CHAPTER 4: ATOMS AND ELEMENTS

Problems: 1-70 then ***after*** Chapter 9, complete 71-94, 103-104, 107-108, 113-114

4.1 Experiencing Atoms at Tiburon

atom: smallest identifiable unit of an element
– All matter is made up of atoms.
  → The properties of specific atoms determine the properties of matter with those atoms.

There are currently 91 naturally occurring elements and 20 man-made elements.

4.2 Indivisible: The Atomic Theory

Greek philosophers were the first to propose explanations for what was observed in nature.
– Surprisingly, some of these Greek ideas led to similar modern ideas.

Democritus (462-370 B.C.): proposed that all matter was made up of tiny, indivisible particles called ***atomos*** (meaning "indivisible") or ***atoms***.

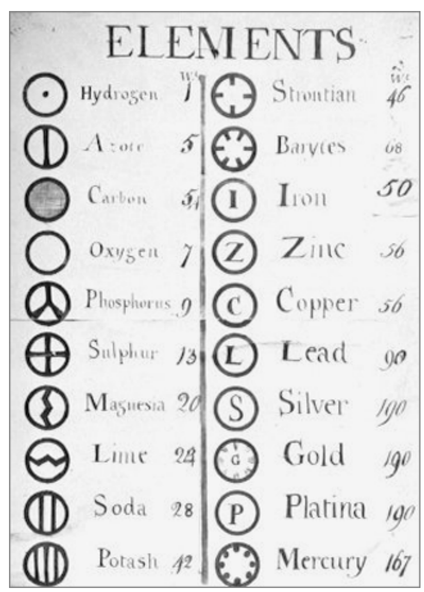
Empedocles (490-430 B.C.): suggested all matter was composed of four basic elements: air, water, fire, and earth.

Aristotle (384-321 B.C.): accepted Empedocles idea and added a fifth element, heavenly ether, which is perfect, eternal, and incorruptible.

Even Democritus' ideas were more correct, Aristotle's idea of five basic elements was accepted for over 2000 years, until John Dalton proposed the modern theory of atoms in 1808.

John Dalton's Modern Atomic Theory
1. An element is composed of tiny, indivisible* particles called atoms.
2. All atoms of an element are identical* and have the same mass and properties.
3. Atoms of one element will differ in mass and properties from atoms of another element.
4. Atoms combine in small whole number ratios to form compounds.
   – e.g., a H_2O molecule has one O atom and 2 H atoms
5. Atoms can combine to form different compounds.
   – e.g., carbon and oxygen combine to form CO_2 or CO

*Later proven wrong

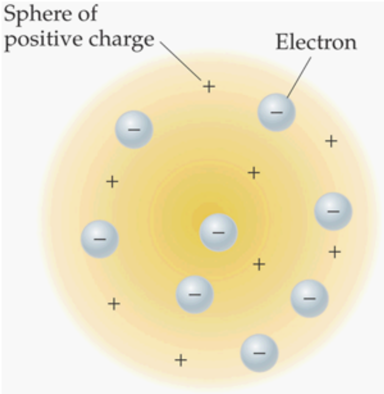


4.3 THE NUCLEAR ATOM: Subatomic Particles

Michael Faraday, William Crookes, and many other scientists carried out experiments
→ discovery of **electrons (e^-)**, tiny *negatively charged* subatomic particles

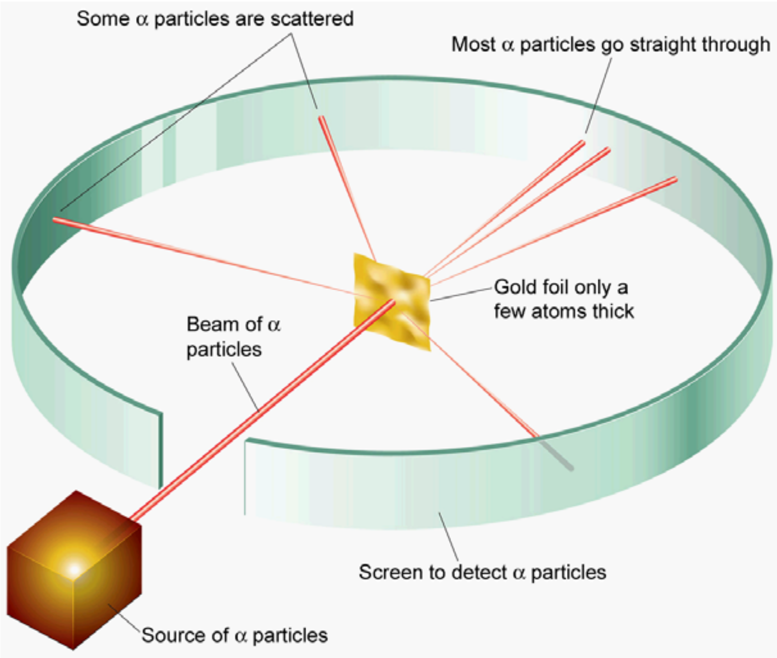
J.J. Thomson was given credit for discovering electron although evidence had accumulated for 20 years before his research group's determination of the electron's charge and mass.

Eugen Goldstein (late 1880s)
– carried out experiments on canal rays and found they consisted of *positively* charged subatomic particles → discovery of **protons (p^+)**



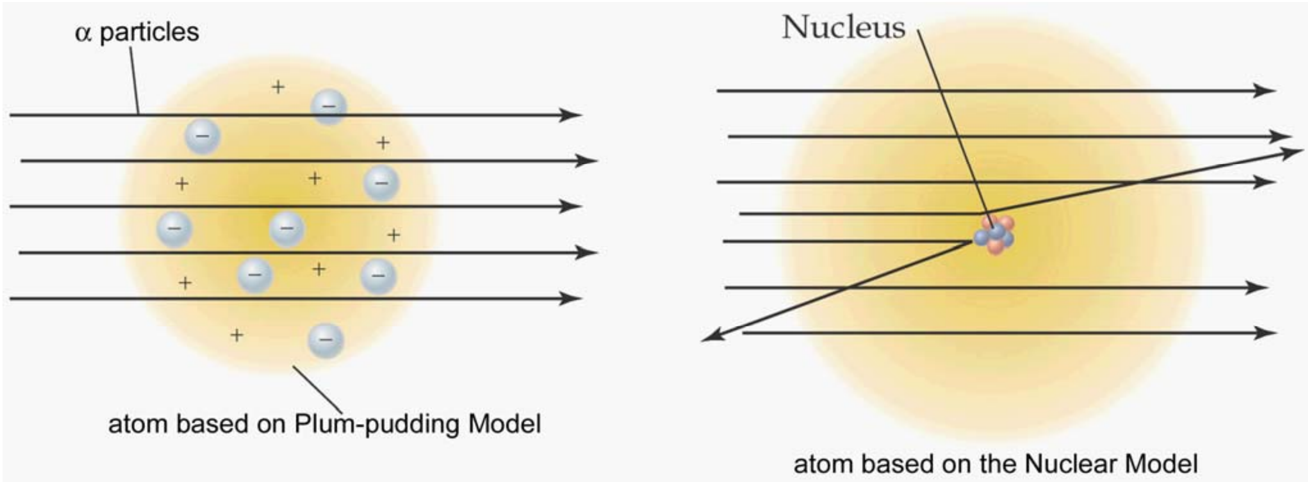
PLUM-PUDDING MODEL OF THE ATOM
– Thomson proposed that the atom was a uniform sphere of positively charged matter in which electrons were embedded
  → Electrons are like raisins in a pudding of protons.

THE NUCLEAR ATOM: PROTONS AND THE NUCLEUS
– Ernest Rutherford was a scientist who did many pioneering experiments in radioactivity.
– He had members of his research group test Thomson's Plum-Pudding Model using radioactive alpha (α) particles.
  – The α particles are positively charged helium atoms.



Rutherford's Alpha-Scattering Experiment
– Alpha (α) particles were shot at a thin gold foil only a few atoms thick.
  – A circular detector was set up around the foil to see what happens to the α particles.
  – If Plum-pudding Model was correct, the α particles (which are much bigger than electrons) should go through the foil like *bullets through tissue paper*.

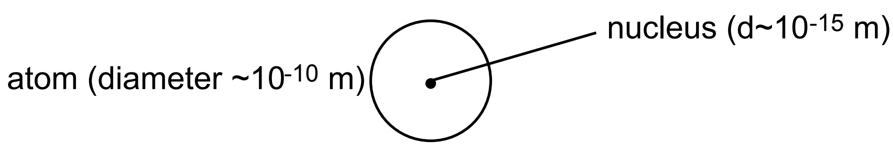
Experimental results:
– Most of the α particles went straight through, but some were deflected, and a few even bounced back!



Rutherford's interpretation of the results:

– Most alpha (α) particles pass through foil.
  → An atom is mostly empty space with electrons moving around that space.
– A few α particles are deflected or even bounce back.
  → Atom must also contain a very small *dense region*, and particles hitting this region are deflected or bounce back towards source.
    → small dense region = **atomic nucleus** (contains atom's protons)
      → Why this is called the ***Nuclear* Model of the Atom**.

Rutherford also estimated the size of the atom and its nucleus:



But these dimensions are difficult for us to imagine.

Ex. 1: An atom is 100,000 times (10^5 or 5 orders of magnitude) bigger than its nucleus.
If a nucleus = size of a small marble (~1 cm in diameter), indicate the length in meters then identify a common item that corresponds to that size for the following:

a. 10 times bigger = ______ dm =______ m = ____________________________

b. 100 times bigger = _____________ m = ____________________________

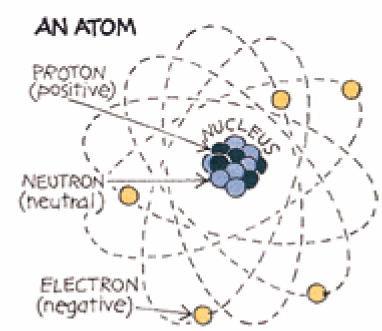
c. 1000 times bigger = _____________ m = ____________________________

d. 10,000 times bigger = _____________ m = ____________________________

e. 100,000 times bigger = ________ m = ______ km = ____________________________

4.4 The Properties of Protons, Neutrons, and Electrons

Decades later, James Chadwick won the Nobel Prize winner for his discovery (1935)
→ **neutron (n)** = neutral subatomic particle



Atoms are made up of subatomic particles:

electron (e^-): negatively charged subatomic particle (charge = –1)

proton (p^+): positively charged subatomic particle (charge = +1)

neutron (n) = *neutral* subatomic particle (charge=0)

Particle	**Symbol**	**Location**	**Charge**	**Relative Mass** (amu*)
electron	e^-	outside nucleus	–1	1/1836 ≈ 0
proton	p^+	inside nucleus	+1	1
neutron	n	inside nucleus	0	1

*amu=atomic mass units

Thus, most of the mass of an atom comes from the protons and neutrons in the nucleus.

What is **electrical charge?**

There are **4 fundamental forces**: gravity, electromagnetic force, strong force, weak force

Let's focus on the **electromagnetic force**, which consists of electricity and magnetism.

electrostatic force: the force resulting from a charge on an object
- Two objects with the **same charge** (both negative or both positive) **repel** one another.
- Two objects with **unlike charges** (one negative and one positive) **attract** one another.

Electrical charge is a fundamental property of protons and electrons.
- Positive and negative charges cancel one another.
  → When paired, a proton and an electron cancel one another's charges → **neutral**.

Note that matter is usually charge-neutral (or neutral).
- If charge imbalances occur, they are usually equalized—often in dramatic ways.
  - Charge imbalance may occur if you walk across carpet, and it's equalized when you get a shock touching a doorknob or other piece of metal.
  - During electrical storms, charge imbalances are usually equalized with stunning displays of lightning.

4.5 Elements: Defined by Their Number of Protons

NAMES & SYMBOLS OF THE ELEMENTS

Every element (or atom) has an individual name, symbol, and number.

Some names come Greek:
- **hydrogen** comes from *hydro*= "water former"
- **argon** comes from *argon*= "inactive"

Convention for writing **chemical symbols**
- Use **first letter** (capitalized) of element name: hydrogen → H, carbon → C
- If symbol already used, include **second letter** (in lower case) of name: helium → He, calcium → Ca, cobalt → Co

Some symbols come from Latin names

lead=*plumbum* → Pb gold= "shining dawn"=*aurum* → Au

Know the **names and symbols for the first 20 elements** on the Periodic Table for Exam #1.
- **Element names and symbols for the all of the elements** are given in the **front cover**.
- You will be given a Periodic Table with only the symbols. Given the name, know the symbol, or given the symbol, be able to write the name. **Spelling of elements names counts!**

COMPOUNDS & CHEMICAL FORMULAS

chemical formulas:
- Symbolically express the number of atoms of each element in a compound.
- Number of atoms is indicated by a subscript following the element's symbol. (If there is no subscript, only *one* atom of that element is in the compound.)

Example: water = H_2O → 2 H atoms, 1 O atom

sodium carbonate = Na_2CO_3 → ____ Na, ____ C, ____ O atoms

Some chemical formulas use parentheses
→ more than one subunit present in compound

Example: $Ba_3(PO_4)_2$ → 3 Ba and 2 PO_4 = 2 P and 8 O
→ TOTAL: **2 Ba**, **2 P**, and **8 O**

How many atoms of each element are present in TNT: $C_7H_5(NO_2)_3$?

____ C, ____ H, ____ N, and ____ O

4.8 ISOTOPES: WHEN THE NUMBER OF NEUTRONS VARIES

An element can be identified using its element name, element symbol, or its atomic number, which indicates the number of protons.

→ An element will always have the same number of protons.
  e.g. carbon always has 6 protons, oxygen always has 8 protons, etc.

However, the number of neutrons may vary.

→ Atoms with differing numbers of neutrons are called **isotopes**.
- The convention for distinguishing elements with various isotopes is to give the element name followed by the mass number
- e.g. carbon-12 (C-12), carbon-13 (C-13) and carbon-14 (C-14) are isotopes of carbon

Nuclear Symbol (also called "Atomic Notation"):
- shorthand for keeping track of number of protons and neutrons in an atom's nucleus

atomic number: whole number of protons = number of electrons in a *neutral* atom

mass number: # of protons + # of neutrons in an atom's nucleus

# of protons + # of neutrons = mass number = A
# of protons = # of electrons = atomic number = Z $^{A}_{Z}\mathbf{E}$ **= element symbol**

Ex. 1: a. Write the atomic notation for sodium-23 at the right:

b. How many neutrons are in each neutral sodium-23 atom? _______

Ex. 2: a. Write the atomic notation for magnesium-26 at the right:

b. How many neutrons are in each neutral magnesium-26 atom? _______

Ex. 3: Fill in the table below:

Isotope of carbon	mass #	# of protons	# of neutrons	# of electrons
carbon-12				
carbon-13				
carbon-14				
argon-39				
Fe-59				

4.9 ATOMIC MASS

Atoms are too small to weigh directly

– e.g. one carbon atom has a mass of 1.99×10^{-23} g—too inconvenient an amount to use!

→ need more convenient unit for an atom's mass

→ **atomic mass unit (amu)**

Carbon-12 was chosen as the **reference** and given a mass value of **12 amu**

→ 1 amu = 1/12th the mass of a carbon-12 atom

→ Masses for all other elements are measured relative to mass of a carbon-12 atom

Weighted **Average Atomic Mass of an Element**

– Why is carbon's mass on the Periodic Table 12.01 amu, NOT 12.00 amu?

– Atomic masses reported on the Periodic Table are ***weighted averages*** of the masses of all the naturally occurring isotopes for each element based on their **percent natural abundance**—i.e., the percentage of existing atoms that are a specific naturally occurring isotope.

Ex. 1: Use the atomic mass reported on the Periodic Table to determine which one of the naturally occurring isotopes is most abundant for each element below:

a. The two naturally occurring isotopes for lithium are: (Circle one)

lithium-6 lithium-7

b. The three naturally occurring isotopes for argon are: (Circle one)

argon-36 argon -38 argon -40

c. The two naturally occurring isotopes for silver (Ag) are: (Circle one)

Ag-107 Ag-109

Note: You cannot simply round the atomic mass of an element to a whole number and assume that's the most abundant isotope because that isotope may not exist.

– For example, in Ex. 1c above, rounding the atomic mass for silver to the nearest whole number would indicate that Ag-108 is the most abundance isotope, but the only two naturally occurring isotopes for silver are Ag-107 and Ag-109.

Some elements have naturally occurring isotopes that are ***radioactive*** and ***unstable***.

→ distinguished on the Periodic Table with parentheses around a ***mass number*** for the most abundant radioactive isotope (instead of a ***weighted average*** of the ***atomic masses*** for all naturally occurring isotopes)

– e.g. the mass number is 222 for the most abundant isotope of radon (Rn), and the mass number is 209 for the most abundant isotope of polonium (Po)

4.6 Looking for Patterns: The Periodic Law and the Periodic Table

PERIODIC TABLE

A ***vertical column*** is called a group or family.
– Elements belonging to the same group exhibit similar chemical properties

A ***horizontal row*** is called a period or series.

Main-Group (Representative or A Group) Elements
Those elements in groups 1, 2, 13, 14, 15, 16, 17, 18 (or IA to VIIIA)
– Group 1 or IA: **alkali metals**
– Group 2 or IIA: **alkaline earth metals**
– Group 17 or VIIA: **halogens**
– Group 18 or VIIIA: **noble gases** (because they are all gases that do not react)

Transition Metals (or B Group Elements)
– Elements in Groups 3 to 12 (middle of the Periodic Table)

Inner Transition Elements (beneath the main body of Periodic Table)
– **Lanthanide series:** Ce-Lu, also called rare earth metals, make up <0.005% of Earth's crust
– **Actinide series:** Th-Lr, also called transuranium elements, generally all man-made and exist for only very short periods of time before decaying to other elements

periodic law: Elements can be arranged to display recurring properties.
→ We can use the Periodic Table to predict the properties of elements.

Dimitri Mendeleev proposed that elements display recurring properties according to *increasing atomic mass*
→ The first Periodic Table arranged elements according to *increasing atomic mass*.

Henry G. J. Moseley's high-energy X-ray radiation experiments of atomic nuclei
→ Repeating properties of elements are more clearly reflected if elements are arranged according to *increasing atomic number* (not increasing atomic mass).
→ Periodic Table's arrangement today
– Trends for increasing atomic mass are identical with those for increasing atomic number, except for Ni & Co, Ar & K, Te & I.

Example: Which of the following elements will behave similarly to **calcium (Ca)**?

Na Cl Mg S Sr Al Ar P

METALS, NONMETALS, and SEMIMETALS (or METALLOIDS)

Properties of Metals
- shiny appearance
- malleable (can be pounded into flat sheets)
- ductile (can be drawn into a fine wire)
- can conduct heat and electricity
- Examples are gold, copper, aluminum, etc.

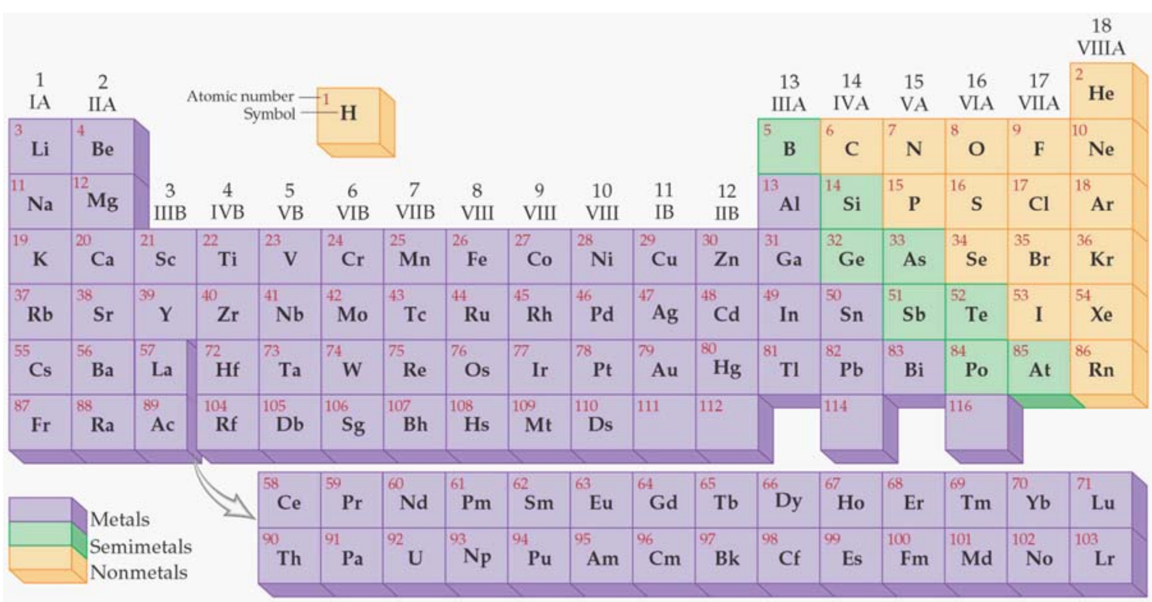
Properties of Nonmetals
- dull appearance
- brittle (will shatter under pressure)
- poor or nonconductor of heat and electricity
- Examples are sulfur, graphite (carbon), oxygen, nitrogen

Properties of Metalloids (or **Semimetals**): Have properties of metals and nonmetals – e.g. silicon (Si) has a shiny appearance and conducts electricity like a metal.

Metals are often used for pots and pans because they conduct heat; they are hammered into tools and armor; and they are used for wiring because they conduct electricity.

METALS, NONMETALS, and SEMIMETALS on the Periodic Table

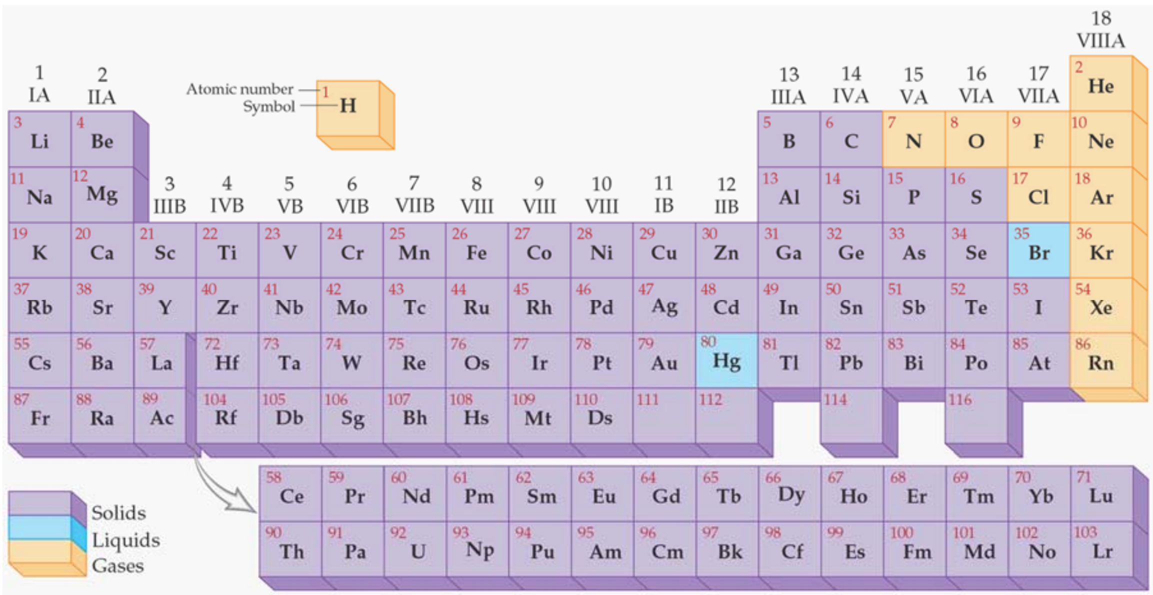
Know which elements are metals, semimetals, nonmetals using the Periodic Table.



SOLIDS, LIQUIDS, AND GASES: KNOW the physical state of each element at 25°C!

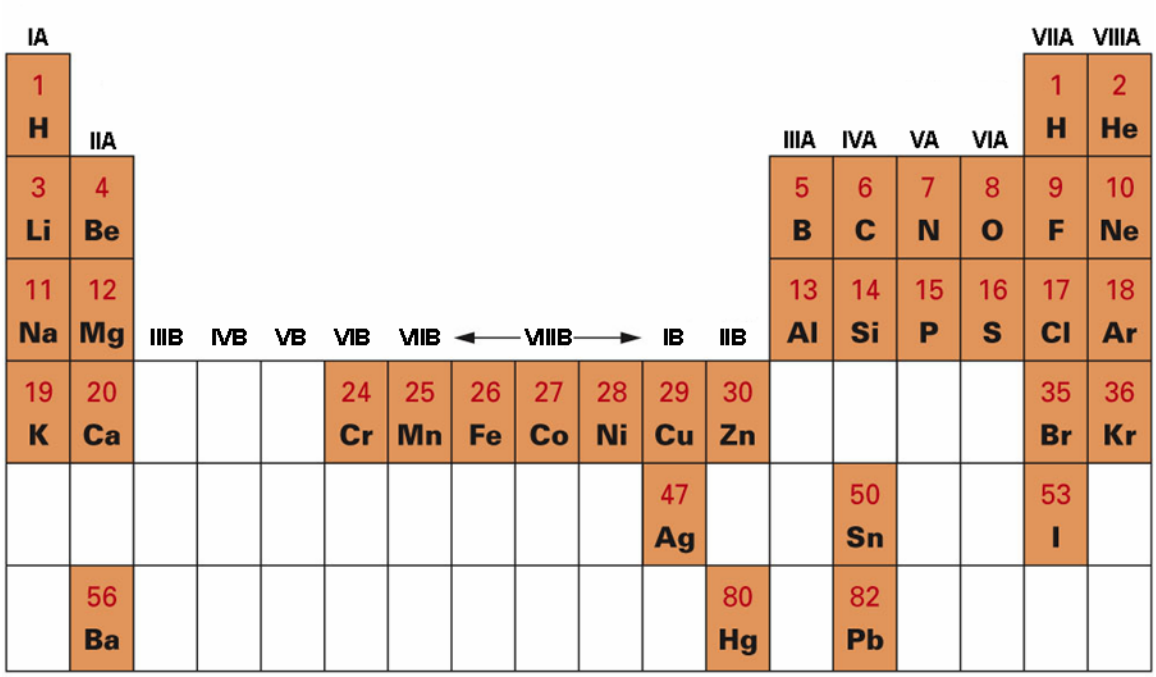
At standard state conditions (25°C and 1 atm):

- Only mercury (Hg) and bromine (Br) are liquid.
- H, N, O, F, Cl, and all Noble gases (group VIIIA) are gases.
- All other elements are solids.



ELEMENTAL SYMBOLS AND THE PERIODIC TABLE

Know the **names and symbols for all the elements** included below, as well as Sr (strontium) and U (uranium). **Spelling counts**!



Be sure the learn the ***American spelling*** shown below, ***NOT the British spelling*** included on some tables found on the Web!

Common Elements

Atomic Number	Symbol	Element	Atomic Number	Symbol	Element	Atomic Number	Symbol	Element
1	H	Hydrogen	13	Al	Aluminum	28	Ni	Nickel
2	He	Helium	14	Si	Silicon	29	Cu	Copper
3	Li	Lithium	15	P	Phosphorus	30	Zn	Zinc
4	Be	Beryllium	16	S	Sulfur	35	Br	Bromine
5	B	Boron	17	Cl	Chlorine	36	Kr	Krypton
6	C	Carbon	18	Ar	Argon	47	Ag	Silver
7	N	Nitrogen	19	K	Potassium	50	Sn	Tin
8	O	Oxygen	20	Ca	Calcium	53	I	Iodine
9	F	Fluorine	24	Cr	Chromium	56	Ba	Barium
10	Ne	Neon	25	Mn	Manganese	80	Hg	Mercury
11	Na	Sodium	26	Fe	Iron	82	Pb	Lead
12	Mg	Magnesium	27	Co	Cobalt			

Note: We skipped the sections covering ions (charged particles), but we will return to those sections after we finish Chapter 9.