Introduction to Chemistry

Physics → Chemistry

Physics is the study of "matter and energy."

Chemistry is the study of "reactions between different types of matter."

The Greeks

Democritus thought that, at some point, you'd get down to a tiny *atomos*, which you couldn't cut in half anymore. That would be the smallest thing in the world. (*Atomos* means "uncuttable.")

Aristotle's followers, on the other hand, thought that you could cut stuff in half forever.

Lavoisier

First serious chemistry was performed by French scientist Lavoisier at the end of the 1700s.

Burning is a chemical reaction.

People breathe oxygen.

Dalton's model

Early 1800s, English scientist John Dalton suggests that:

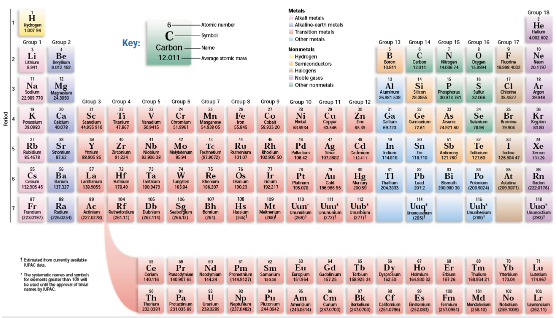
a. All matter consists of small, indivisible particles (atoms).
b. All of the atoms of the same element are the same; that is, have the same size, weight, color, etc. Atoms of different elements are different.
c. Compounds consist of combinations of atoms of different elements in whole number ratios.

The Atomic Nature of Matter

Elements are distinct kinds of atoms that combine in various ways to form all the different types of matter.

The different types of elements are organized into the *Periodic Table of the Elements*.

Periodic Table



Common Elements

Aluminum (Al)
Calcium (Ca)
Carbon (C)
Chlorine (Cl)
Fluorine (F)
Hydrogen (H)
Iron (Fe)
Magnesium (Mg)
Nitrogen (N)
Oxygen (O)
Phosphorus (P)
Potassium (K)
Silicon (Si)
Sodium (Na)
Sulfur (S)
Titanium (Ti)

Hydrogen

Hydrogen is the most abundant element in the universe: ~90% of the atoms.

Helium makes up most of the other 10%, although we don't see it much on earth.

All of the atoms that we see are made from the original material that was present when universe first formed 12 billion years ago.

The vast majority of the atoms that we see on earth are *the same atoms* that were present when the earth was formed, about 6 billion years ago.

Atoms are Old

Atoms get recycled--most atoms that we have on our earth have been around for at least 6 billion years or so, and many are much older than that.

Trick question: Where do the atoms that make up a new baby come from?

Trick question: Which is older: the atoms in a new baby, or the atoms in the baby's grandmother?

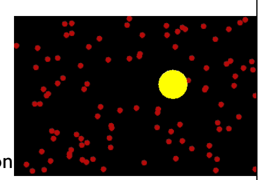
Atoms are Small

Atoms are incredibly small--so small that you will never be able to see one, even with a really good microscope. (To be able to see something, light has to bounce off it, and atoms are too small to even reflect light.)

Yeah, but... how big are they? The typical atom has a diameter of around 0.0000000001 m, = 1×10^{-10} m, or 1 Å (angstrom).

Evidence of Atoms

1827, Scottish botanist Robert Brown noticed that pollen grains he was examining under a microscope would jiggle around: *Brownian motion*. This motion, we now know, results from the motion of nearby atoms and molecules.



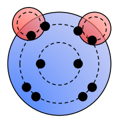
SEM (scanning electron microscope uses a beam of electrons (which has a smaller wavelength than visible light) to reveal the presence of atoms.

There is lots--*lots*!--of other evidence, that might seem rather indirect at this point, but "the atomic theory" is very, very good.

Compounds. Molecules.

A *compound* is made of atoms of different elements combined in a fixed proportion.

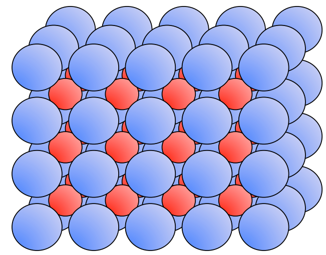
One type of compound is a *molecule* is a particle formed of atoms: H_2, H_2O, etc. Most matter that is gas or liquid at room temperature is made of molecules.



(Shown: H_2O water molecule)

Compounds. Molecules.

Metals & crystalline solids are compounds (made of atoms) that are *not* molecules. In these substances, atoms are bonded together, but in a larger matrix structure (not as individual molecules).



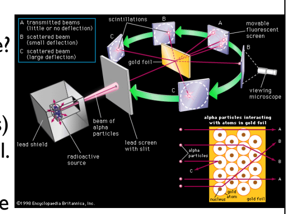
(Shown: Na^+ and Cl^- ions in a cubic crystalline structure.)

Review

- Atoms are individual particles of an element.
- Atoms sometimes combine to form larger particles called "molecules."
- Atoms sometimes combine to form substances that are *not* made of individual particles.
- Combinations of atoms in fixed proportions, whether they're molecules or not, are called *compounds*.

The Atomic Nucleus

An atom has a *nucleus*, where most of its matter is concentrated, lots of space around that, and then *electrons*, which surround the nucleus in *clouds*.



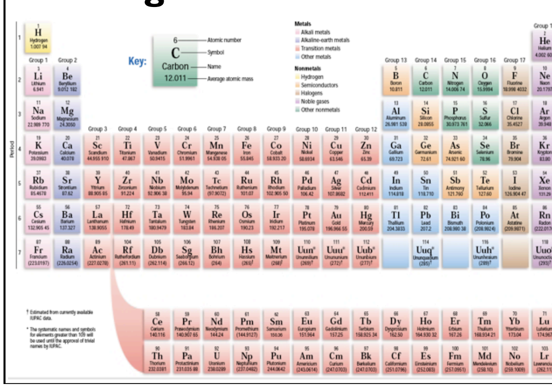
How do we know that the nucleus is surrounded by space? Ernest Rutherford, in 1911, directed alpha particles (He^{2+}, two protons and two neutrons) through a thin piece of gold foil. Many particles continued in a pretty straight path through the foil, but some got reflected back.

Atomic Structure

The *nucleus* contains both positively-charged *protons* and neutrally-charged *neutrons.* Negatively-charged *electrons* moved around in "electron clouds" around the nucleus.

Understanding the organization of these electrons is important, and we have a number of different *models* for trying to understand them. In this class, we'll be considering the electrons to be organized in *shells*. You'll learn additional details of electron behavior next year in your Chemistry class.

Building an Atom



Atomic Number, Atomic Mass

- Atomic Number = # of protons in an atom of that element
- Atomic Mass (Weight) = # of *nucleons* (protons *and* neutrons) in an atom of that element
- Atomic Number = # of electrons in an *electrically neutral* atom of that element

Ions

It's common for some atoms to gain or lose electrons, usually from the outermost *valence* shell of the atom.

Gaining an electron makes the atom more negatively charged, so the Chlorine ion is written as Cl^-. Sulfur tends to gain two electrons, so it is written S^{2-}.

Losing an electron makes an atom more positively charged, so the Hydrogen ion is written H^+. Calcium tends to lose two electrons, it is written Ca^{2+}.

How does one know how many electrons an atom tends to gain or lose?

Ions – Completing the Octet

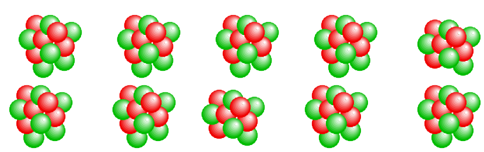
The valence shell in an atom "likes to have" a complete octet—this is a stable configuration for an atom.

Atoms tend to gain or lose electrons in order to "complete the octet."

It's these electrons—especially the valence electrons—that determine the chemical properties of an atom.

Isotopes

Isotopes are atoms with different numbers of neutrons in the nucleus. Here are ten atoms of Boron, chosen "randomly" in nature.
What is the atomic mass of each individual atom?
What is the *average* atomic mass of Boron?



Isotope Identification

Isotopes are indicated by the name of the atom followed by the *atomic mass* of that atom.

Hydrogen-1

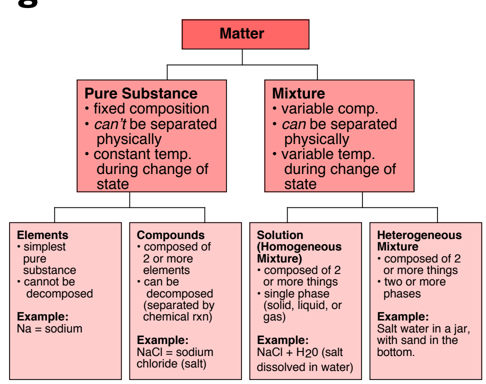
Hydrogen-2

Hydrogen-3

Boron-10

Boron-11

Organization of Matter



States of Matter

Five states of matter:

1. **Bose-Einstein Condensate** -
2. **Solid** - matter that has definite volume, shape; atoms/molecules are relatively fixed in place, and relatively close together
3. **Liquid** - matter that has definite volume (for given P-T), but flows to fill shape of container; atoms/molecules aren't fixed in place, but do exhibit some attraction to each other.
4. **Gas** - matter that has no definite shape or volume; atoms/molecules have relatively high KE.
5. **Plasma** - very high energy matter consisting of ions and free electrons

Density

Density is a measure of how tightly matter is packed together.

$$Density = \frac{mass}{Volume}$$

The hard thing for most people to remember about density is that it doesn't depend on *mass* or *size*: it depends on *both* mass and size, in relation to each other.

$$\frac{g}{cm^3}$$

$$\frac{g}{ml} \; or \; \frac{g}{mL}$$

$$\frac{kg}{m^3}$$

Example

1. A small rock, with mass 8.5 g, is placed in a beaker of water. The water level goes up 3.14 milliliters. What is the density of the rock?
2. What is the density of the rock in g/cm^3?
3. How much would one cubic meter of this rock weigh, in pounds?

Example

1. Which has more mass: a pound of feathers or a pound of lead?
2. Which has more volume: a pound of cotton or a pound of lead?
3. Which has more volume: 30 cm^3 of water, or 30 ml of water?