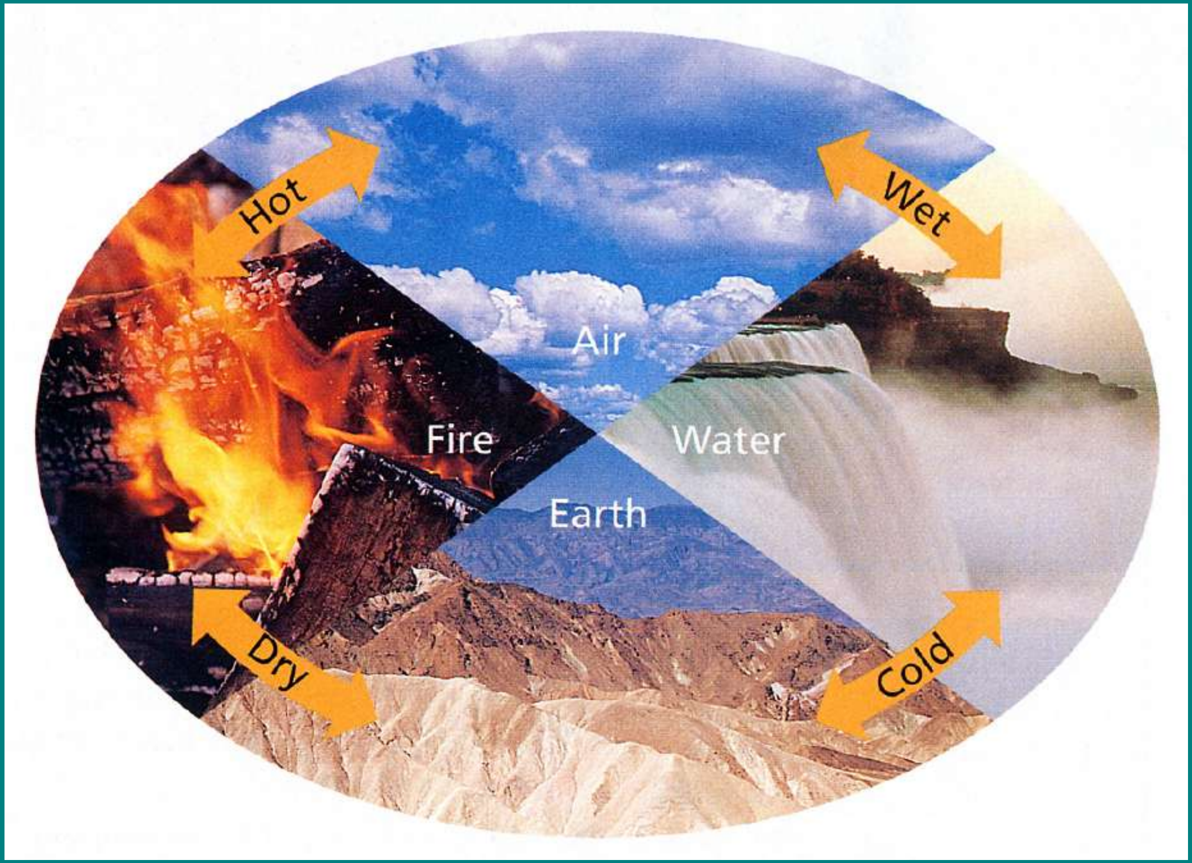
# Chapter 3
# Chemical Foundations: *elements, atoms, and ions*

big chapter; buckle your seat belts



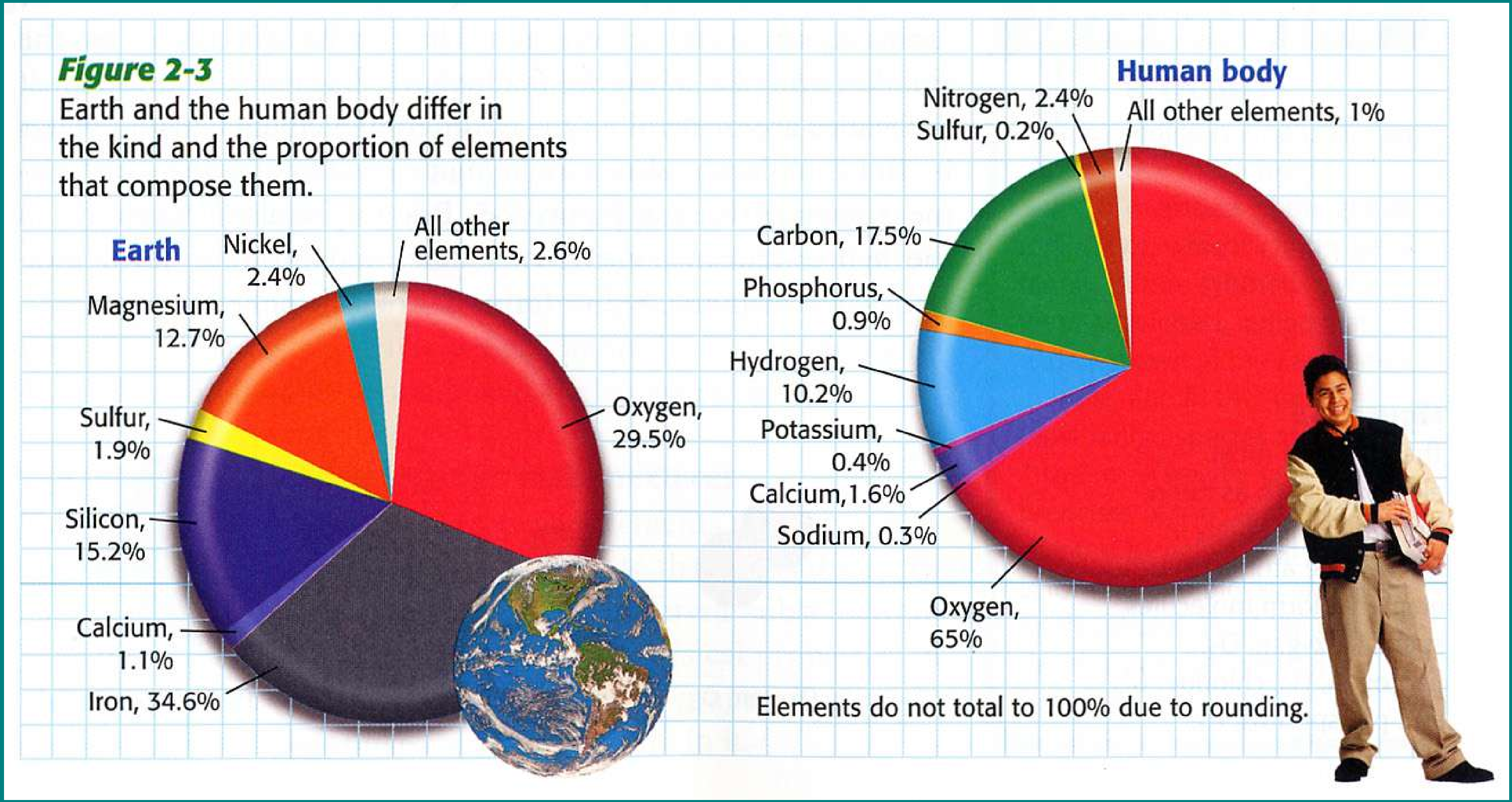

- The building blocks of life and the changes they undergo are **unbelievably** important and a great source of curiosity
- **Greeks** first tried to figure out what every thing is made of
- They believed all was made of **air, water, fire, and earth**

- For 2000 years people just dabbled
- When **Robert Boyle** came along (17th century) things began to change
- He insisted on ***experimentation***
- He argued that an element should be anything that *could not be broken down (an atom)* *(not air and water, etc.)*

# 3.1 The Elements

- Remember there are only over 100 of these things which make up everything in the **universe**
- of 115 known elements, 88 are natural
- what are the others?

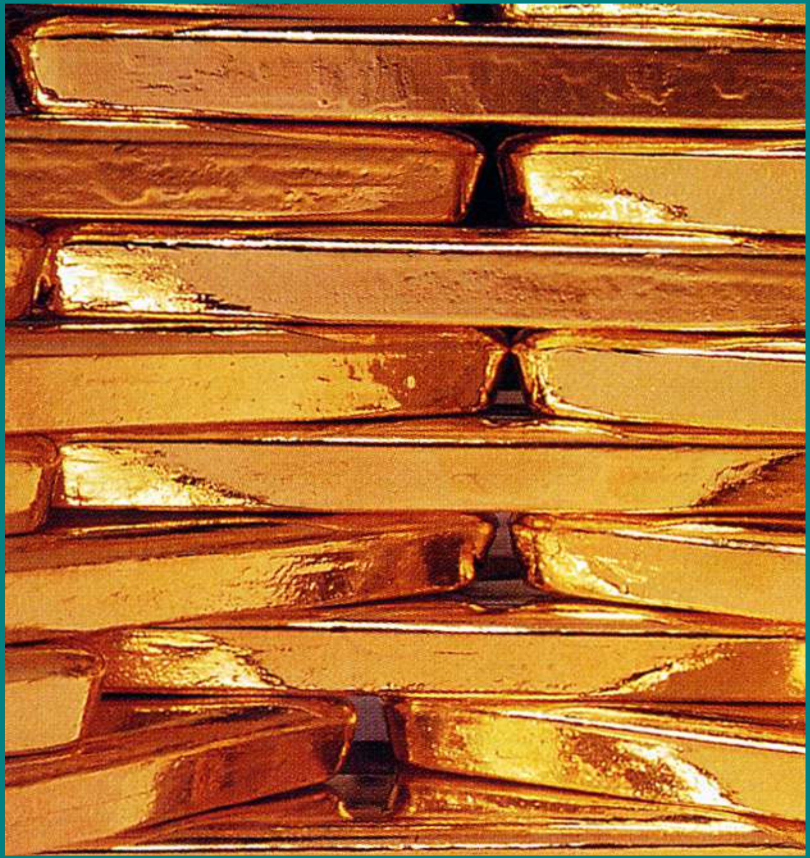
How would you like to memorize the periodic table?
Need help?




Only a **few** of these elements make up **most** of Earth *and* your body

- ***Note***:
  *Even though oxygen is the clear winner in both places, it is mostly wrapped up in compounds (such as iron **oxide**)*
- ***Clarification***:
  "Element" can be used:
- to mean a **single atom**
  - ✓ to mean a **sample** (as in *air contains the element oxygen*)
  - ✓ **generically** (as in *the body contains the element sodium*)

# 3.2 Symbols for the Elements



- Some names of elements come from **Greek, Latin, and German**
- example: Gold was called ***aurum*** – "Au" (Latin) meaning *the dawn*
- Bromine comes from βρωμος, Greek for *stench*
- Some named for **places or people** (e.g. plutonium for Pluto, Einsteinium for Einstein)

- Usually names are abbreviated called **symbols**
- First letter ALWAYS capitalized
- second letter, if there is one, is not
- sometimes the original Greek or Latin is preserved in the symbol if not the name (e.g. gold is Au)
- *you must know the following chart*

**TABLE 3.3**

**The Names and Symbols of the Most Common Elements**

| Element | Symbol | Element | Symbol |
|---|---|---|---|
| aluminum | Al | lithium | Li |
| antimony (stibium)* | Sb | magnesium | Mg |
| argon | Ar | manganese | Mn |
| arsenic | As | mercury (hydrargyrum) | Hg |
| barium | Ba | neon | Ne |
| bismuth | Bi | nickel | Ni |
| boron | B | nitrogen | N |
| bromine | Br | oxygen | O |
| cadmium | Cd | phosphorus | P |
| calcium | Ca | platinum | Pt |
| carbon | C | potassium (kalium) | K |
| chlorine | Cl | radium | Ra |
| chromium | Cr | silicon | Si |
| cobalt | Co | silver (argentium) | Ag |
| copper (cuprum) | Cu | sodium (natrium) | Na |
| fluorine | F | strontium | Sr |
| gold (aurum) | Au | sulfur | S |
| helium | He | tin (stannum) | Sn |
| hydrogen | H | titanium | Ti |
| iodine | I | tungsten (wolfram) | W |
| iron (ferrum) | Fe | uranium | U |
| lead (plumbum) | Pb | zinc | Zn |

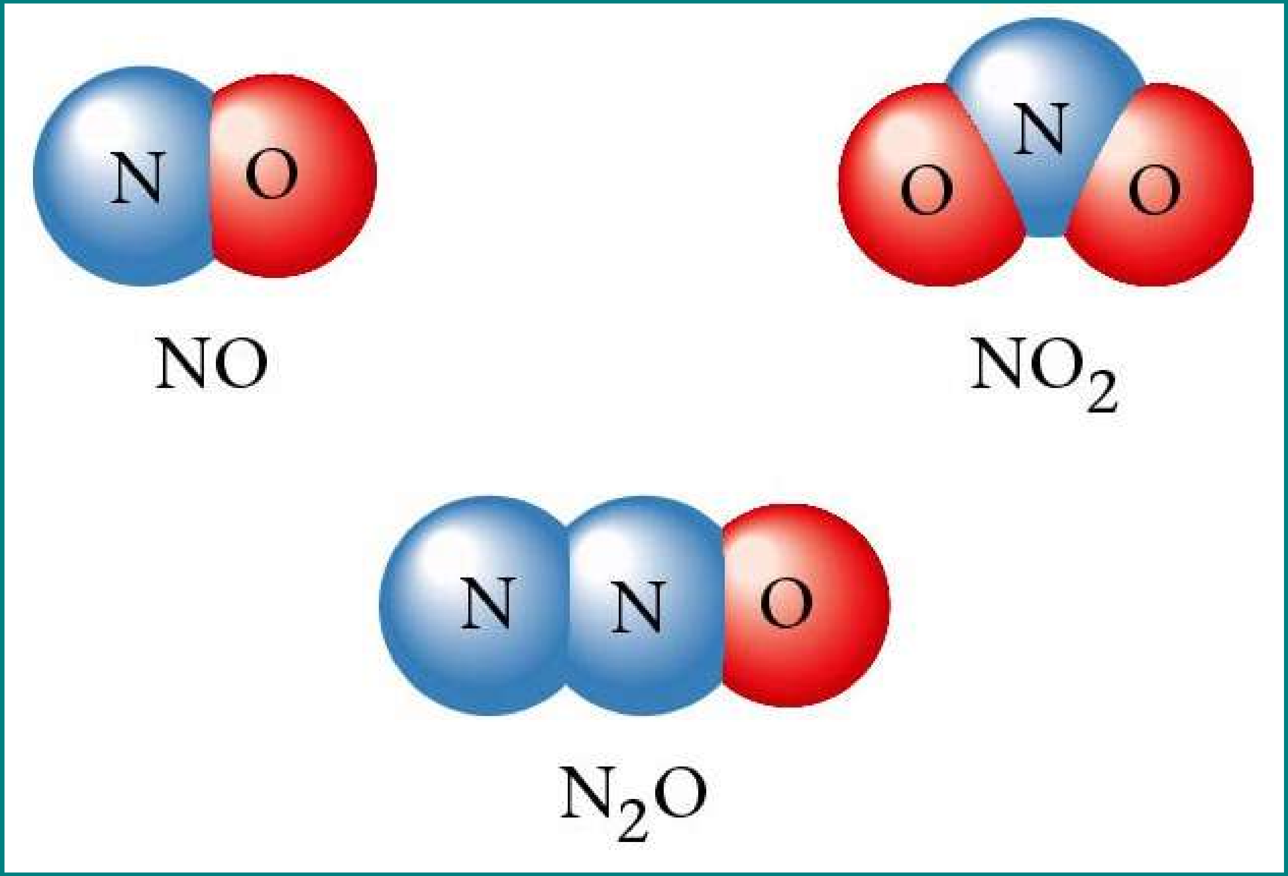
*Where appropriate, the original name is shown in parentheses so that you can see the sources of some of the symbols.

# 3.3 Dalton's Atomic Theory

- In the 1700s people knew these:
  - ✓ most natural things were really *mixtures*
  - ✓ pure substances are either *elements* or *compounds*
  - ✓ a compound is made of the *same ratio of stuff* no matter where it comes from (law of constant composition)
- **John Dalton** in early 1800s knew this and developed theory…

## Dalton's Atomic Theory

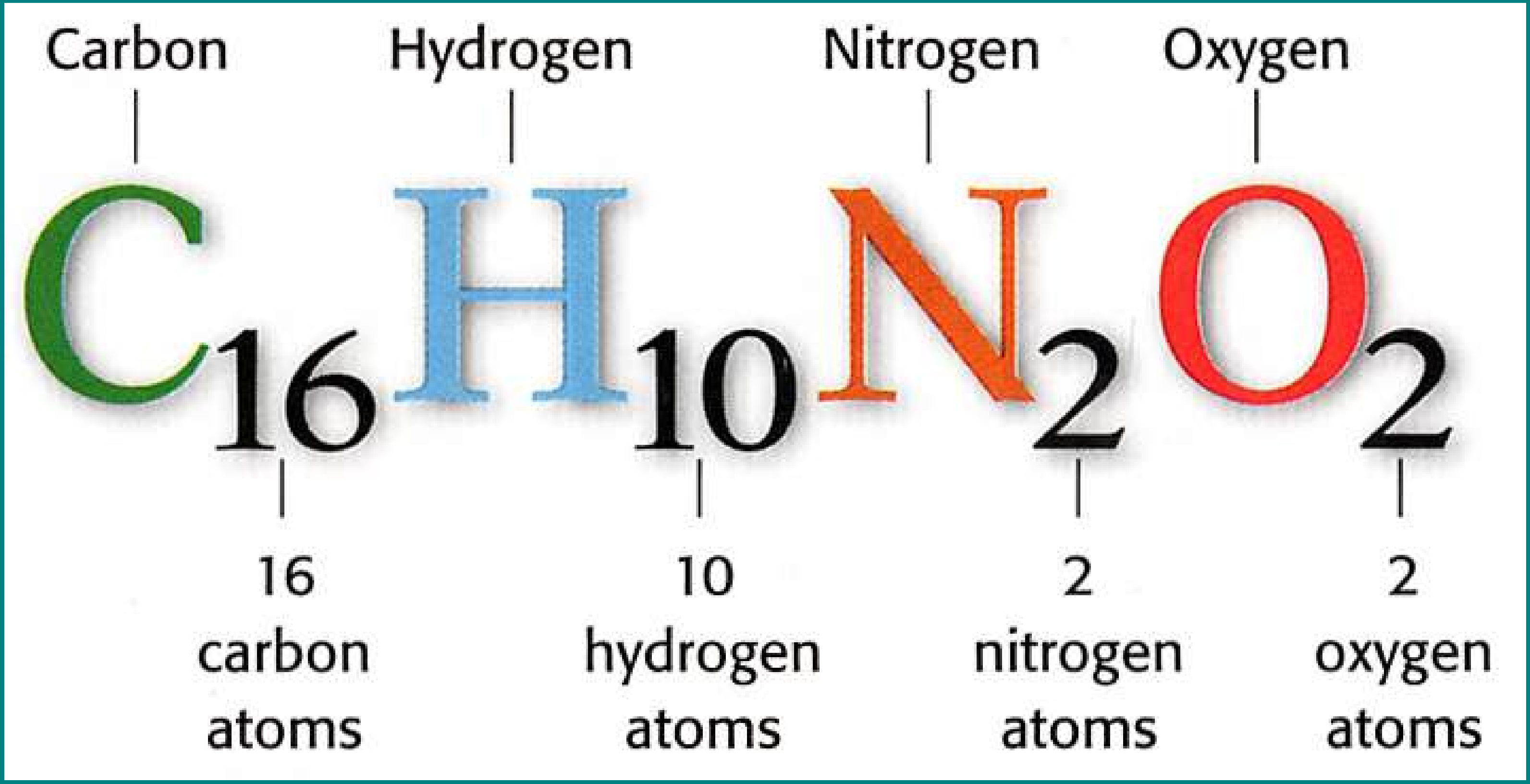
1. Elements are made of tiny particles called **atoms.**
2. All atoms of a given element are identical.
3. The atoms of a given element are different from those of any other element.
4. Atoms of one element can combine with atoms of other elements to form compounds. A given compound always has the same relative numbers and types of atoms.
5. Atoms are indivisible in chemical processes. That is, atoms are not created or destroyed in chemical reactions. A chemical reaction simply changes the way the atoms are grouped together.




- his model *explained* a lot and even ***predicted*** the existence of other chemicals like these
- Dalton's Atomic Theory was not perfect *but was a great start*

# 3.4 Formulas of Compounds

- Chemical formulas tell you ***what*** and relatively ***how many*** atoms are in a compound



## Rules for Writing Formulas

1. Each atom present is represented by its element symbol.
2. The number of each type of atom is indicated by a subscript written to the right of the element symbol.
3. When only one atom of a given type is present, the subscript 1 is not written.

# 3.5 The Structure of the Atom

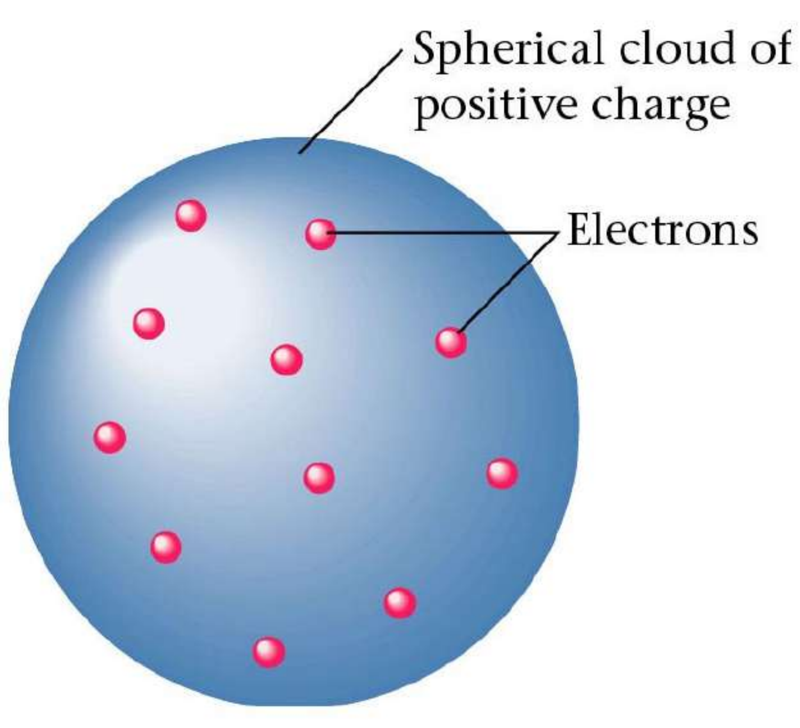
- In Dalton's time scientists believed elements were made of atoms, and compounds were atoms somehow held together
- *but what is an atom?*
- *why do they stick?*
- took nearly 100 years to figure it out!

# Thomson's Experiment

- in 1890s **JJ Thomson** of Cambridge U discovered that all atoms have negative bits called ***electrons***
- if so, must also have positive part…

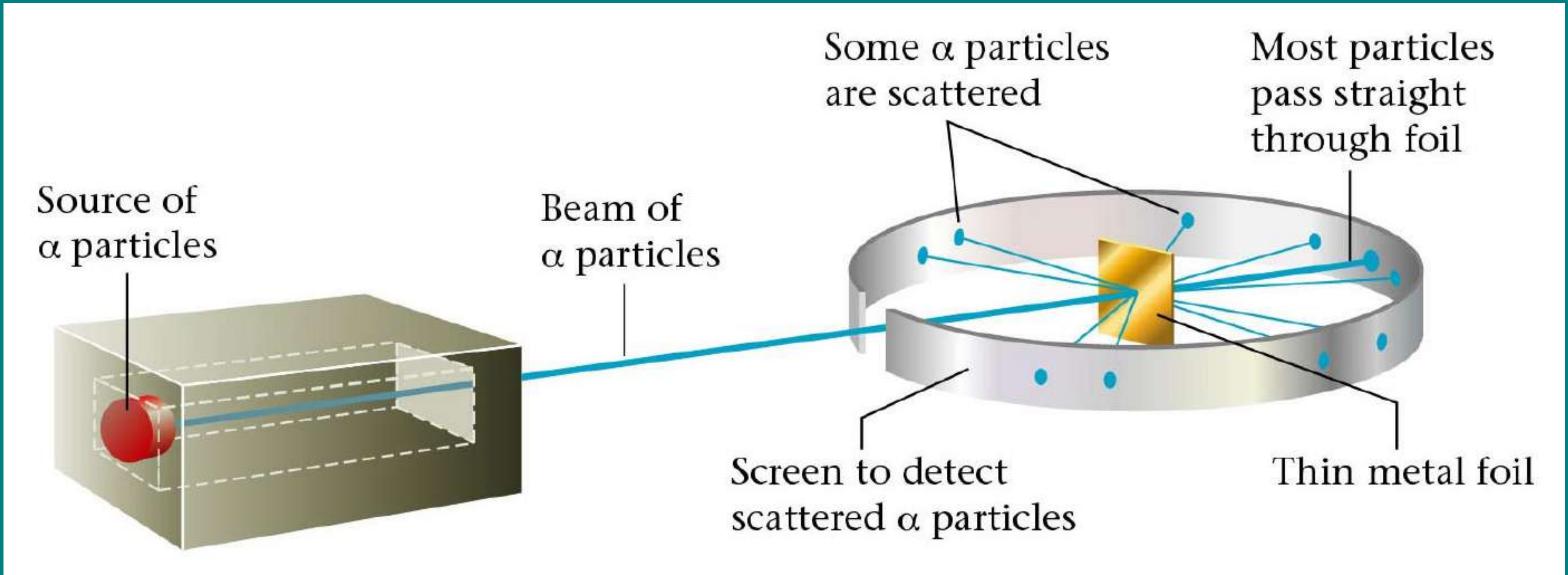
# The Plum Pudding model

- William Thomson (aka Lord Kelvin) modeled the atom as a positive cloud filled with electrons called **the Plum Pudding Model**
- positive cloud + electrons = neutral atom

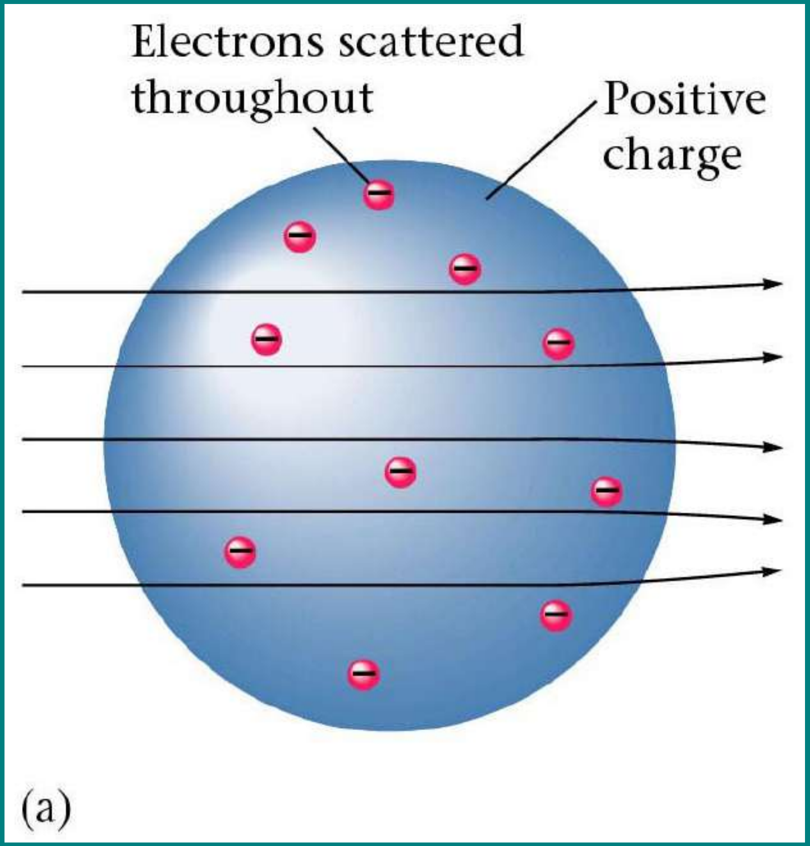


# Rutherford’s experiment

- **Ernest Rutherford’s** exp changed the plum pudding model
- he liked shooting “alpha” particles through things to see what would happen
- so he shot some through really thin gold foil…

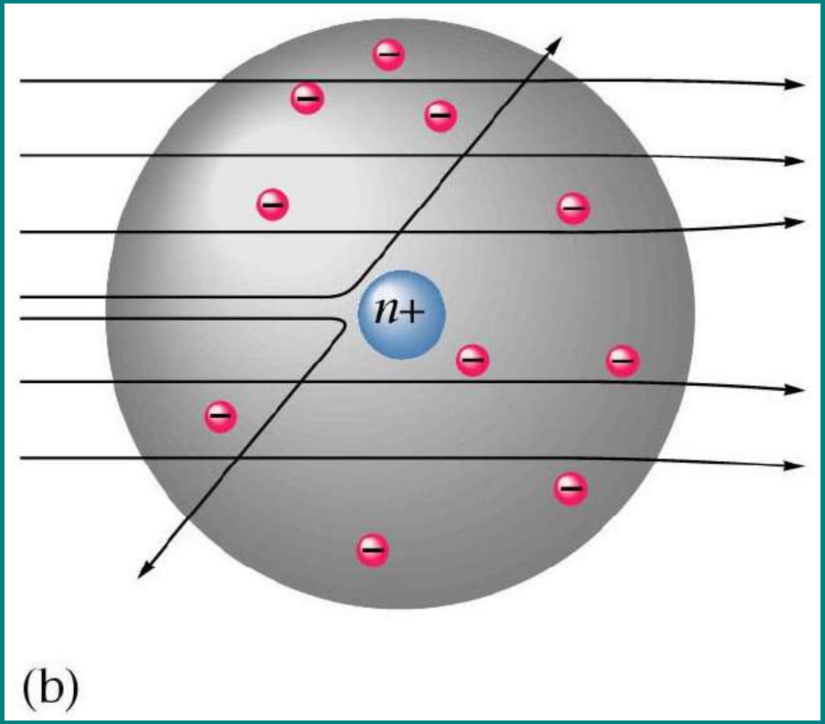


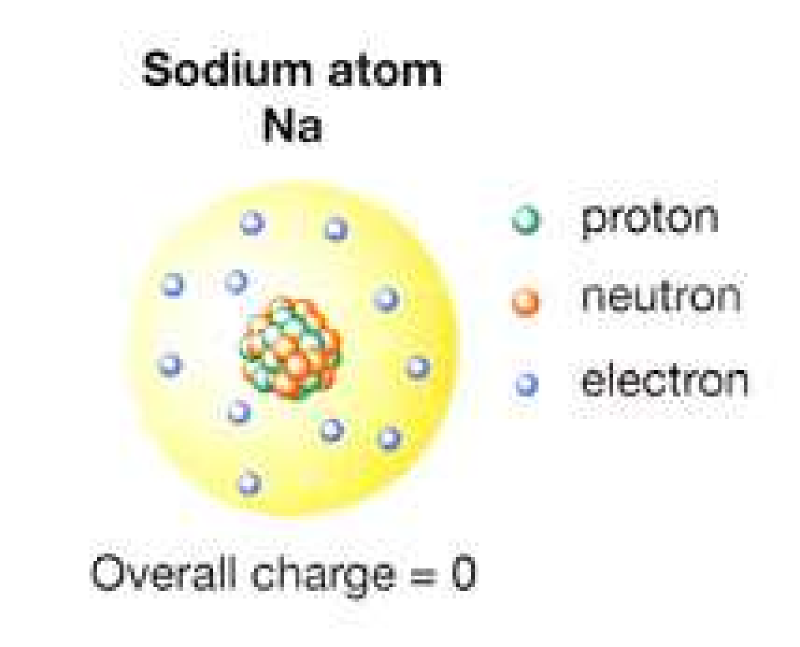

- to his great surprise, the positive alpha particles didn’t all plough right through!
- ***some were deflected!***
- implying there was some positive **area** in the atom that was deflecting the positive alphas




- this is what should have happened if plum pudding model was correct
- Rutherford said since *most* made it, but *some* strongly deflected so that the atom looks like…

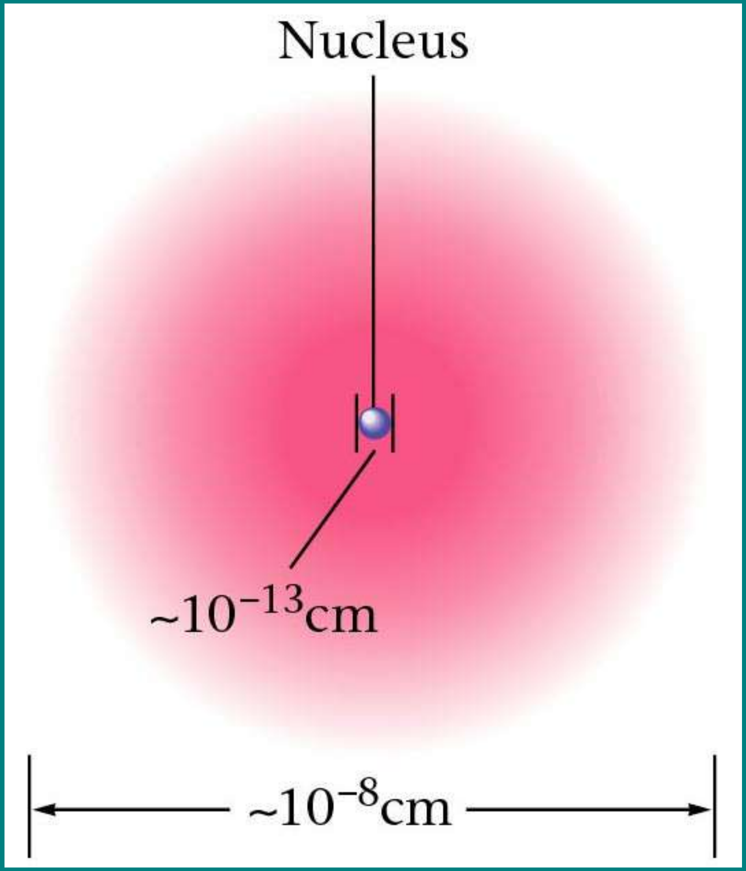
- ooooh look! a new player
- This is the **nuclear atom** (one with a **nucleus**)
- not until 1919 did they figure out the nucleus was made of particles called **protons**
- proton had same size - but opposite - charge as electron






- Rutherford reasoned that hydrogen has just one proton, one electron buzzing around it
- also reasoned that other atoms just had more protons and electrons
- by 1932, a neutral particle - the **neutron** - was discovered in the nucleus to complete the puzzle

# 3.6 *Introduction* to the Modern Concept of Atomic Structure




- today's model looks something like this
- ultra-small nucleus
- atom is about **100,000** times bigger than the nucleus!
- *like a grain of sand in the middle of the stadium*
- the players are…

**TABLE 3.4**

**The Mass and Charge of the Electron, Proton, and Neutron**

| Particle | Relative Mass* | Relative Charge |
|---|---|---|
| electron | 1 | 1 − |
| proton | 1836 | 1 + |
| neutron | 1839 | none |

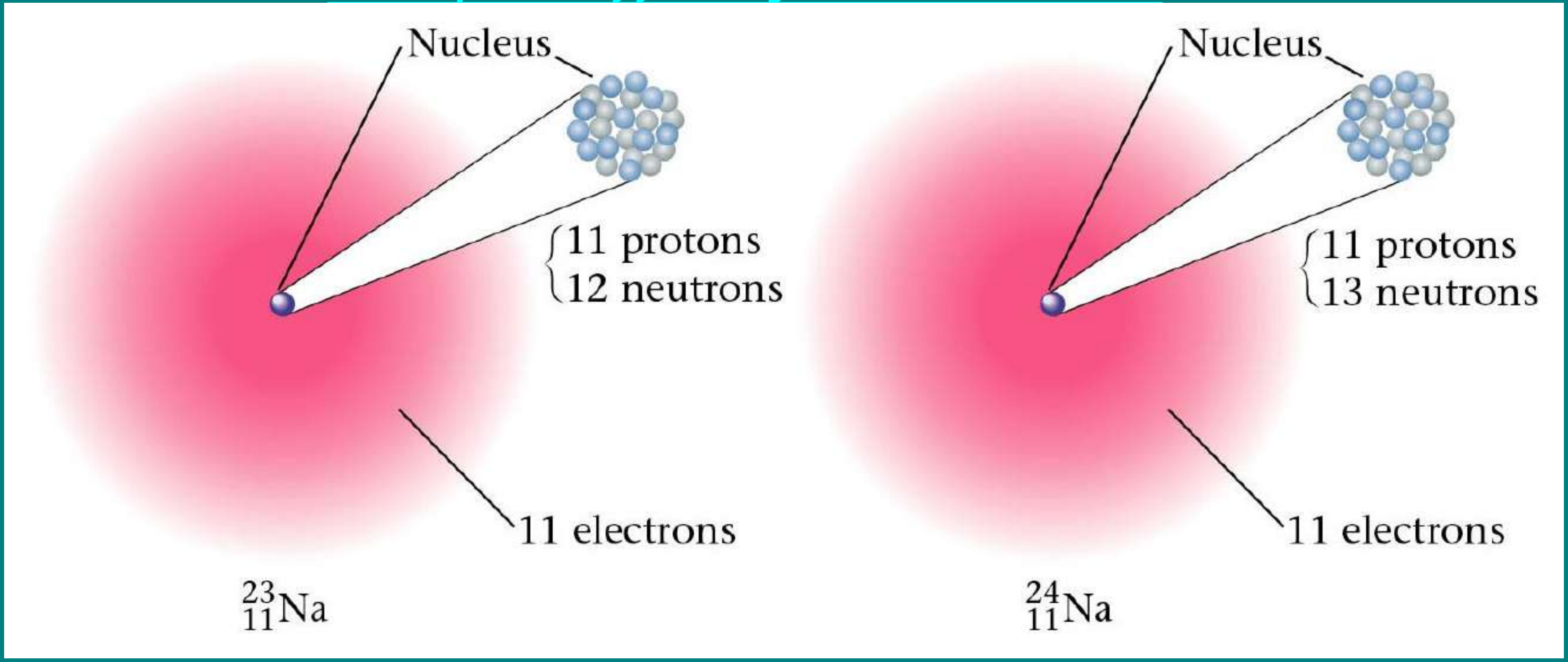
*The electron is arbitrarily assigned a mass of 1 for comparison.

- Important!!! if all atoms are made of just these three things, ***why do they all act differently?***
- It has to do with **how many** there are and how they are **arranged**

# 3.7 Isotopes

- Turns out that Dalton was sorta wrong - not all atoms of the same element are alike
- Turns out that although protons and electrons are the same (for any element), but ***neutrons*** can differ!

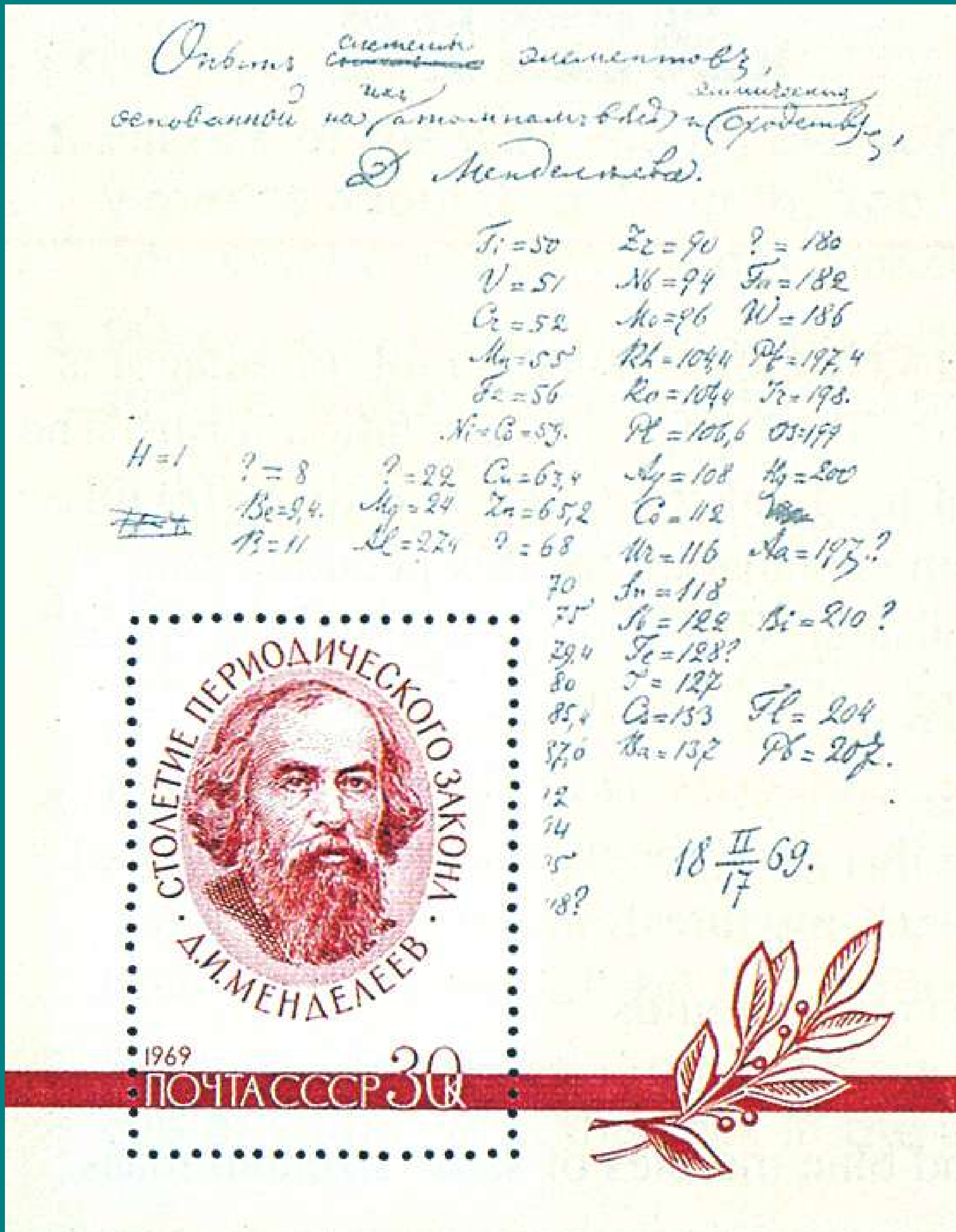
- these are **isotopes**
- *same p, same e, different n*
- number of protons = **atomic number**
- p + n = **mass number**
- therefore *isotopes differ by mass number*



$^{A}_{Z}X$

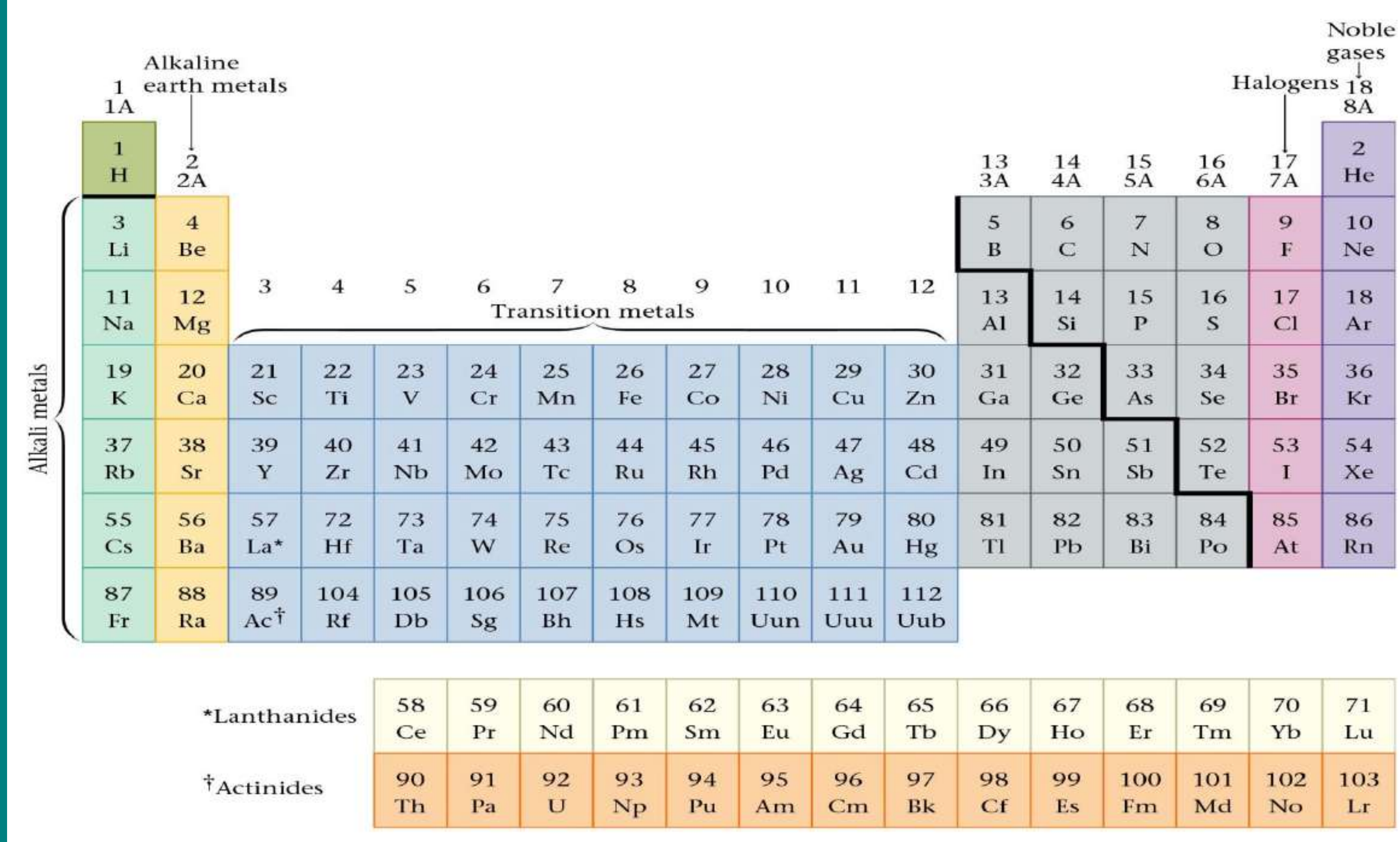
- X = chemical symbol
- A = mass number
- Z = atomic number
- named by *element followed by mass number*
- e.g…
- carbon with 6 protons and 8 neutrons is called C-14 (carbon-14) and represented like…

$^{14}_{6}C$

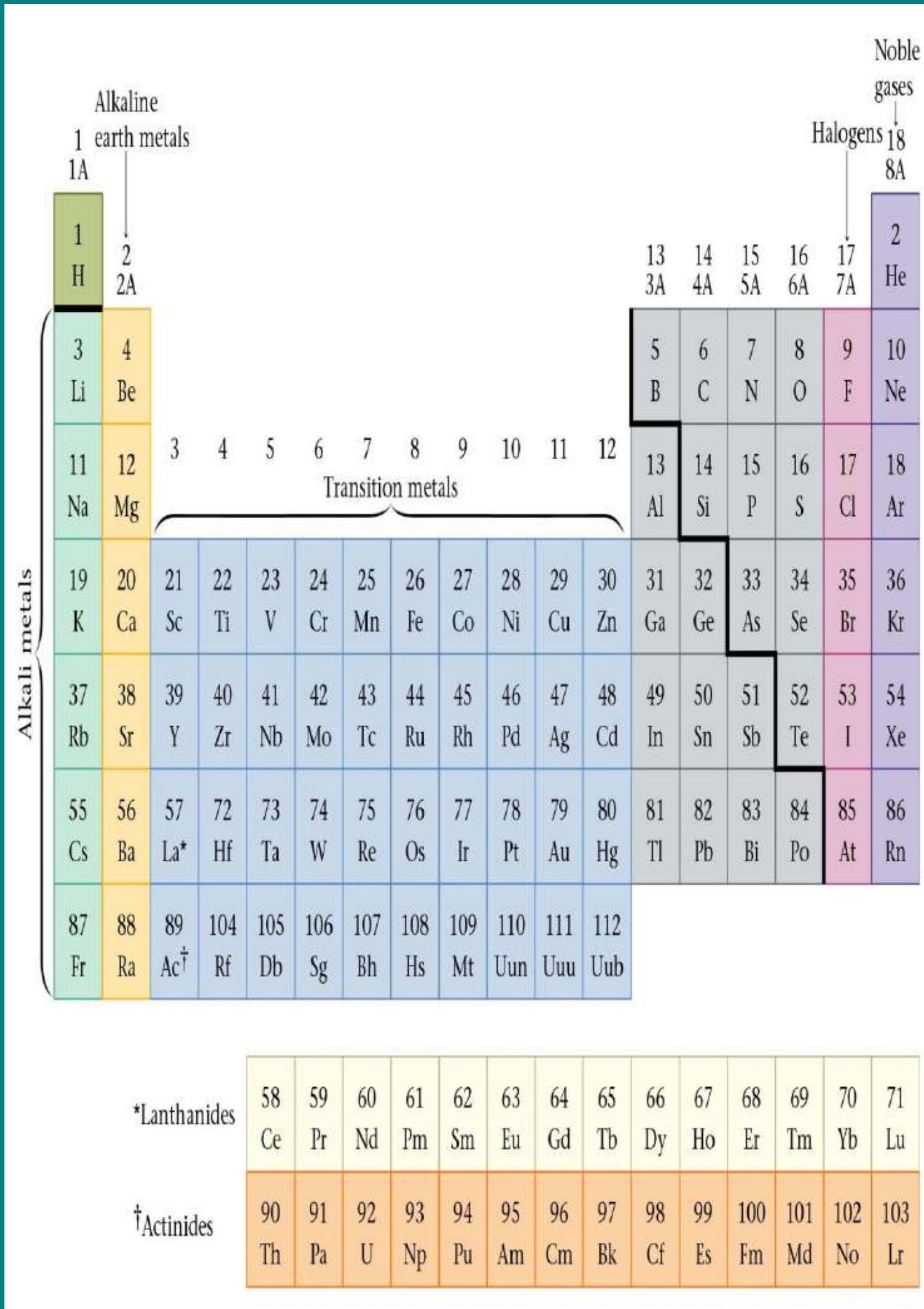



# 3.8 Introduction to the Periodic Table

- want a quick reference guide to all the known elements?
- that's the **periodic table**
- first introduced by **Dmitri Mendeleev**




- notice in this simple Periodic Table: ordered by increasing atomic #
- Mendeleev ordered vertical columns by **similar properties**
- the properties repeat periodically (∴ **periodic table**)

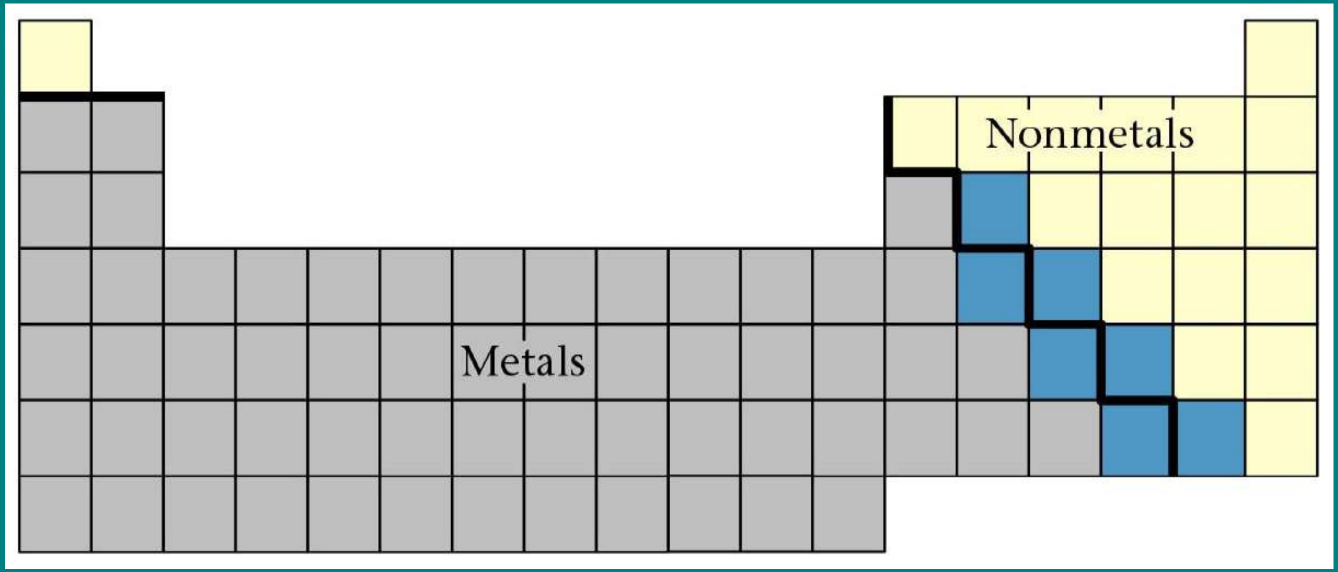


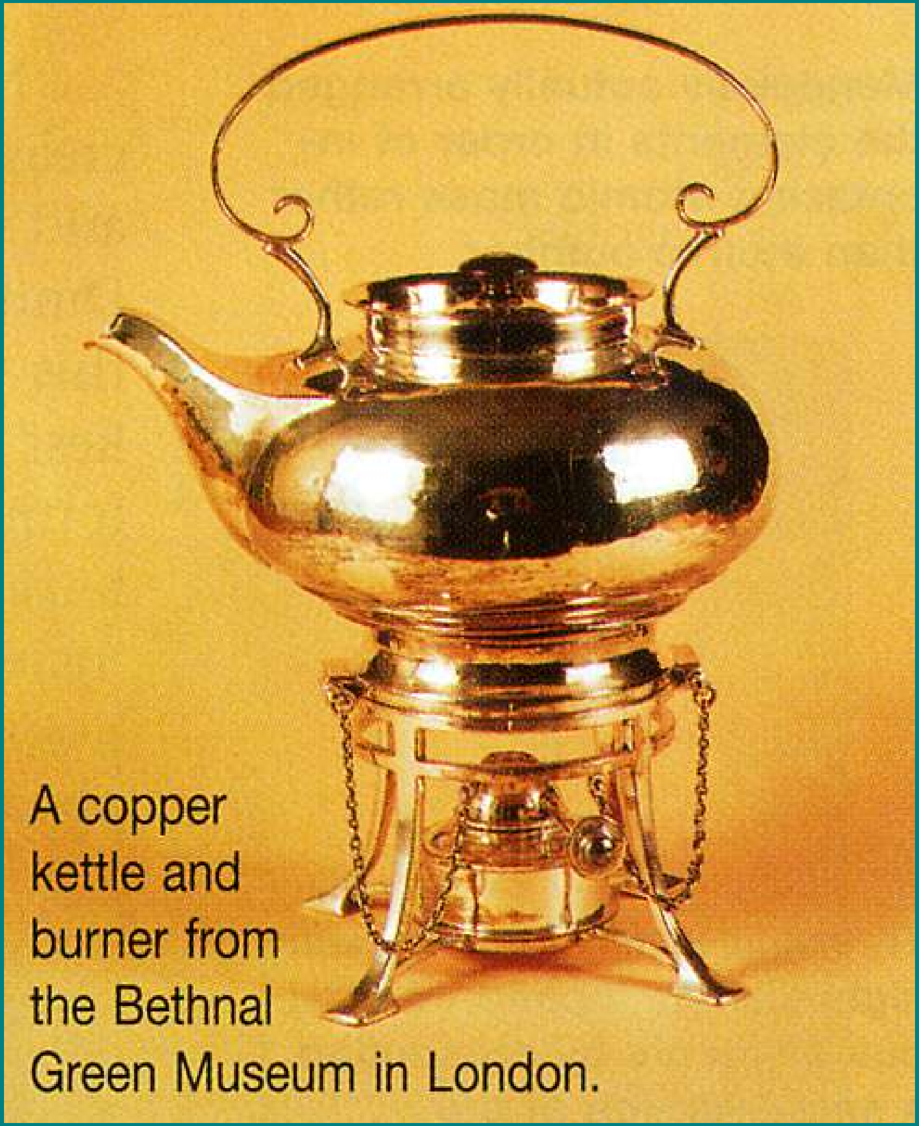

- the vertical groups are called families or simply "**groups**"
- numbered 1-18, or by A and B groups
- group 1 = **alkali metals**
- group 2 = **alkaline earth metals**
- group 17 = **halogens**
- group 18 = **noble gases**
- group 3-12 = **transition metals**
- know them!

## Physical Properties of Metals

1. Efficient conduction of heat and electricity
2. Malleability (they can be hammered into thin sheets)
3. Ductility (they can be pulled into wires)
4. A lustrous (shiny) appearance

- metals make up most of the Periodic Table
- they can be found here…

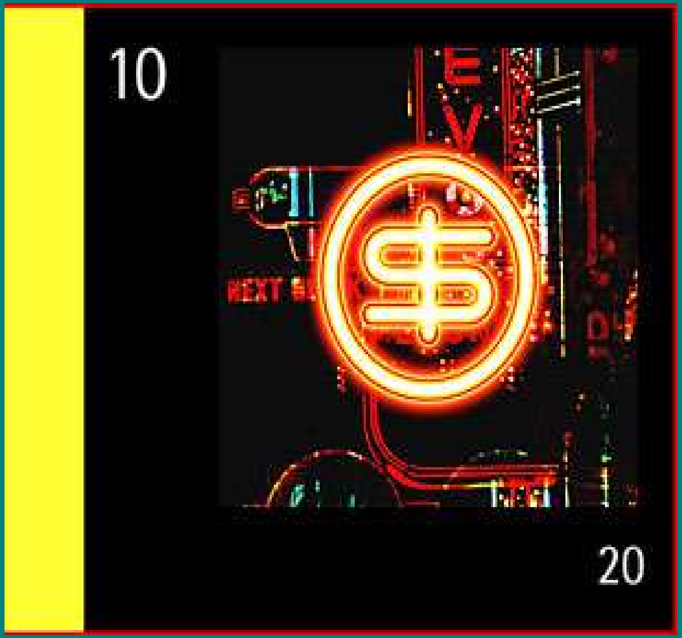




A copper kettle and burner from the Bethnal Green Museum in London.

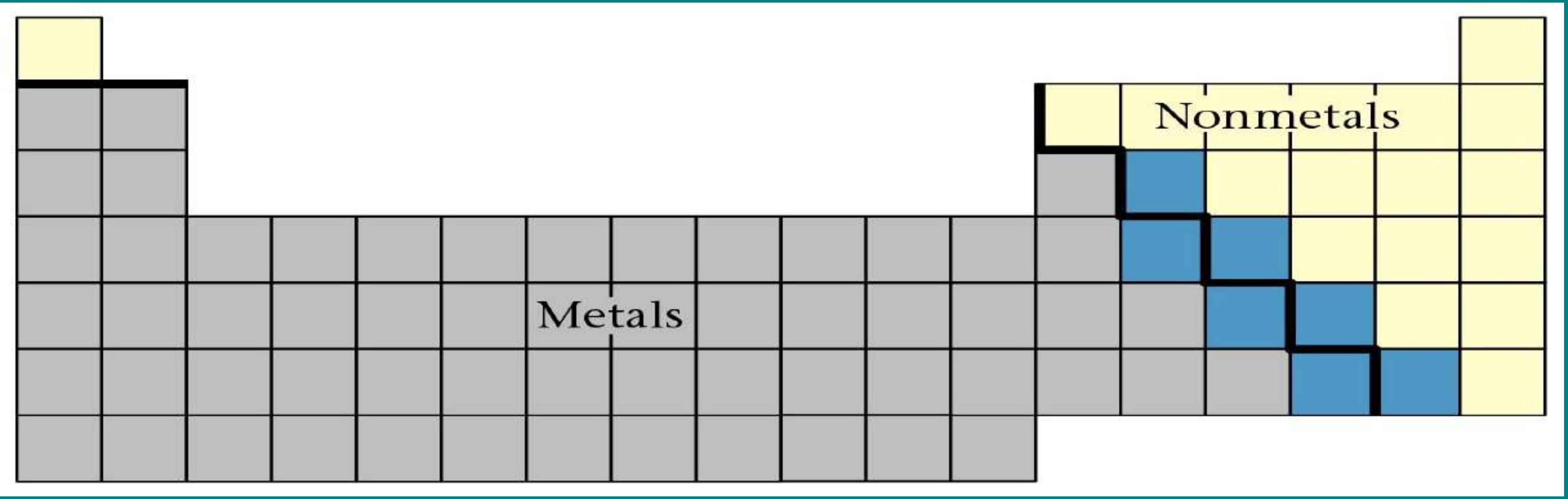
- copper is perfect example
- is very lustrous (<u>shiny</u>)
- easily shaped (<u>malleable</u>)
- can be drawn out into copper wire (<u>ductile</u>)
- but what about things which aren't metal-like?...

- non-metals are called… <u>**nonmetals**</u>
- they have <u>properties</u> practically <u>opposite of metals</u>
- <u>*brittle, dull, nonconductive*</u>




Bromine

Iodine




- some elements have <u>both metal and nonmetal properties</u>
- called **<u>metalloids</u>** or **semimetals**
- located on staircase


Silicon

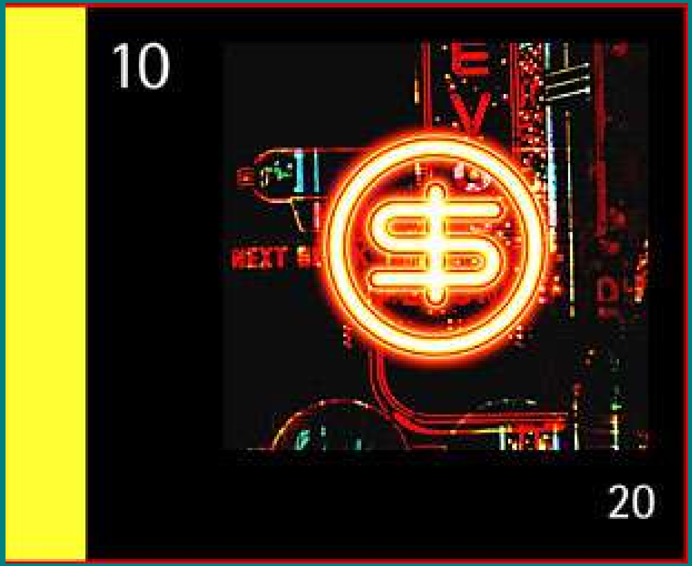
# example

Symbol, Atomic number, M/NM, Family

- Argon Ar 18NM noble gas
- Chlorine Cl 17NM halogen
- Barium Ba 56 Malkali earth
- Cesium Cs 55 M alkali

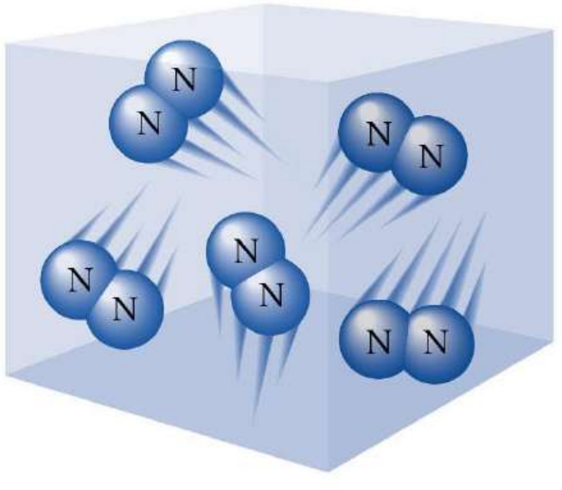
# 3.9 Natural States of the Elements

Platinum

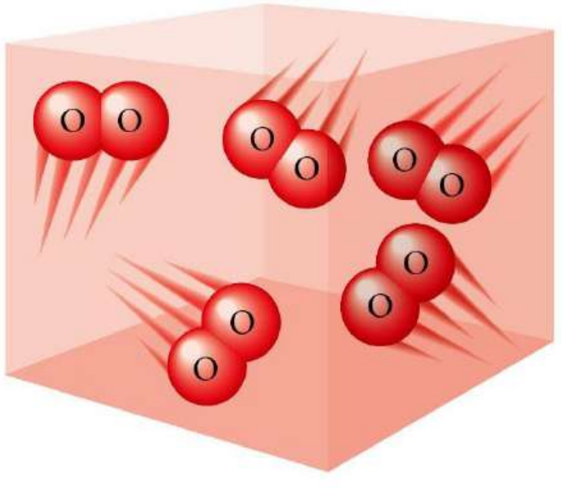



Neon

- not a whole lot of elements occur alone (i.e. uncombined)
- some metals (**noble metals**) can be found in their pure, uncombined state
- so do the **noble gases** (group 8)
- but so do…



(a)



(b)

- **<u>Diatomic</u>** elements!
- these critters <u>travel in twos</u>
- notice they are elements - not compounds!
- hydrogen is almost always with another element, *but when separated is diatomic*

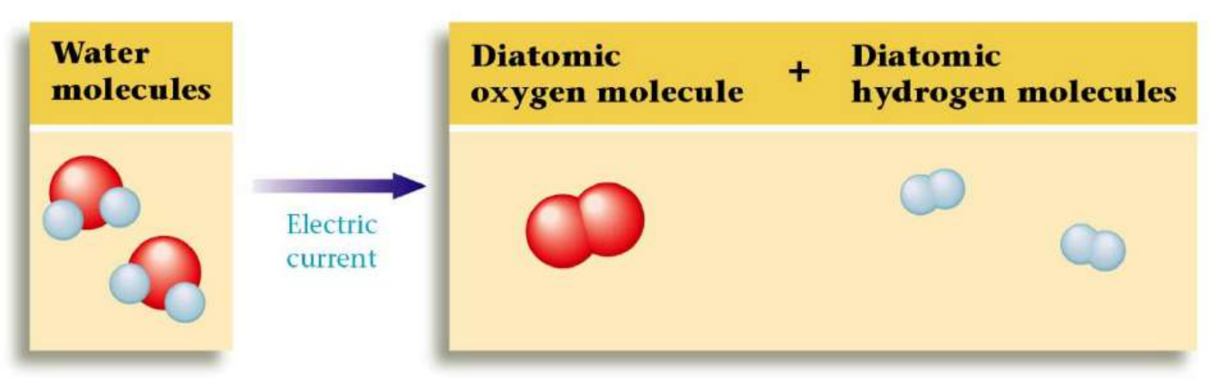


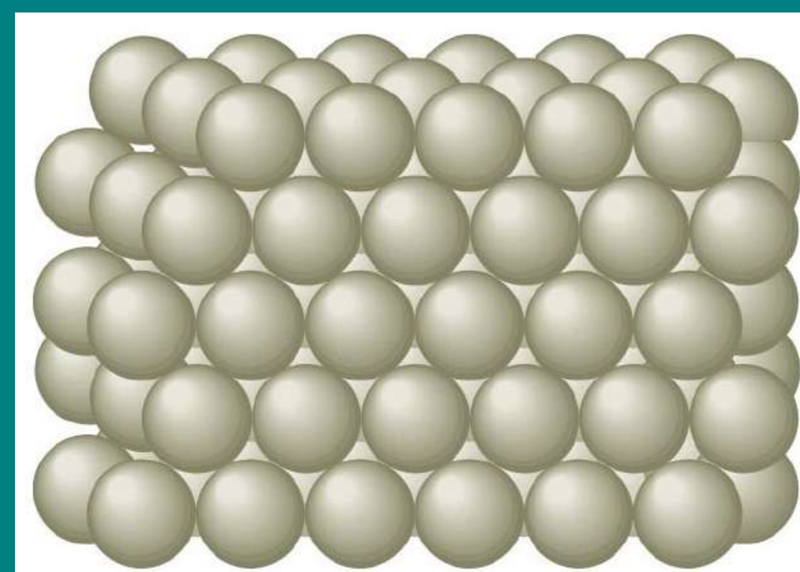
**TABLE 3.5**

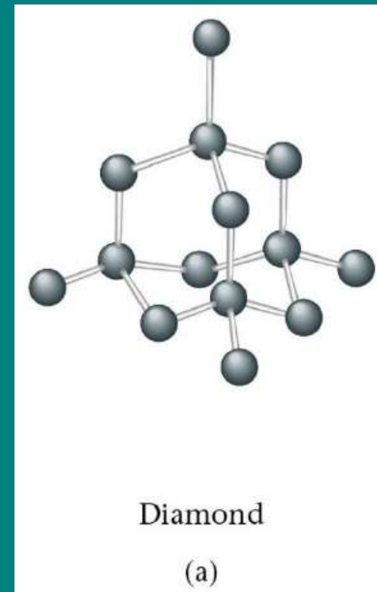
**Elements That Exist as Diatomic Molecules in Their Elemental Forms**

| Element Present | Elemental State at 25 °C | Molecule |
| --- | --- | --- |
| hydrogen | colorless gas | $H_2$ |
| nitrogen | colorless gas | $N_2$ |
| oxygen | pale blue gas | $O_2$ |
| fluorine | pale yellow gas | $F_2$ |
| chlorine | pale green gas | $Cl_2$ |
| bromine | reddish-brown liquid | $Br_2$ |
| iodine | lustrous, dark purple solid | $I_2$ |

- here are *diatomic* molecules
- remember: **Professor BrINClHOF**
- notice: many are halogens

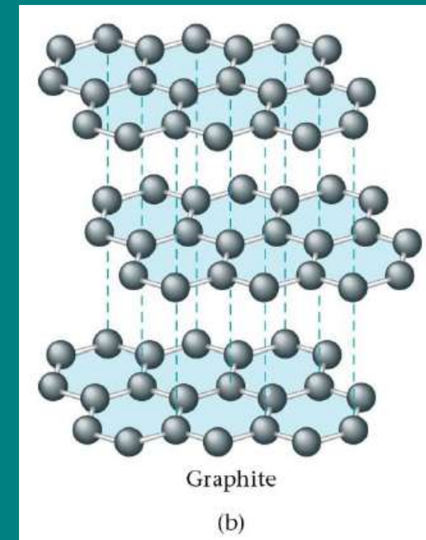
- the noble gases and the BrINClHOF guys are **gases**
- only two elements occur as **liquids** at $25^{\circ}$C (bromine and mercury)
- all the rest are **solids**, which are usually just atoms packed in real tight





Diamond

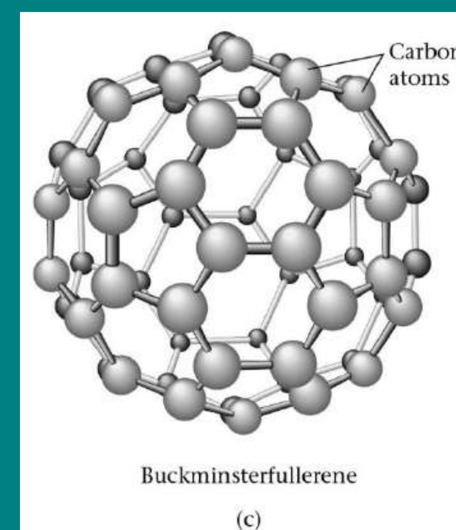
(a)



Graphite

(b)

- the <u>nonmetals</u> can take on <u>all kinds of arrangements</u>
- *different arrangements of same element* called **<u>allotropes</u>**
- allotropes have <u>diff properties</u> because of different arrangements

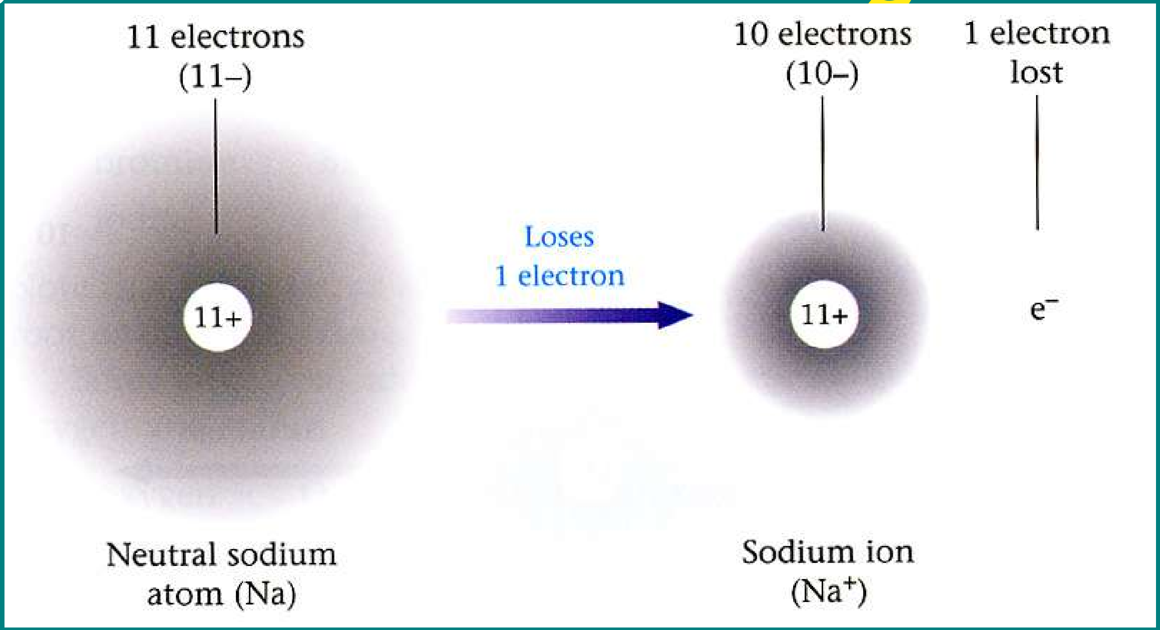



Buckminsterfullerene

(c)

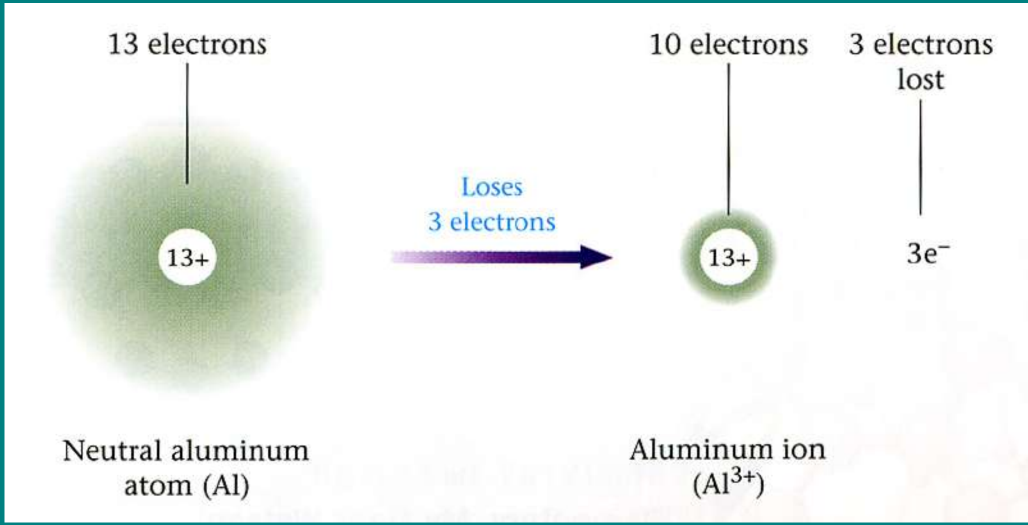
# 3.10 Ions

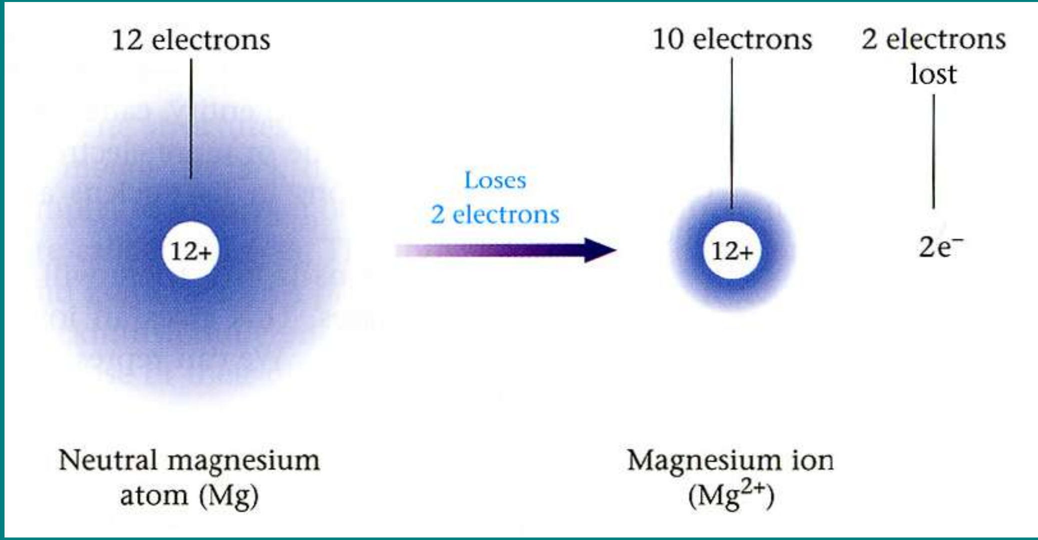
- Atoms have a *zero net charge*, i.e. *protons = electrons*
- But what if you strip an electron off or put an extra one on?
- a charged thing called an **ion = "charged" atom**



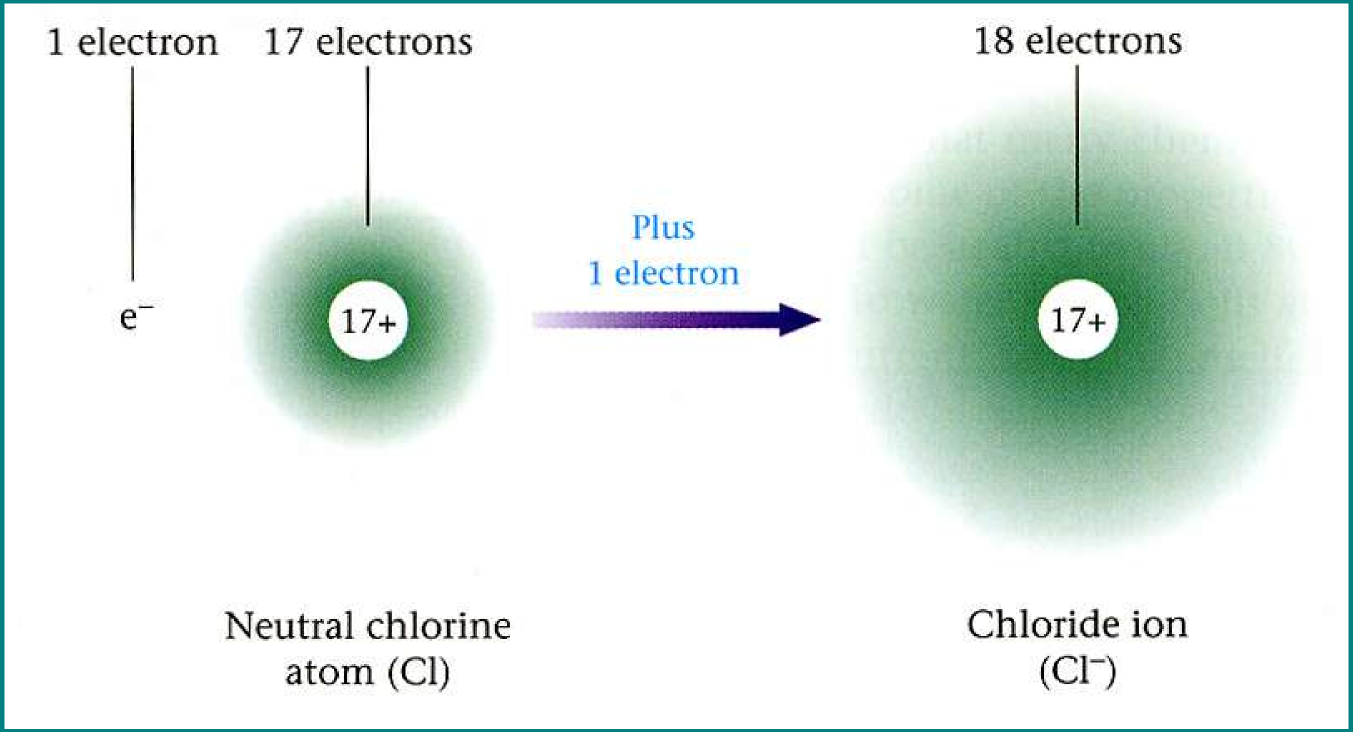
# Cations and Anions

- When an atom loses an $e^-$, we get a positive ion called a **cation**
- lose one $e^-$, get a 1+ charge; lose two $e^-$, get a 2+ charge
- The ion is named after parent atom
- e.g. aluminum ion, magnesium ion



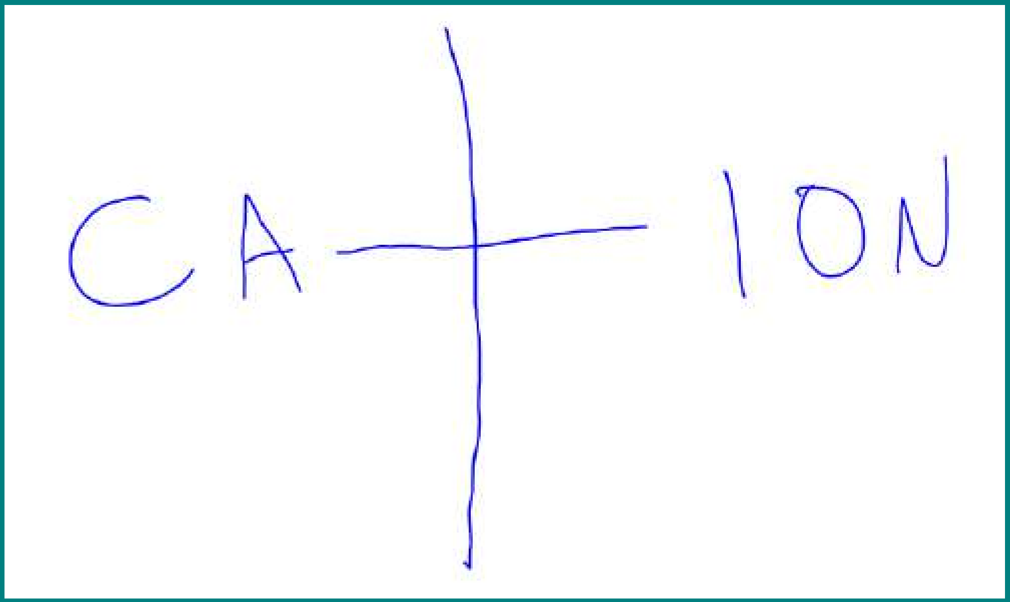



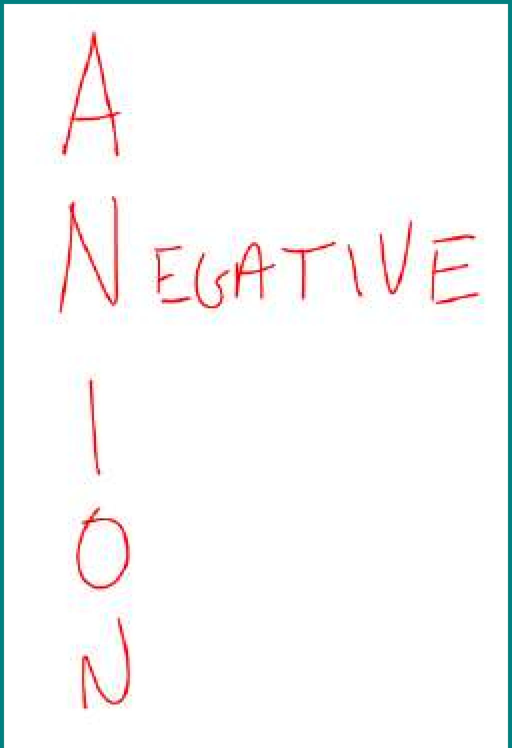
- What if it gains an electron? **anion**
- The name, however, changes! adds an **-ide** to the end (e.g. chloride)
- !!! *ions only formed by changing electrons, not protons*
- !!! *never happens alone; something always makes them fall off or add on*



# Two types of Ions

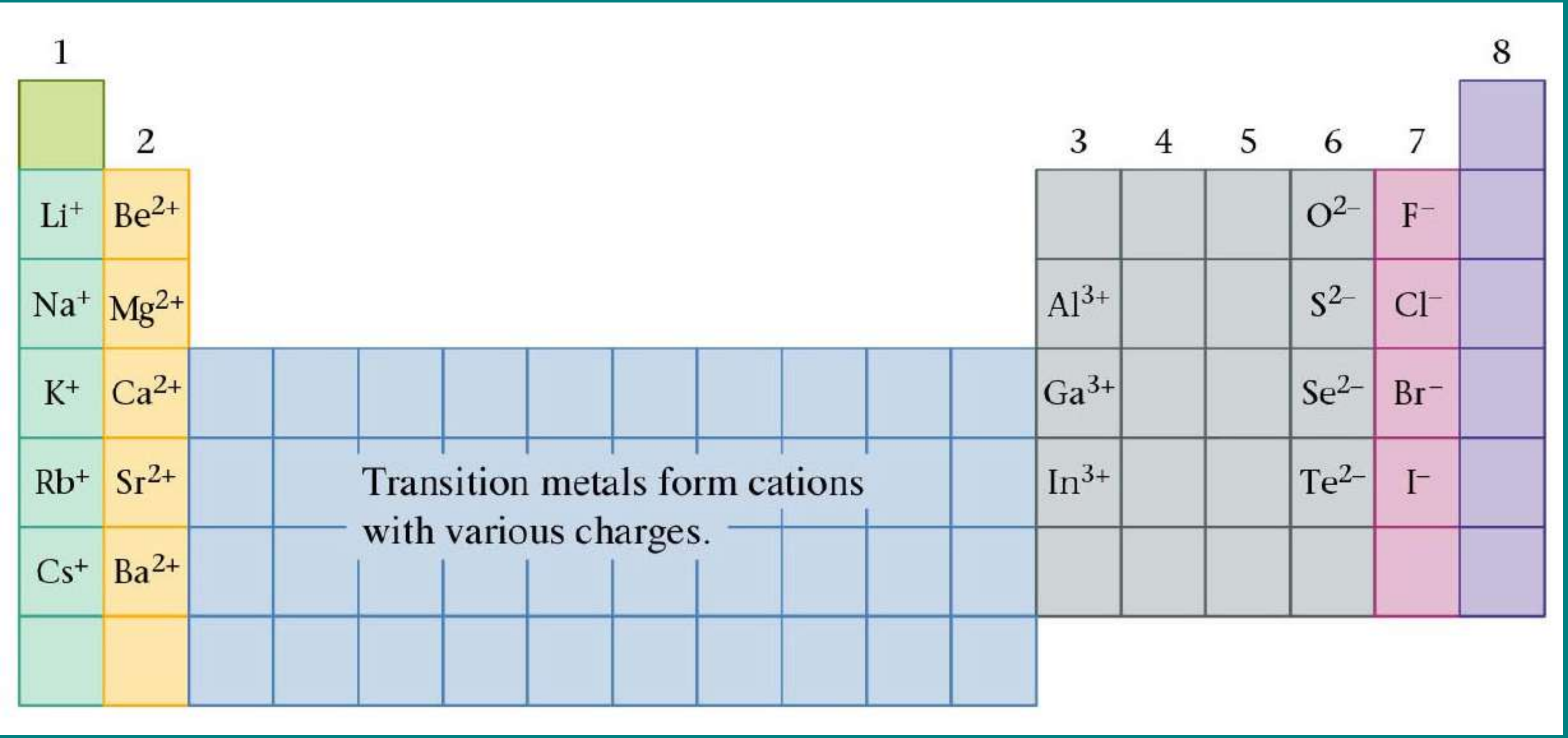
- Positive ion (cation)
- Negative ion (anion)



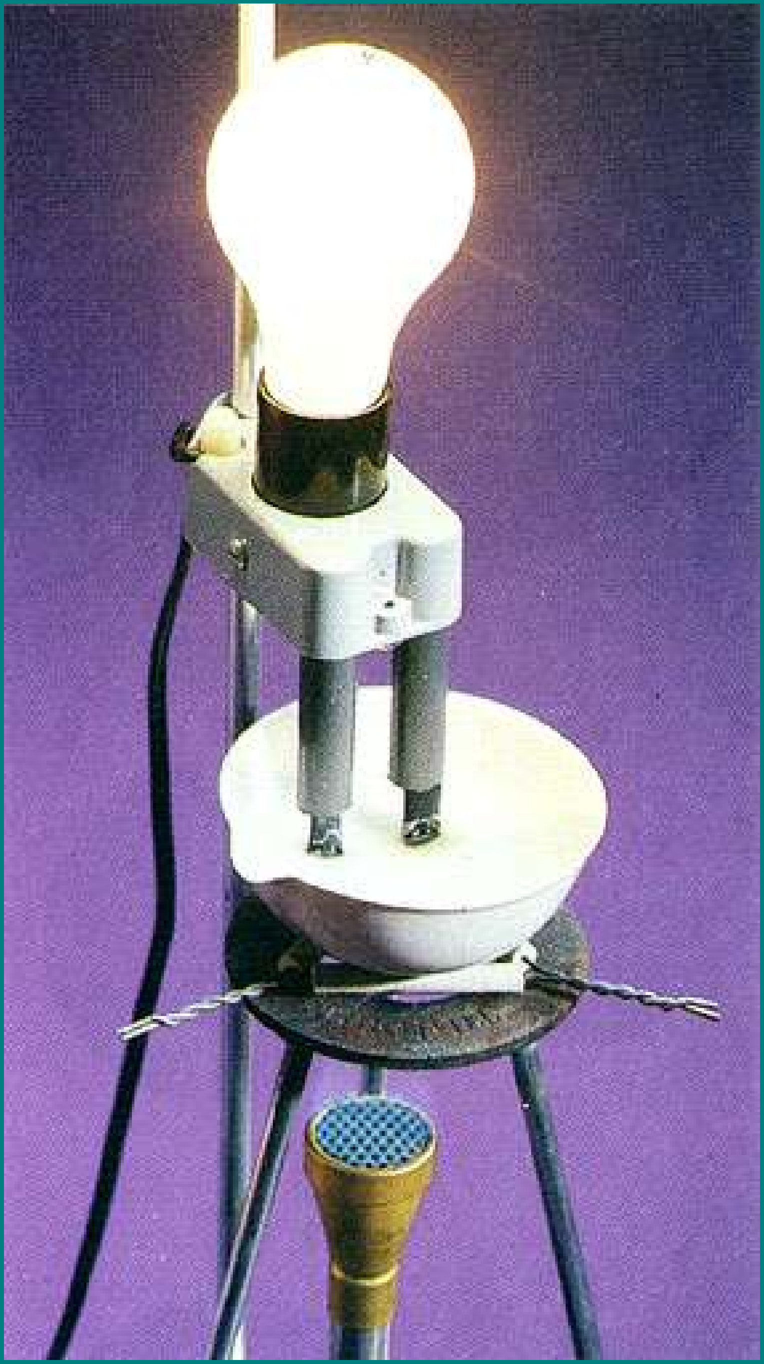
# Ion charges and the Periodic Table

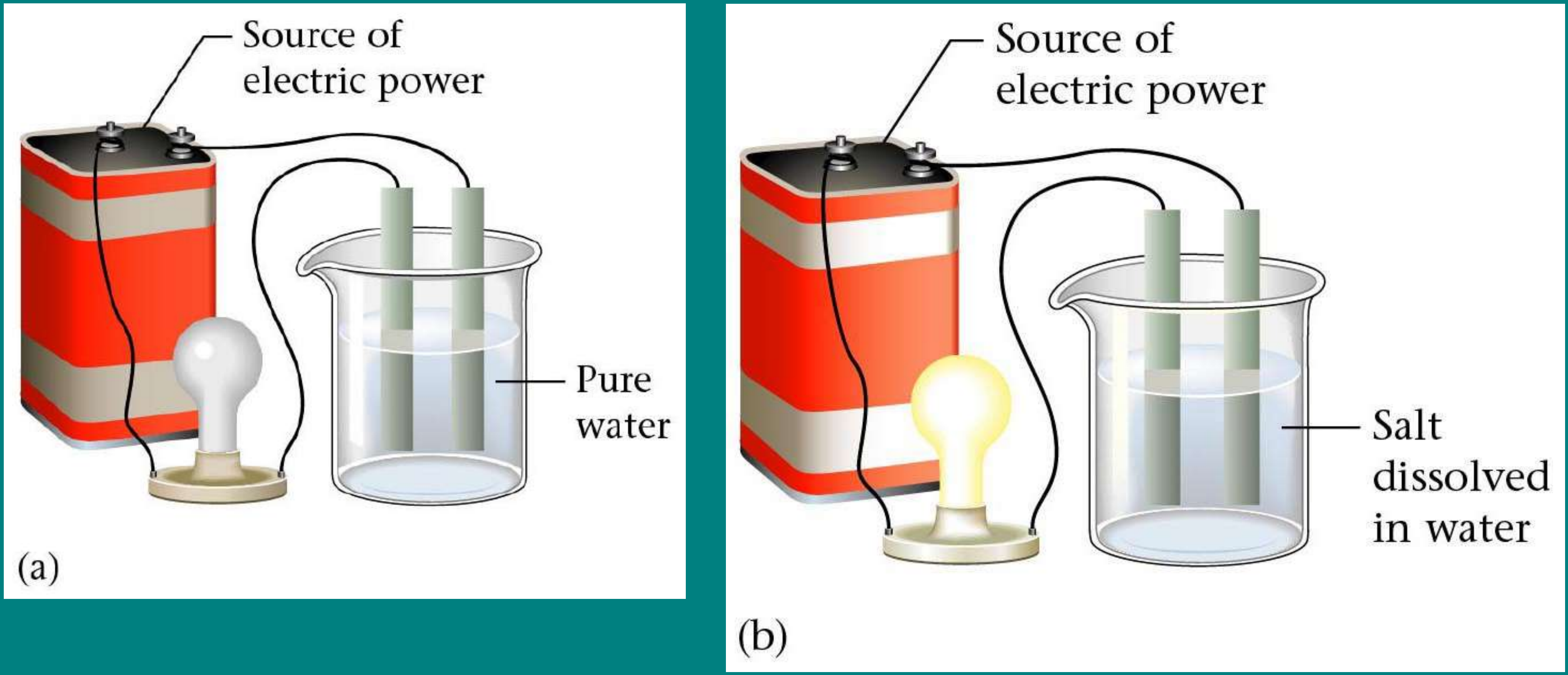
- want an easy way to remember these charges?
- metals lose $e^-$ (form cations)
  nonmetals gain $e^-$ (form anions)
- see the pattern? know the pattern! ;)



# 3.11 Compounds that contain Ions

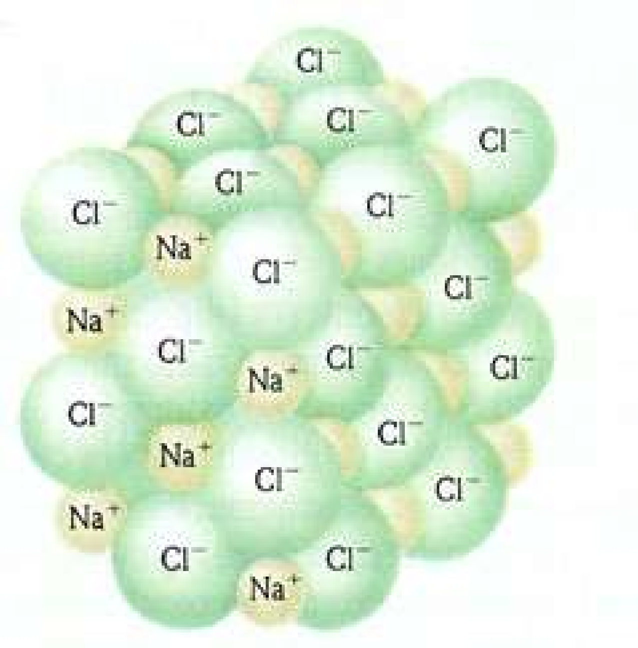
- Evidence that compounds contain ions?
- When melted down salt will conduct electricity, but not in the solid state
- hmmmm…

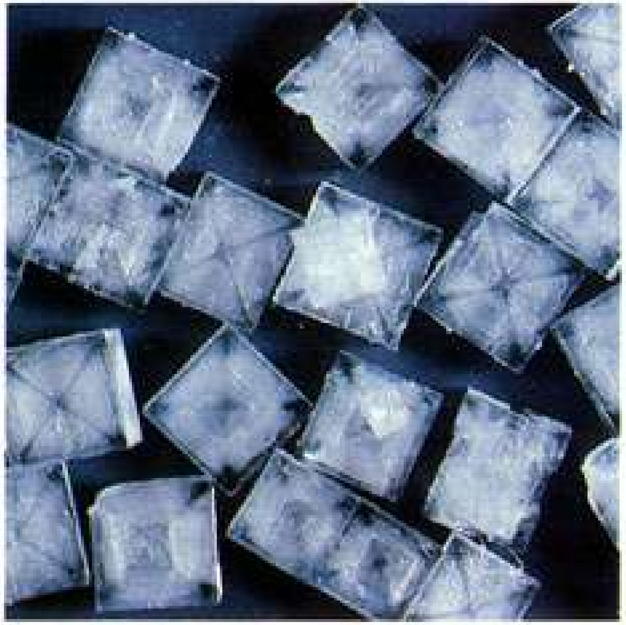





- Also lights the light when it is dissolved in water
- Electricity only flows if there are charged things allowing electrons to flow

- Conclusion? Salt must be made of positive and negative particles held together tightly



- These compounds made of ions are called **ionic compounds**
- When putting these together we must remember that overall their charges will cancel out
- i.e. **total positive charge = total negative charge**
- So! When you write formulas for these remember to have cations AND anions, and make sure there are enough so + = -

# examples

Calcium & Chlorine

Ca Cl

$Ca^{2+}$ $Cl^{-}$

You need two Cl for every Ca

Therefore, **$CaCl_2$**

Magnesium & Oxygen

Mg O

$Mg^{2+}$ $O^{2-}$

One to one,

therefore **MgO**

*Aluminum & Bromine*

$Al^{3+}$   $Br^{-}$

**$AlBr_3$**

*Sodium & Sulfur*

$Na^{+}$   $S^{2-}$

**$Na_2S$**