Atoms, Molecules and Ions

Unit 2

Early History (2.1)

- Democritus: Proposed that when cutting matter, there is a limit to how much it can be cut
  - “Atomos”: indivisible
- Aristotle: Disagreed with Democritus, proposing that matter could be cut indefinitely

Antoine Lavoisier

- 1743-1794
- Discovered oxygen and hydrogen
- Helped create the metric system
- Helped put together one of the first lists of the elements

http://en.wikipedia.org/wiki/Antoine_Lavoisier

Conservation of Mass

- Showed that several reactions were occurring because of interactions with oxygen.
- Highly quantitative chemical reactions lead him to the Law of Conservation of Mass
  - The mass of the reactants must equal the mass of the products

Law of Conservation of Mass:

The total mass of substances does not change during a chemical reaction.

reactant 1 + reactant 2 $\longrightarrow$ product

total mass = *total mass*

calcium oxide + carbon dioxide $\longrightarrow$ calcium carbonate

$CaO + CO_2 \longrightarrow CaCO_3$

56.08g + 44.00g $\longrightarrow$ 100.08g

Law of Definite Proportions

"Proust's Law"

No matter what its source, a particular chemical compound is composed of the same elements in the same parts (fractions) by mass.

$CaCO_3$

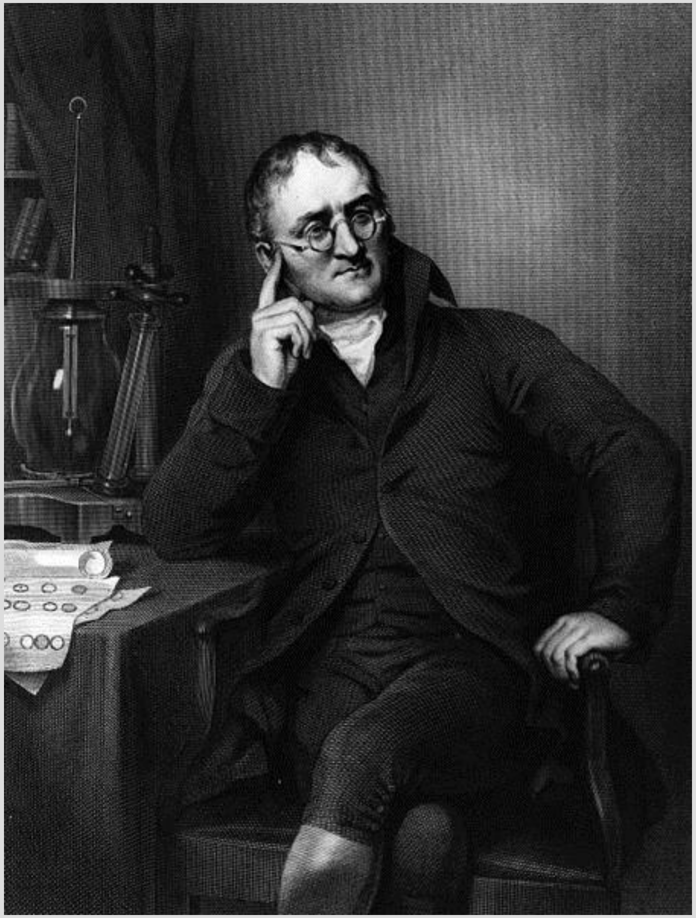
1 atom of Ca	40.08 amu
1 atom of C	12.00 amu
3 atoms of O	3 x 16.00 amu
	100.08 amu

$$\frac{40.08 \text{ amu}}{100.08 \text{ amu}} = 0.401 \text{ parts Ca}$$

$$\frac{12.00 \text{ amu}}{100.08 \text{ amu}} = 0.120 \text{ parts C}$$

$$\frac{48.00 \text{ amu}}{100.08 \text{ amu}} = 0.480 \text{ parts O}$$

John Dalton



- 1766-1844
- Studied color blindness
- Studied the properties of gases
- Published the first table of relative atomic weights.

http://pmrb.net/blog/2011/06/21/history-of-atomic-theory-ii-its-all-gas/

Law of Multiple Proportions (2.2)

If elements A and B react to form two compounds, the different masses of B that combine with a fixed mass of A can be expressed as a ratio of small whole numbers:

Example: Nitrogen Oxides II & IV

Nitrogen Oxide II : 46.68% Nitrogen and 53.32% Oxygen
Nitrogen Oxide IV : 30.45% Nitrogen and 69.55% Oxygen

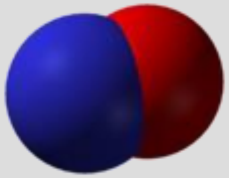
Assume that you have 100g of each compound.
In 100 g of each compound: g O = 53.32g for oxide II & 69.55g for oxide IV

g N = 46.68g for oxide II & 30.45g for oxide IV

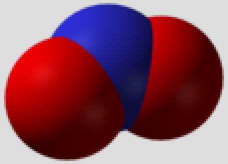
$$\frac{gO}{gN} = \frac{53.32}{46.68} = 1.142 \qquad \frac{gO}{gN} = \frac{69.55}{30.45} = 2.284$$

$$\frac{2.284}{1.142} = 2$$

Law of Multiple Proportions (2.2)



Nitrogen Monoxide (a.k.a. Nitrogen Oxide II)



Nitrogen Dioxide (a.k.a. Nitrogen Oxide IV)

Nitrogen Oxide II : 46.68% Nitrogen and 53.32% Oxygen
Nitrogen Oxide IV : 30.45% Nitrogen and 69.55% Oxygen

Assume that you have 100g of each compound.
In 100 g of each compound: g O = 53.32g for oxide I & 69.55g for oxide II

g N = 46.68g for oxide I & 30.45g for oxide II

$$\frac{gO}{gN} = \frac{53.32}{46.68} = 1.142$$

$$\frac{gO}{gN} = \frac{69.55}{30.45} = 2.284$$

$$\frac{2.284}{1.142} = 2$$

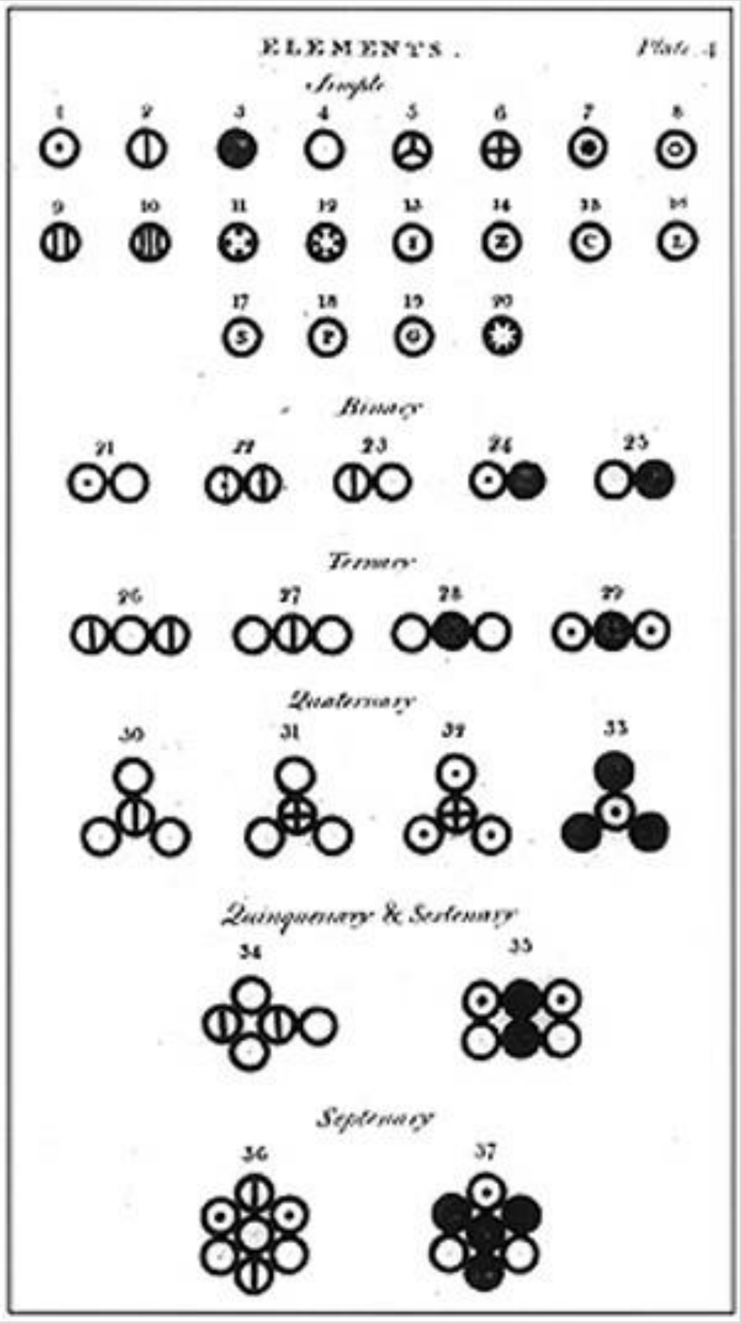
Dalton's Atomic Theory (2.3)

1. Elements consist of small particles called *atoms*
2. Atoms of one element are *identical* in size, mass, properties, etc.; Atoms of different elements are different in size, mass, properties, etc.
3. Atoms cannot be subdivided, created, or destroyed
4. Atoms can combine in whole-number ratios to form compounds, A given compound always has the same number and type of atoms.
5. Chemical reactions combine, separate, or rearrange atoms

Various Atoms & Molecules

Published in *A New System of Chemical Philosophy* (1808).

http://en.wikipedia.org/wiki/John_Dalton



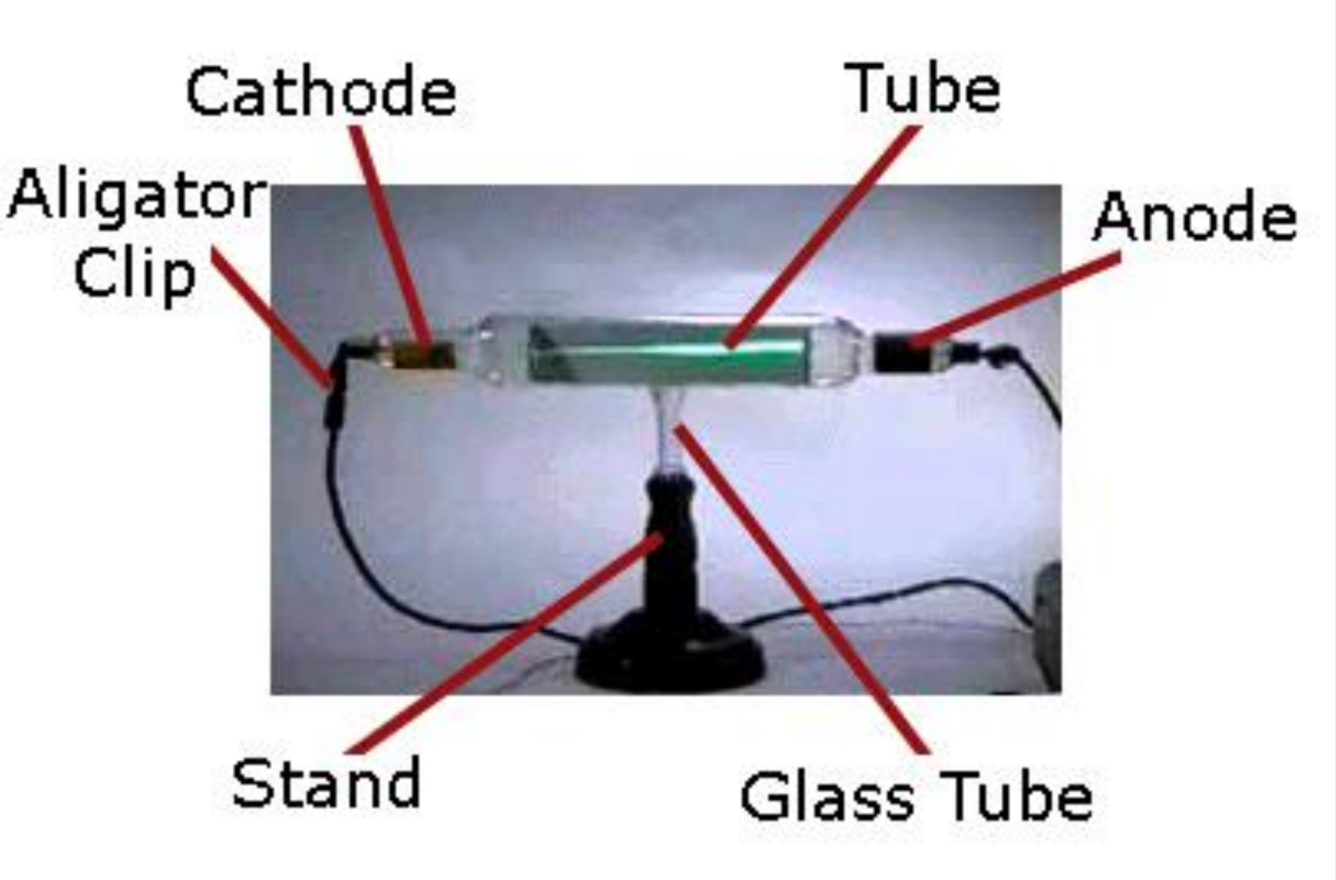
Joseph John (J.J.) Thomson

- 1856-1940
- Discovered the electron and isotopes
- Invented the mass spectrometer
- Received the Nobel Prize in 1906 partly for his discovery of the electron

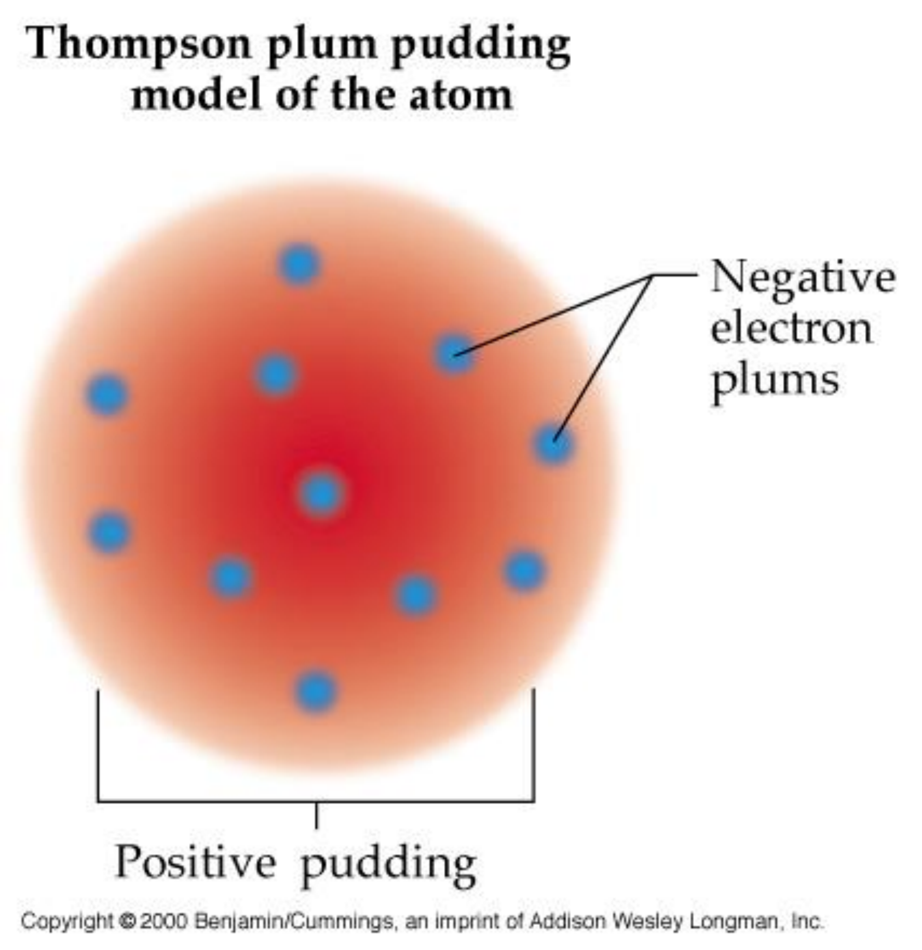
J. J. Thomson

- Thomson knew that the atom was neutral overall.
- If electrons existed, there must also be something positive
- Thomson proposed model became known as the *Plum-Pudding Model*

J. J. Thomson



Plum-Pudding Model



Lord Ernest Rutherford

- 1871-1937
- Father of Nuclear Physics
- Proved that radioactivity involved the *transmutation* of one element into another
- Received the Nobel Prize in Chemistry in 1908

http://en.wikipedia.org/wiki/Ernest_Rutherford

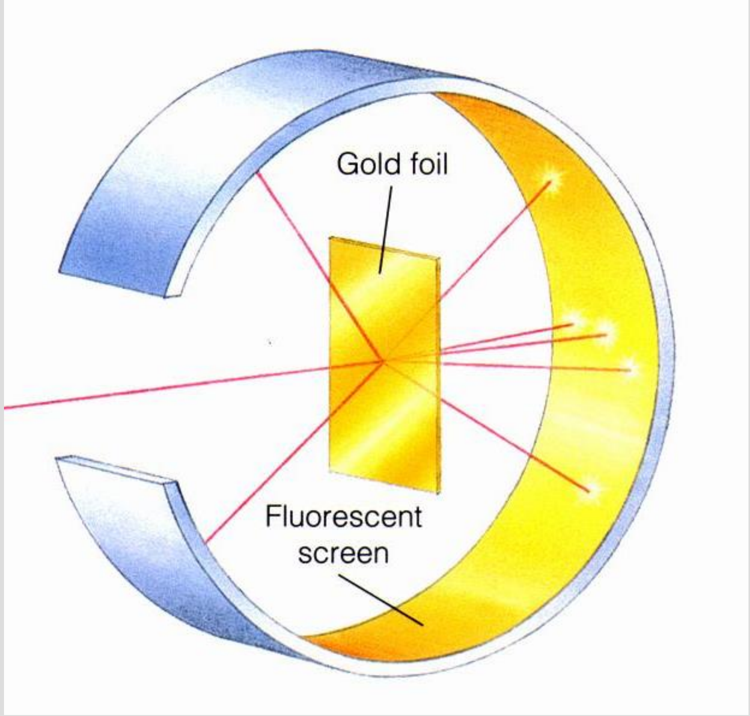
Gold Foil Experiment

- A beam of alpha particles ($2p^+$, 2n) were directed at a thin gold foil
- The Plum-Pudding Model
  - Atoms had very low density.
  - Almost all the particles should pass through the atoms in the gold foil

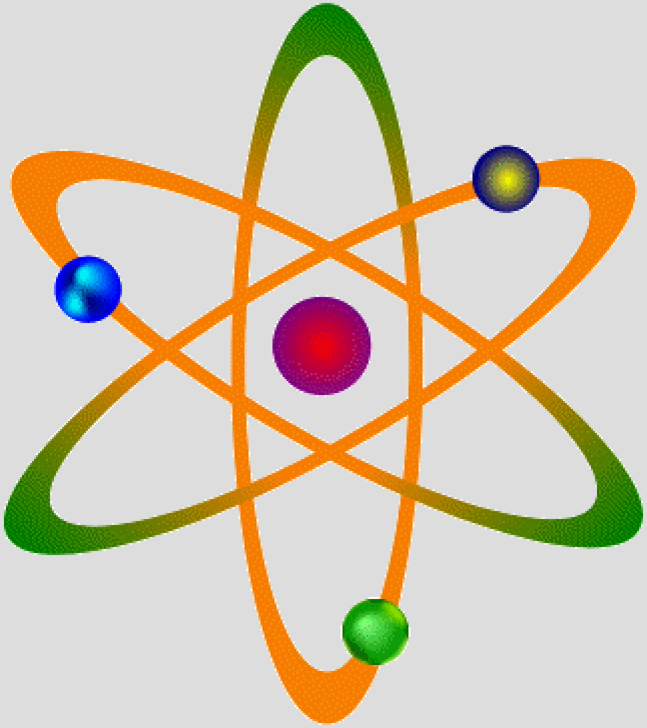
Gold Foil Experiment

Actual Observations:

- Some particles went straight through the gold foil
- Some were deflected
- Some bounced back at a high angle



The “Planetary” Model



http://profstelmark.com/Chapter_2.html

Neils Bohr

- 1885-1962
- Nobel Prize in Physics in 1922
- Worked on the Manhattan Project
- Principle of Complementarity
  - Items could be analyzed as having several contradictory properties (light)

http://en.wikipedia.org/wiki/File:Niels_Bohr.jpg

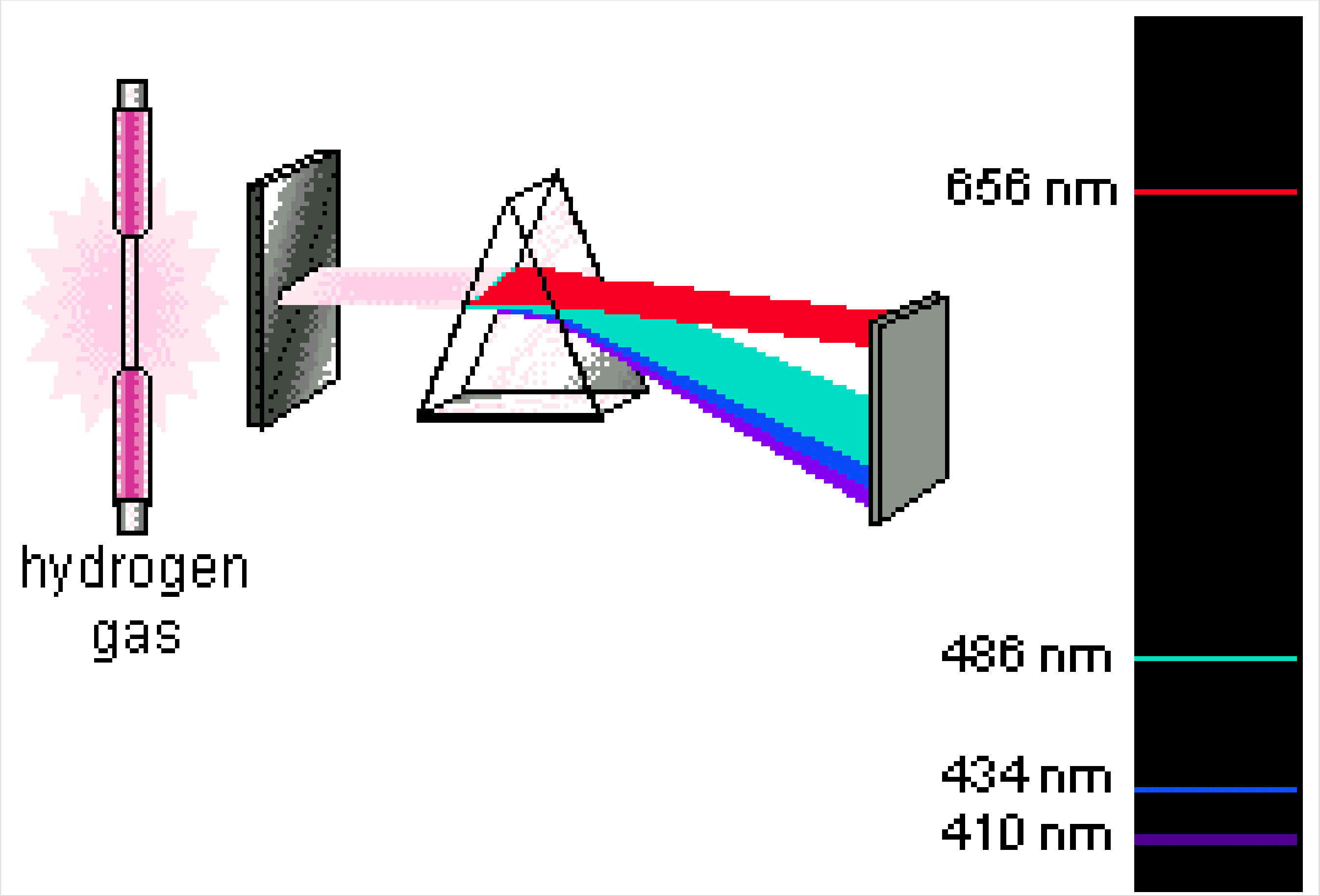
Problems / Unexplained Data

1. Orbiting electrons could be at any distance from the nucleus
   - Electrons should eventually spiral into the nucleus
   - Rotating electrons should emit radiation

Problems / Unexplained Data

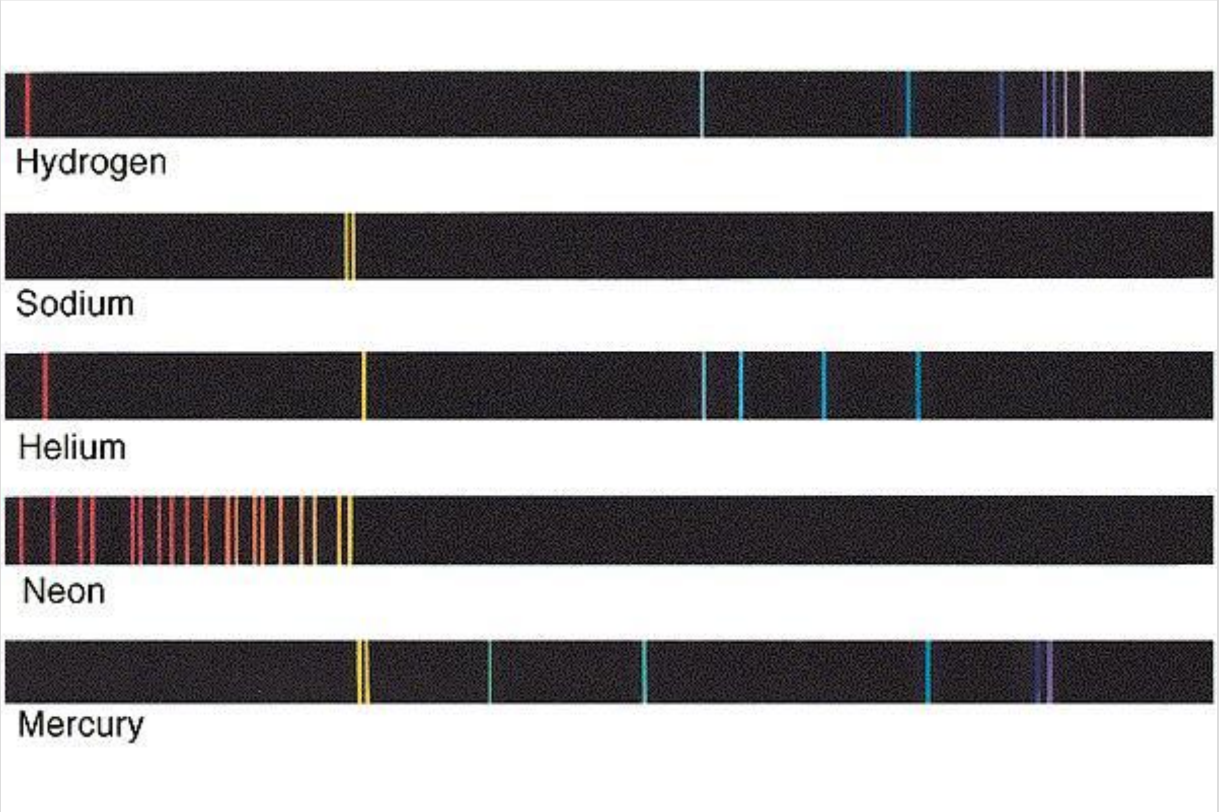
2. Line-Emission Spectra
   - Current passed through hydrogen gas produces a characteristic lavender light
   - When passed through a prism, this light separates into distinct lines

Problems / Unexplained Data



Problems / Unexplained Data

Each element emits a different and distinct line-emission spectrum

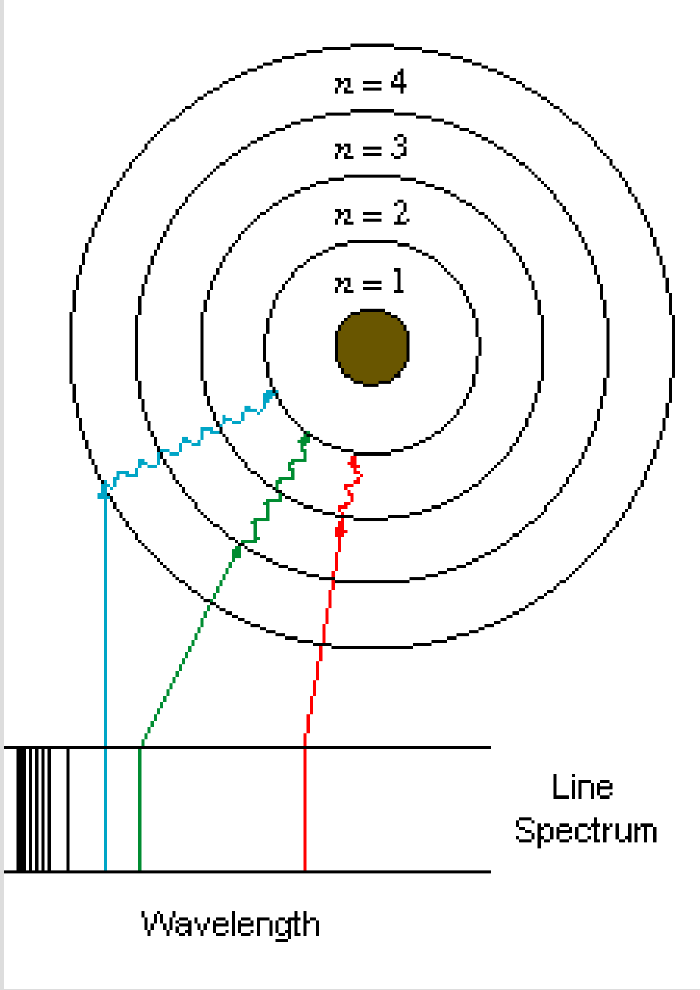


Bohr Model

Bohr discovered that the emission spectra could be explained if:

- Electrons existed in specific energy states
- Electrons could move from higher to lower energy states
- Movement between states causes emission of light

Bohr Model



The lowest state is the *ground state*

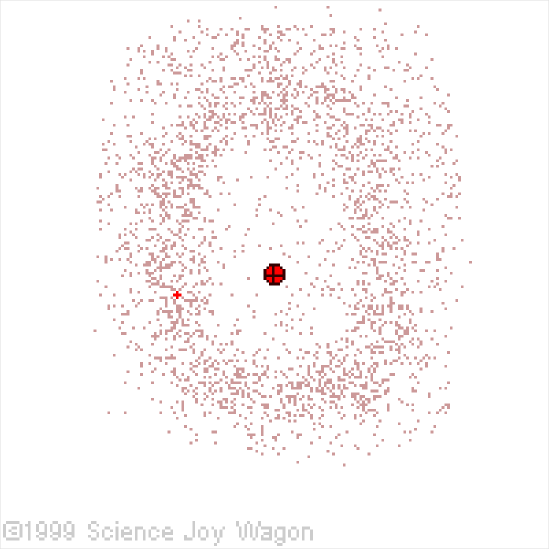
Electrons with additional energy can occupy an *excited state*

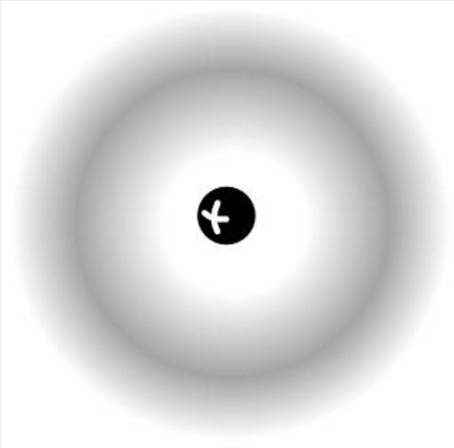
Schrodinger

- 1887-1961
- Studied chemistry, Italian painting, botany, theoretical physics
- Hated memorizing and learning from books!
- 1926- develops the wave equation
- Different way to explain behavior of atoms
- Won the Nobel Prize in 1933
- Disliked the generally accepted idea of the dual nature of atoms- particle and wavelike behavior

Electron Cloud Model

- The most current model of the location of electrons in the atom.
- The electron cloud is 100,000 times larger than the diameter of the nucleus, but each electron is smaller than the proton.
- Electrons are so small, and moving so fast, that they are difficult to find.



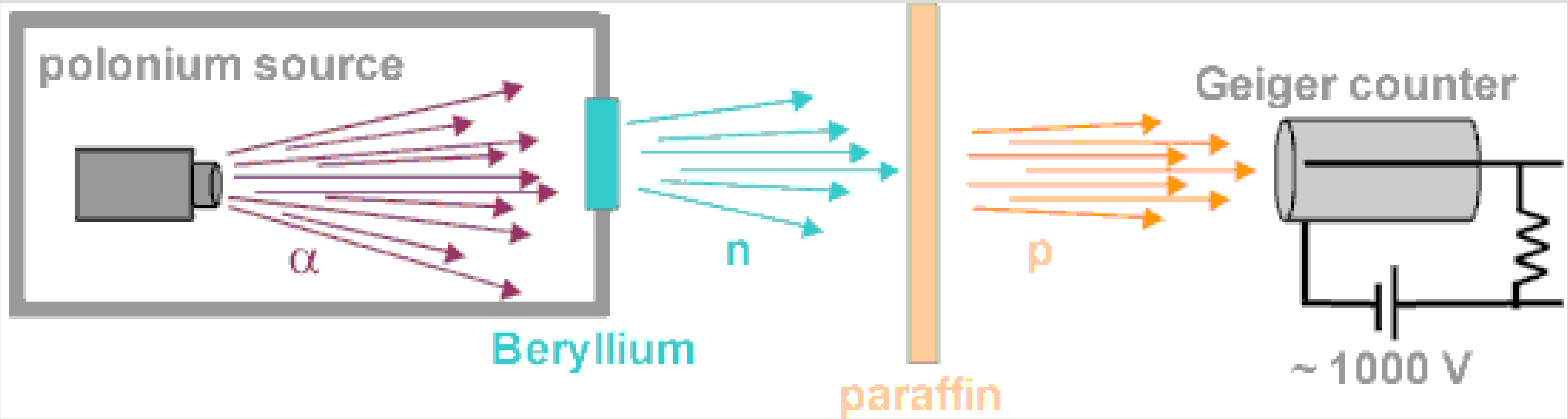


Chadwick

- Student of Rutherford
- His research focused on radioactivity
- Experiments had determined that the atomic number of elements was less than the atomic mass. Electrons had no mass.
- What accounted for the additional mass that must be located in the nucleus?
- In 1932 Chadwick proposes the existence of the neutron based on the results of his experiments
- Won Nobel Prize for his work in 1935

Chadwick's Experiment

In 1920, Ernest Rutherford postulated that there were neutral, massive particles in the nucleus of atoms. This conclusion arose from the disparity between an element's atomic number (protons = electrons) and its atomic mass (usually in excess of the mass of the known protons present). James Chadwick was assigned the task of tracking down evidence of Rutherford's tightly bound "proton-electron pair" or **neutron**



Modern View of Atomic Structure

Protons: have a positive charge equal in magnitude to the electrons negative charge. Mass equivalent to a Neutron

Neutrons: Have the same mass as protons but no charge.

Electrons: Have a negative charge equal in magnitude to a proton.

Mass and Charge		
Particle	**Mass**	**Charge***
Electron	9.11×10^{-31} kg	1-
Proton	1.67×10^{-27} kg	1+
Neutron	1.67×10^{-27} kg	0

* Magnitude and charge of electron & proton is 1.60×10^{-19} C

Modern View of Atomic Structure

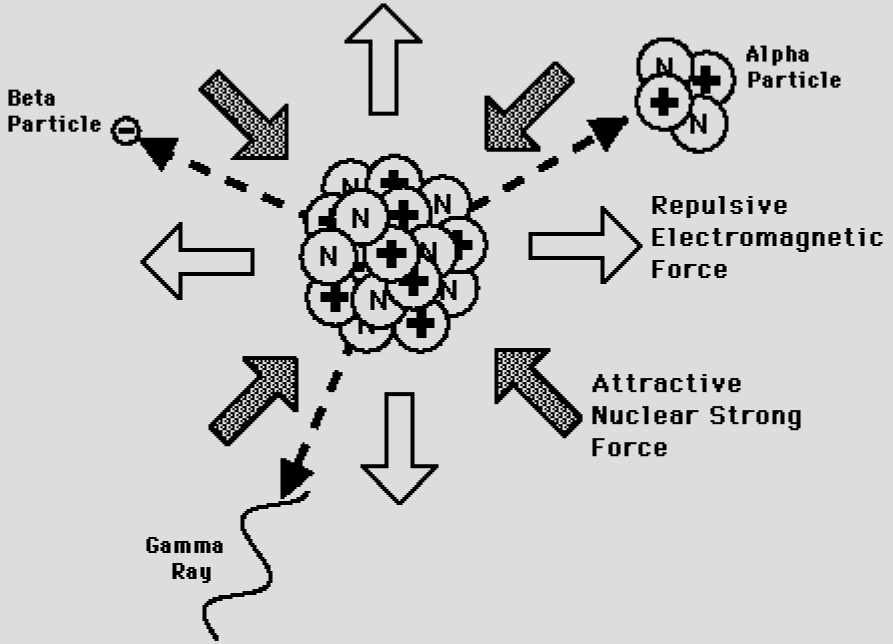
Radioactivity: the spontaneous emission of a stream of particles or electromagnetic rays in nuclear decay

3 types of Decay:

Gamma (γ) rays

Alpha (α) particles

Beta (β) particles



Modern View of Atomic Structure

Atomic Mass(A)

Charge (if ion)

Symbol

Atomic Number(Z)

$^{23}_{11}Na$

Isotopes and Charges

- **Isotopes** are atoms of the same element that have different masses.
- In order to have a neutral atom, the number of electrons must equal the number of protons *or* Atomic Number.
- The **mass number** is the total number of protons and neutrons in the nucleus of an isotope.

	Atomic Number	Number of Neutrons	Mass Number	Number of Electrons
Protium	1	0	1	1
Deuterium	1	1	2	1
Tritium	1	2	3	1

Average Atomic Masses

- Not all isotopes are abundant in the same amounts (Note their symbols):

Isotope	Mass Number	Percent Abundance	Atomic Mass (amu)	Average Atomic Mass (amu)
H-1 H-2	1 2	99.985 0.015	1.007 825 2.014 102	1.007 94
C-12 C-13 C-14	12 13 14	98.90 1.10 trace	12 13.003 355 14.003 242	12.0111
Ce-133	133	100	132.905 429	132.905

Molecules and Ions

Chemical Bonds: forces that hold atoms together

Covalent Bonding: bonds between atoms formed by the sharing of electrons.

Ionic Bonding: bonds between atoms formed by the attractions among opposite charged ions.

Cation – an atom that has lost electrons forming a positive ion.

Ex: $Na \rightarrow Na^+ + e^-$

Anion – an atom that has gained electrons forming a negative ion.

Ex: $Cl + e^- \rightarrow Cl^-$

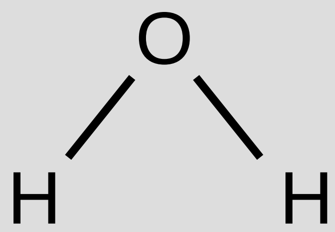
Molecules and Ions

Chemical Formula: where symbols for elements are used to indicate the types and numbers of elements present.

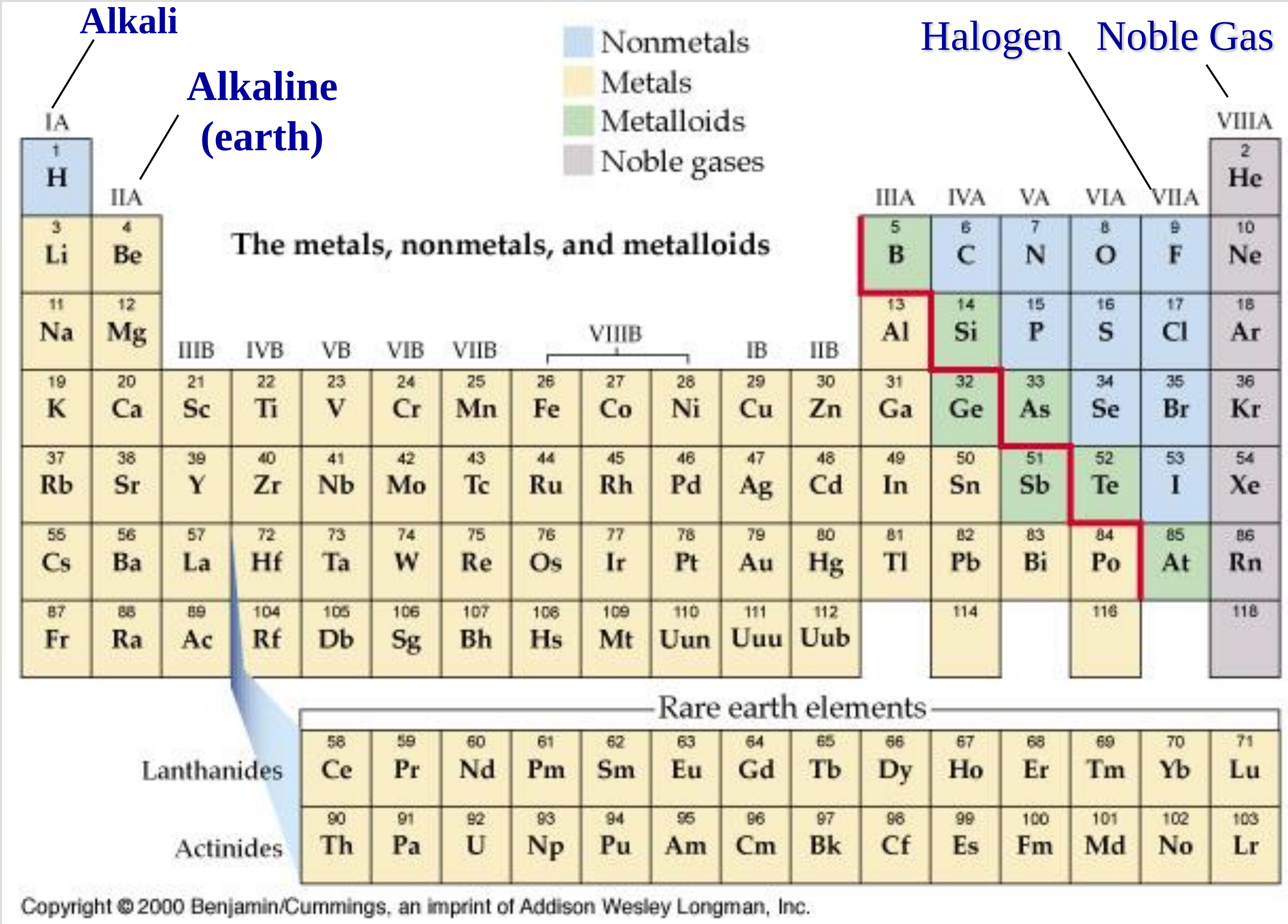
Ex: $KClO_4$

Structural Formula: where individual bonds for elements are used to indicate the types and numbers of elements present. Structural formulas may or may not show the actual shape of the molecule.

Ex: $H-O-H$

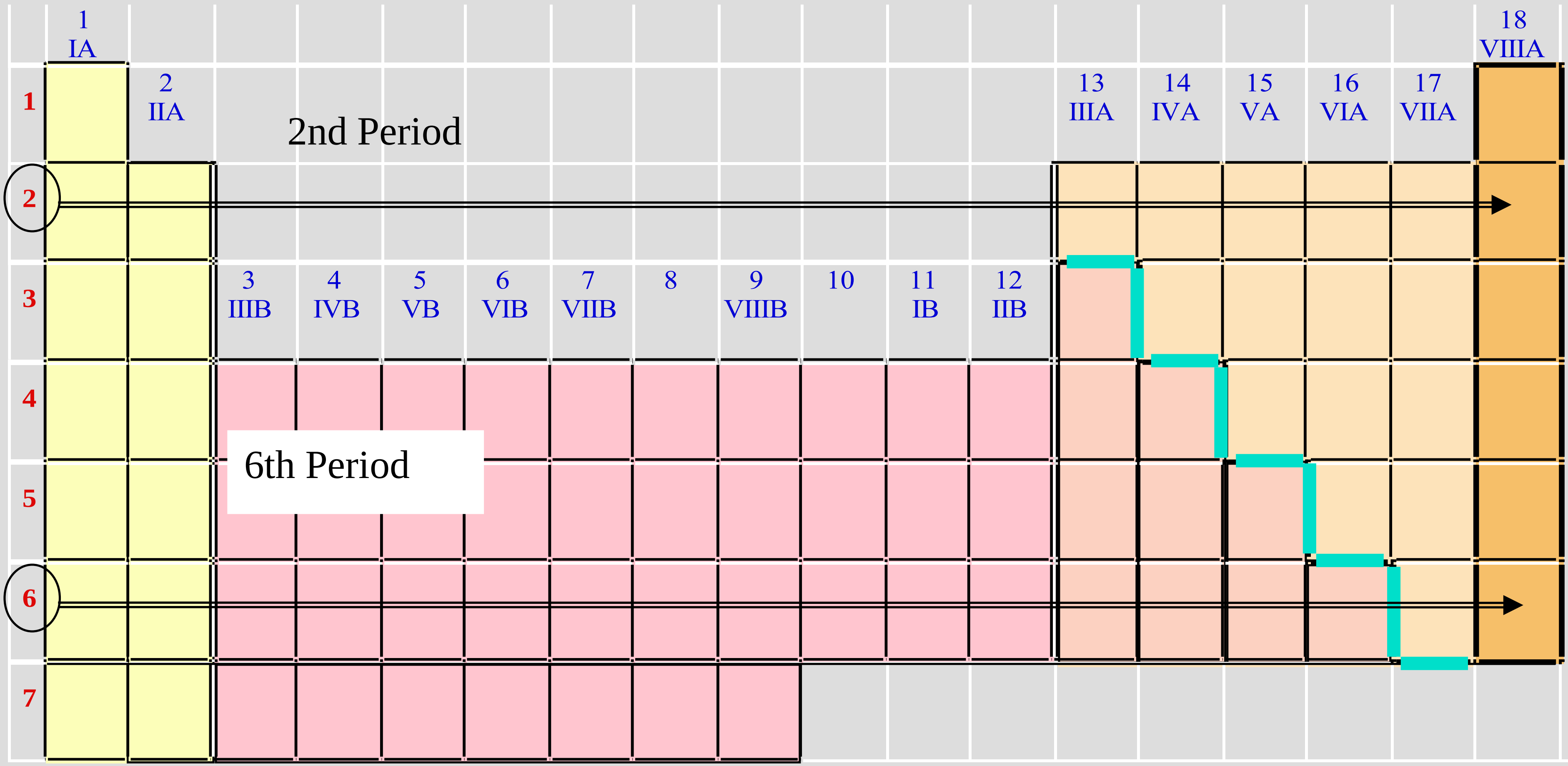


The Periodic Table



The Periodic Table

- Periods: Are arranged horizontally across the periodic table (rows 1-7)
- These elements have the same number of valence shells.



Naming Simple Compounds (2.8)

Binary Ionic Compounds

Type 1

1. The cation is always named first and the anion second

2. The monatomic cation takes its name from the element.

3. A monatomic anion is named by taking the root of the element name and adding – *ide*.

Naming Simple Compounds (2.8)

Binary Ionic Compounds

Type 1 cont:

Compound	Ions Present	Name
NaCl	Na^{+}, Cl^{-}	Sodium Chloride
Li_3N	Li^{+}, N^{3-}	Lithium Nitride
MgO	Mg^{2+}, O^{2-}	Magnesium Oxide

Naming Compounds (2.8)

Principle of Charge Balance

1. Write each ion, cation first. Don't show charges in the final formula.
2. Overall charge must equal zero.
    - If charges cancel, just write symbols.
    - If not, use subscripts to balance charges.
3. Use parentheses to show more than one of a particular polyatomic ion.
4. Use Roman numerals to indicate the ion's charge when needed.

Naming Compounds (2.8)

Binary Ionic Compounds

Type 2

Many metals can form more than one type of cation. In this case we have to determine the charge on the ion.

Example: $FeCl_3$ and $FeCl_2$

We know Chlorine readily forms the Cl^- ion but if this is the case then the two Iron atoms must have different charges.

Naming Compounds (2.8)

Binary and Polyatomic Ionic Compounds

Type 2

Example: $FeCl_3$ and $FeCl_2$

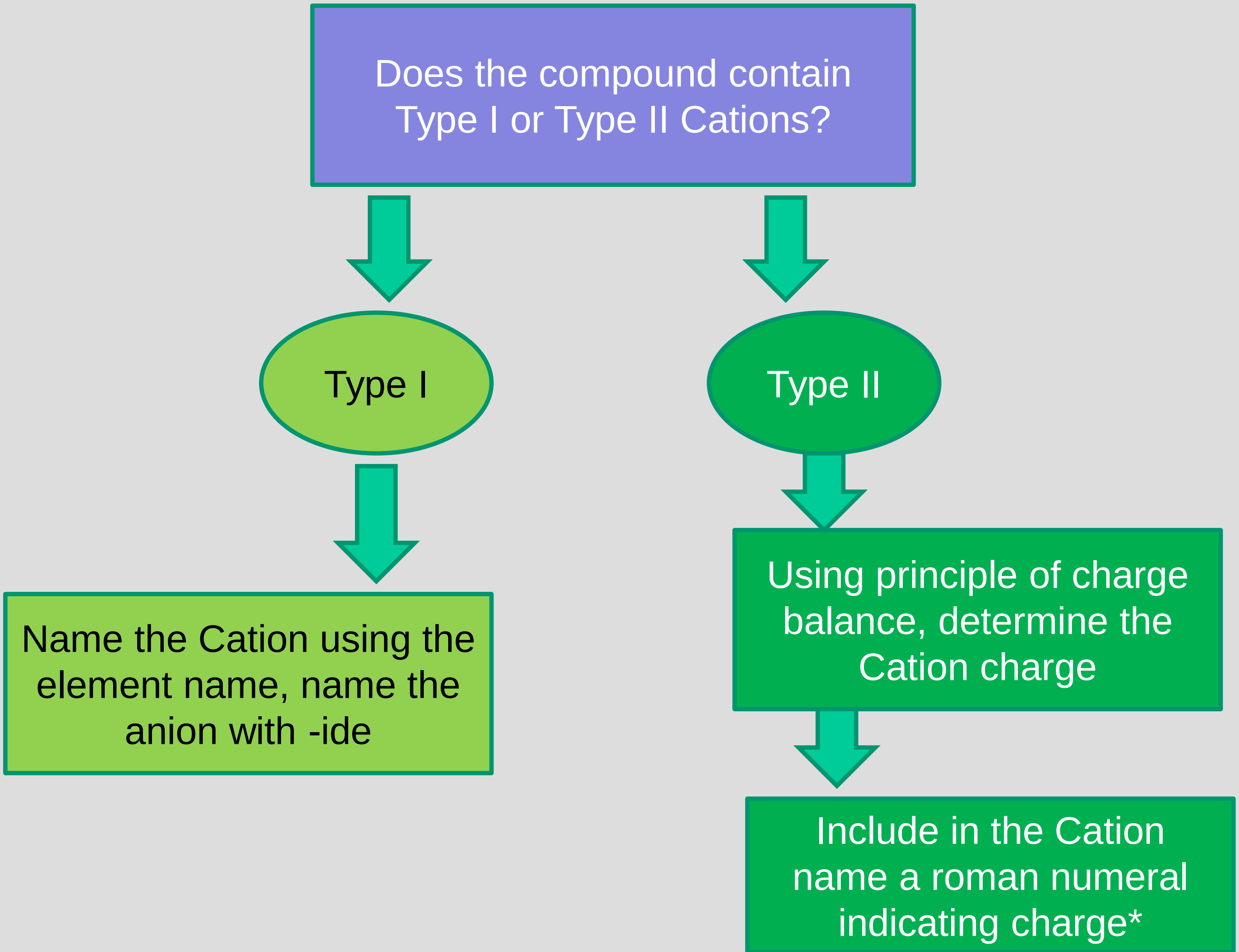
In $FeCl_3$ the Iron must have a charge of 3+ to satisfy an electrically neutral molecule while the Iron in $FeCl_2$ Must carry a 2+ charge.

The ion with the Higher charge will have its name changed to add ***–(III)***, and the one with the lower charge will have a name ending in ***–(II). These Roman numerals correspond to the Cations charge.***

$FeCl_3$ would be Iron (III) Chloride

$FeCl_2$ would be Iron (II) Chloride

Naming Ionic and Polyatomic Compounds (2.8)



Naming Covalent Compounds (2.8)

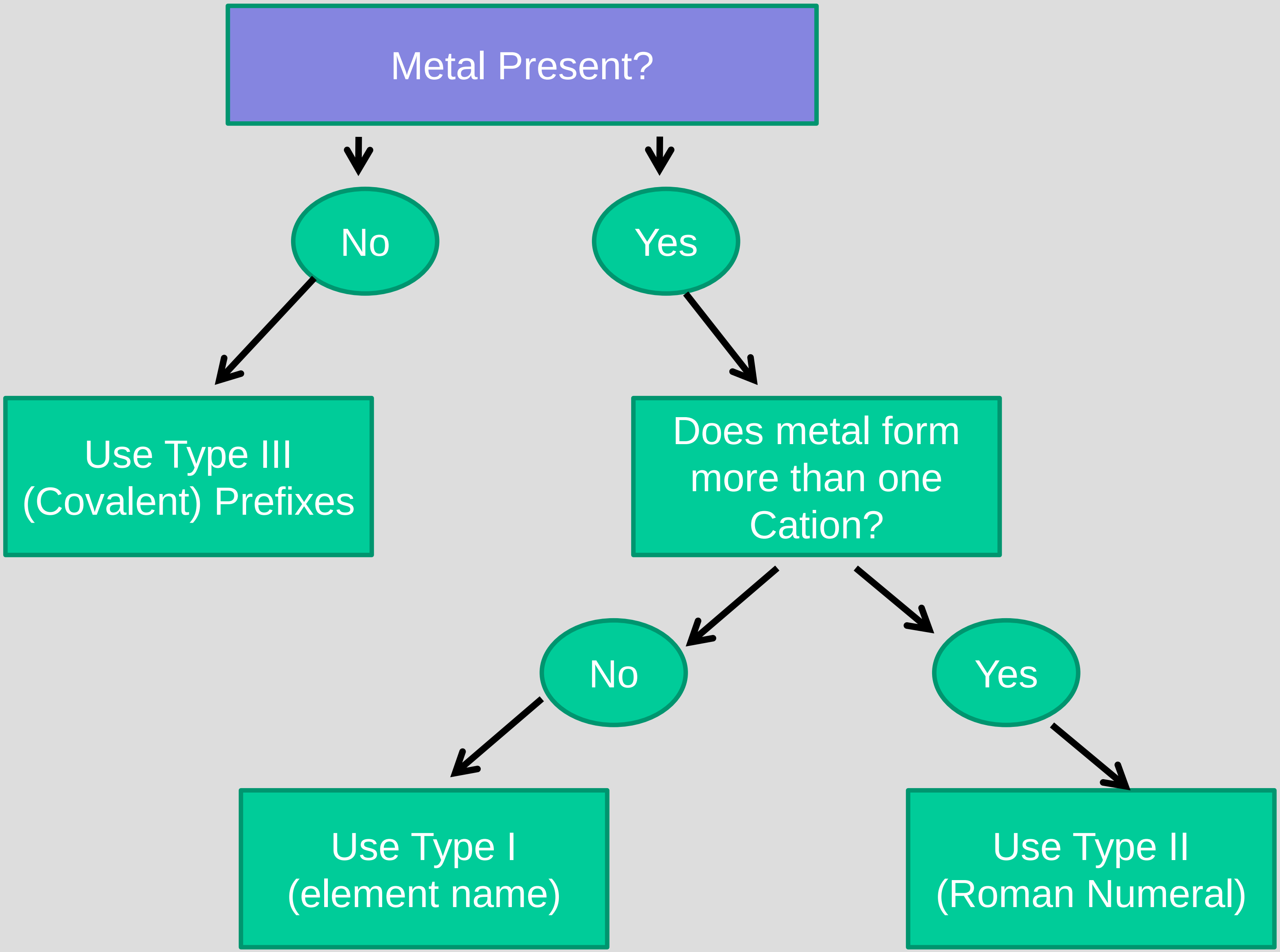
1. The first Element in the formula is named first, using the full element name
2. The second element is named as if it were an anion.
3. Prefixes are used to denote the numbers of atoms present.
4. The prefix mono- is NEVER used for naming the first element.

Naming Covalent Compounds (2.8)

Prefixes used in Covalent Compounds

Prefix	Number Indicated
mono-	1
di-	2
tri-	3
tetra-	4
penta-	5
hexa-	6
hepta-	7
octa-	8
nona-	9
deca-	10

Naming Covalent Compounds (2.8)



Naming Acids (2.8)

When dissolved in water, certain molecules will produce a solution containing free H^+ ions (protons).

An acid can be viewed as a molecule with one or more H^+ attached to the Anion. The rules for naming acids depend on whether the anion contains oxygen.

Examples: HCl, $HClO$, H_2SO_4

Naming Acids (2.8)

Anion does not contain Oxygen:

1. The acid is named with a prefix of Hydro-

2. The acid has a suffix of -ic

Ex: HCl is named **Hydro**chlor**ic** acid

Anion contains Oxygen:

1. If the Anion ends in –ate, the suffix of –ic is added to the root name.

   Ex: H_2SO_4 is named Sulfuric Acid

2. If the Anion ends in –ite, the suffix of –ous is added to the root name.

   Ex: H_2SO_3 is named Sulfurous Acid

Naming Acids(2.8)