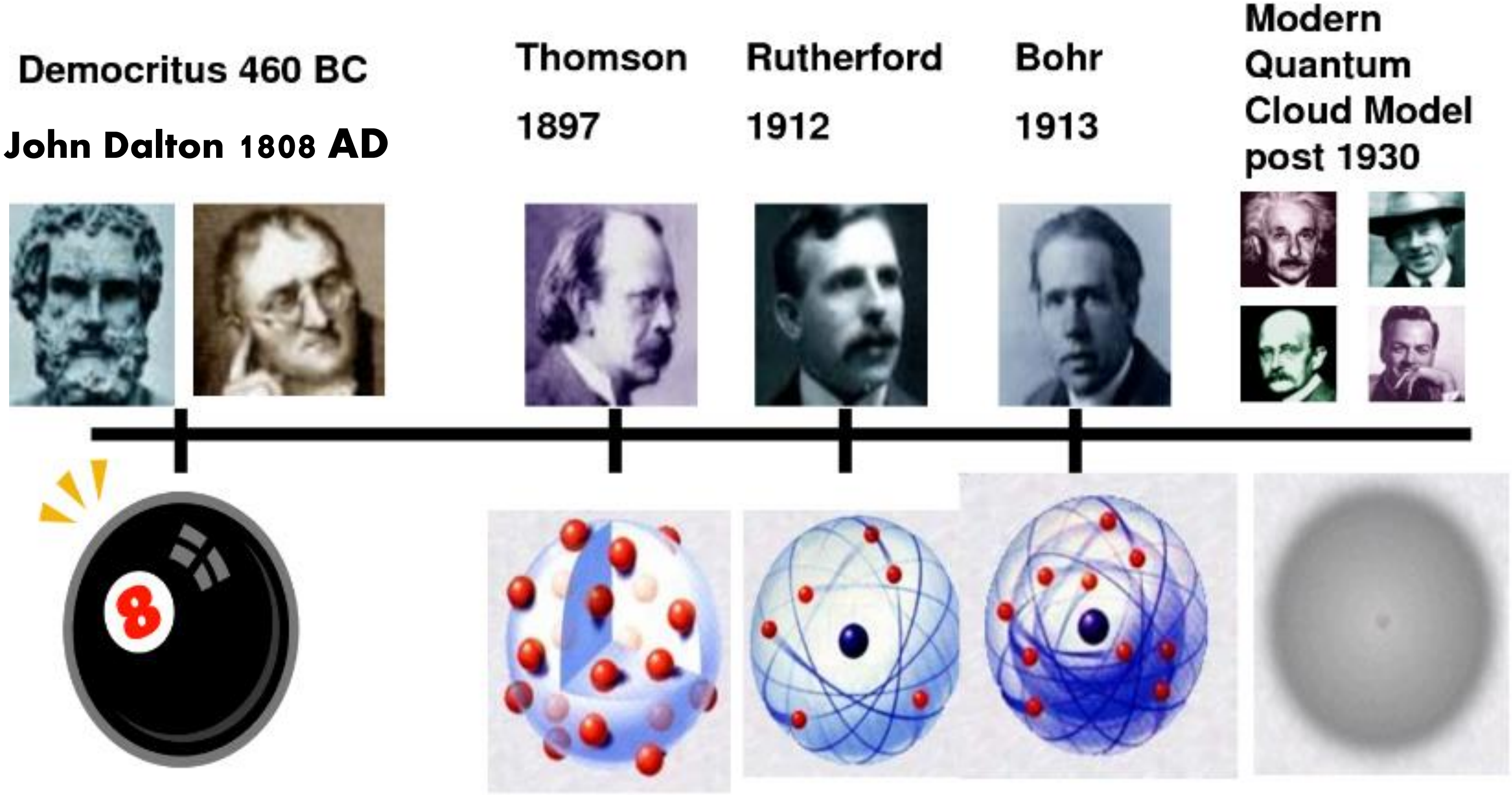
GENERAL CHEMISTRY
CHE 101

Lecture :   Atoms, Molecules and Ions

Lecture Plan

- Atomic Theories
- Structure of an atom
- Discovery of electron, proton and neutrons
- Atomic number , mass number, isotopes
- Molecules and ions
- Compounds

History of the Atom Timeline



Democritus 460 BC

John Dalton 1808 AD

Thomson

1897

Rutherford

1912

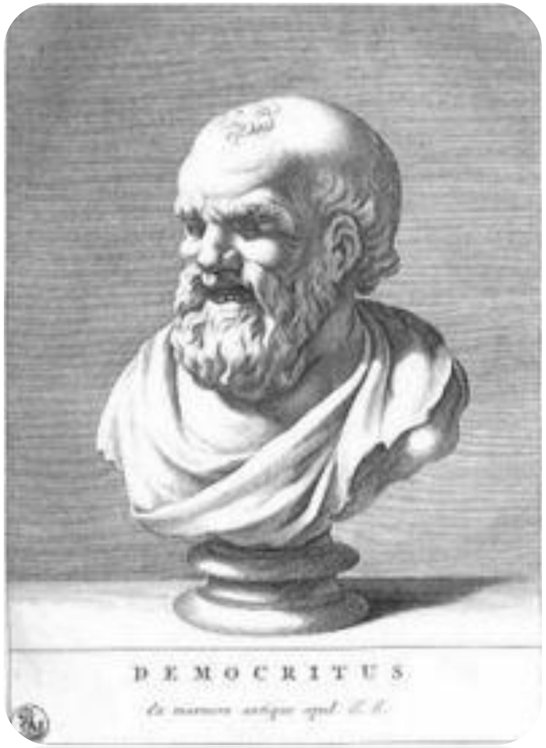
Bohr

1913

Modern Quantum Cloud Model post 1930

The Atomic Theory

- In the fifth century B.C. the Greek philosopher **Democritus** said matter consists of very small indivisible particles, named **atomos** (meaning indivisible).



The Atomic Theory

- 1808 - English scientist and school teacher, **John Dalton**, formulated a precise definition of the individual building block of matter that we call **atom**.
- Dalton's ideas were so brilliant that they have remained essentially intact up to the present time and has only been slightly corrected.

Daltons atomic theory was based on the following hypotheses :

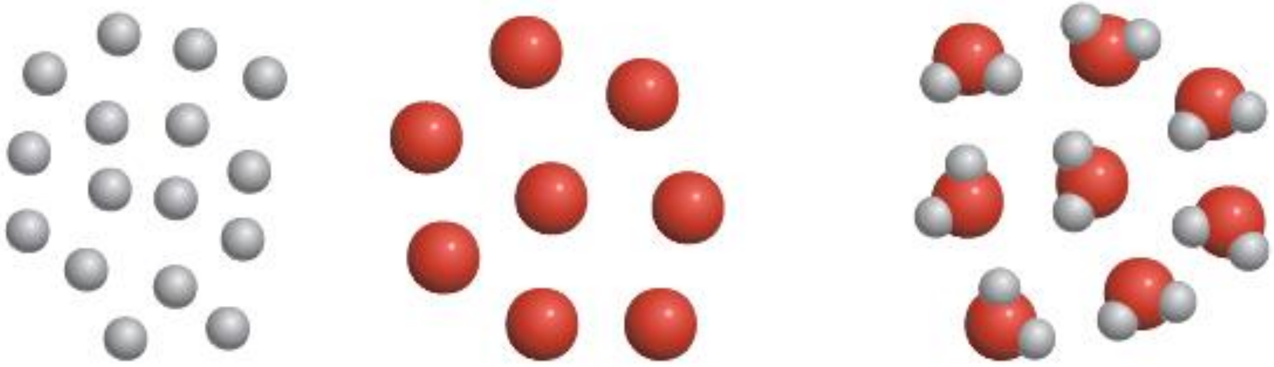
1. Elements are composed of extremely small particles called ***atoms***.

2. All ***atoms*** of a given element are identical, having the same size, mass and chemical properties. The atoms of one element are different from the atoms of all other elements.

3. ***Compounds*** are composed of atoms of more than one element. In any compound, the ratio of the numbers of atoms of any two of the elements present is either an integer or a simple fraction.

4. A ***chemical reaction*** involves only the separation, combination, or rearrangement of atoms; it does not result in their creation or destruction.

Dalton’s Atomic Theory (Hypothesis no.2 & 3)



Atoms of element X

Atoms of element Y

(a)

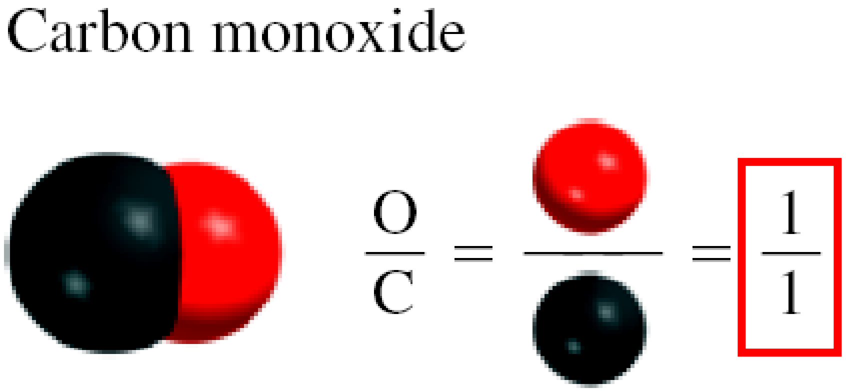
Compound of elements X and Y

(b)

Figure 2.1

(a) According to Dalton's atomic theory, atoms of the same element are identical, but atoms of one element are different from atoms of other elements. (b) Compounds formed from atoms of elements X and Y. In this case, the ratio of the atoms of element X to the atoms of element Y is 2:1.

Dalton's Atomic Theory (Hypothesis no. 3)

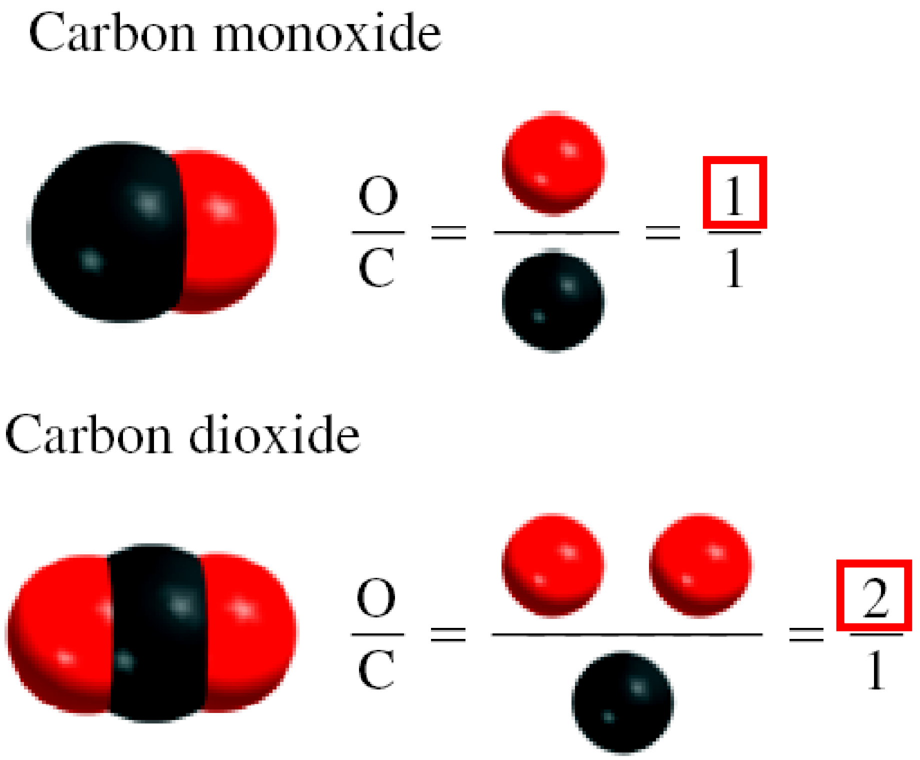


Law of Definite Proportions
(Joseph Proust 1799)

"Different samples of the same compound always contain its constituent elements in the same proportion by mass."

- – the ratio of the masses of different elements in a given compound is fixed,
- – the ratio of the atoms in the compound is also constant.

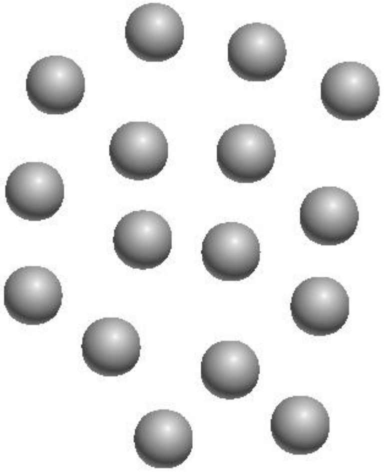
Dalton's Atomic Theory (Hypothesis no. 3)



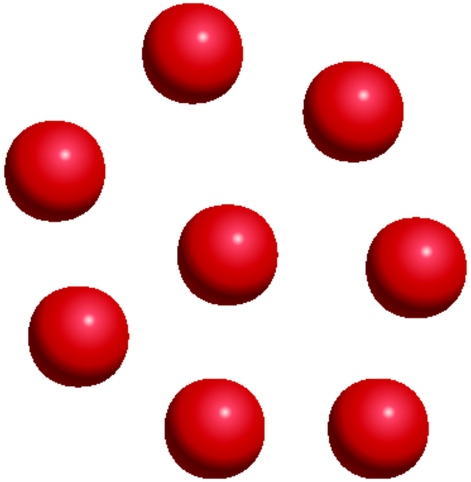
Law of Multiple Proportions

"If two elements can combine to form more than one compound, the masses of one element that combine with a fixed mass of the other element are in ratios of ***small whole number.****"*

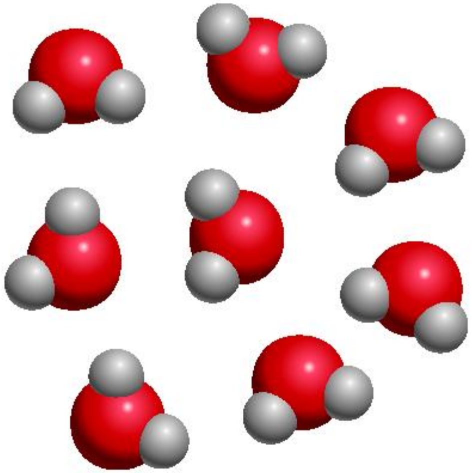
Dalton's Atomic Theory (Hypothesis no. 4)



Atoms of element X



Atoms of element Y



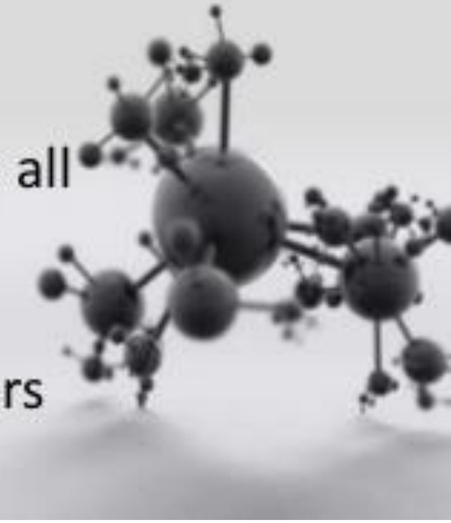
Compounds of elements X and Y

$$16\ X \quad + \quad 8\ Y \longrightarrow 8\ X_2Y$$

Law of Conservation of Mass

"Matter can be neither created nor destroyed."

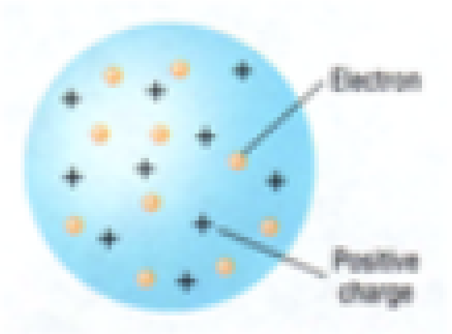
Limitations of Dalton's Atomic Theory



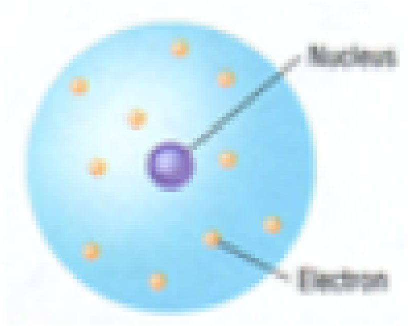
- With the discovery of sub-atomic particles, e.g., electrons, neutrons and protons, the atom can no longer be considered indivisible.

- The atoms of same elements are not similar in all respect. They may vary in mass and density. These are known as **Isotopes**. For example: chlorine has two isotopes having mass numbers 35 a.m.u and 37 a.m.u.

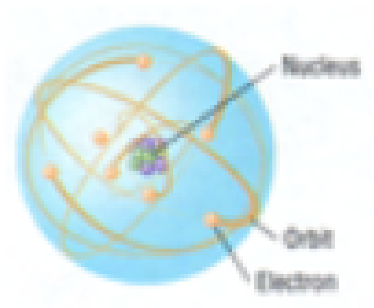
Development of Atom Models



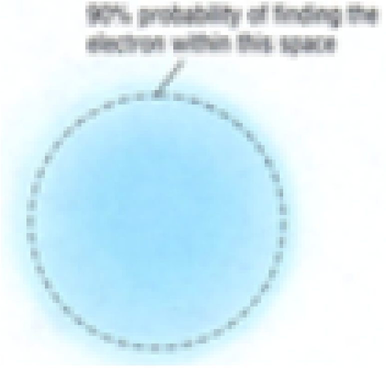
Thomson Model
In the nineteenth century(1904), Thomson described the atom as a ball of positive charge containing a number of electrons



Rutherford Model
In the early twentieth century(1911), Rutherford showed that most of an atom's mass is concentrated in a small, positively charged region called the



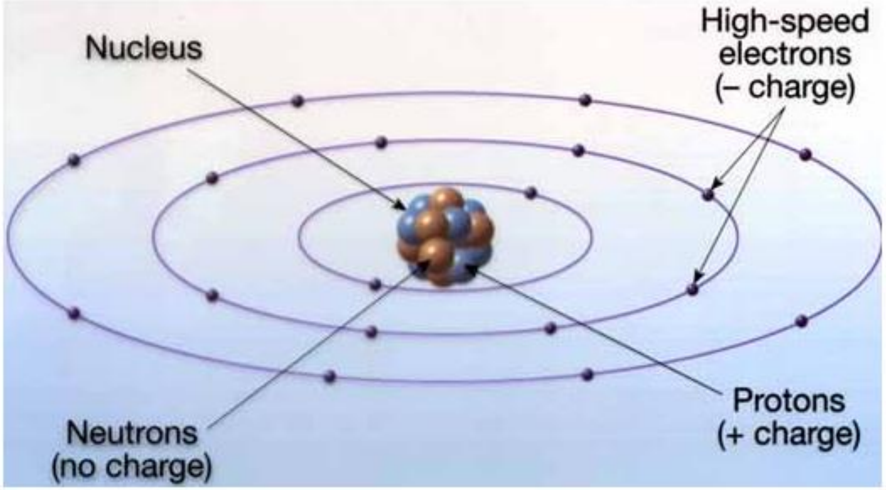
Bohr Model
In 1913 Neils Bohr proposed that the electrons travel in definite orbits around the nucleus



Quantum Mechanical Model
Modern atom theory describes the electronic structure of the atom as the probability of finding electrons within certain regions of space

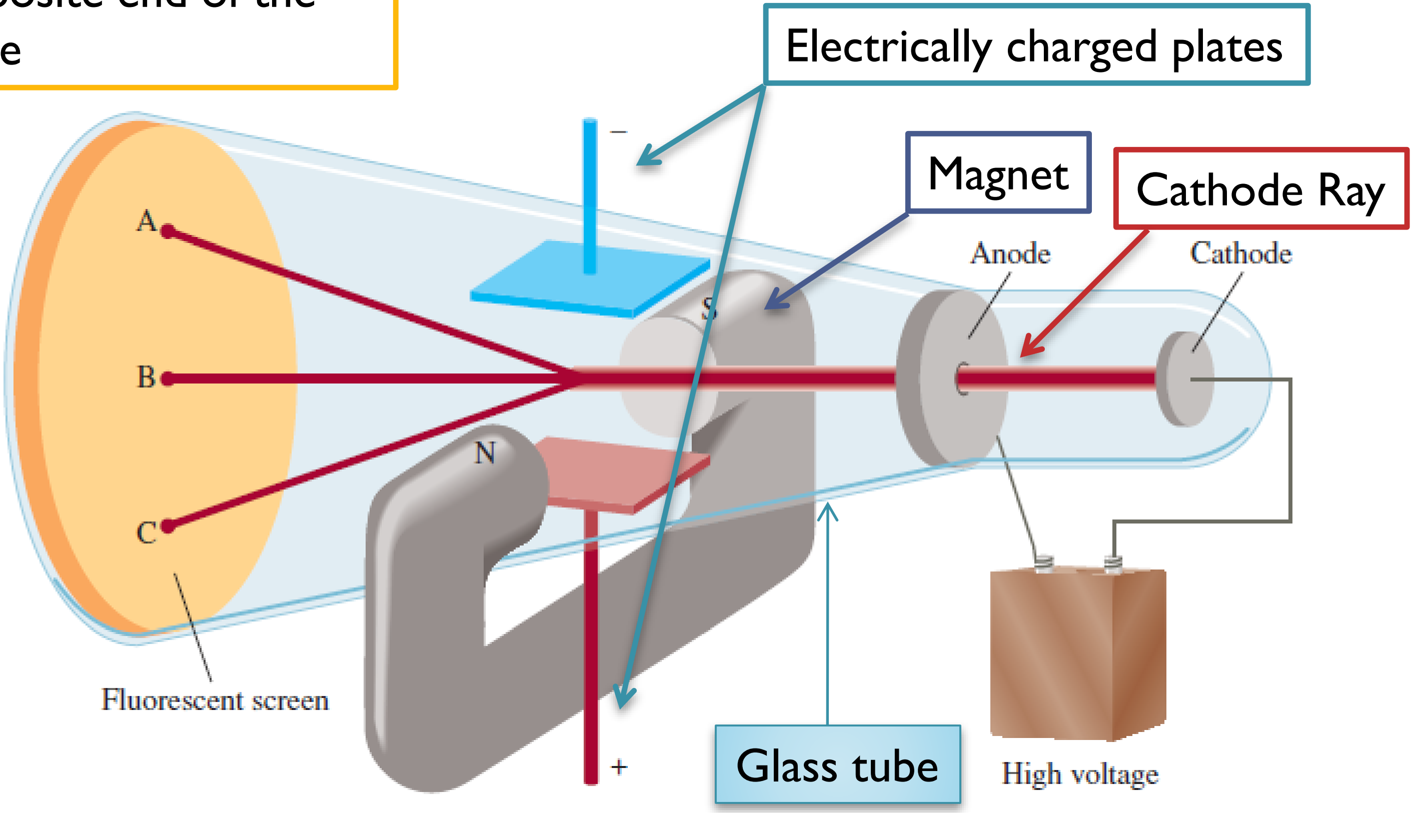
Structure of the Atom

- Atom is the basic unit of an element that can enter into chemical combination.
- Atom has internal structure and the smaller particles are called **subatomic particles**- electron, proton and neutron.



Electron

Cathode Ray Tube Experiment: Discovery of Electron By J. J. Thomson (1896)



Coated surface at the opposite end of the tube

Electrically charged plates

Magnet

Cathode Ray

Glass tube

Cathod Ray in a Discharge Tube

Figure : *(a) A cathode ray produced in a discharge tube. The ray itself is invisible, but the fluorescence of a zinc sulfide coating on the glass causes it to appear green. (b) The cathode ray is bent downward when a bar magnet is brought toward it. (c) When the polarity of the magnet is reversed, the ray bends in the opposite direction.*

Cont..

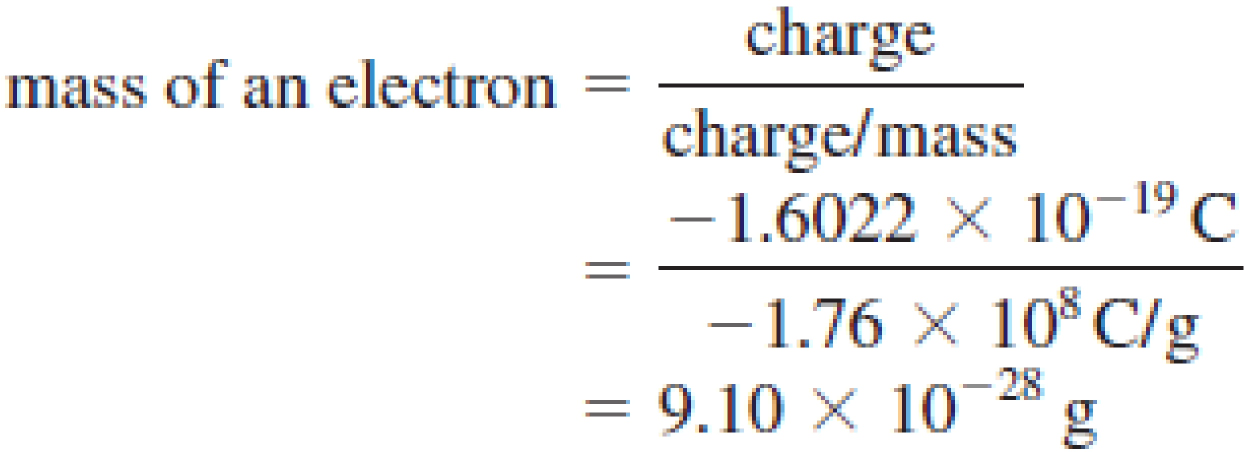
- Dutch Physicist **H.A. Lorentz** named these cathode particles ‘Electron’.
- Thomson measured the charge to mass ratio (e/m) of the cathode particle.
- In SI units the value is -1.76 X 10 ^{8} coulombs per gram.
- Millikan’s Measured charge of e^- by his oil drop experiment and the value is -1.60 X 10 $^{-19}$ coulombs.

Mass of an Electron

Millikan's e^- charge = -1.60×10^{-19} C

Thomson's (charge/mass) of e^- = -1.76×10^{8} C/g

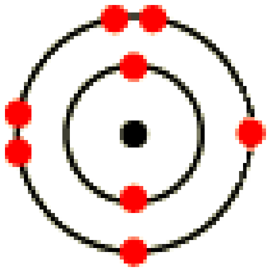
Mass of electron = 9.10×10^{-28} g



$$\begin{aligned}\text{mass of an electron} &= \frac{\text{charge}}{\text{charge/mass}}\\ &= \frac{-1.6022 \times 10^{-19}\,\text{C}}{-1.76 \times 10^{8}\,\text{C/g}}\\ &= 9.10 \times 10^{-28}\,\text{g}\end{aligned}$$

Structure of the Atom-Electron

- An electron can be bound to the nucleus of an atom by the attractive Coulomb force.
- Negatively charged.
- A system of one or more electrons bound to a nucleus is called an atom.



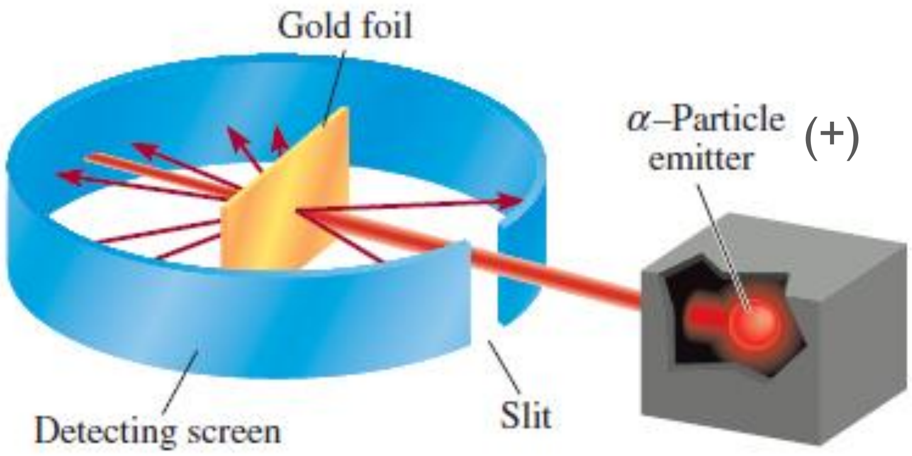
oxygen atom,
O 2,6

Mass	**9.109×10^{-31}kilograms/ 5.489×10^{-4} atomic mass units (amu)**
charge	**-1.602×10^{-19} coulomb**

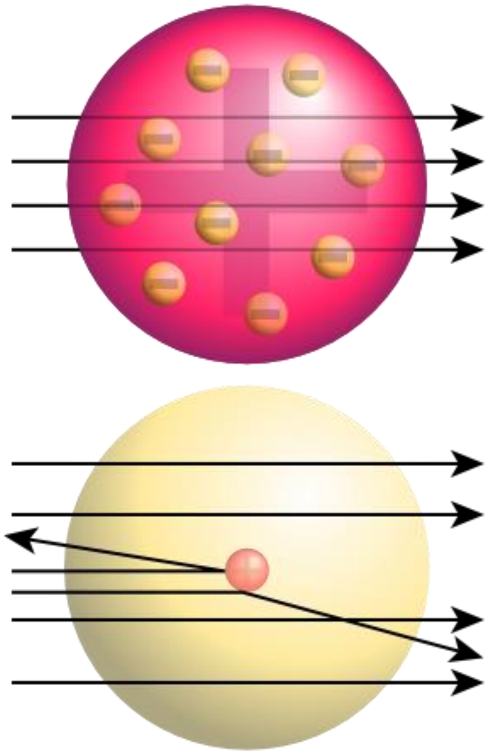
Proton

The Nuclear Model of the Atom:

Rutherford's Experiment



ZnS screen

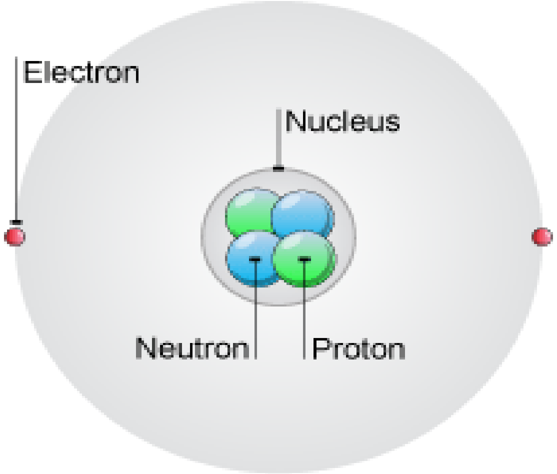


Rutherford's postulation on nuclear atomic structure:

- Atom has a tiny dense central core or the nucleus which contains practically the entire mass of the atom, leaving the rest of the atom almost empty.
- The entire positive charge of the atom is located on the nucleus, while electrons were distributed in vacant spaces around it.
- The electrons were moving in orbits or closed circular paths around the nucleus like planets around the sun.

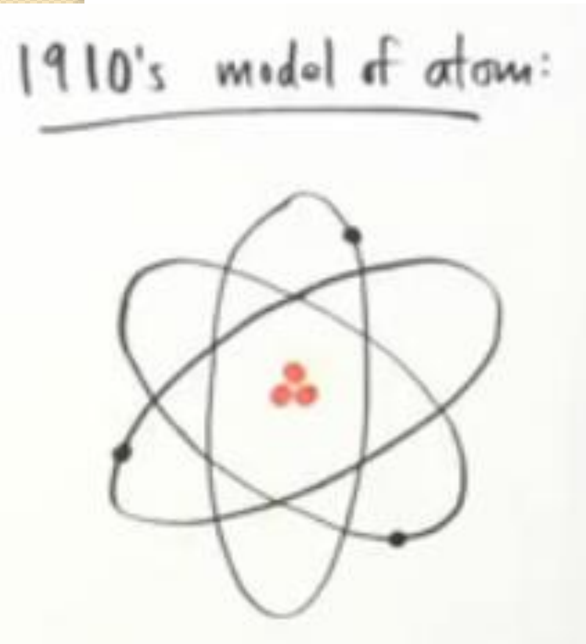
Proton

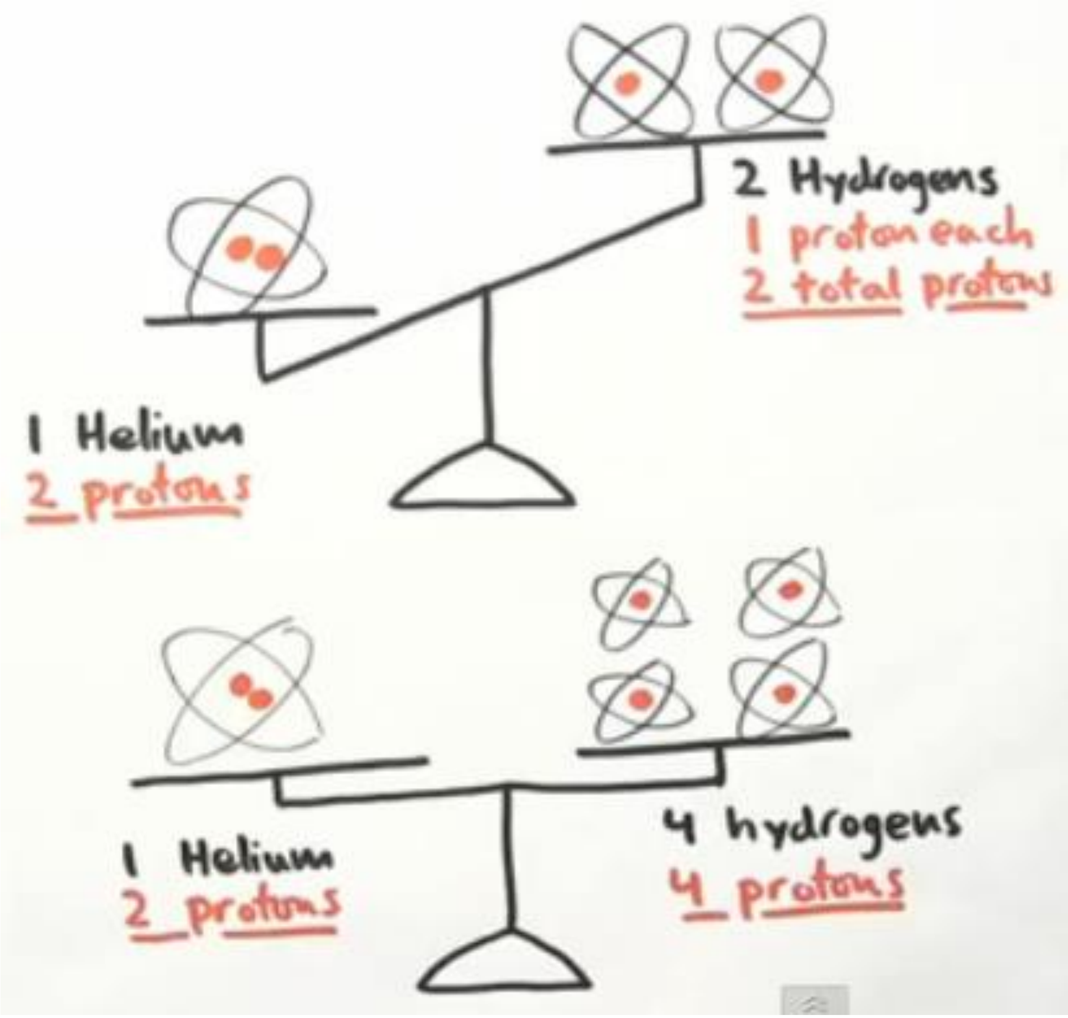
- As an atom is neutral and contains (-) charged electrons, it must contain equal amount of (+)ly charged particles.
- Proton is positively charged particles and remains in the nucleus of the atom.



Mass	**1.67262 x 10^{-24} g (1840 times the mass of e^{-})**
charge	**1.602×10^{-19} coulomb**

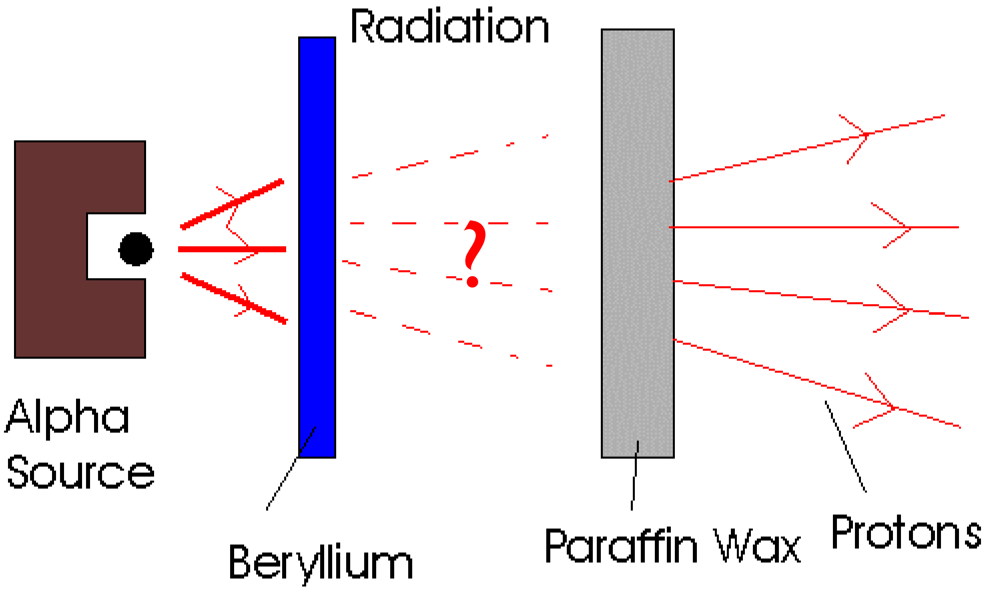
Discovery of Neutron





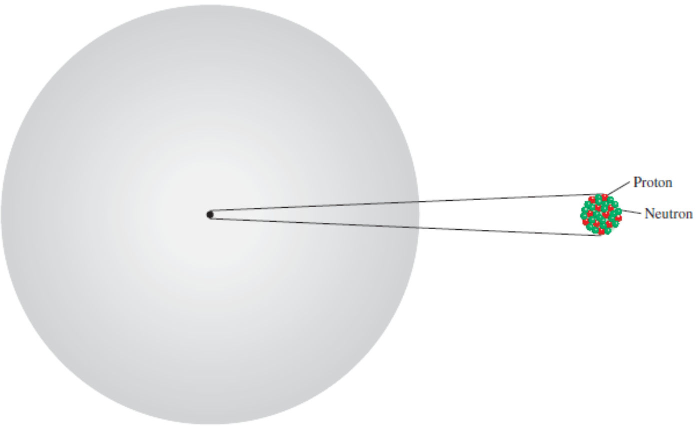
Neutron

- In 1932 Sir James Chadwick discovered neutron.
- A stream of alpha particles were directed at a beryllium target.
- He found that a new particle were ejected which had a property like γ ray. It had almost the same mass as the proton and has no charge.



Structure of the Atom-Neutron

- Third type of subatomic particle.
- Electronically neutral
- Mass is slightly higher than proton
- Remains with proton in the nucleus.



Mass	**1.67493 x 10^{-24} g**
charge	**0**

Atomic Number

- Atomic number (Z) is the number of <u>protons</u> in the nucleus of each atom of an element.
- In a neutral atom,

  number of electrons = number of protons
- Chemical identity of an atom is the 'atomic number'.
- Example:

  atomic number of fluorine is 9. It means it has,

  9 protons. /

  proton number 9 indicates that the atom is 'fluorine' .

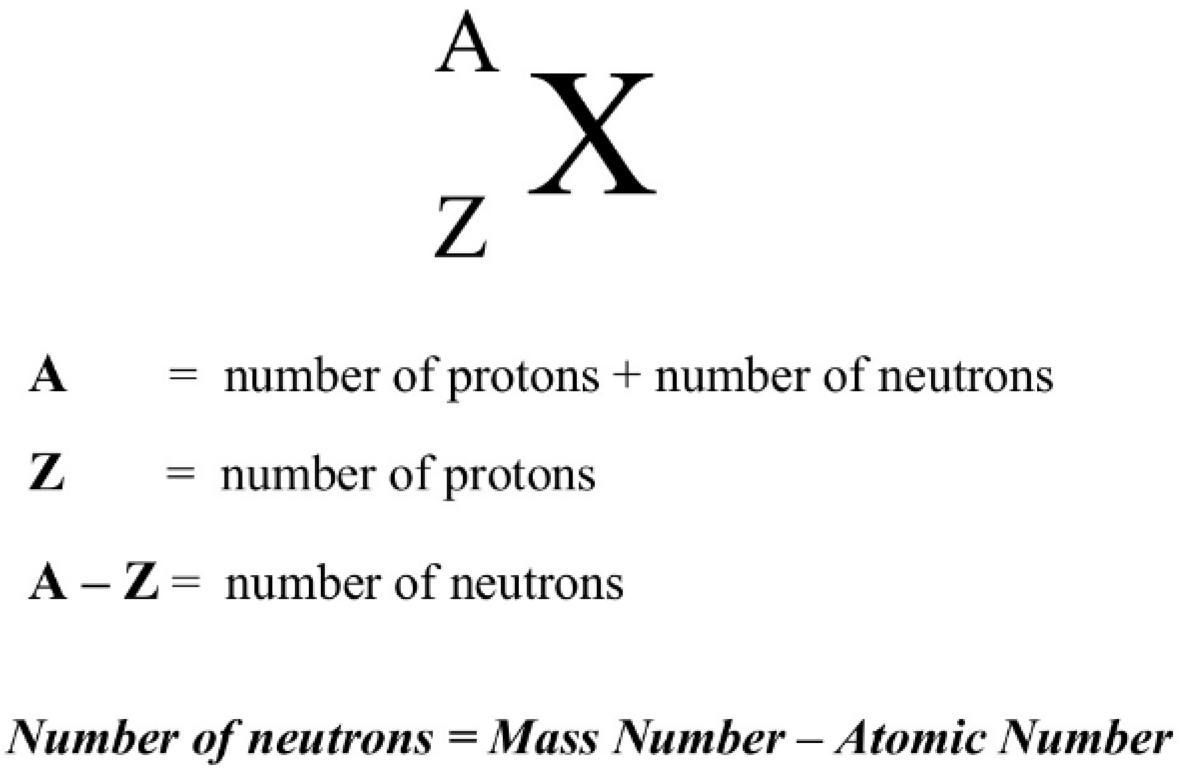
Mass Number

- Mass number (A) is the total number of <u>neutrons</u> and <u>protons</u> in the nucleus of an atom of an element.
- Mass number = numbers of protons+ numbers of neutrons

  = atomic number + numbers of neutrons

* Atomic number, mass number and numbers of protons and neutrons all must be **positive integers(whole numbers)**

An Atom Can be Written as…



$$^{A}_{Z}X$$

A = number of protons + number of neutrons

Z = number of protons

A – Z = number of neutrons

Number of neutrons = Mass Number – Atomic Number

Isotopes

- Atoms that have same atomic number but different mass number.
- Most elements have two or more isotopes.
- Example:

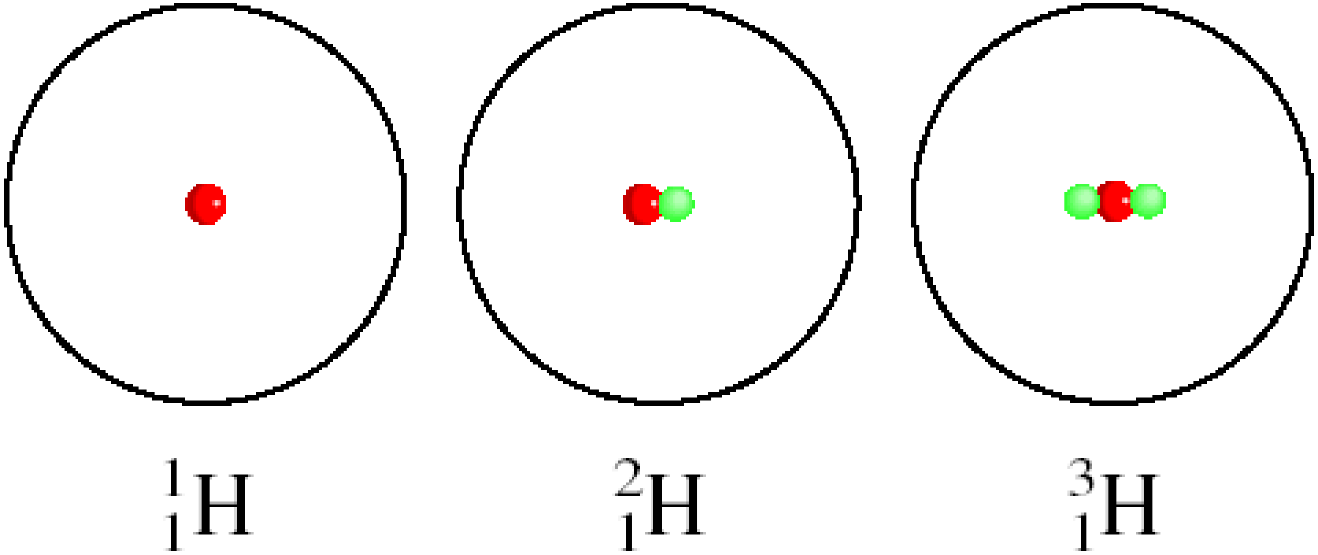
Mass number ⟶ A

X :Element symbol

Atomic number ⟶ Z

$^{1}_{1}H$ $^{2}_{1}H(D)$ $^{3}_{1}H(T)$ / $^{235}_{92}U$ $^{238}_{92}U$

The Isotopes of Hydrogen



Hydrogen

Deuterium

Tritium

Counting Protons, Neutrons & Electrons

How many protons, neutrons, and electrons are in ${}^{14}_{6}C$?

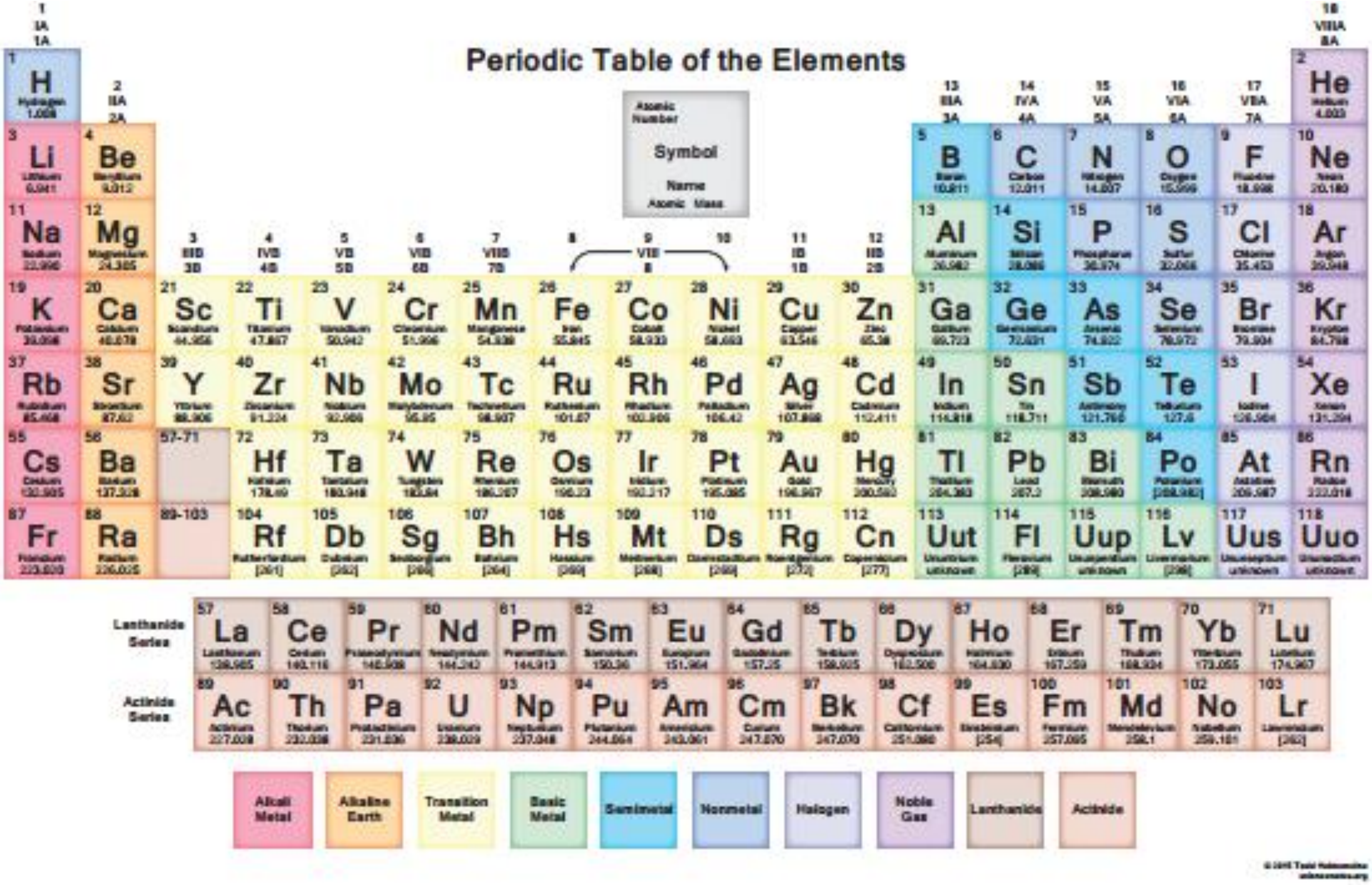
How many protons, neutrons, and electrons are in ${}^{11}_{6}C$?

1. Give the number of proton, neutrons and electrons in each of the following species:

$^{17}_{8}\mathrm{O}$, $^{199}_{80}\mathrm{Hg}$, $^{200}_{80}\mathrm{Hg}$,

$^{63}_{29}\mathrm{Cu}$

Periodic Table



Periodic Table of the Elements

Atomic Number
Symbol
Name
Atomic Mass

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Lanthanide Series	57 La	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
Actinide Series	89 Ac	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

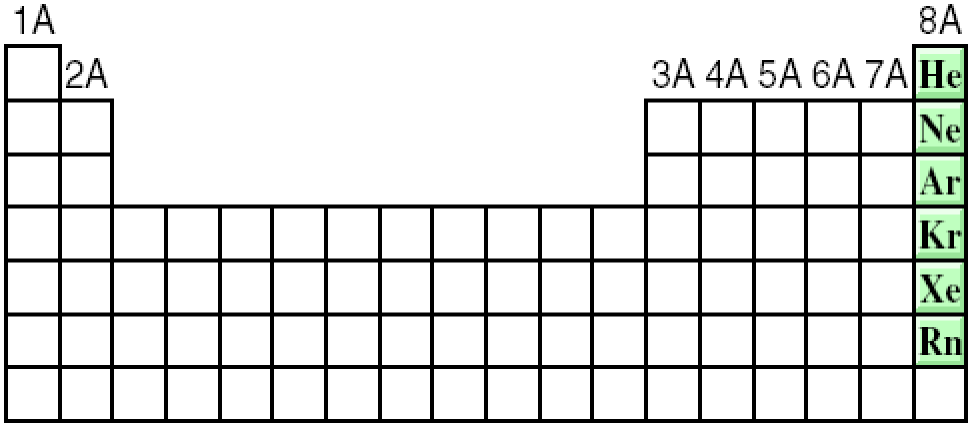
Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Semimetal
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide

Molecules

- Molecules: is an aggregate of at least two atoms in a definite arrangement held together by chemical forces(bonds).
- Molecules can contain atoms of same elements or different elements.
- They should join in a fixed ratio.
- **Electrically *neutral* like atom.**

Molecules

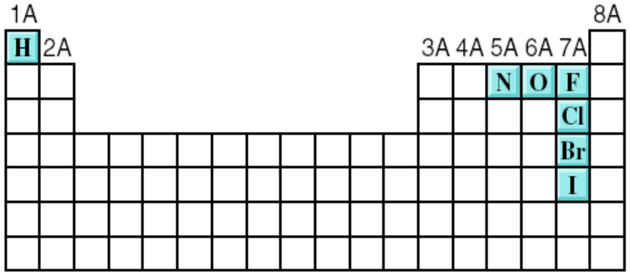
Of all the elements, only the six noble gases in Group 8A exist in nature as single atoms, called ***monatomic*** gases.



Most matter is composed of molecules or ions formed by atoms.

A ***diatomic molecule*** contains only two atoms.

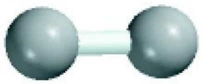
H_2, N_2, O_2, Br_2, HCl, CO



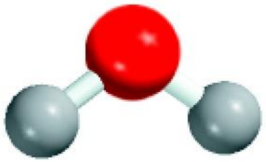
diatomic elements

A ***polyatomic molecule*** contains more than two atoms.

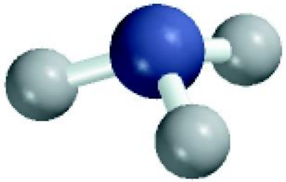
O_3, H_2O, NH_3, CH_4



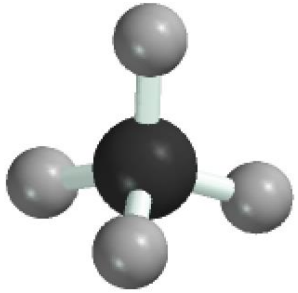
H_2



H_2O



NH_3



CH_4

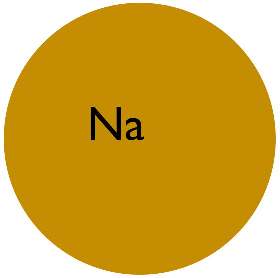
Ions

- An Ion is an atom or a group of atoms that has a net ***positive*** or ***negative*** charge.
- The number of "Proton" in the nucleus remains same during chemical reaction.
- "electrons" are lost/gained during a reaction.
    - The loss of 1/more electrons from a neutral atom results "cation" : an ion with (+) charge .
    - The gain of 1/more electrons from a neutral atom results "anion": an ion with (-) charge.

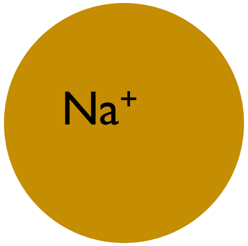
Ions

cation – ion with a positive charge

If a neutral atom **loses** one or more electrons
it becomes a cation.



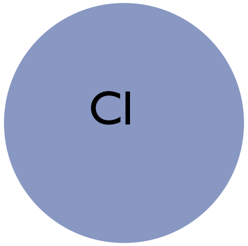
11 protons
11 electrons



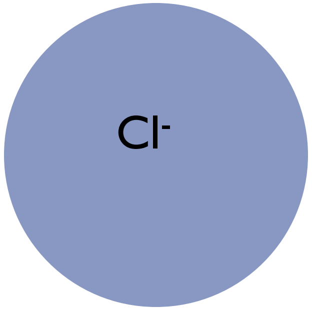
11 protons
10 electrons

anion – ion with a negative charge

If a neutral atom **gains** one or more electrons
it becomes an anion.



17 protons
17 electrons



17 protons
18 electrons

Ions

Na Atom	**Na^+ Ion**
11 protons	11 protons
11 electrons	10 electrons

Cl Atom	**Cl^- Ion**
17 protons	17 protons
17 electrons	18 electrons

NaCl is an ionic compound, because it is composed of cation (Na^+) and Anion (Cl^-)

Monatomic Ions & Polyatomic Ions

A ***monatomic ion*** contains only one atom

Na^+, Cl^-, Ca^{2+}, O^{2-}, Al^{3+}, N^{3-}

A **polyatomic ion**, also known as a molecular **ion**, is a charged chemical species (**ion**) composed of two or more atoms covalently bonded or of a metal complex that can be considered to be acting as a single unit.

OH^-, CN^-, NH_4^+, NO_3^-

Counting Protons, Neutrons & Electrons

How many protons, neutrons and electrons are in $^{27}_{13}\mathrm{Al}^{3+}$?

13 protons, 14 neutrons, 10 (13 – 3) electrons

How many protons, neutrons and electrons are in $^{78}_{34}\mathrm{Se}^{2-}$?

34 protons, 44 neutrons, 36 (34 + 2) electrons

Compounds

- A **chemical compound** is a pure chemical substance consisting of two or more different chemical elements that can be separated into simpler substances by chemical reactions.

- Chemical compounds have a unique and defined chemical structure; they consist of a fixed ratio of atoms.

- They are held together in a defined spatial arrangement by chemical bonds.

Compounds

Characteristic properties of compounds:

- *Elements in a compound are present in a definite proportion*

  Example- 2 atoms of hydrogen + 1 atom of oxygen becomes 1 molecule of compound-water.

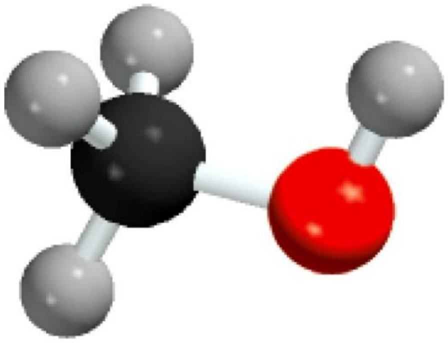
- *Compounds have a definite set of properties*

  Elements that comprise a compound do not retain their original properties.

Naming Compounds

Organic compounds

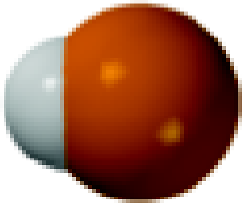
- Contain carbon.
- Usually in combination with elements such as H, O, N, and S.
- Can contain functional groups.



CH_3OH

Inorganic compounds

- All other compounds are classified as inorganic compounds.
- CO, CO_2, CS_2, and compounds containing $CN^–$, $CO_3^{2–}$, and $HCO_3^–$ groups.



Compounds

Figure: CuSO4.5H2O (left) is blue; CuSO4 (right) is white.

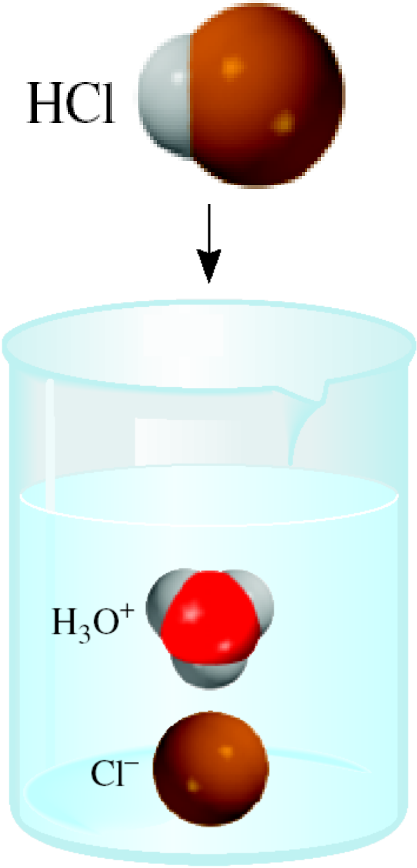


Figure: When dissolved in water, the HCl molecule is converted to the H+ and Cl- ions. The H+ ion is associated with one or more water molecules, and is usually represented as H3O+.

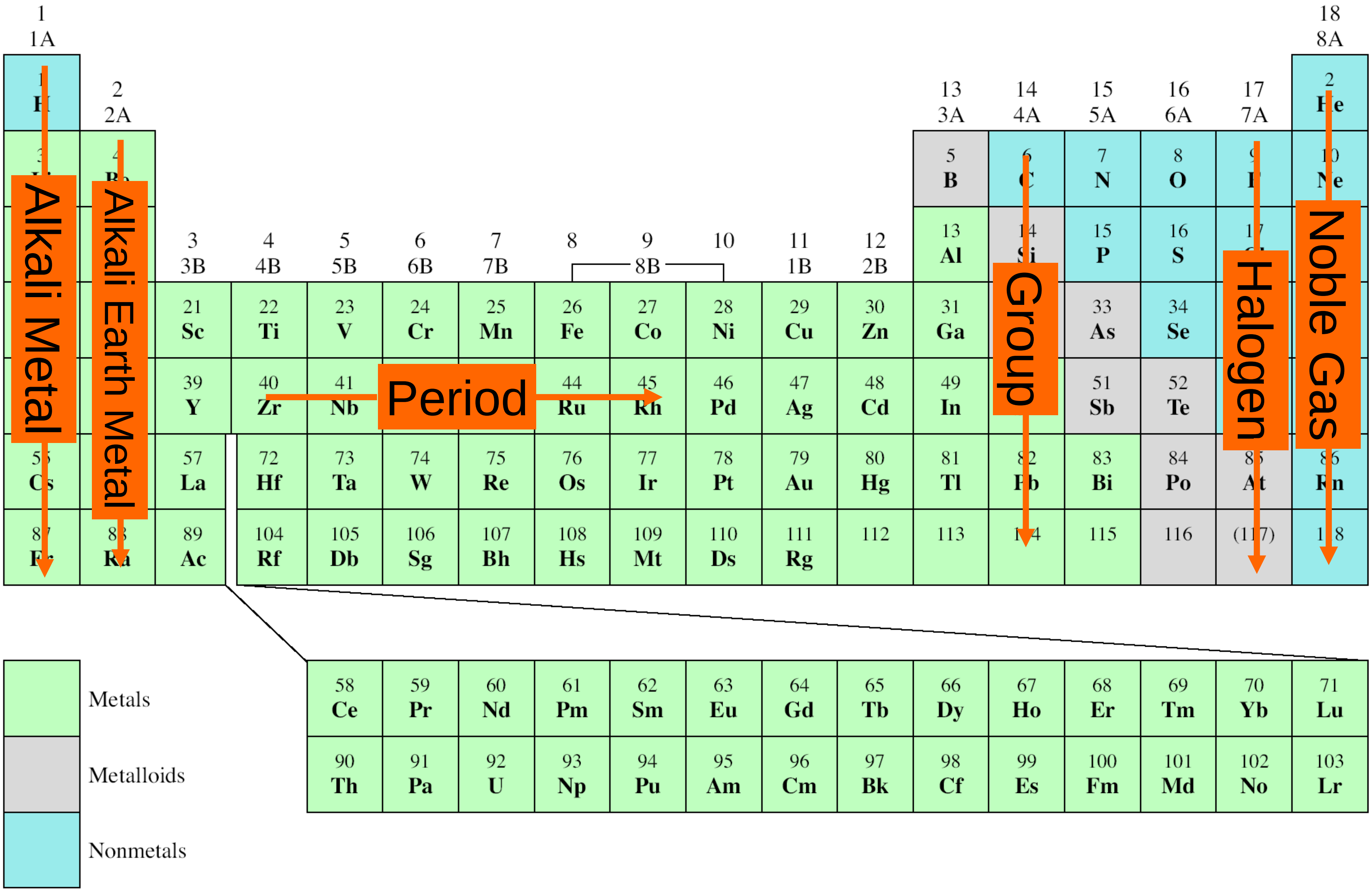
Inorganic Compounds

Inorganic compounds are divided into **four** categories:

- **Ionic compounds:** often metal + non metals. e.g. $Mg(OH)_{2,}$ $KNO_{3,}$ NaCl etc.
- **Molecular compounds:**nonmetal + nonmetal/metaloids. e.g. H_2O, $NH_{3,}$ $CH_{4.}$
- **Acids and bases:**H^+ / proton donar/acceptor: acids and bases respectively. e.g: HCl, NaOH.
- **Hydrates:** specific number of water molecules will be attached. e.g. $BaCl_2{\bullet}2H_2O$: barium chloride dihydrate.
  $LiCl{\bullet}H_2O$: lithium chloride monohydrate

Periodic Table and Ionic Charge

The Modern Periodic Table



1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H**																	2 **He**
3 **Li**	4 **Be**											5 **B**	6 **C**	7 **N**	8 **O**	9 **F**	10 **Ne**
												13 **Al**	14 **Si**	15 **P**	16 **S**	17	
		21 **Sc**	22 **Ti**	23 **V**	24 **Cr**	25 **Mn**	26 **Fe**	27 **Co**	28 **Ni**	29 **Cu**	30 **Zn**	31 **Ga**		33 **As**	34 **Se**		
		39 **Y**	40 **Zr**	41 **Nb**			44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**		51 **Sb**	52 **Te**		
55 **Cs**		57 **La**	72 **Hf**	73 **Ta**	74 **W**	75 **Re**	76 **Os**	77 **Ir**	78 **Pt**	79 **Au**	80 **Hg**	81 **Tl**	82 **Pb**	83 **Bi**	84 **Po**	85 **At**	86 **Rn**
87 **Fr**	88 **Ra**	89 **Ac**	104 **Rf**	105 **Db**	106 **Sg**	107 **Bh**	108 **Hs**	109 **Mt**	110 **Ds**	111 **Rg**	112	113	114	115	116	(117)	118

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**
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**

- 🟩 Metals
- ⬜ Metalloids
- 🟦 Nonmetals

Alkali Metal

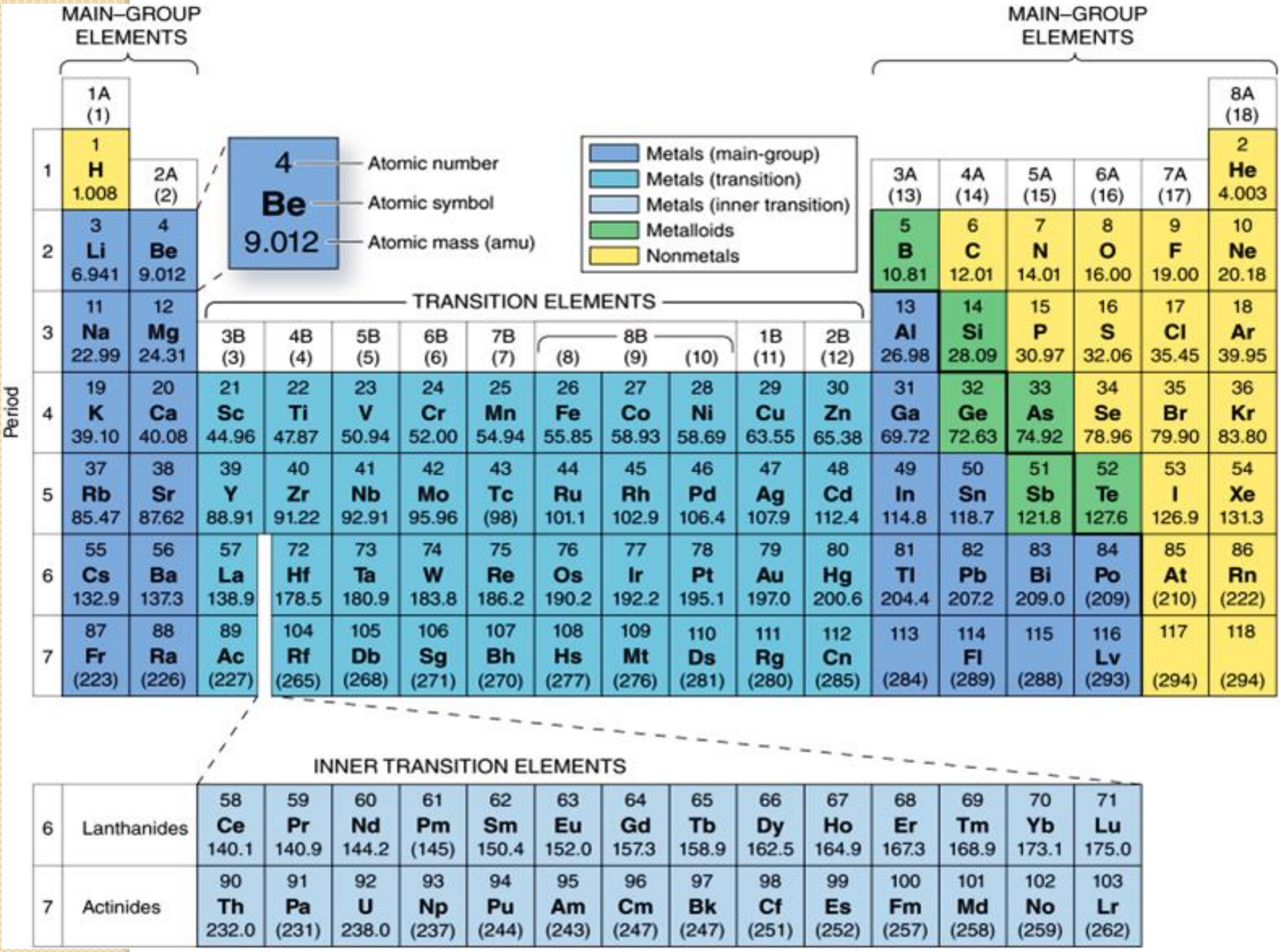
Alkali Earth Metal

Period

Group

Halogen

Noble Gas



MAIN–GROUP ELEMENTS

TRANSITION ELEMENTS

INNER TRANSITION ELEMENTS

4	Be	9.012
Atomic number	Atomic symbol	Atomic mass (amu)

🟦 Metals (main-group)

🟦 Metals (transition)

⬜ Metals (inner transition)

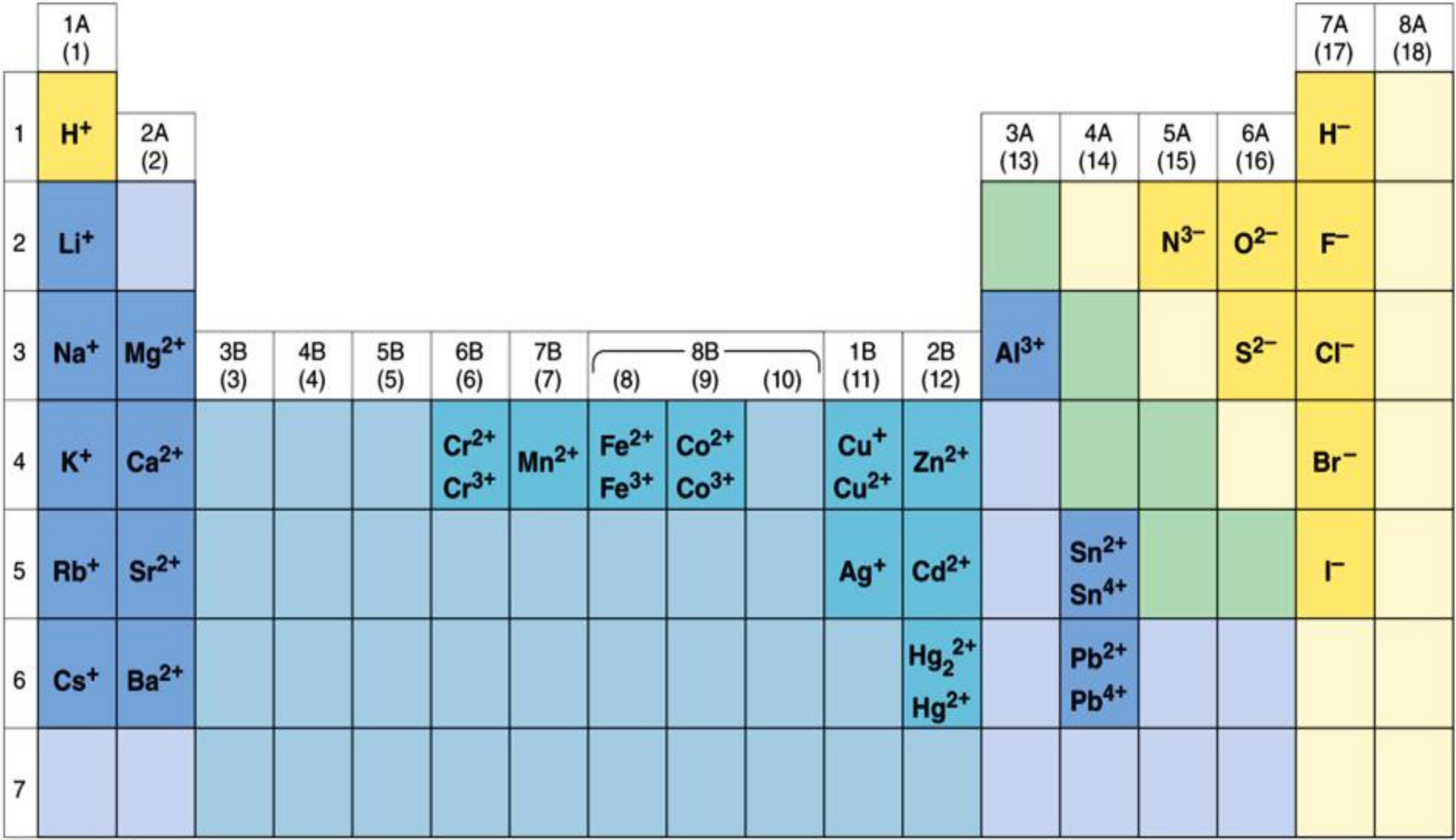
🟩 Metalloids

🟨 Nonmetals

Period	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	(9)	(10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (265)	105 **Db** (268)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 (284)	114 **Fl** (289)	115 (288)	116 **Lv** (293)	117 (294)	118 (294)

6	Lanthanides	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.1	71 **Lu** 175.0
7	Actinides	90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Common Ions Related to the Group Numbers



Period	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	(9)	(10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	H^+																H^-	
2	Li^+														N^{3-}	O^{2-}	F^-	
3	Na^+	Mg^{2+}											Al^{3+}			S^{2-}	Cl^-	
4	K^+	Ca^{2+}				Cr^{2+} Cr^{3+}	Mn^{2+}	Fe^{2+} Fe^{3+}	Co^{2+} Co^{3+}		Cu^+ Cu^{2+}	Zn^{2+}					Br^-	
5	Rb^+	Sr^{2+}									Ag^+	Cd^{2+}		Sn^{2+} Sn^{4+}			I^-	
6	Cs^+	Ba^{2+}										Hg_2^{2+} Hg^{2+}		Pb^{2+} Pb^{4+}				
7																		

Molecular Masses from Chemical Formulas

- **Molecular Mass = Sum of Atomic Masses**

For the H_2O molecule,

Molecular mass = (2 × atomic mass of H) + (1 × atomic mass of O)

= (2 × 1.008 amu) + (1 × 16.00 amu)

= 18.02 amu

- **Molar Mass = Molecular Mass in grams**

1 mole of H_2O has a mass of 18.02 grams

1 mole of H_2O contains **6.022×10^{23}** H_2O molecules (***Avogadro Number***)

Quiz 1

Practice related problems from Raymond Chang 9th/10th Ed.

THANK YOU