ATOMS AND ELEMENTS

Chapter Four

Evolution of Atomic Theory

- The ancient Greek scientist Democritus is often credited with developing the idea of the atom
- Democritus proposed that matter was, on the smallest scale, composed of particles described as *atomos*, meaning "indivisible"
- While atoms can in fact be broken down into smaller particles, the atoms of each element are distinct from each other, making them the fundamental unit of matter.

Dalton's Atomic Theory

- Compiling experimental information available during his lifetime, John Dalton described an accurate picture of atoms in 1803 with his atomic theory.
- Dalton's Atomic Theory maintains that
  - All elements are made up of tiny, indivisible particles called atoms, which can be neither created nor destroyed in reactions.
  - Atoms of the same type of element are the same; those of different elements are different.

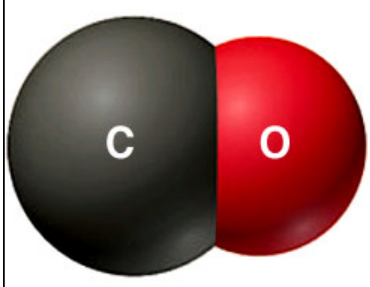
Dalton's Atomic Theory

- Atoms of different elements form compounds by combining in fixed, whole number ratios.
  - This is also called "The Law of Definite Proportions"
- If the same elements combine to make more than one compound, there can be a different, but definite, atom ratio for each compound.
  - This is also called "The Law of Multiple Proportions"
  - In actuality, atoms combining in the same ratio can make different compounds.

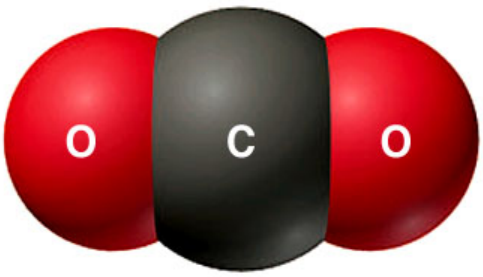
Dalton's Atomic Theory

- A chemical reaction does not involve a fundamental change of the atoms themselves, but of the way they are combined together.

Atomic Basis of the Law of Multiple Proportions



Carbon oxide I
(carbon monoxide)



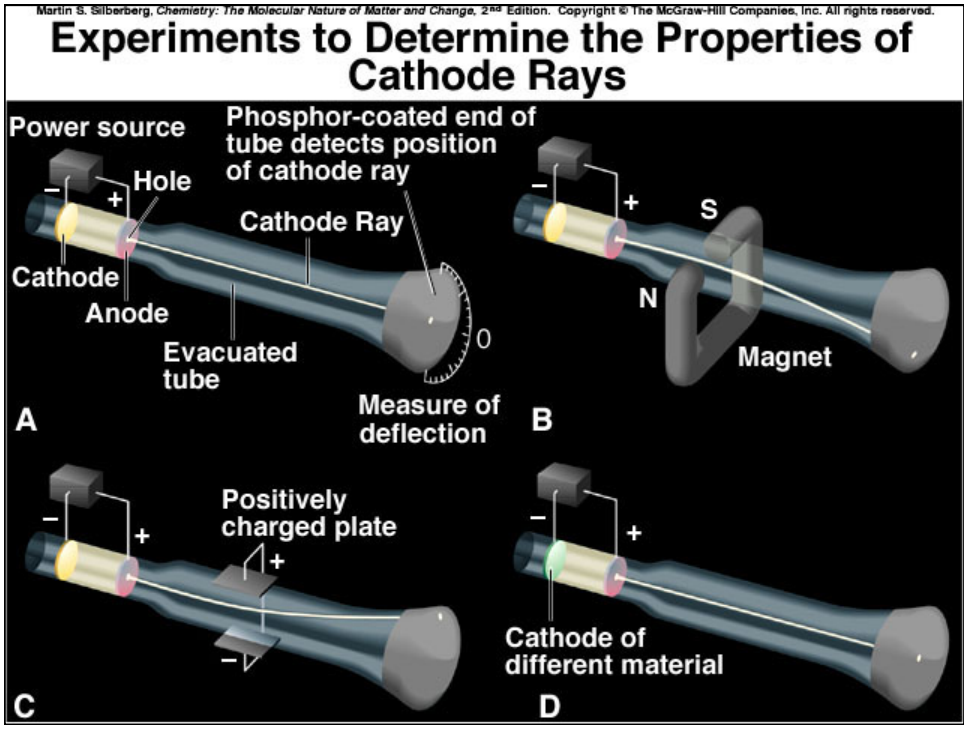
Carbon oxide II
(carbon dioxide)

Probing Further into Atomic Structure: The Electron

- One of the three particles which make up all atoms is the electron
- Benjamin Franklin observed that, when a cloth was rubbed across a glass rod, a charge was developed on each.
- The charges, called positive (+) and negative (-), show an attractive force between opposites and repulsion between identical charges.

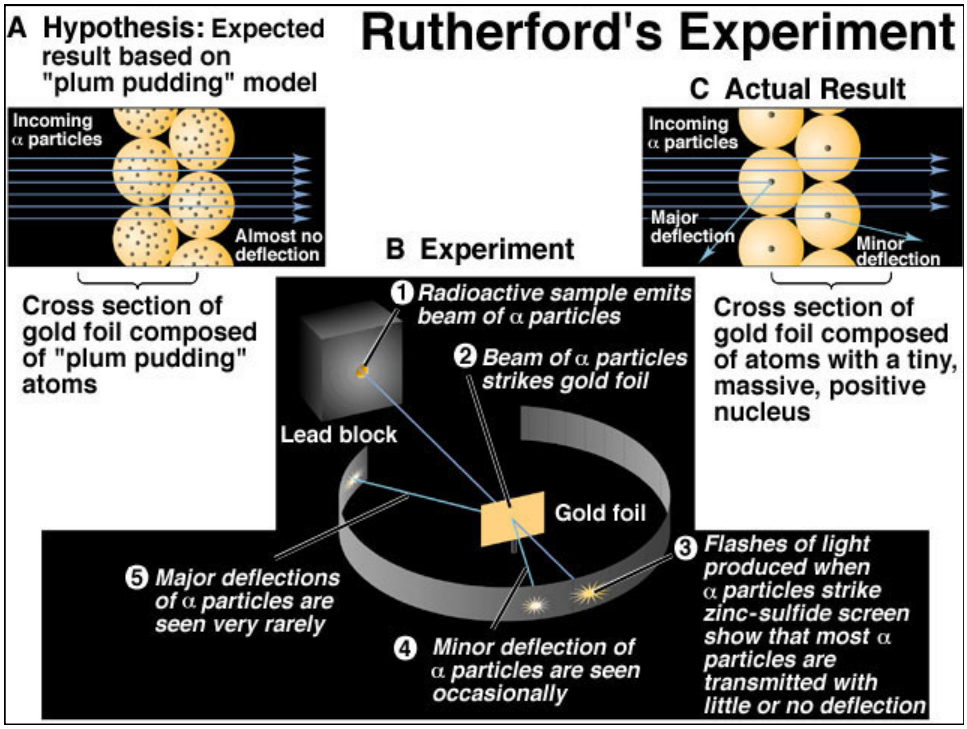
Cathode Rays

- J. J. Thompson, in his "cathode ray tube" experiment, provided evidence for the existence of negatively charged particles.
  - The experiment uses a Crookes tube, a glass tube which has had the air removed and metal plates (electrodes) at both ends.
  - A power source is connected to the plates, causing the sides to develop an opposite charge.
  - A stream of particles (a cathode ray) was observed to flow from the negative electrode towards the positive.
  - These particles were identified as the electrons.



The Plum Pudding Model

- The cathode ray tube showed that the atoms making up the metal electrodes contained electrons which were ejected to product the rays.
- J.J. Thompson theorized that these electrons floated around in the atom, immersed in a positive cloud.
  - Picture raisins in pudding; the raisins represent the electrons, while the pudding is the positive cloud.
- With this image in mind, what would happen if we shot *positively charged* particles at the positively-charged cloud?
  - How do positive charges "feel" about each other?



Rutherford's Gold Foil Experiment

- Positively charged particles from a radiation source mostly pass right through a sheet of gold foil.
- This indicates that the plum pudding model is incorrect.
  - If positive charge was spread all throughout the atom, the positive charges should be able to pass right through.
- Conclusion:
  - Since some of the positive charges are deflected, the positive charge of an atom is centered in a compact region at the heart of the atom, called the nucleus.

The Atom: A Complete Picture

- Each atom contains at its core a nucleus, a region of positive charge.
- Positively charged particles, called protons, are contained in the nucleus.
- Electrons (negatively charged particles) "orbit" around the nucleus throughout the atom.
- Later experiments also confirmed that all atoms except hydrogen must contain one or more neutral (non-charged) particles called neutrons.
- Note that the protons and neutrons are each almost 2,000 times more massive than an electron; therefore, most of the mass of an atom is in the nucleus.
- The protons and neutrons are called the nucleons.

General Features of the Atom

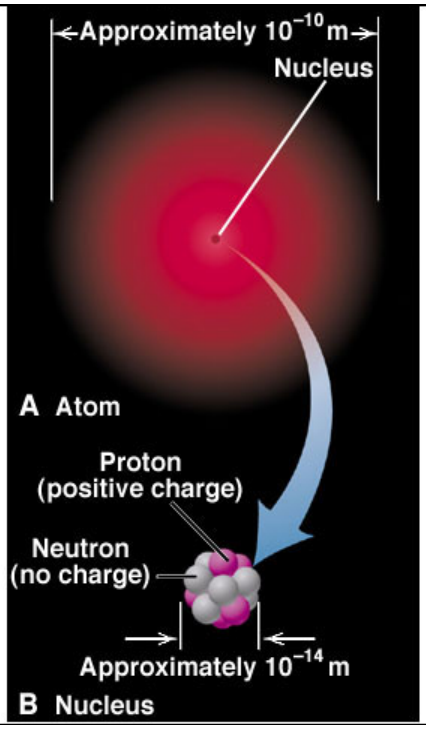


Table 3.1 Properties of Subatomic Particles

Particle	Charge (e)*	Mass (amu)†	Location in the Atom
Proton	1+	1.0073	In the nucleus
Neutron	0	1.0087	In the nucleus
Electron	1−	0.000549	Outside the nucleus

*The charges given are relative charges, based on the charge on the electron, e, as the fundamental unit of charge ($1\ e = 1.60 \times 10^{-19}$ coulomb).
†The masses are given in atomic mass units (amu), described in Section 3.4.

Elements

- There are over one hundred known elements.
- Elements are listed on the Periodic Table of the Elements.
  - The periodic table includes a tremendous amount of information, not only in its values but in the very way the Table is arranged.
- Each element has a unique symbol which we use as a shorthand notation.
  - Each symbol contains from one to three letters. The first letter is *always* capitalized; the remainders are not.

Some Atomic Symbols

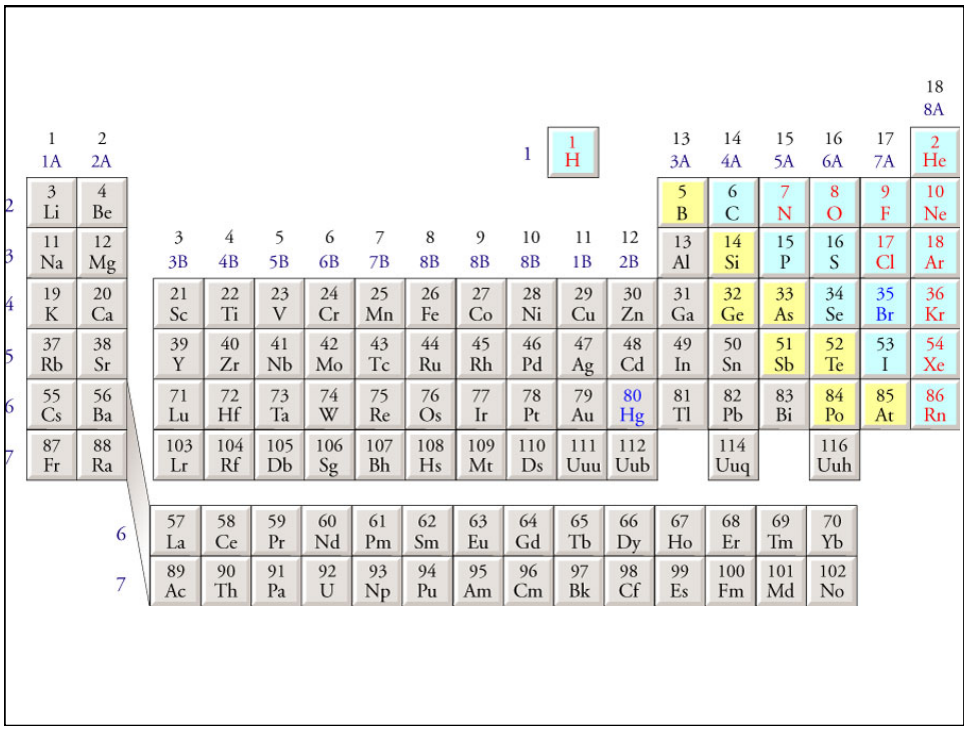
H: Hydrogen O: Oxygen

C: Carbon N: Nitrogen

Na: Sodium Cu: Copper

Cl: Chlorine K: Potassium

Note that some of these symbols are unusual!



Structure of the Periodic Table

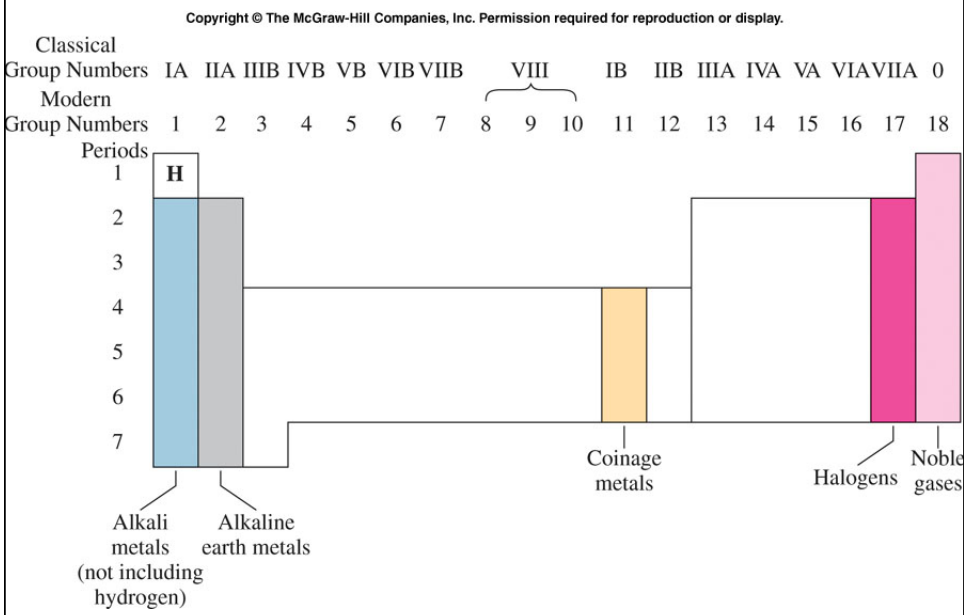
- Elements on the periodic table can be classified in two ways:
  - Elements in the same period are on the same row.
    - Example: N, O, and F are in the same period.
    - The periods are numbered from the top down
  - Elements in the same column are said to be in the same group or family
    - Example: F, Cl, and Br are in the same group.
  - There are two different methods used to number groups
    - Using standard digits, from 1 to 18
    - Using digits (sometimes Roman Numerals), some of which end in A, others in B
    - Example: Group 17 is also called Group 7A (or VIIA)

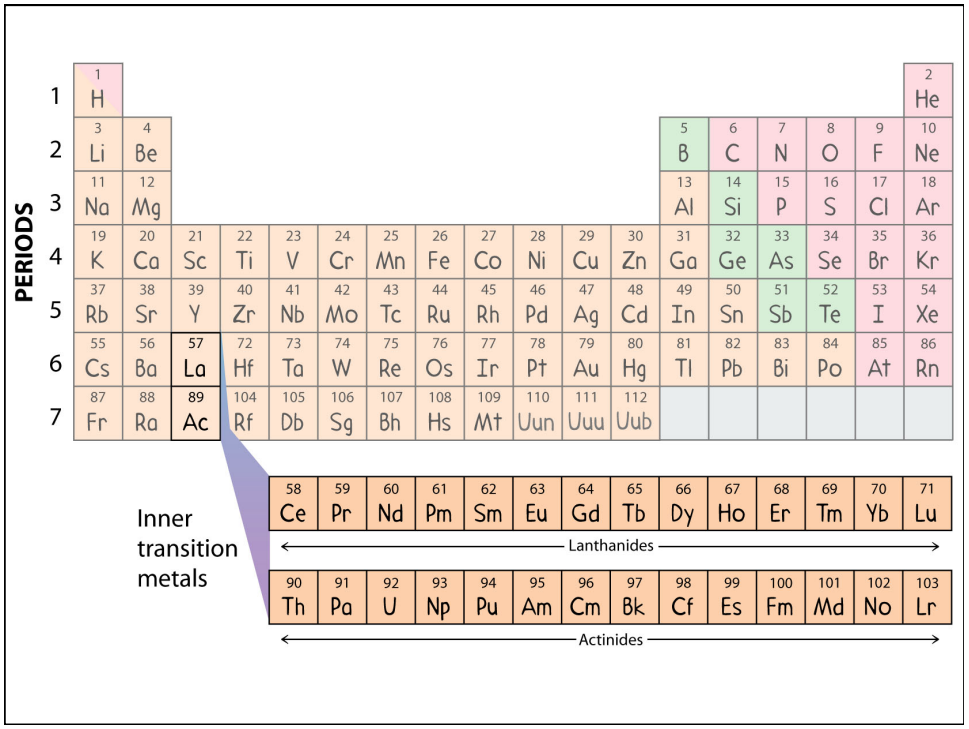
Groups

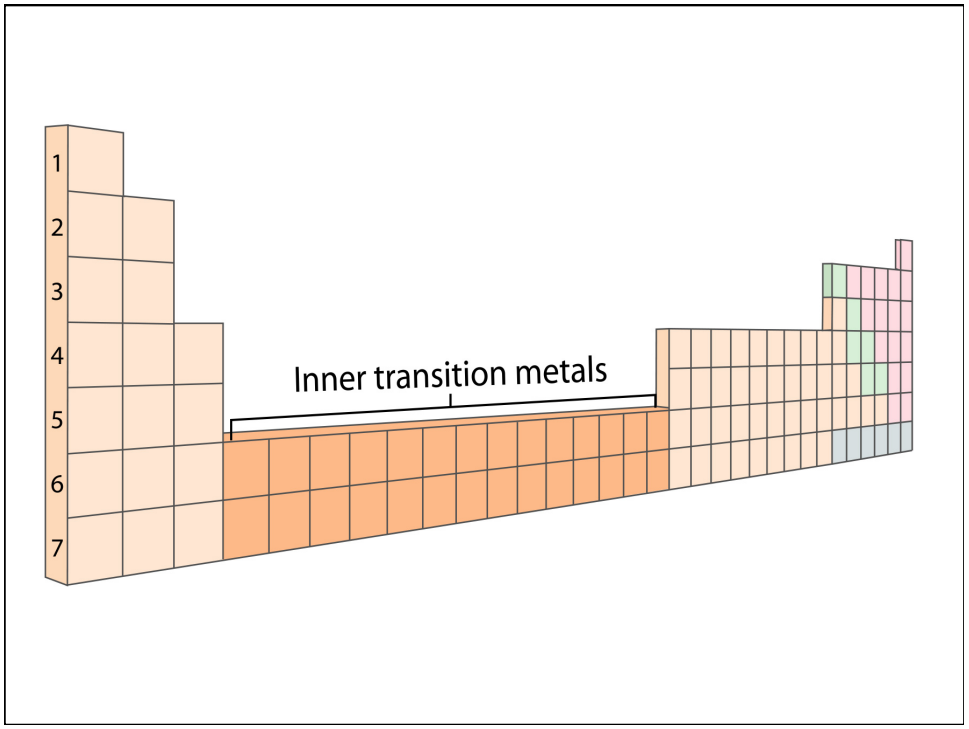
- Some groups have their own name, which you must know:
  - Group 1A elements are called the "Alkali Metals" (hydrogen is not included).
  - Group 2A elements are called the "Alkaline Earth Metals."
  - Group 7A elements are called the "Halogens."
  - Group 8A elements are called the "Noble Gases."

Other Classifications

- The elements on the right and left of the table are collectively called the "Main group elements" or the "Representative Elements"
- The elements in the *middle* are called the "Transition metals."
  - The classical group numbers for transition metals end in the letter B or have no letter at all (group VIII).
  - Group IB metals (copper, silver, and gold) are often called the coinage metals.
- The elements in the two rows listed below the periodic table are collectively called the inner transition metals.

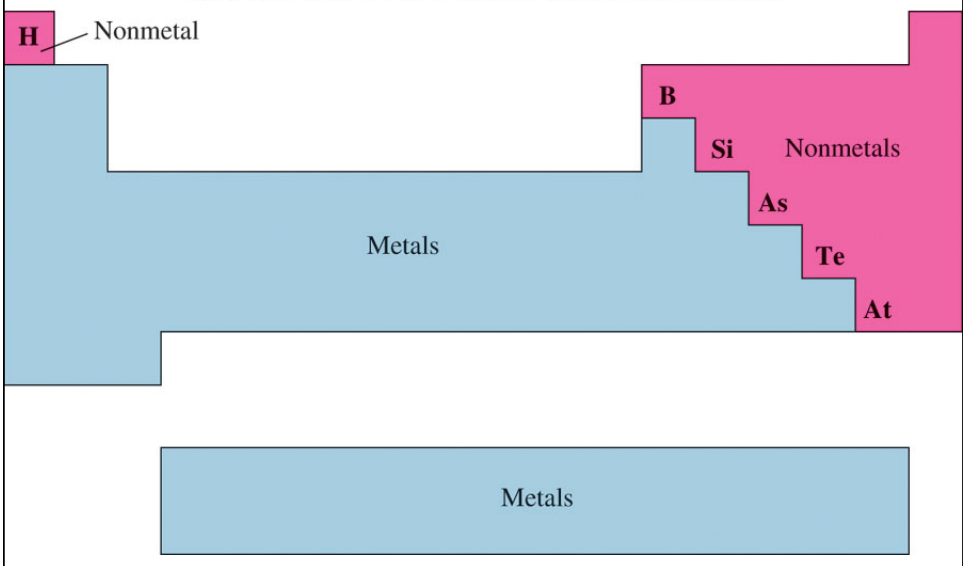



PERIODS
1 H He
2 Li Be B C N O F Ne
3 Na Mg Al Si P S Cl Ar
4 K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
5 Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
6 Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
7 Fr Ra Ac Rf Db Sg Bh Hs Mt Uun Uuu Uub
Inner transition metals
58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
Lanthanides
90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr
Actinides


1
2
3
4
5
6
7
Inner transition metals

Metals

- The metals include many elements found on the left side of the periodic table.
- Many metals are known for having the following properties
  - They are malleable (meaning they are soft and easily shaped)
  - They are ductile (they can be twisted and drawn into a wire)
  - They can conduct both electricity and heat.
  - They tend to be lustrous (shiny).
  - All metals are solids at room temperature except for mercury, which is a liquid.



Nonmetals

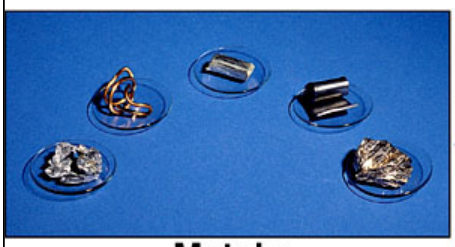
- Nonmetals are generally found on the right side of the periodic table (except hydrogen, which is placed on the left).
- Their properties are generally the opposite of the metals.
  - Those which are solids tend to be brittle.
  - Most are poor conductors of electricity at room temperature (insulators) and do not conduct heat well.
  - Some are gases at room temperature; others are solids. Bromine is the only liquid nonmetal at room temperature.

Metalloids

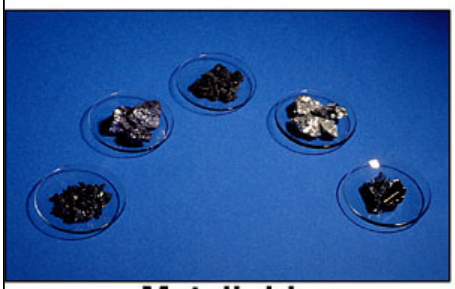
- Metalloids are found between the metals and the nonmetals on the periodic table.
  - They include B, Si, Ge, As, Sb, and Te.
- The properties of the metalloids are often a cross between those of the metals and the nonmetals.
- All the metalloids listed are solids at room temperature.

  (I do not include Po and At with the metalloids, as they are rather unstable.)

Metals, Metalloids, and Nonmetals



Metals

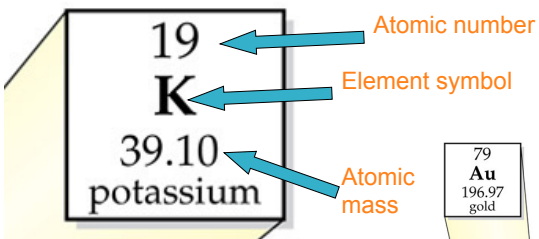


Metalloids

Nonmetals

The Periodic Table of Elements

30



Tro's "Introductory Chemistry", Chapter 4

Important Groups—Hydrogen

31

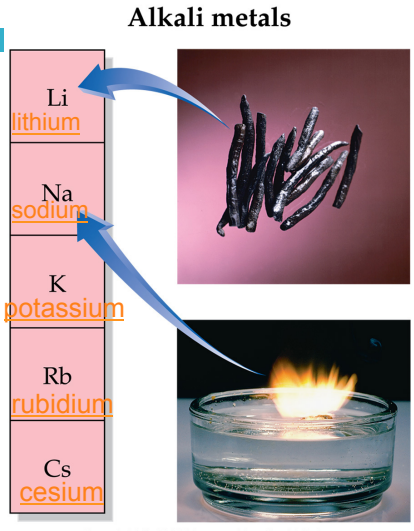
- Nonmetal.
- Colorless, diatomic gas.
  - Very low melting point and density.
- Reacts with nonmetals to form molecular compounds.
  - HCl is an acidic gas.
  - H_2O is a liquid.
- Reacts with metals to form hydrides.
  - Metal hydrides react with water to form H_2.
- hydrogen halides dissolve in water to form acids.

Important Groups—Alkali Metals

32

- Group IA = Alkali metals.
- Hydrogen is usually placed here, though it doesn't belong.
- Soft, low melting points, low density.
- Flame tests: Li = red, Na = yellow, and K = violet.
- Very reactive, never found uncombined in nature.
- Tend to form water soluble compounds that are crystallized from seawater then molten salt electrolyzed.
  - Colorless solutions.
- React with water to form basic (alkaline) solutions and H_2:

  $2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2$
  - Releases a lot of heat.

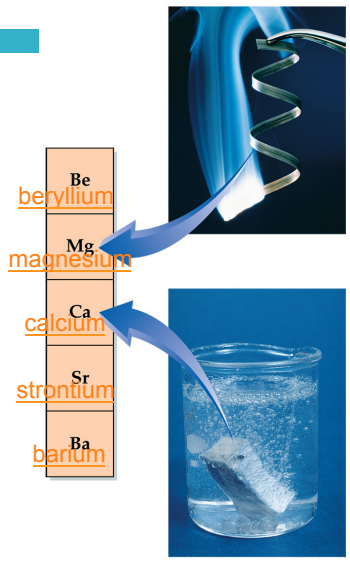


Important Groups—Alkali Earth Metals

33

- Group IIA = Alkali earth metals.
- Harder, higher melting, and denser than alkali metals.
  - Mg alloys used as structural materials.
- Flame tests: Ca = red, Sr = red, and Ba = yellow-green.
- Reactive, but less than corresponding alkali metal.
- Form stable, insoluble oxides from which they are normally extracted.
- Oxides are basic = alkaline earth.
- Reactivity with water to form H_2:

  Be = none, Mg = steam, Ca, Sr, Ba = cold water.

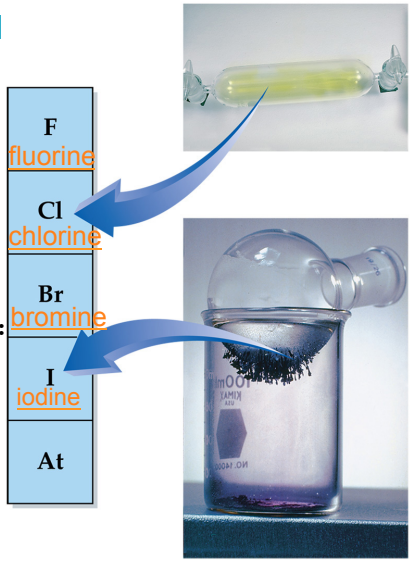


Important Groups—Halogens

34

- Group VIIA = Halogens.
- Nonmetals.
- F_2 and Cl_2 gases, Br_2 liquid, and I_2 solid.
- All diatomic.
- Very reactive.
- Cl_2 and Br_2 react slowly with water:

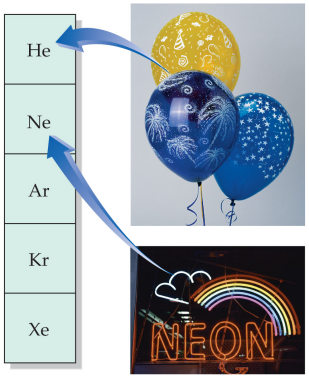
  $Br_2 + H_2O \rightarrow HBr + HOBr$
- React with metals to form ionic compounds.
- hydrogen halides all acids:
  - HF weak < HCl < HBr < HI.



Important Groups—Noble Gases

35

- Group VIIIA = Noble gases.
- All gases at room temperature.
  - Very low melting and boiling points.
- Very unreactive, practically inert.
- Very hard to remove electron from or give an electron to.



Characteristics of an Atom

- The number of protons in an atom is called the elements atomic number, which is symbolized by *Z*.
- The number *Z* indicates which type of element that atom represents.
- These values are found in order on the periodic table.
- Example: Which element contains 5 protons? 10? 34?

Characteristics of an Atom

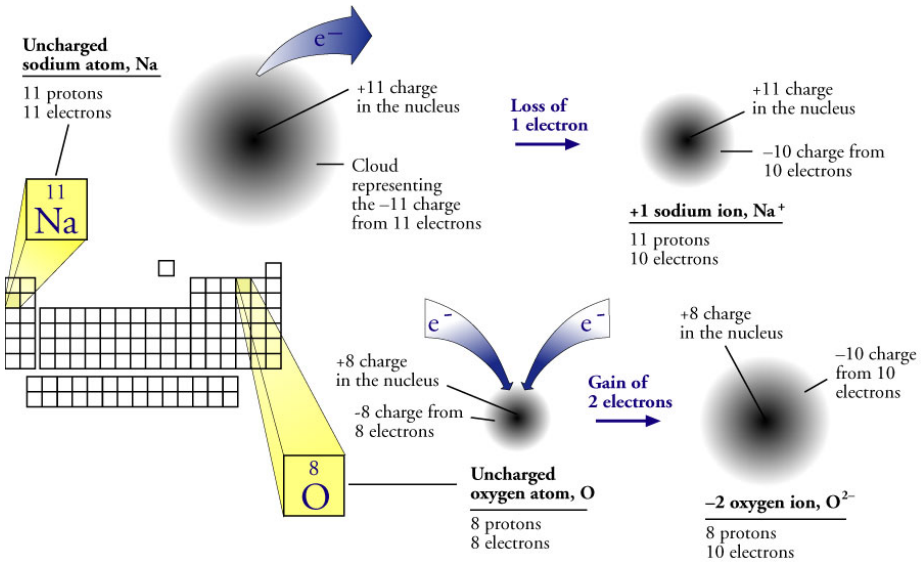
- Atoms that have no charge must have the same amount of positive charge as negative charge.
- Therefore, the number of electrons in an atom is equal to the number of protons in an atom (Z) for any *neutral* atom.
- Atoms which contain more or less electrons than protons therefore must have a charge. These are called ions.

Ions:
A Lesson in Thinking Backwards

- Suppose an ion has exactly one more electron than it does protons.
  - Will the ion be positively or negatively charged?
- What if an atom lost two electrons?
  - Will the ion be positively or negatively charged?
- For each electron an ion has more than it does protons, we indicate it with a – as a superscript.
- For each electron an ion has less than it does protons, we indicate it with a + as a superscript.
- We call positively-charged ions cations and negatively-charged ones anions

Examples of Ions

- A bromine atom normally has____protons and_____electrons.
- Suppose we add exactly one electron; now we have_____protons and_____electrons.
- We symbolize this as Br^- (or Br^{1-}).
- An aluminum atom normally has____protons and_____electrons.
- Suppose the atom loses three electrons.
- We symbolize this ion as Al^{3+}.
- Note that losing electrons is indicated with +, and gaining electrons is indicated with -.



Practice—Fill in the Table.

41

Ion	p^+	e^-
Cl^{-1}		
K^{+1}		
S^{-2}		
Sr^{+2}		

Practice—Fill in the Table, Continued.

42

Ion	p^+	e^-
Cl^{-1}	17	18
K^{+1}	19	18
S^{-2}	16	18
Sr^{+2}	38	36

Practice—Complete the Following Table.

	Atomic Number	Mass Number	Number of protons	Number of electrons	Number of neutrons
Calcium-40					
Carbon-13					
Aluminum-27^{+3}					

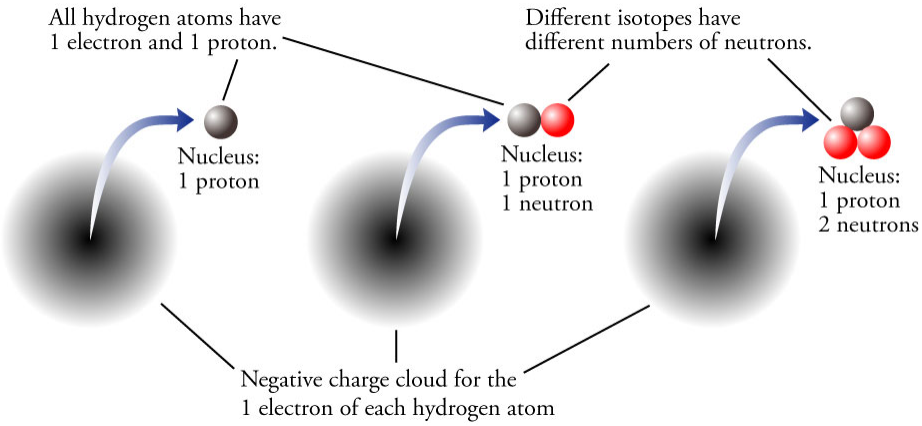
Practice—Complete the Following Table, Continued.

	Atomic Number	Mass Number	Number of protons	Number of electrons	Number of neutrons
Calcium-40	20	40	20	20	20
Carbon-13	6	13	6	6	7
Aluminum-27^{+3}	13	27	13	10	14

Neutrons and Isotopes

- The number of neutrons in an atom *cannot* be easily predicted or found on the periodic table.
- Atoms of the same element (i.e. have the same number of protons) can have different numbers of neutrons. They are called isotopes of one another.
- Examples:
  - A carbon atom must contain 6 protons, but it may contain 6, 7, or 8 neutrons.
  - Almost all hydrogen atoms contain *zero* neutrons. The isotopes of hydrogen which contain one and two neutrons are called *deuterium* and *tritium*, respectively; they are symbolized as D and T, but do not appear on the periodic table.

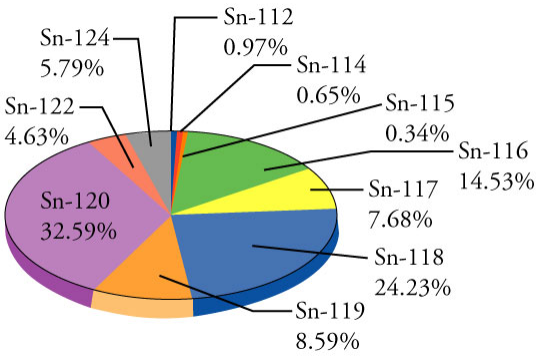
Isotopes of Hydrogen



More on Isotopes

- The sum of the number of protons and neutrons in an atom is called the mass number of that atom, and is symbolized by *A*.
- Isotopes are named by stating the name of the element, followed by *A*.
  - Carbon (Z=6) with 6 neutrons is "carbon-12"
  - Carbon with 7 neutrons is "carbon-13"
  - Carbon with 8 neutrons is "carbon-14"

Isotopes of Tin



More on Isotopes

- Isotopes can be written in shorthand notation in two different ways,

$$^{A}_{Z}X \quad \text{or} \quad ^{A}X$$

- Either method is acceptable.
  - Why is it okay to leave out Z?

Example 4.8—How Many Protons and Neutrons Are in an Atom of $^{52}_{24}Cr$?

Given:	$^{52}_{24}Cr$ therefore A = 52, Z = 24
Find:	# p^+ and # n^0
Solution Map:	symbol → atomic & mass numbers → # n^0
Relationships:	mas
Solution:	Z = 24 = # p^+ A = Z + # n^0 52 = 24 + # n^0 28 = # n^0
Check:	For most stable isotopes, $n^0 > p^+$.

Examples

- For each of the following, indicate how many protons, electrons, and neutrons each atom or ion possesses.
  - ^{35}Cl
  - $^{81}Br^-$
  - $^{27}Al^{3+}$

The Mass of an Atom

- Recall that virtually all of the mass of an atom comes from its nucleus.
- Knowing the mass of protons and neutrons allows us to calculate the mass of one atom of a particular isotope.
- Since most elements have more than one isotope, and these isotopes are mixed in nature, it is not possible to provide an *exact* mass for the element.
- Instead, we consider a *weighted average* mass, based on the weight of each individual isotope and its abundance in nature.

The Mass of an Atom

- The periodic table provides the *atomic weight* of each element, which corresponds to this weighted average mass.
- These values are in *atomic mass units (amu)*, a very small unit of mass.
  - 1 amu = 1.66×10^{-24} g
- For example, the mass of a single helium atom is 4.003 amu.

Calculating Atomic Weights

- The atomic weight of an element can be calculated if we know:
  - The atomic weight of each isotope of that element, and
  - The percent abundance of that element in nature.

Example

There are three isotopes of potassium, as the data in the table below indicates. Calculate the atomic weight of potassium from this data.

Isotope	Mass(amu)	% Abundance
^{39}K	38.963707	93.2581
^{40}K	39.963999	0.001171
^{41}K	40.961826	6.7302

Example

- Chlorine has only two naturally occurring isotopes. The atomic weight of ^{35}Cl is 34.96885 amu, and its % abundance is 75.53%. What is the atomic weight of the other isotope, ^{37}Cl?