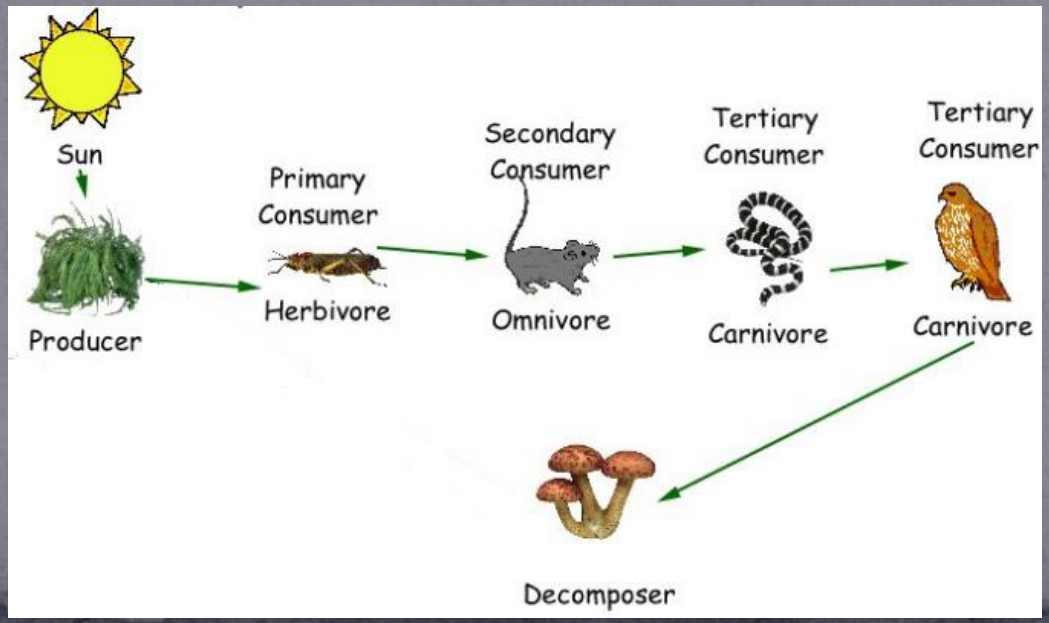
Food Chains

- In a biological community, energy can be tracked with a diagram called a food chain.
  (Movement of energy is shown by arrows)



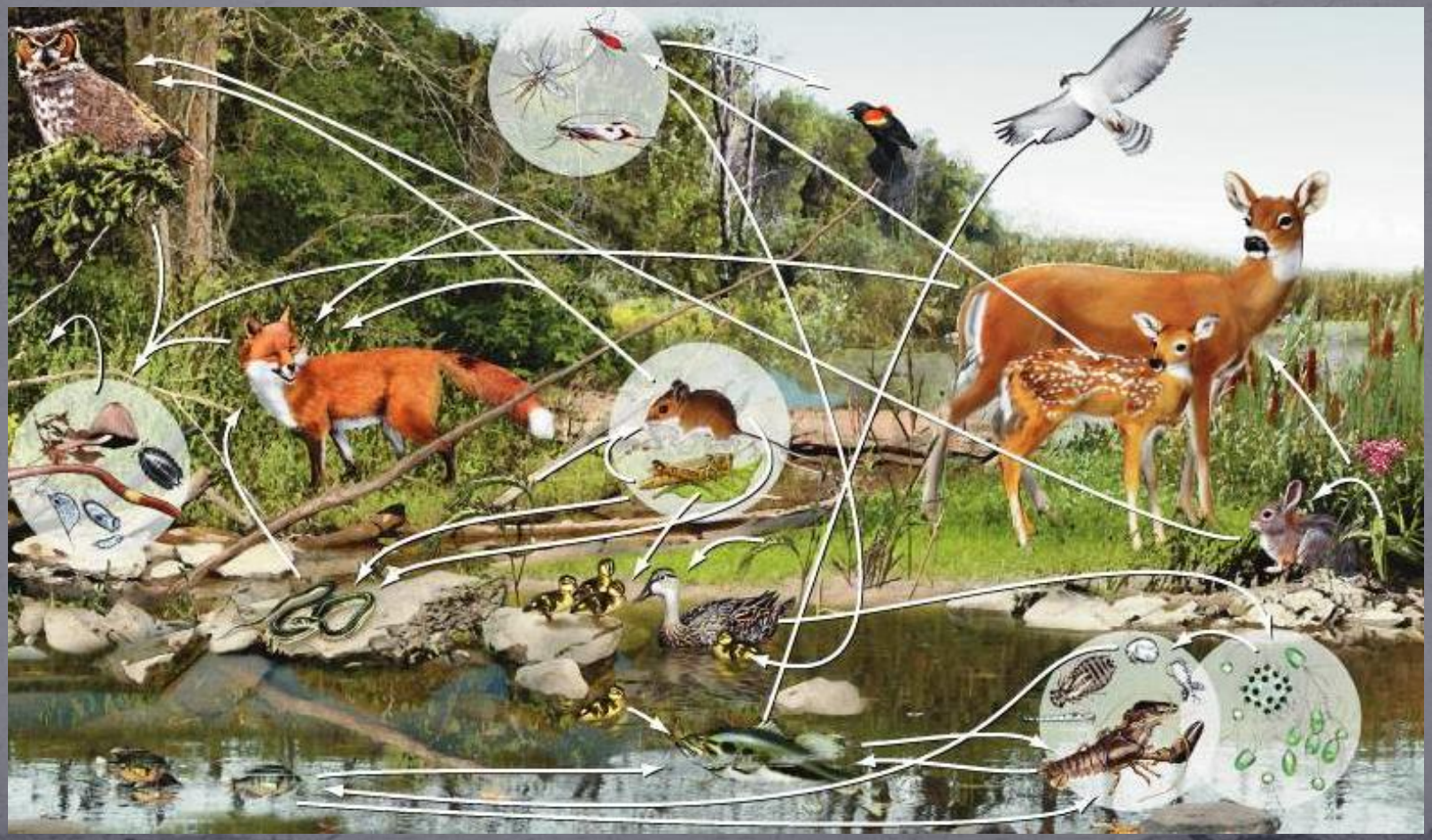
Trophic Levels

- Each trophic level within a food chain represents an organism with a separate energy source.
  - Producers - absorb energy from the sun. (Autotrophs)
  - Consumers - ingest other organisms. (Heterotrophs)
    (Primary → Secondary → Tertiary)
  - Decomposers - break down dead or decaying matter.



Food Webs

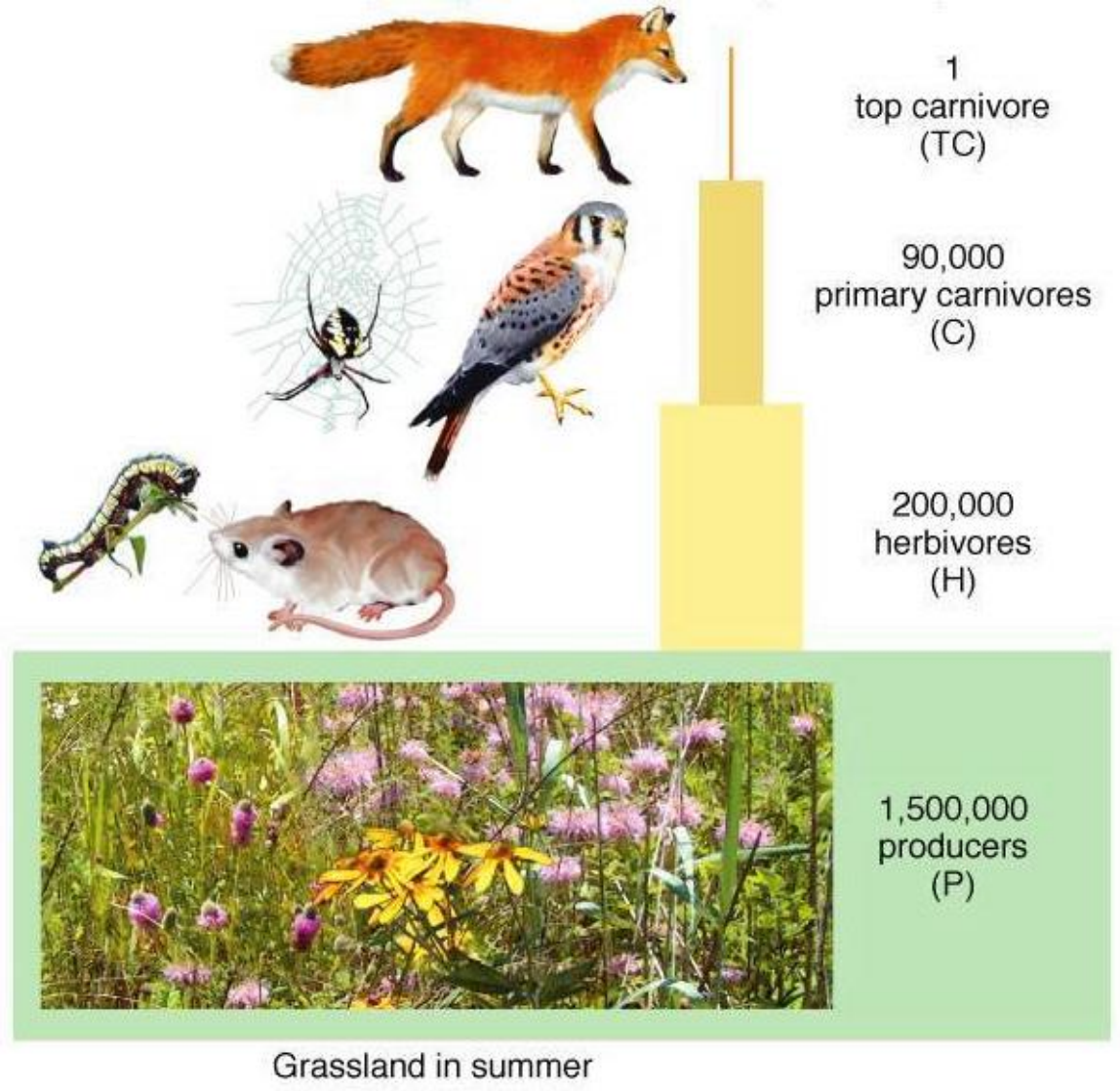
- A food web shows all of the food chains within a community interwoven together.



- Food webs in more harsh ecosystems tend to be simpler and more vulnerable. (Like Antarctica)

Energy Pyramids

- As stated by the Second Law of Thermodynamics, some energy is lost with each transformation.
- The 10% rule is an estimation of how much energy is incorporated from one level of a food chain into the next.

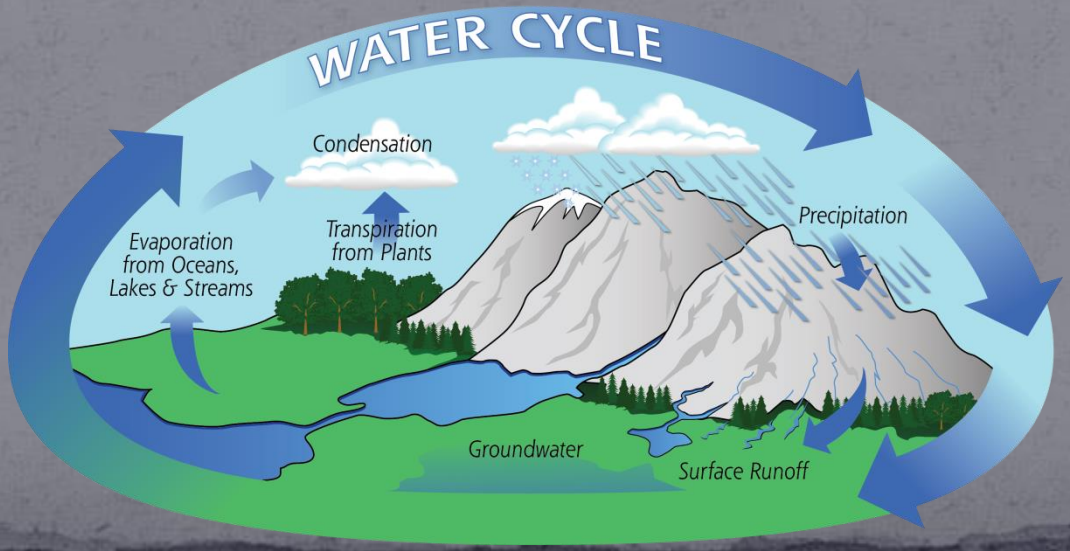


Matter Cycles

- Most life on Earth could not exist without a constant input of energy from the sun.
- Matter, however, only enters the earth in miniscule amounts.
  - The Earth is essentially a closed system to matter.
- A series of biogeochemical cycles exist to constantly recycle the essential elements of life from one organism to another.

The Water Cycle

- As discovered by Joseph Priestley, much of the matter gained by a plant as it grows is due to water absorption.
  - The water absorbed by the plant's roots originated from precipitation.
  - The water vapor that formed the precipitation evaporated from a body of water, soil, or other life form.



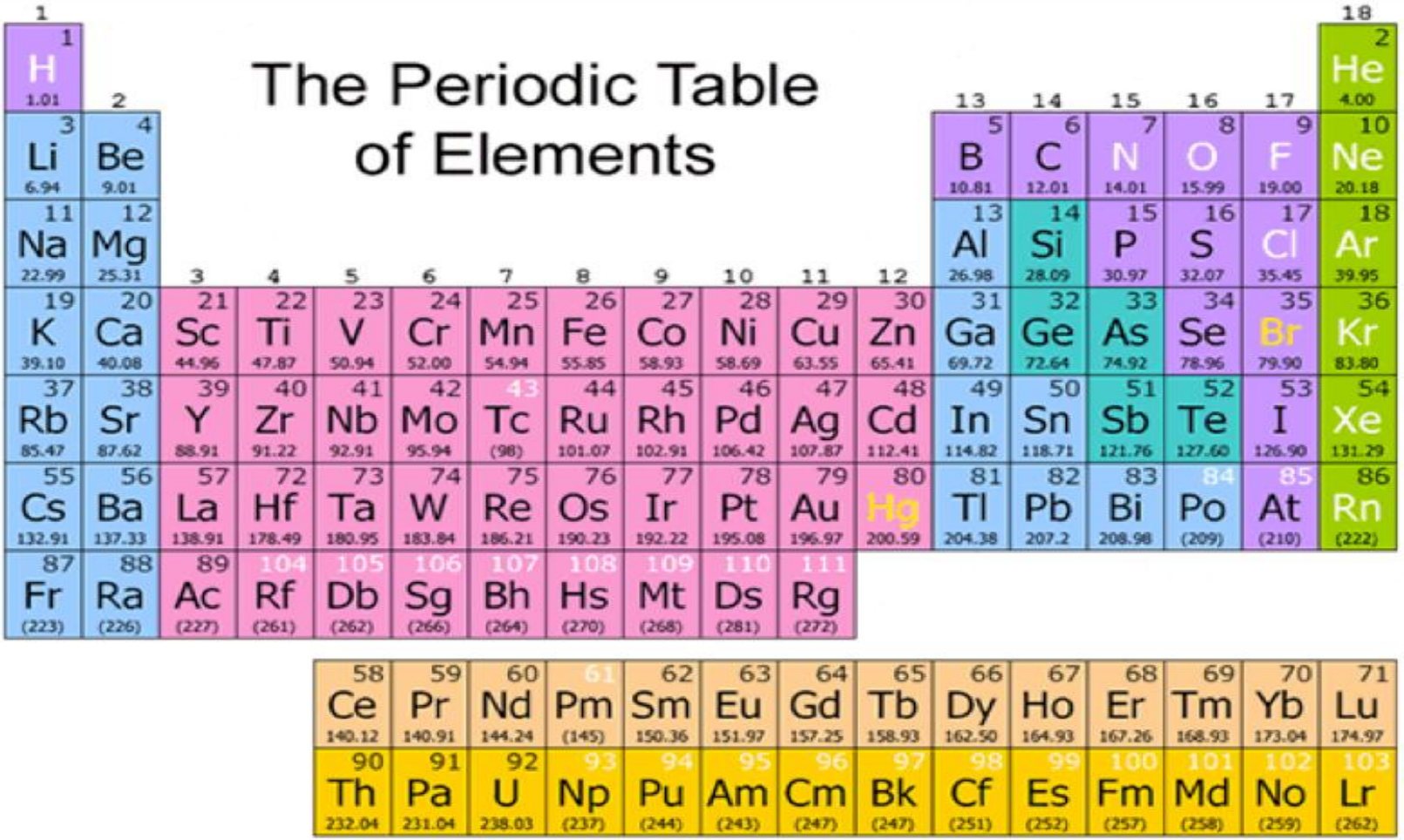
“So all the water on Earth - the water in your Evian bottle, the water in your glass of water, the water you use to boil a pot of spaghetti - all that water is 4.3 or 4.4 billion years old.

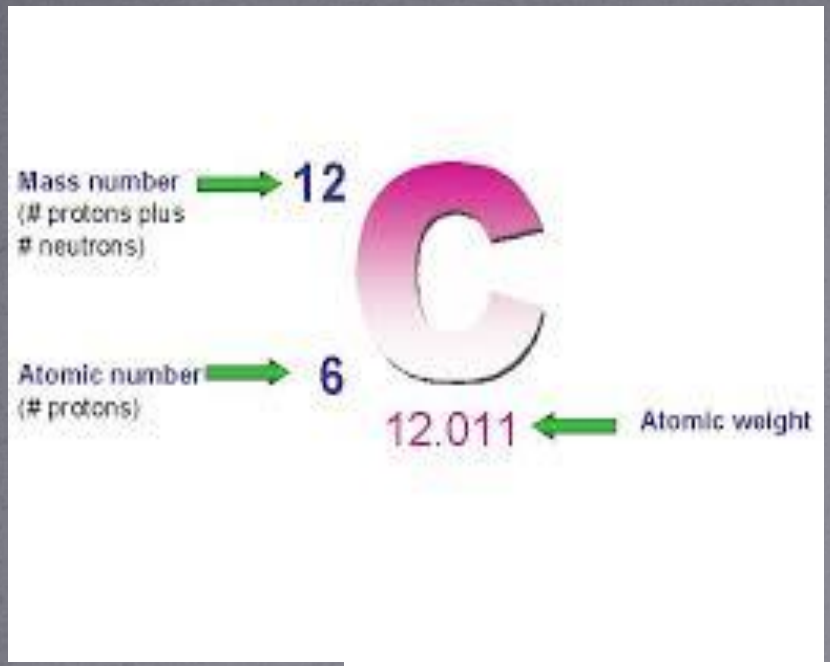
...all the water we've got right now has been used over and over again.

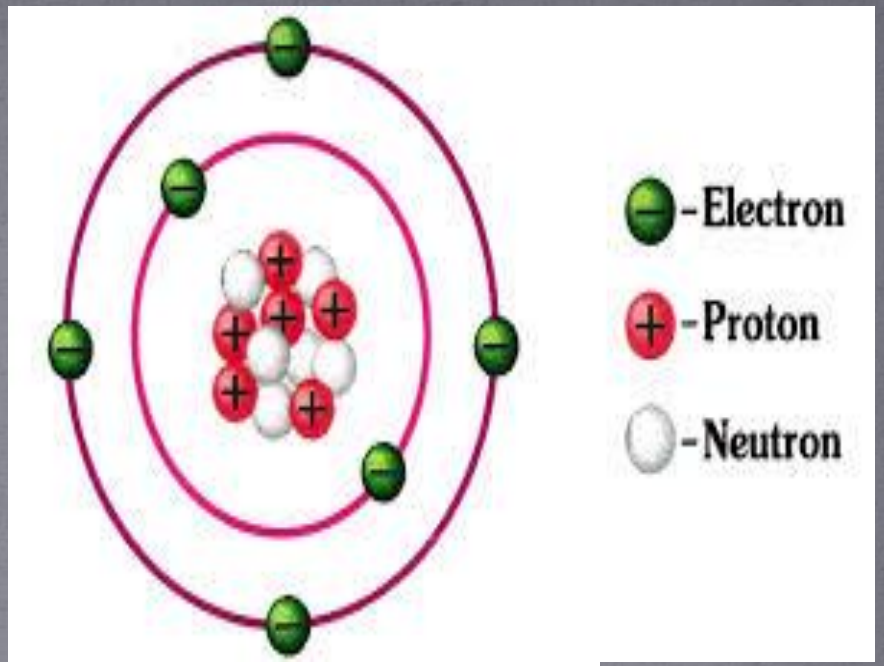
Every drink of water you take, every pot of coffee you make is dinosaur pee, because it's all been through the kidneys of a Tyrannosaurus Rex or an Apatosaurus many, many times, because all the water we have is all the water we have ever had.”

- Charles Fishman, The Big Thirst

- Similar biogeochemical cycles exist for all of the primary elements of life:
  - Carbon
  - Sulfur
  - Phosphorus
  - Nitrogen
  - Oxygen
- The elements are released during combustion or decomposition, end up in soil, and are reabsorbed by plants as the cycle continues…


The Periodic Table of Elements
1 H 1.01
2 He 4.00
3 Li 6.94
4 Be 9.01
5 B 10.81
6 C 12.01
7 N 14.01
8 O 15.99
9 F 19.00
10 Ne 20.18
11 Na 22.99
12 Mg 25.31
13 Al 26.98
14 Si 28.09
15 P 30.97
16 S 32.07
17 Cl 35.45
18 Ar 39.95
19 K 39.10
20 Ca 40.08
21 Sc 44.96
22 Ti 47.87
23 V 50.94
24 Cr 52.00
25 Mn 54.94
26 Fe 55.85
27 Co 58.93
28 Ni 58.69
29 Cu 63.55
30 Zn 65.41
31 Ga 69.72
32 Ge 72.64
33 As 74.92
34 Se 78.96
35 Br 79.90
36 Kr 83.80
37 Rb 85.47
38 Sr 87.62
39 Y 88.91
40 Zr 91.22
41 Nb 92.91
42 Mo 95.94
43 Tc (98)
44 Ru 101.07
45 Rh 102.91
46 Pd 106.42
47 Ag 107.87
48 Cd 112.41
49 In 114.82
50 Sn 118.71
51 Sb 121.76
52 Te 127.60
53 I 126.90
54 Xe 131.29
55 Cs 132.91
56 Ba 137.33
57 La 138.91
72 Hf 178.49
73 Ta 180.95
74 W 183.84
75 Re 186.21
76 Os 190.23
77 Ir 192.22
78 Pt 195.08
79 Au 196.97
80 Hg 200.59
81 Tl 204.38
82 Pb 207.2
83 Bi 208.98
84 Po (209)
85 At (210)
86 Rn (222)
87 Fr (223)
88 Ra (226)
89 Ac (227)
104 Rf (261)
105 Db (262)
106 Sg (266)
107 Bh (264)
108 Hs (270)
109 Mt (268)
110 Ds (281)
111 Rg (272)
58 Ce 140.12
59 Pr 140.91
60 Nd 144.24
61 Pm (145)
62 Sm 150.36
63 Eu 151.97
64 Gd 157.25
65 Tb 158.93
66 Dy 162.50
67 Ho 164.93
68 Er 167.26
69 Tm 168.93
70 Yb 173.04
71 Lu 174.97
90 Th 232.04
91 Pa 231.04
92 U 238.03
93 Np (237)
94 Pu (244)
95 Am (243)
96 Cm (247)
97 Bk (247)
98 Cf (251)
99 Es (252)
100 Fm (257)
101 Md (258)
102 No (259)
103 Lr (262)





What are atomic numbers and mass numbers for atoms?

- **Mass number:** Number of protons and neutrons in an atom. → $^{12}_{6}C$
- **Atomic number:** Number of protons in atom. →
- **Number of neutrons:** Subtract the two values: 12-6=6.