Lecture Notes: Atomic and Molecular Structure

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Early Experimental Insights Into Atomic Structure

John Dalton's Atomic Theory (1808):

1. All matter is composed of atoms. Atoms are indivisible and indestructible
2. All atoms of a given element are identical in mass and properties.
3. Compounds are formed by a combination of two or more different kinds of atoms.
4. A chemical reaction is a rearrangement of atoms, i.e. a change in the way they are bound together. The atoms themselves are not changed.

Figure 1: John Dalton (1766-1844)

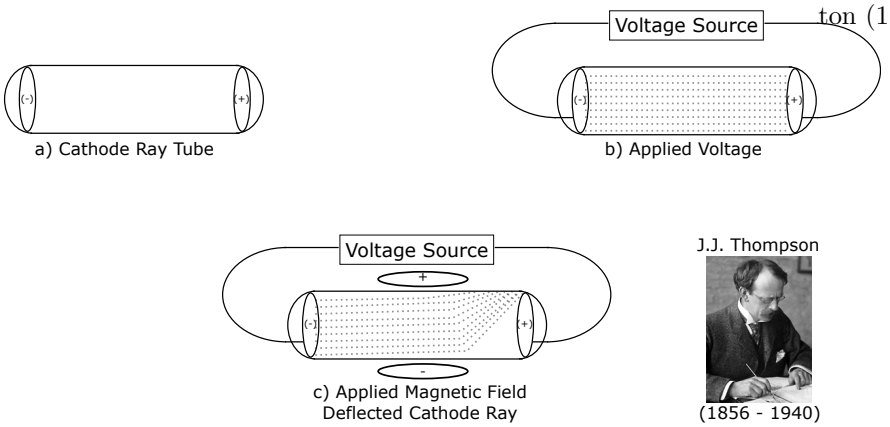


Figure 2: Schematic representation of J.J. Thomson's cathode ray tube experiment. a) The bare cathode ray tube is pictured with a negatively and positively charged metal plate at each end. b) A voltage bias is applied to the tube which causes an electrical current to flow through the system from the negative to the positive plate. c) A magnetic field is applied to the system causing the current to bend toward the positive plate.

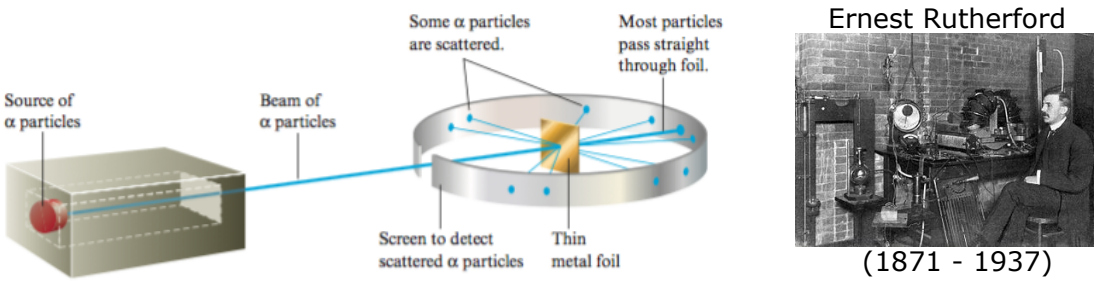


Figure 3: Schematic representation of Ernest Rutherford's experiment involving the bombardment of gold foil with α-particles.

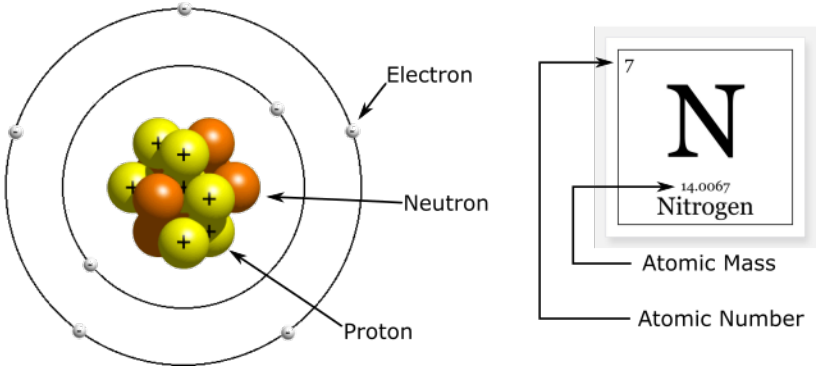


Figure 4: Schematic of electronic structure. The nucleus is composed of positively charged particles called **protons** and neutral particles called **netrons**. The atom itself has a neutral overall charge that is balanced by negatively charged particles called **electrons**. The amount of subatomic particles determines the identity of the element which can be determined from its periodic table entry.

Atomic Structure: Isotopes and Ions

Problem 1: If the volume of a proton were similar to the volume of an electron, how will the densities of these two particles compare to each other?

- **Isotopes**: atoms with the same number of protons but a different number neutrons giving is a non-standard atomic mass
- **Ions**: an atom or group of atoms that have a net positive or negative charge

Ions

$$\mathrm{Na} \longrightarrow \mathrm{Na}^{+} + \mathrm{e}^{-} \qquad \text{Formation of sodium } \textbf{cation}$$

$$\mathrm{Cl} + \mathrm{e}^{-} \longrightarrow \mathrm{Cl}^{-} \qquad \text{Formation of chlorine } \textbf{anion}$$

Problem 2: Write symbols for each of the following ions:

a) 63 protons, 60 electrons, 88 neutrons

b) 50 protons, 68 neutrons, 48 electrons

c) 16 protons, 18 neutrons, 18 electrons

d) 16 protons, 16 neutrons, 18 electrons

Molecules, Molecular Structure, and Bonding

- **Molecule**: a collection of atoms held together via chemical bonds
- **Chemical Bond**: the forces that hold atoms together
- **Covalent Bond**: chemical bonds that result from the sharing of electrons

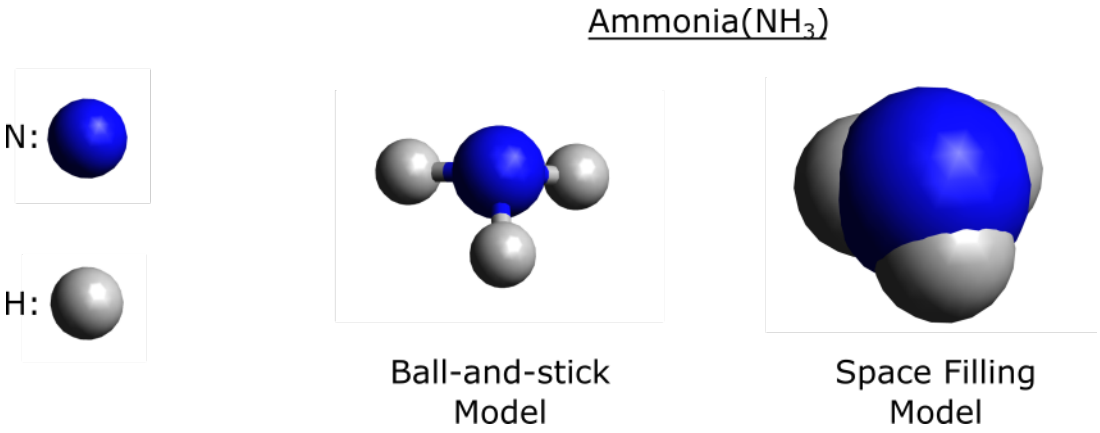


Figure 5: Example of covalent bonding in the ammonia molecule (NH_3) the nitrogen and 3 hydrogen atoms explicitly share electrons in order to form this molecule. Two molecular models are shown for ammonia, the "ball and stick" model which most explicitly highlights the molecular geometry and orientation while the "space filling" model highlights the relative atomic sizes.

Fundamental Laws of Chemistry

- **Law of Conservation of Mass**: Mass is neither created nor destroyed in a chemical reaction.
- **Law of Definite Proportion**: A given compound always contains exactly the same proportion of elements by mass.
- **Law of Multiple Proportions**: When two elements form a series of compounds, the ratios of the masses of the second element that combine with 1g of the first element can always be reduced to small whole numbers.

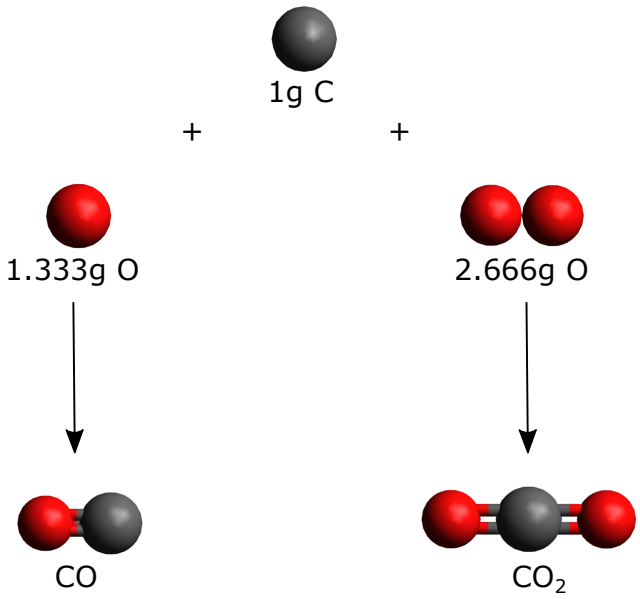


Figure 6: Illustration of the law of multiple proportions: Carbon can form a series of two different compounds with oxygen based on the ratio of the masses of oxygen with 1g of carbon.

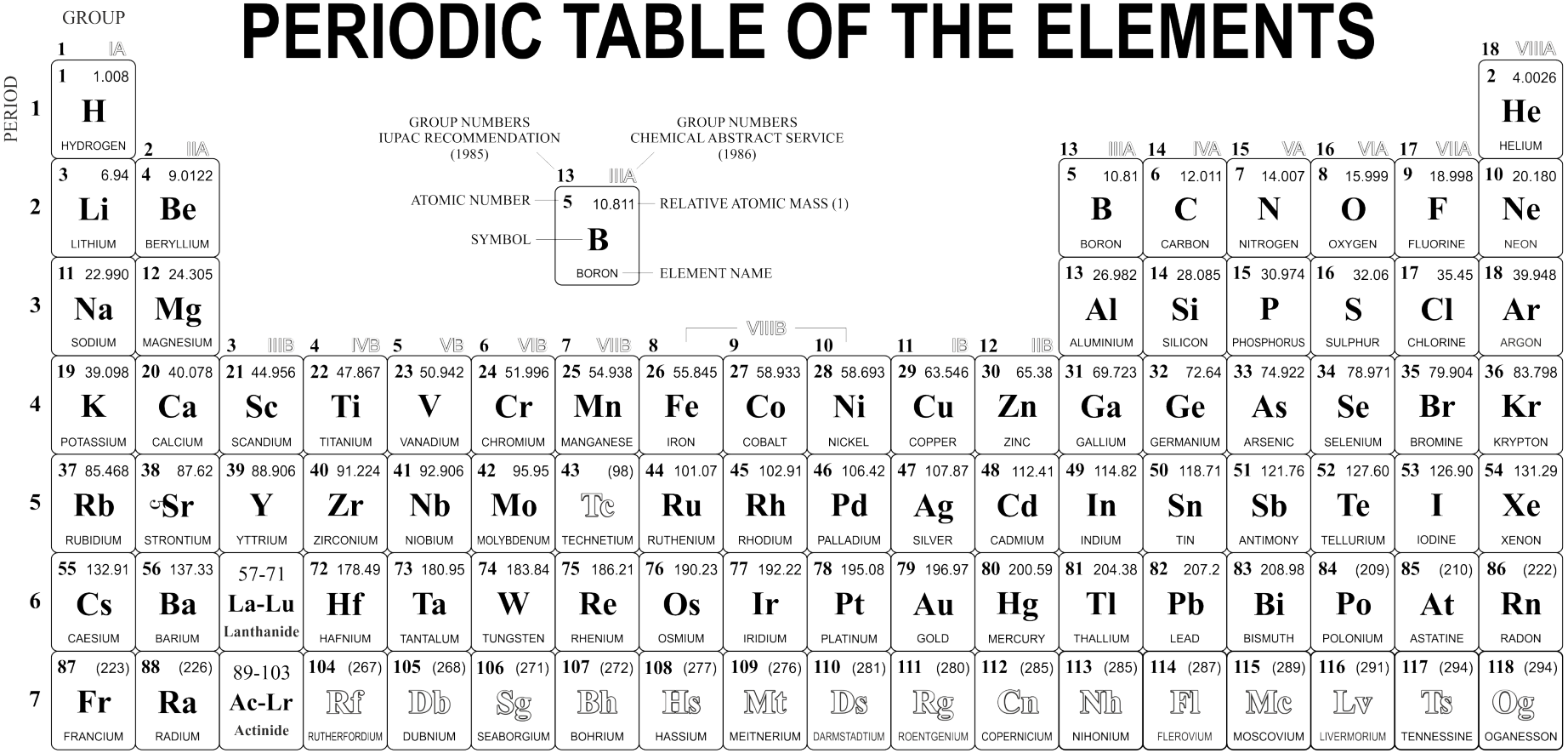
Problem 1: The following data were collected for two compounds of phosphorus and chlorine:

	Mass of Chlorine That Combines with 1 g of Phosphorus
Compound A	3.432 g
Compound B	5.725 g

A Show that this experimental data follows the law of multiple proportions.

B If it is discovered that Compound A is PCl_3, propose a plausible formula for Compound B.

PERIODIC TABLE OF THE ELEMENTS



LANTHANIDE

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
138.91	140.12	140.91	144.24	(145)	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.05	174.97
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
LANTHANUM	CERIUM	PRASEODYMIUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLMIUM	ERBIUM	THULIUM	YTTERBIUM	LUTETIUM

ACTINIDE

89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
(227)	232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
ACTINIUM	THORIUM	PROTACTINIUM	URANIUM	NEPTUNIUM	PLUTONIUM	AMERICIUM	CURIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MENDELEVIUM	NOBELIUM	LAWRENCIUM

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(1) Atomic weights of the elements 2013, Pure Appl. Chem., **88**, 265-291 (2016)