Chapter 2

Atoms, Molecules, and Ions

Topics

- The atomic theory
- The structure of the atom
- Atomic number, mass number and isotopes
- The Periodic Table
- The atomic mass scale and the average atomic mass
- Molecules and molecular compounds
- Ions and ionic compounds

2.1 The Atomic Theory

- Matter is composed of fire, earth, water and air
- The Greek philosopher Democritus (460 B.C. – 370 B.C.) was among the first to suggest the existence of atoms (from the Greek word "atomos")
  - He believed that atoms were indivisible (undividable) and indestructible
  - No support was given to this theory by contemporaries Plato or Aristotle
  - His ideas did agree with later scientific theory, but did not explain chemical behavior, and was not based on the scientific method – but just philosophy

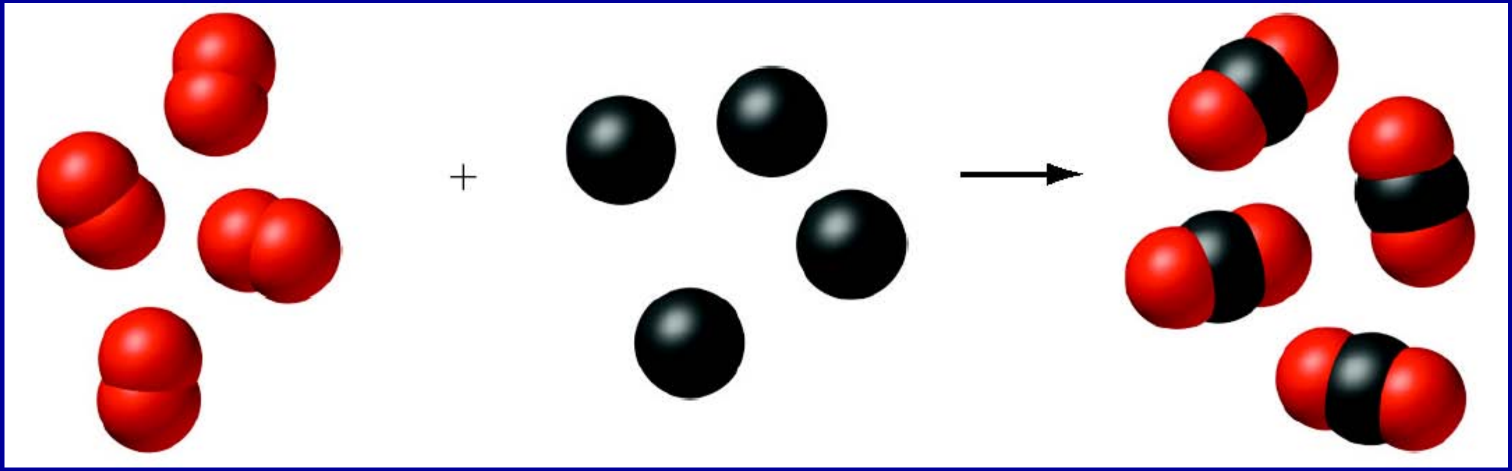
2.1 The Atomic Theory

- **1808 - English scientist and school teacher John Dalton formulated an accurate definition of the indivisible building blocks of matter that we call atoms**

Dalton's Atomic Theory (1808)

- Elements are made up of extremely small particles called atoms
- Atoms of <u>one</u> element are identical. Atoms of <u>different</u> elements are different.
- Compounds are formed when atoms combine.
- Each compound has always same type and relative number of atoms
- Chemical reactions are rearrangement of atoms but atoms of one element are never changed into atoms of other element. , or created or destroyed.

- A chemical reaction rearranges atoms in chemical compounds; it does not create or destroy them.



Combination of oxygen and carbon to form carbon dioxide

- **Dalton’s made no attempt to describe the structure or composition of atoms.**
- **He attributed the difference in chemical properties of various elements to the fact that atoms of one element are different from atoms of the others.**
- **Accordingly, at that time, in order to form a certain compound a specific number of atoms of the right kind must combine.**
- **This idea came as a support for the law of definite proportions and law of multiple proportions** which were known at that time.

Law of Definite Proportion (Proust's Law)

- A given compound always contains exactly the same proportion of elements by mass.
- Water is composed of 11.1% H and 88.9% O (w/w)

Law of definite proportions

- **Different samples of a given compound always contain the same elements in the same mass *ratio.***
  - **Examples**

Sample	Mass of O (g)	Mass of C (g)	Ratio (g O : g C)
123 g carbon dioxide	89.4	33.6	2.66:1
50.5 g carbon dioxide	36.7	13.8	2.66:1
88.6 g carbon dioxide	64.4	24.2	2.66:1

Sample	Mass of O (g)	Mass of C (g)	Ratio (g O : g C)
16.3 g carbon monoxide	9.31	6.99	1.33:1
25.9 g carbon monoxide	14.8	11.1	1.33:1
88.4 g carbon monoxide	50.5	37.9	1.33:1

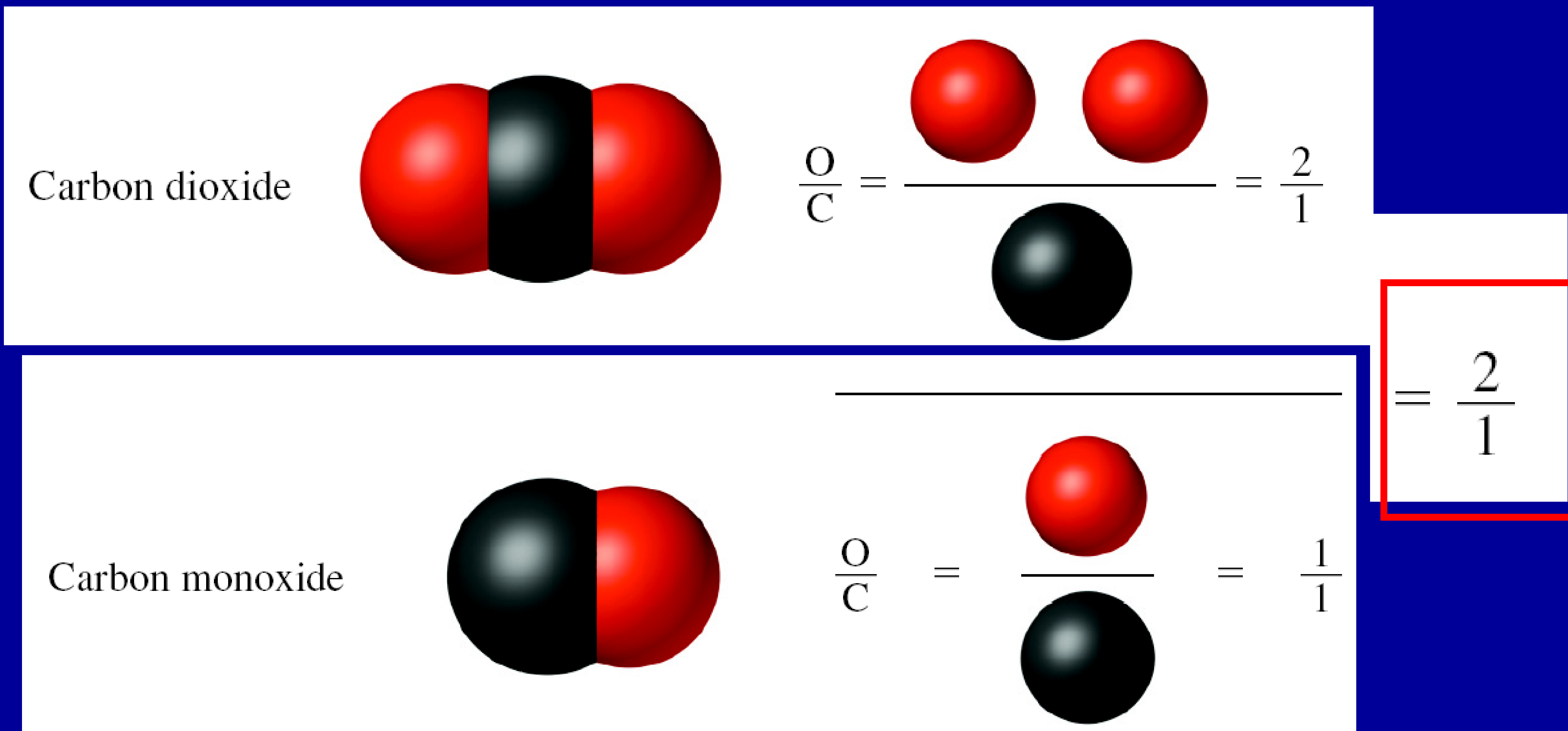
Law of Multiple Proportions

- When two elements form a series of compounds, the ratios of the masses of the second element that combine with a fixed mass(1 gram) of the first element can always be reduced to small whole numbers.
- The ratio of the masses of oxygen that combine with 1g of H in H_2O and H_2O_2 will be a small whole number ("2").

Example

- Water, H_2O has 8 g of oxygen per 1g of hydrogen.
- Hydrogen peroxide, H_2O_2, has 16 g of oxygen per 1g of hydrogen.
- 16/8 = 2/1
- Small whole number ratio.
- This fact could be explained in terms of atoms

$$\frac{\text{ratio of O to C in carbon dioxide}}{\text{ratio of O to C in carbon monoxide}} = \frac{2.66}{1.33} = 2{:}1$$



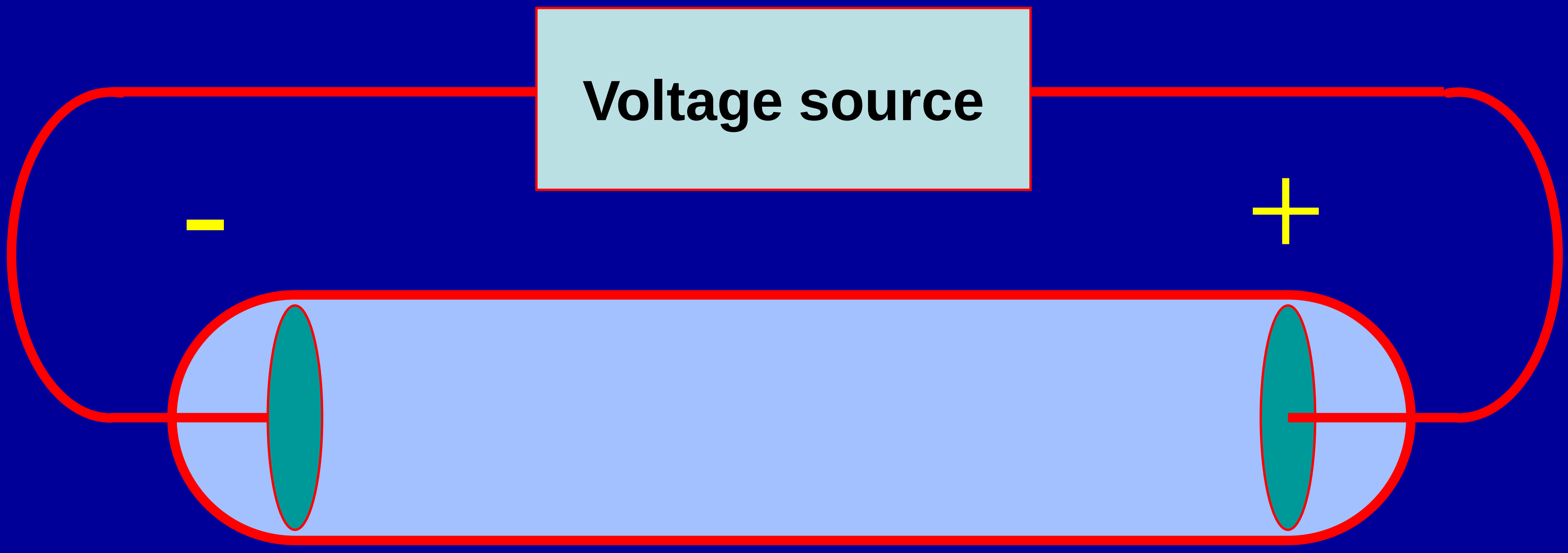
2.2 The Structure of the Atom

- **Atoms are the basic unit of an element that can enter into a chemical reaction**
- **By mid 1800's it became evident that atoms are divisible - there is an internal structure to the atom. (subatomic particles)**

Discovery of the electron

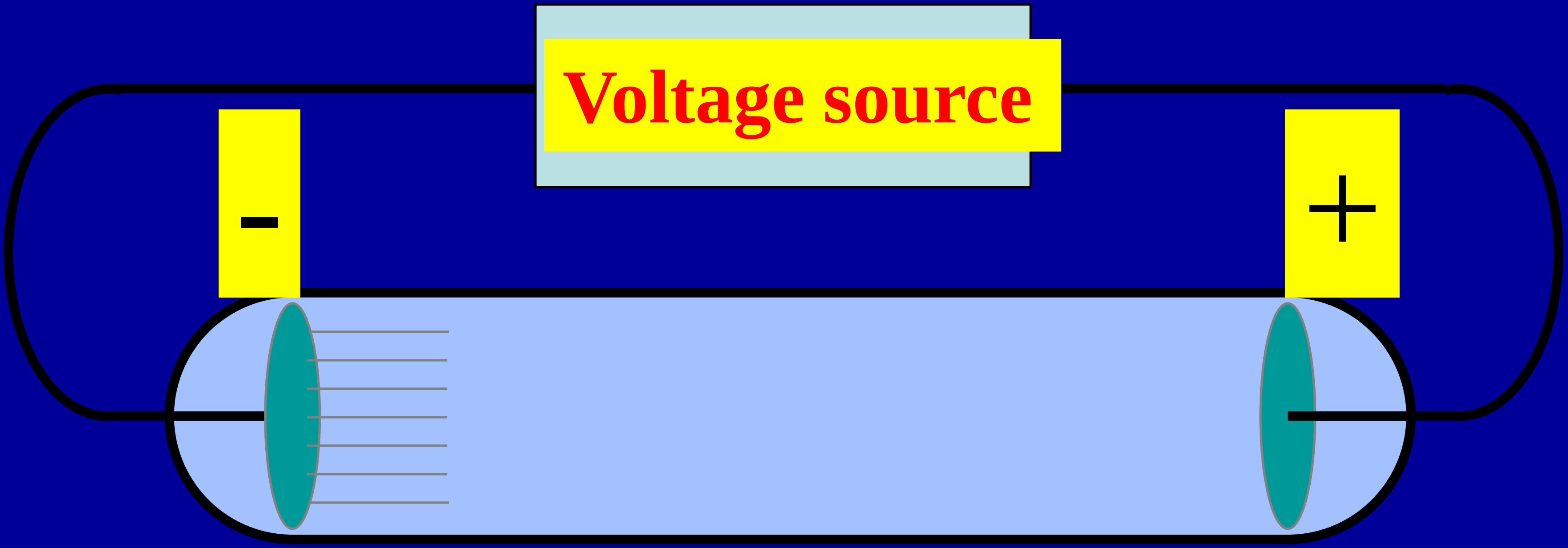
- **When high voltage is applied to a cathode ray tube a ray emanates from the cathode is called cathode ray.**
- **If the cathode rays are charged they should be deflected by an electric and magnetic fields.**

Thomson's Experiment

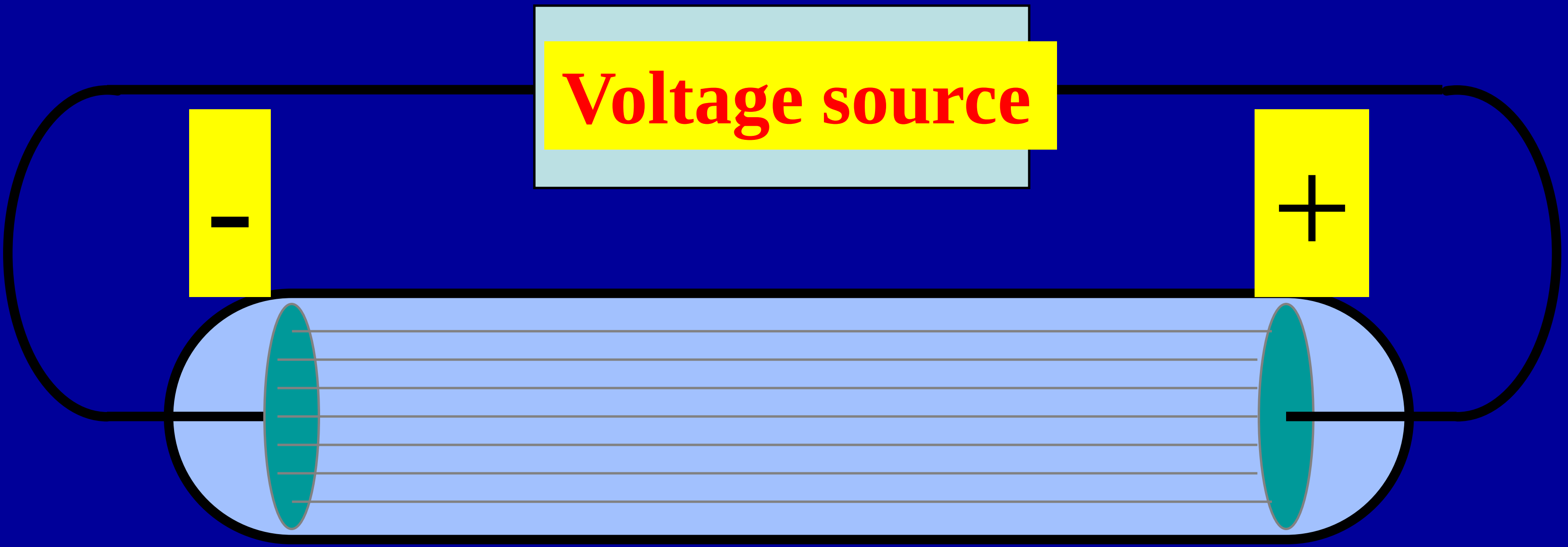


When high voltage is applied to the tube a ray emanates from the cathode is called cathode ray.

Thomson's Experiment

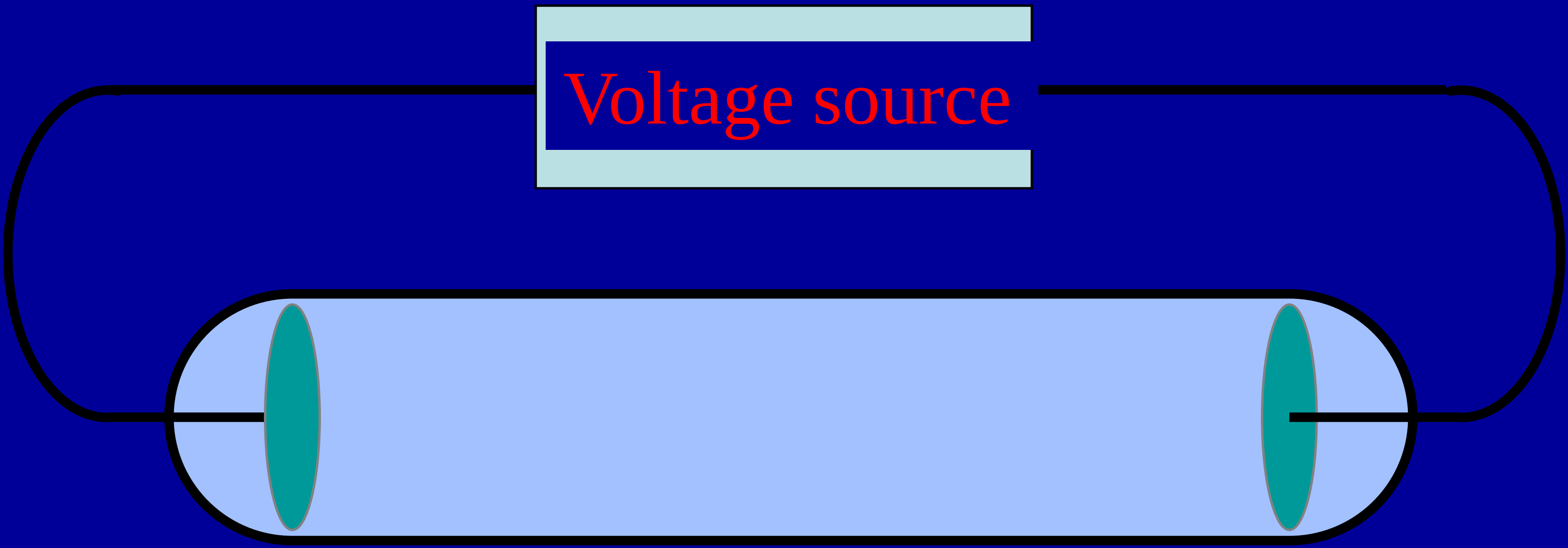


Thomson's Experiment



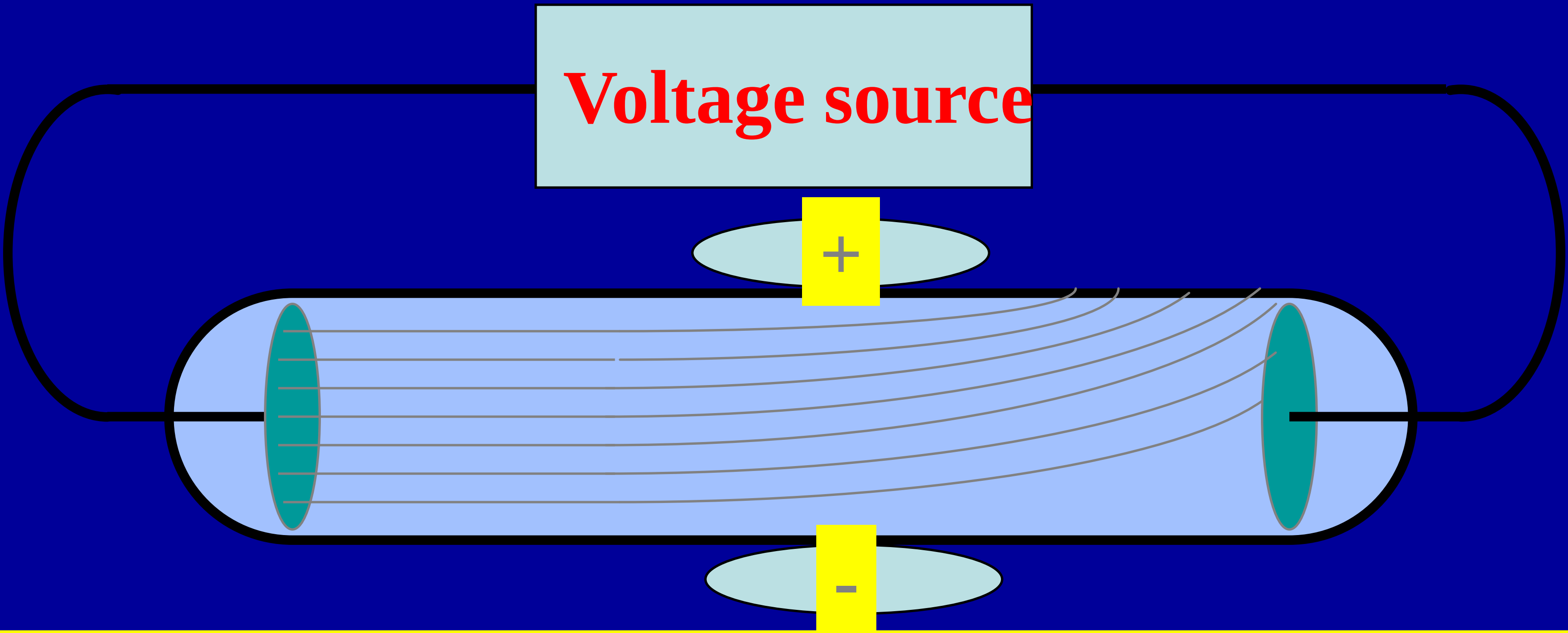
- **Passing an electric current makes a beam appear to move from the negative to the positive end.**

Thomson’s Experiment



- By adding an electric field

Thomson's Experiment

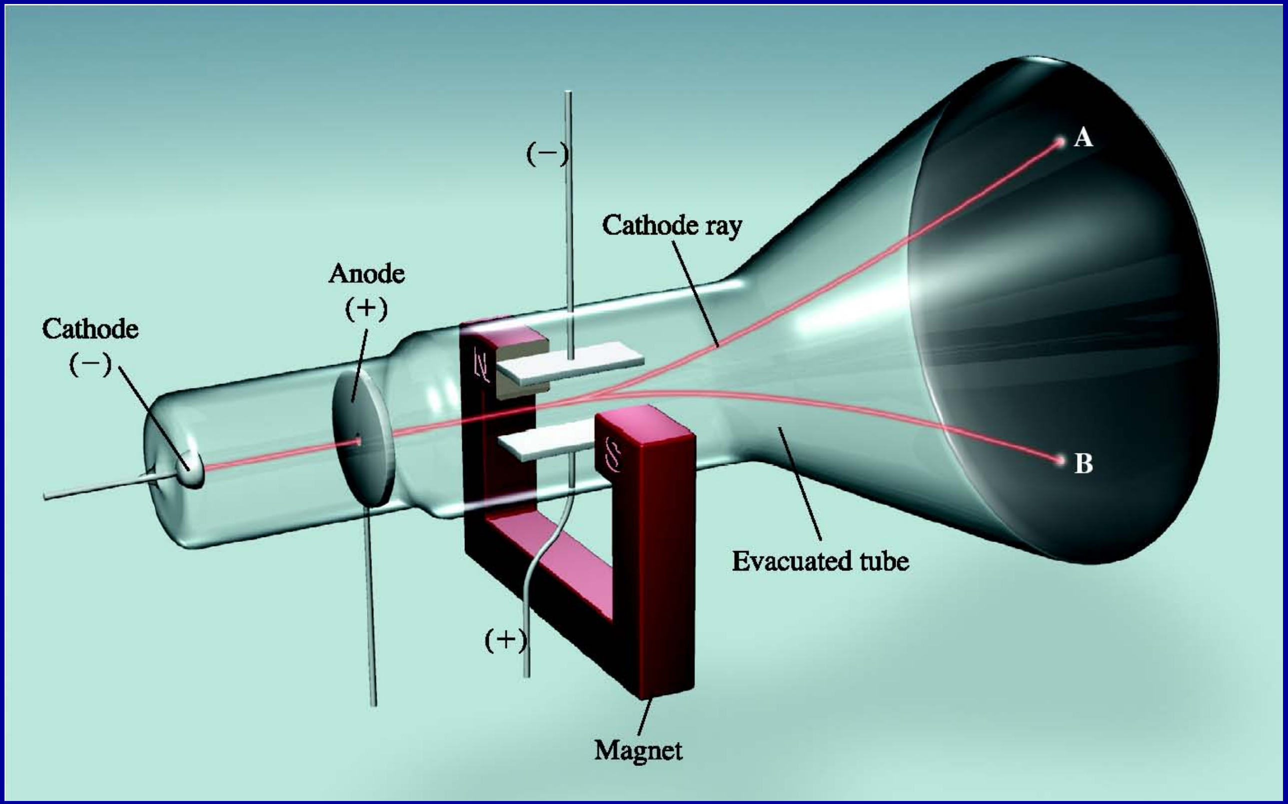


- By adding an electric field, he found that the moving particles were negatively charged

Effect of a Magnetic Field on a Cathode Ray

- J. J. Thomson - postulated the existence of electrons using cathode ray tubes.

Discovery of the electron

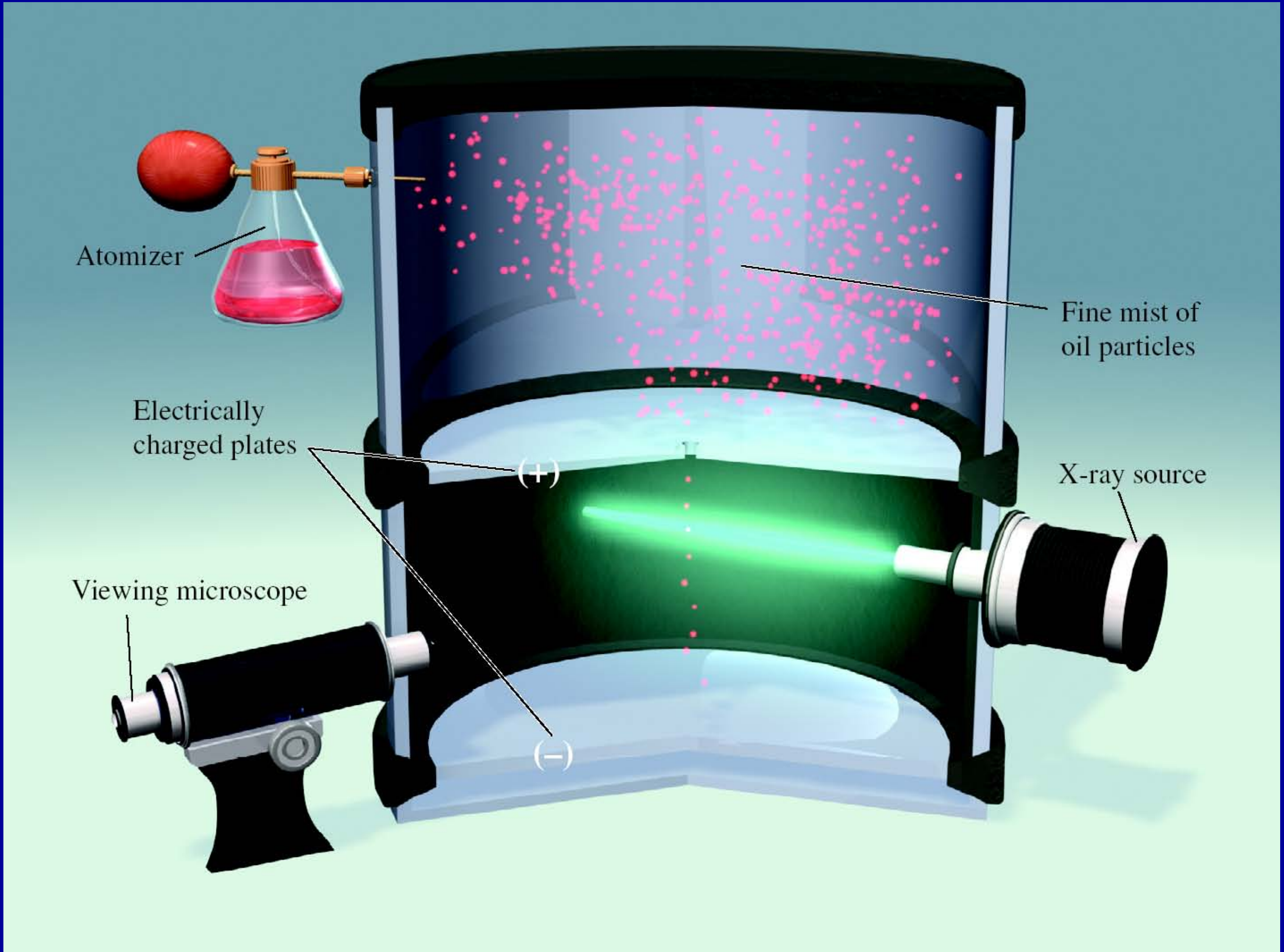


– J.J. Thomson
  - discovered the ratio of the electric charge to the mass of an individual electron using the cathode ray tube
  - (-1.76×10^{8} C/g); C = *coulomb*

Results of Thomson Experiment

- Electrons are produced from electrodes made from various types of metals, all atoms must contain electrons.
- Since atoms are electrically neutral, they must contain positively charged particles.

- **Millikan Experiment**
  - **Millikan determined the charge on an electron**
    - **-1.66022×10^{-19} C**



– The mass of the electron could be derived from

- Millikan's **charge**

  -1.66022×10^{-19} C

- Thomson's **charge to mass** ratio

  -1.76×10^{8} C/g

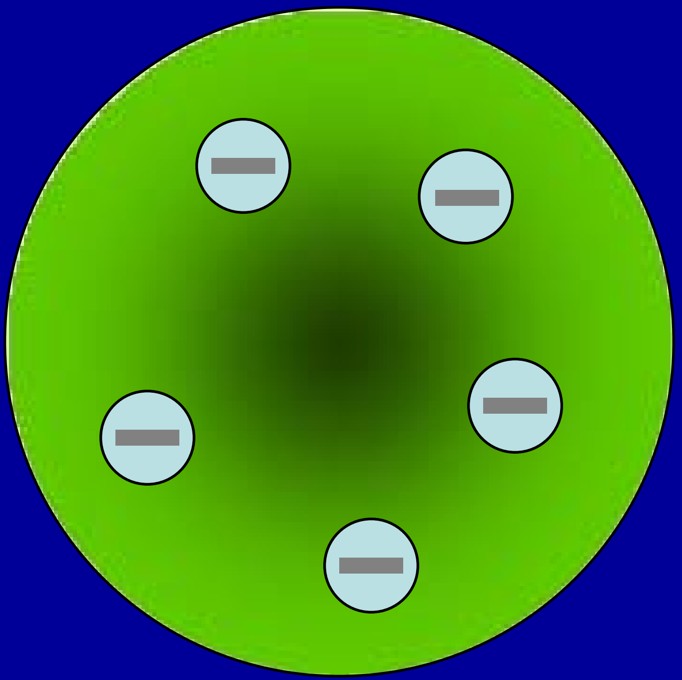
$$\text{mass of an electron} = \frac{\text{charge}}{\text{charge/mass}}$$

$$\frac{-1.6022 \times 10^{-19}\ \text{C}}{-1.76 \times 10^{8}\ \text{C/g}} = 9.10 \times 10^{-28}\ \text{g}$$

mass of electron

Thomson's Model

- Atom is consisted of a diffuse cloud of positive charge with negative electrons embedded randomly
- Atom was like **plum pudding.**
- Thomson believed that the electrons were like plums embedded in a positively charged "pudding," thus it was called the "plum pudding" model.

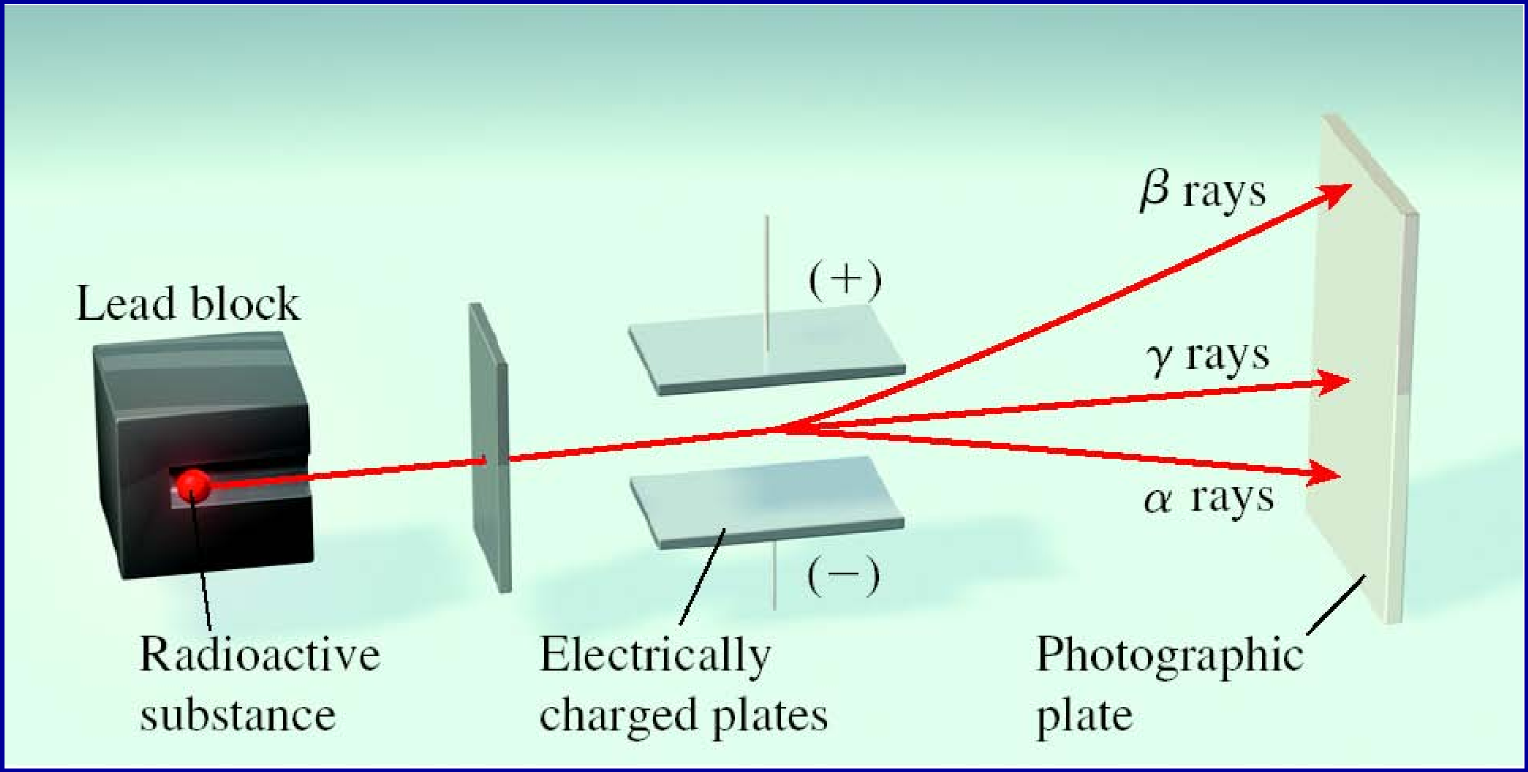


Radioactivity – historical prespective

- 1895 -Wilhelm Röentgen - German physicist
  - Noticed that cathode rays caused glass and metal to emit another type of ray
  - He named the rays “X rays” because of their mysterious nature
    - Caused fluorescence
    - Were not deflected by a magnet

- **Antoine Becquerel** - French physicist
  - Accidentally discovered that uranium darkened photographic film
- **Marie Curie** (a student of Becquerel) suggested name "radioactivity"
  - Rays were highly energetic and not deflected by a magnet
  - However, rays arose spontaneously unlike the rays discovered by Röentgen

- Radioactive material, a substance that **spontaneously** emits radiation
- Type of radioactivity
  - Alpha (α) - positively charged particles
  - Beta (β) - electrons
  - Gamma (γ) - no charge and are unaffected by external electric or magnetic fields.



Radiations produced from radioactivity

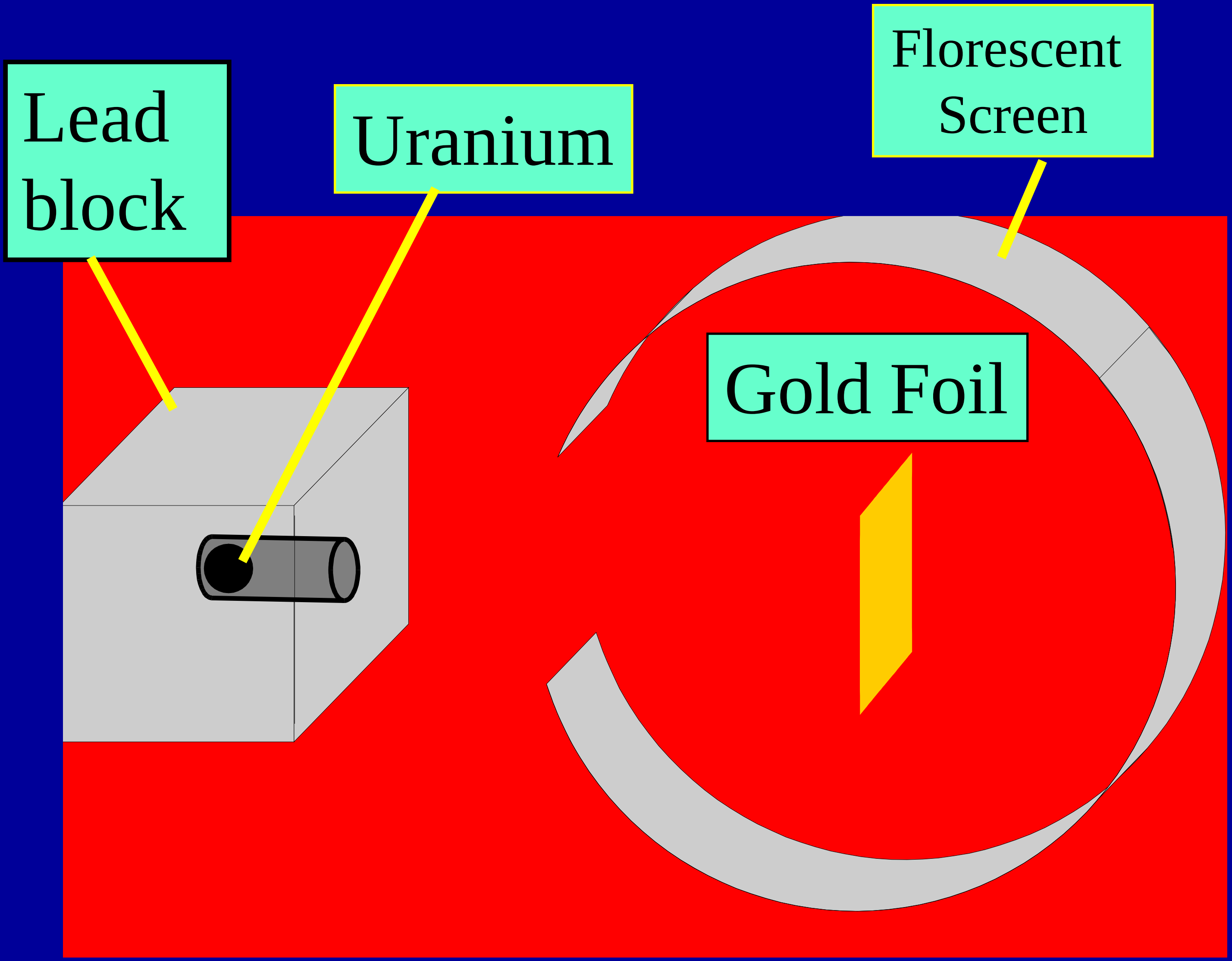
- Three types of radiation were known:
  - alpha- helium nucleus (+2 charge, 7300 times that of the electron)
  - beta- high speed electron
  - gamma- high energy light

The Nuclear Atom

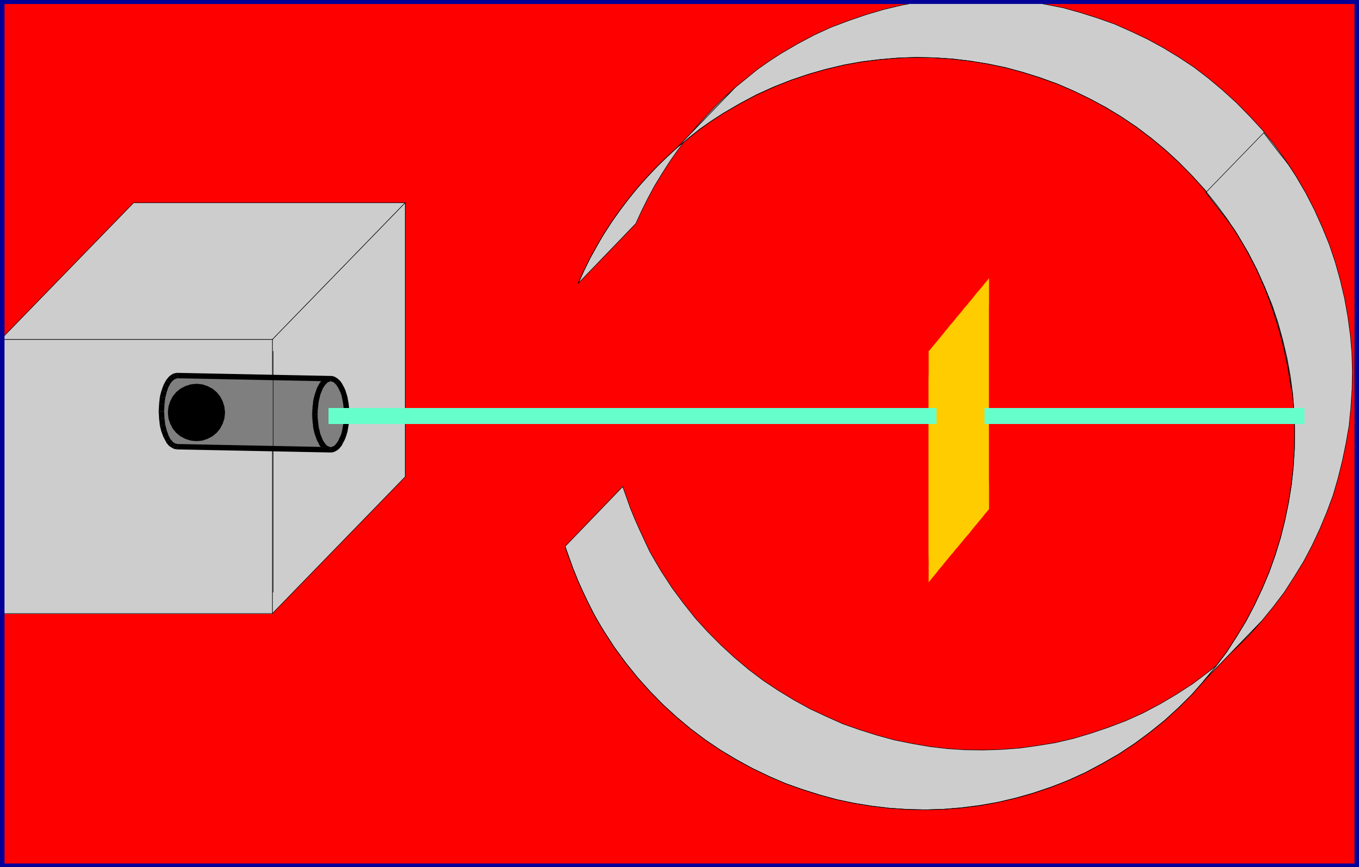
- **1900's - atoms consisted of positively charged matter with electrons scattered throughout (plum-pudding model by Thomson)**
- **1910 - Rutherford performed "gold-foil" experiment.**
  - **Proposed a new model of the atom**
  - **Nucleus contained**
    - **Positive charges (later called protons)**
    - **Most of the mass of the atom**

The nuclear atom
Rutherford's Experiment

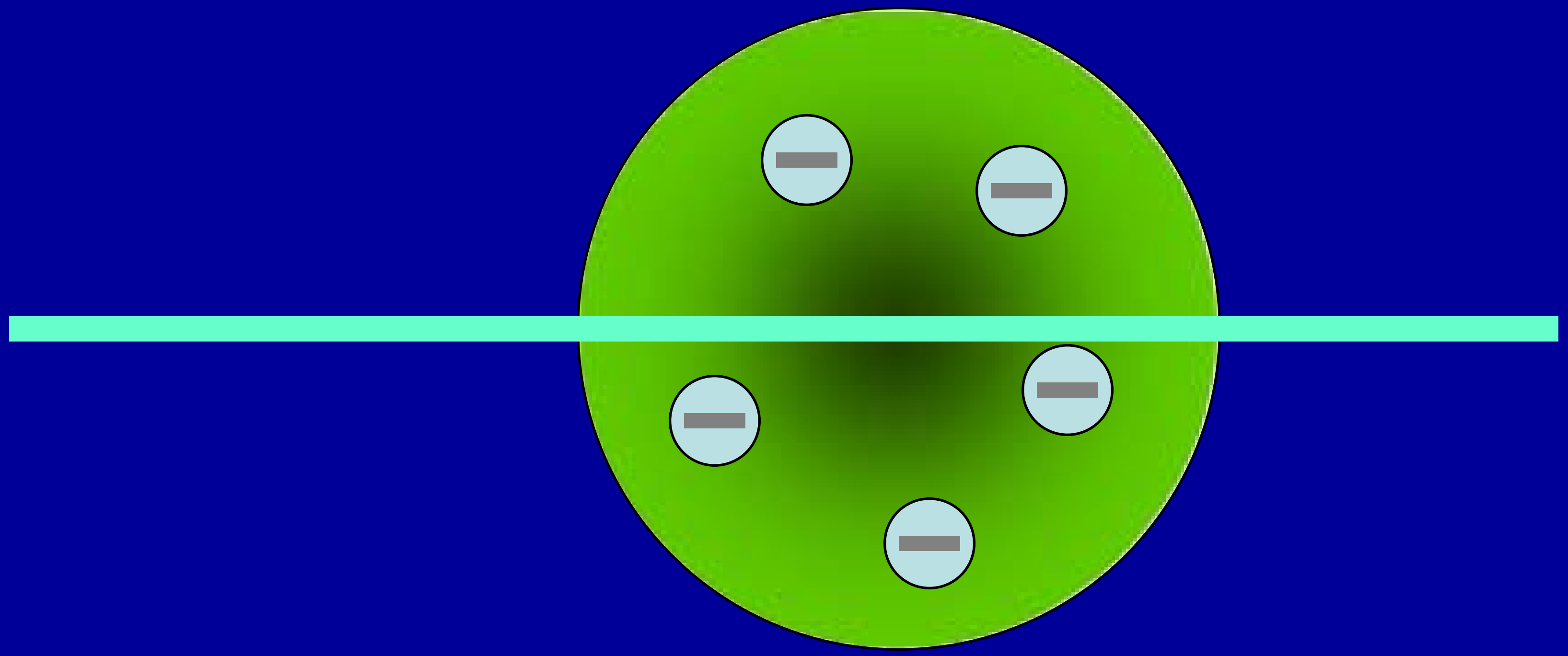
- Aimed at testing Thomson's plum pudding model
- Used uranium to produce alpha particles.
- Alpha particles are directed at gold foil through hole in lead block.
- Since the mass is evenly distributed in gold atoms alpha particles should go straight through.
-


Lead block
Uranium
Florescent Screen
Gold Foil

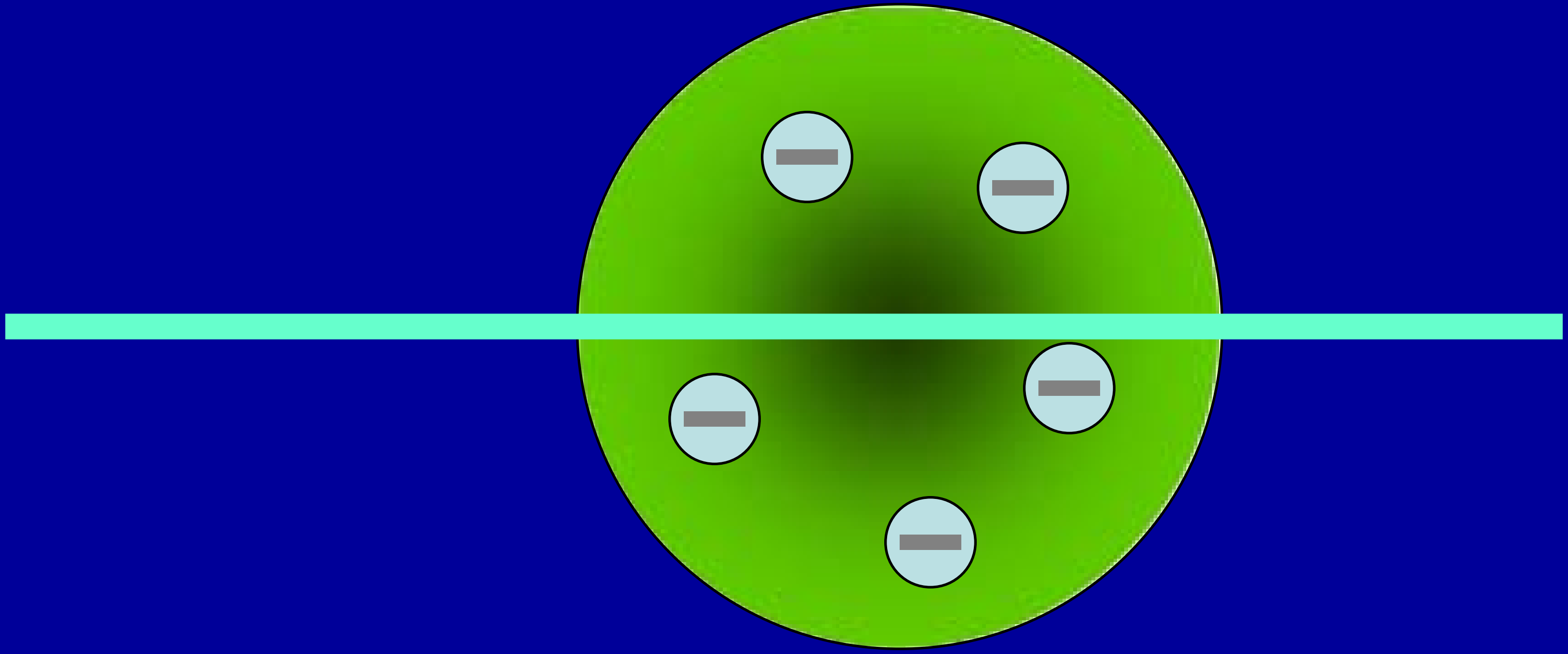
What he expected



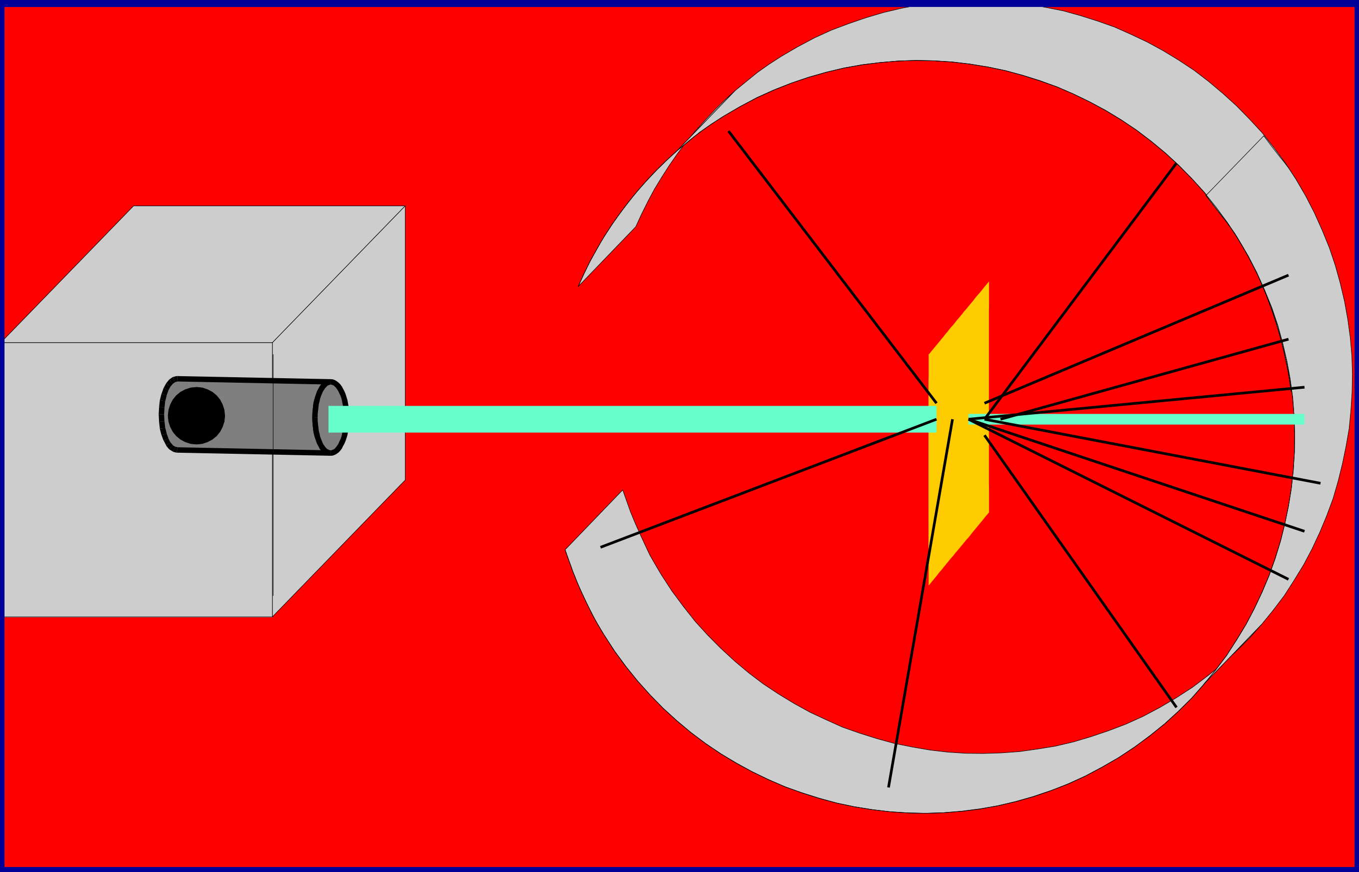
Because



Because, he thought the mass was evenly distributed in the atom.

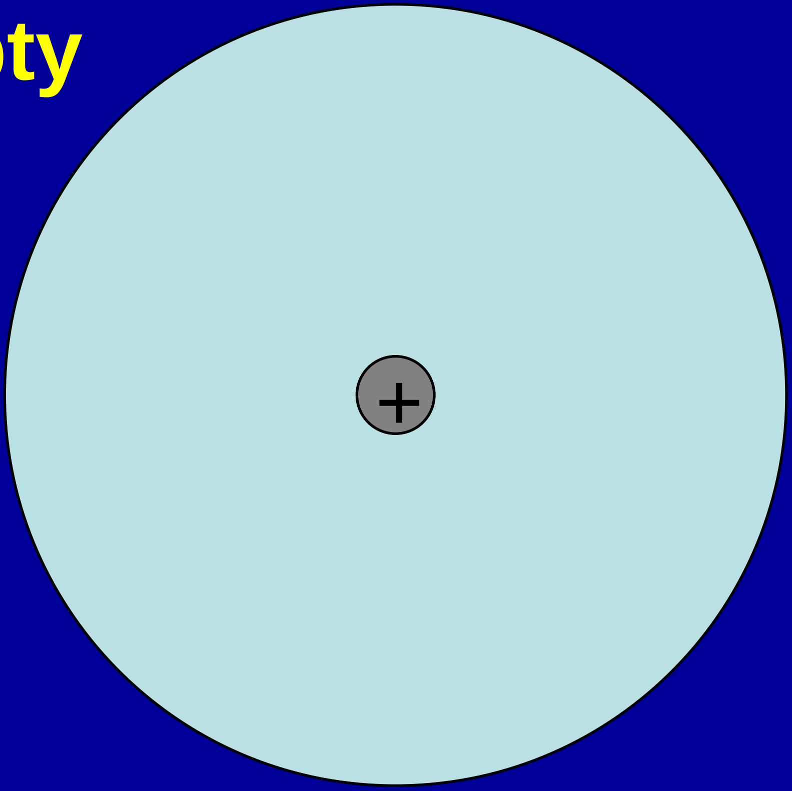


What he got

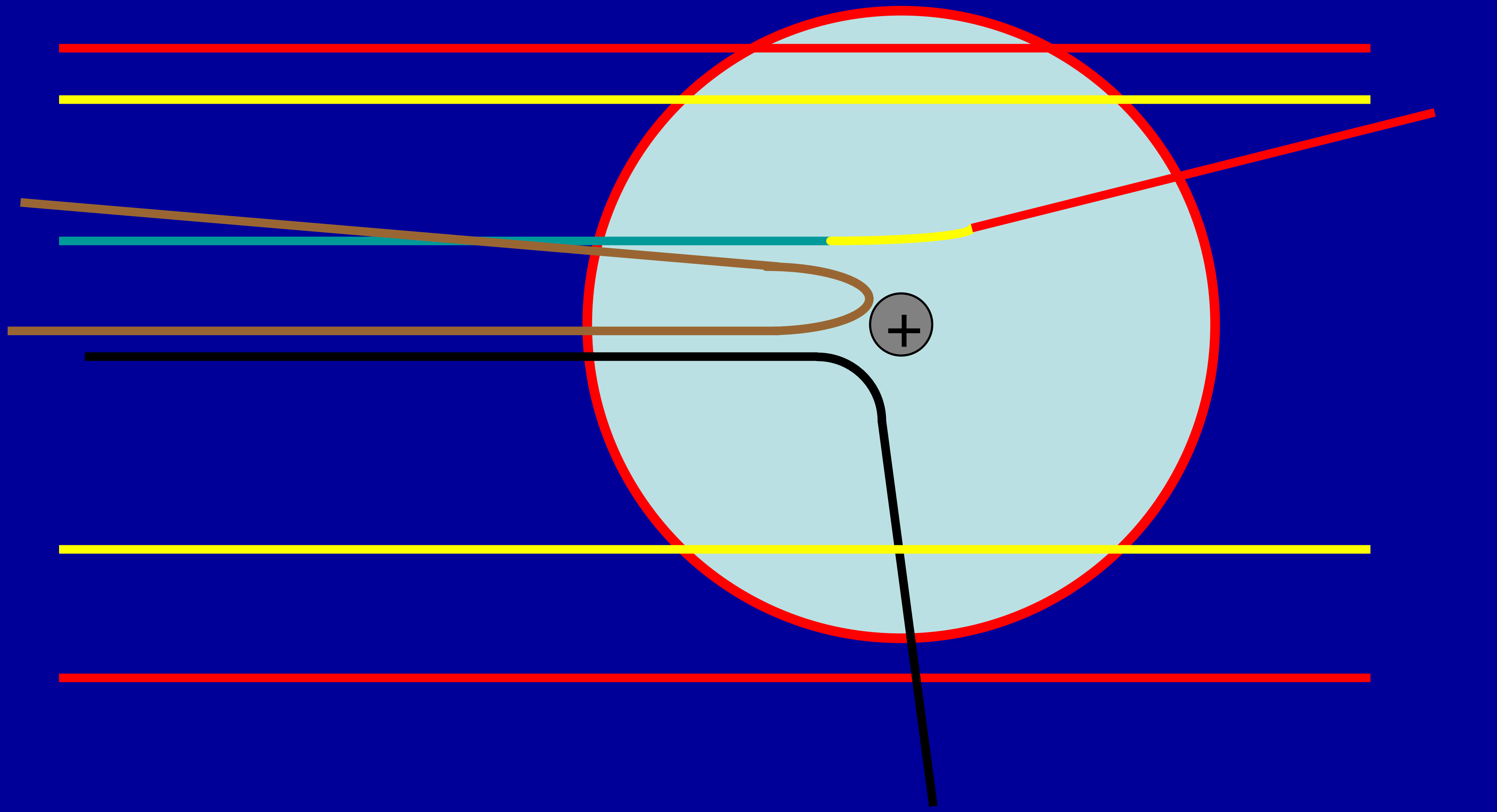


How he explained it

- Atom is mostly empty
- Small dense, positive particle at center.
- Alpha particles are deflected by it if they get close enough.



Proof for nuclear atom



Nuclear atom model

- **According to Rutherford:**

The atom consists of a dense center of positive charge (Nucleus) with electrons moving around it at distance that is large relative to the nuclear radius

- **Rutherford's model left one problem:**
  - **If H has a mass of 1**
  - **Then He should have a mass of 2**
  - **But its mass is 4!**
- **1932 - James Chadwick**
  - **Discovered the neutron**
    - **Third subatomic particle**
    - **Neutral charge**

Mass and charge of nuclear particles

Particle	Mass (Kg)	Charge
Electron	$9.11X10^{-31}$	-1
Proton	$1.67X10^{-27}$	+1
Neutron	$1.67X10^{-27}$	None

2.3 Atomic Number, Mass Number and Isotopes

- **The chemical identity of an atom can be determined solely from its atomic number**
- ***Atomic number (Z)*** **- number of protons in the nucleus of each atom of an element**
  - **Also indicates number of *electrons* in the atom—since atoms are *neutral***

- ***Mass number (A)*** **- total number of neutrons *and* protons present in the nucleus**

mass number (A) = number of protons (Z) + number of neutrons

- **Standard notation:**

Mass number
(number of protons + neutrons)

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

Element symbol

Atomic number
(number of protons)

- **Isotopes**
  - **All atoms are *not* identical**

    (as had been proposed by Dalton)
  - **Atoms of the same element have same atomic number (*Z*) but different mass numbers (*A*)**
- **Isotopes of Hydrogen**
  - **Hydrogen (protium)** $^{1}_{1}\mathrm{H}$
  - **Deuterium** $^{2}_{1}\mathrm{H}$
  - **Tritium** $^{3}_{1}\mathrm{H}$

Symbols

Mass number → A

Atomic number → Z

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

$$^{23}_{11}Na$$

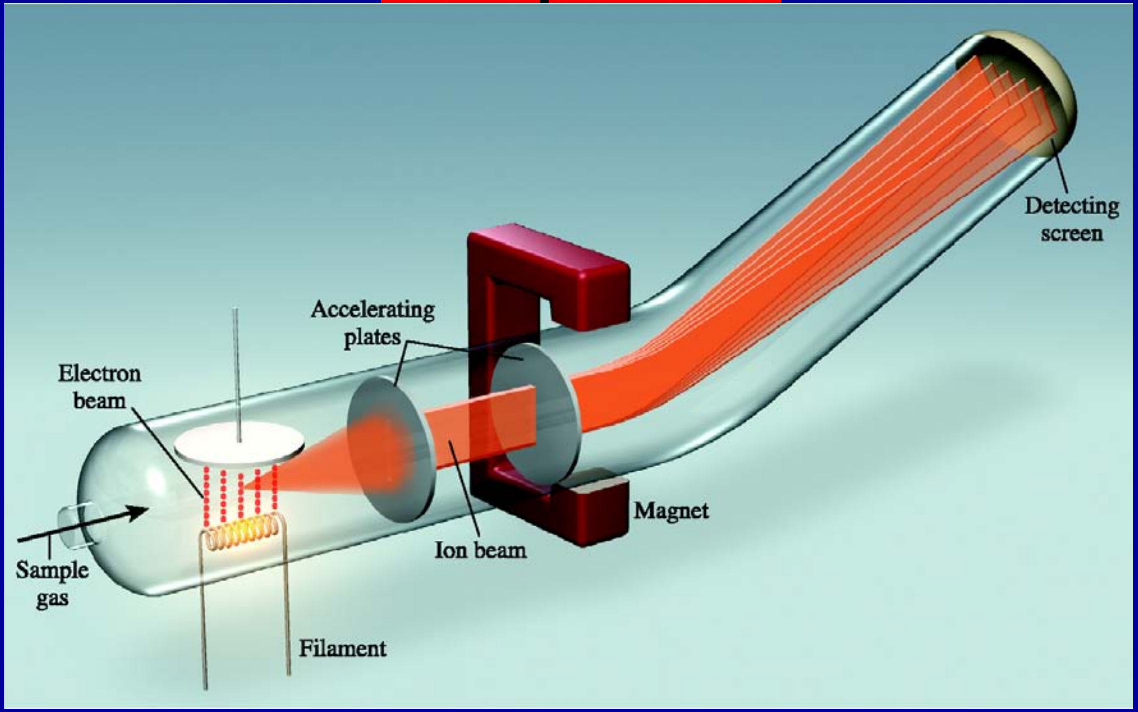
Na-23

More Atomic Symbols

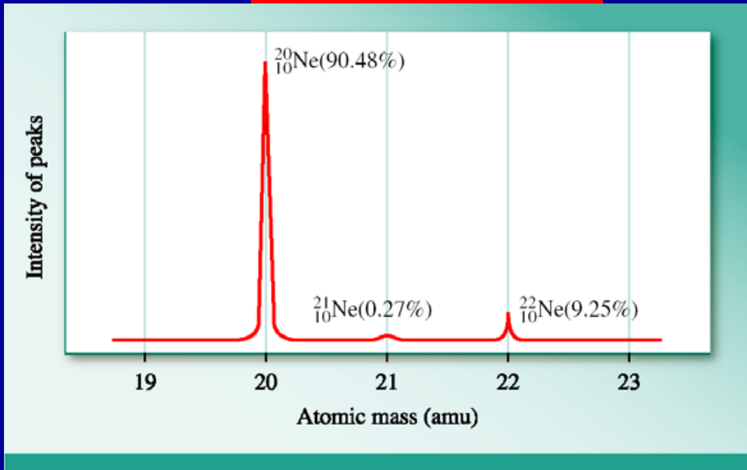
$^{65}_{30}Zn$	$^{31}_{15}P$	$^{16}_{8}O$
30 p^+	15 p^+	8 p^+
35 n	16 n	8 n
30 e^-	15 e^-	8 e^-

Mass Spectrometery

Sample In



Data Out



2.4 The Periodic Table

- Periods - horizontal rows
- Families (Groups) - vertical columns
  - Elements in the same family have similar chemical and physical properties
- Arranged in order of increasing atomic number

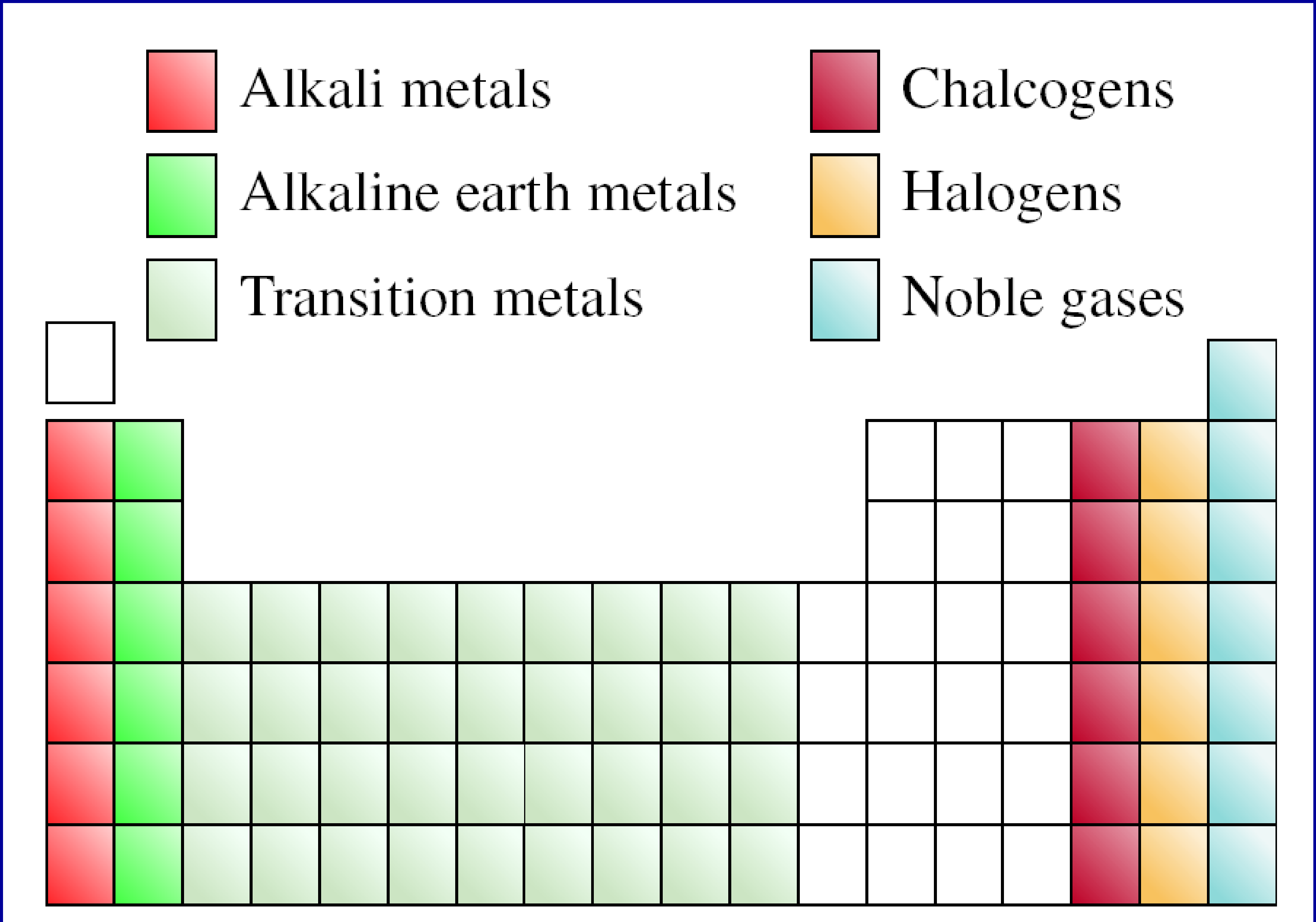
The Modern Periodic Table

1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	71 Lu Lutetium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 — -	113 — -	114 — -	115 — -	116 — -	117	118 — -

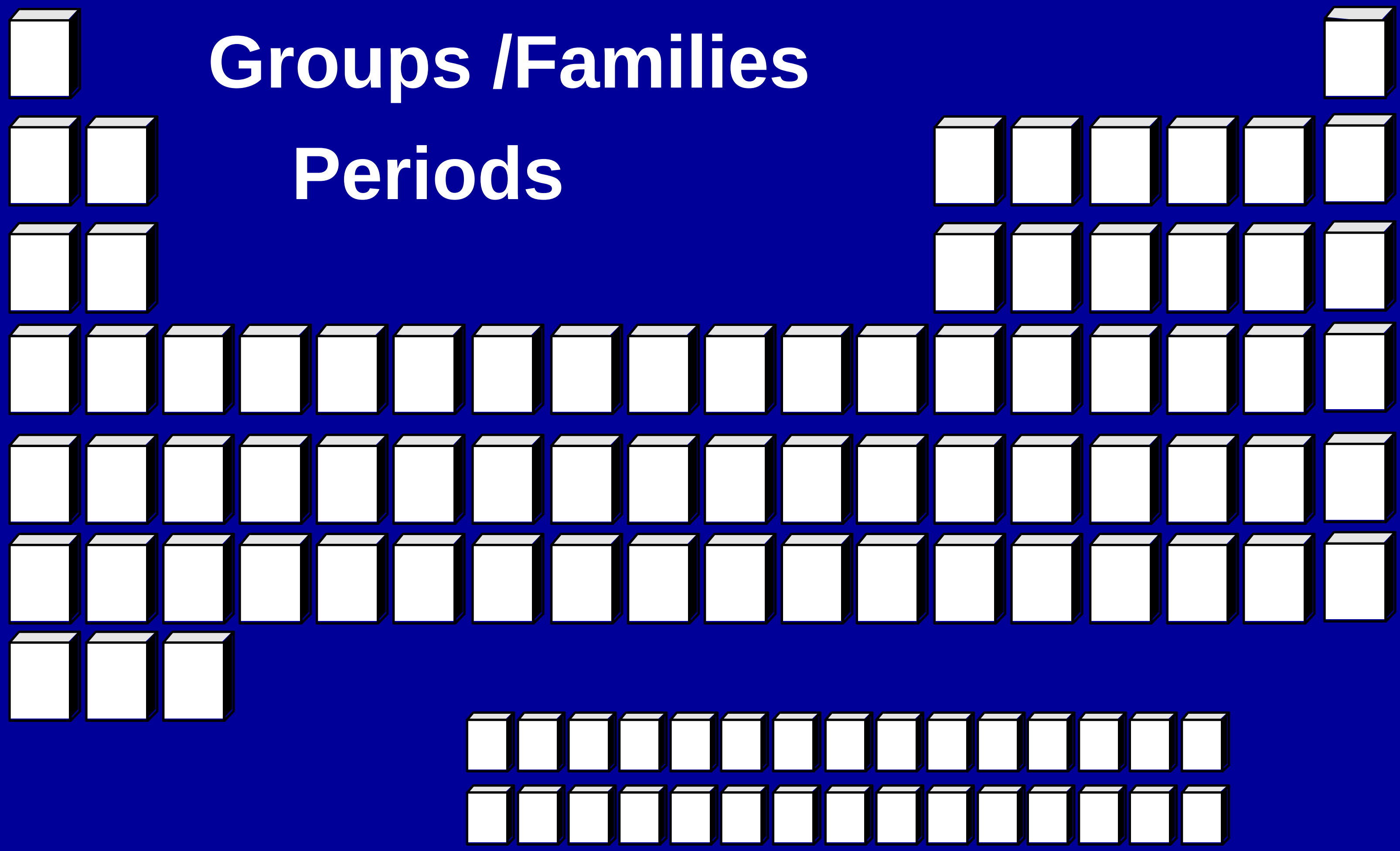
57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium
89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium

- **Metals** - good conductors of heat and electricity (majority of elements on the table, located to the left of the stair step)
- **Nonmetals** - nonconductors (located in upper right-hand corner)
- **Metalloids** - in between metals and nonmetals (those that lie along the separation line)

Groups (Families) on the Periodic Table

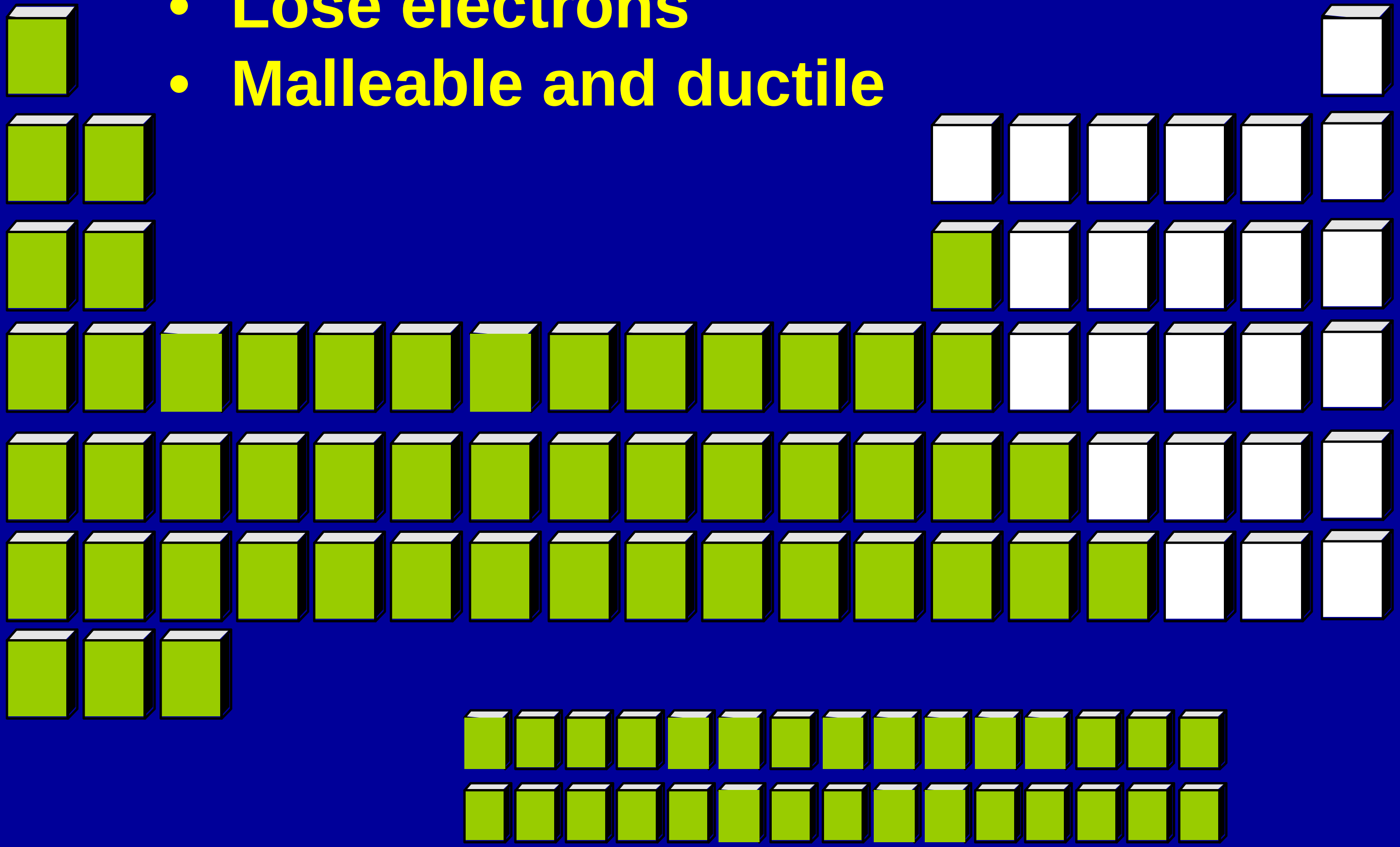


Periodic Table



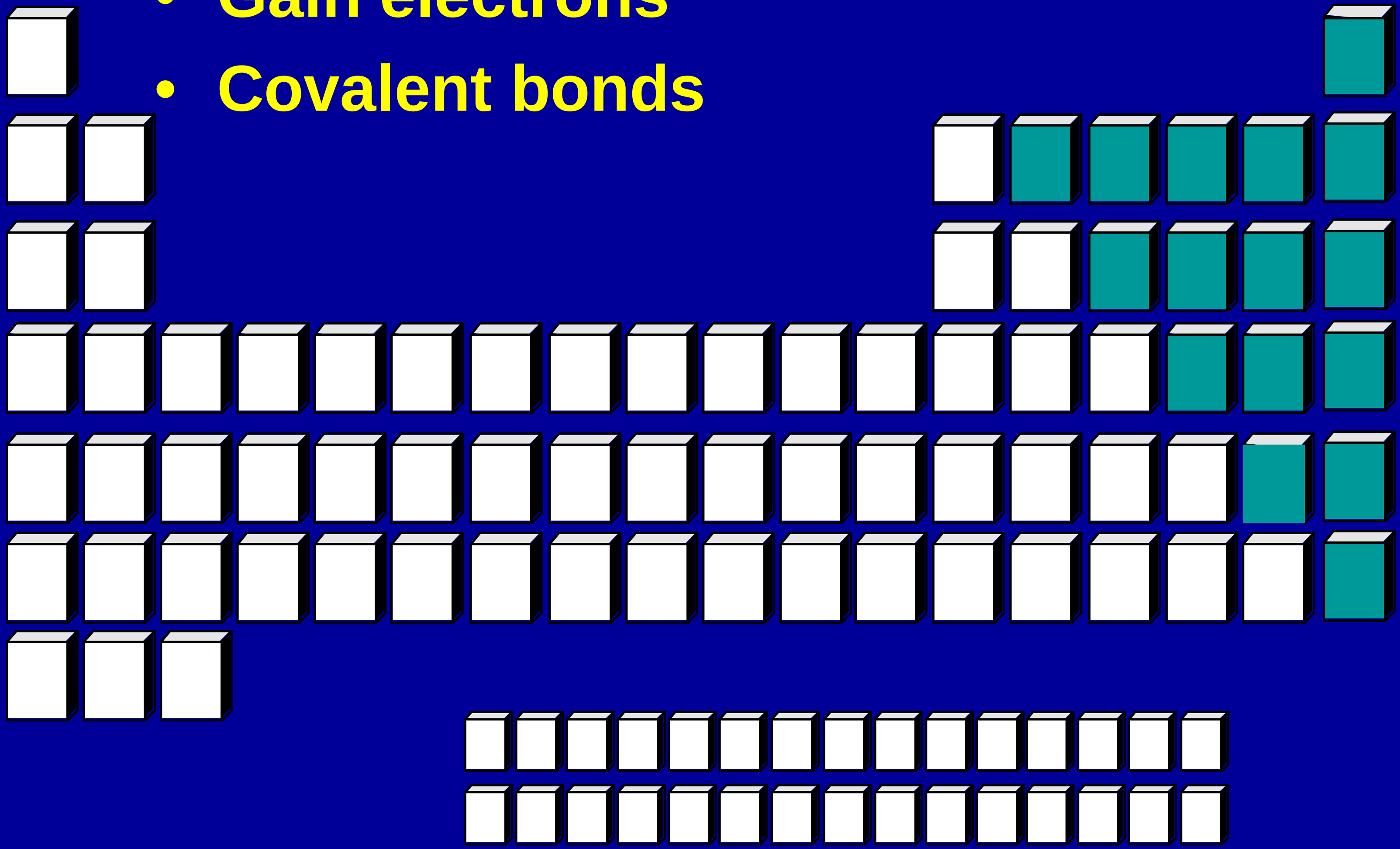
Metals

- Conductors
- Lose electrons
- Malleable and ductile

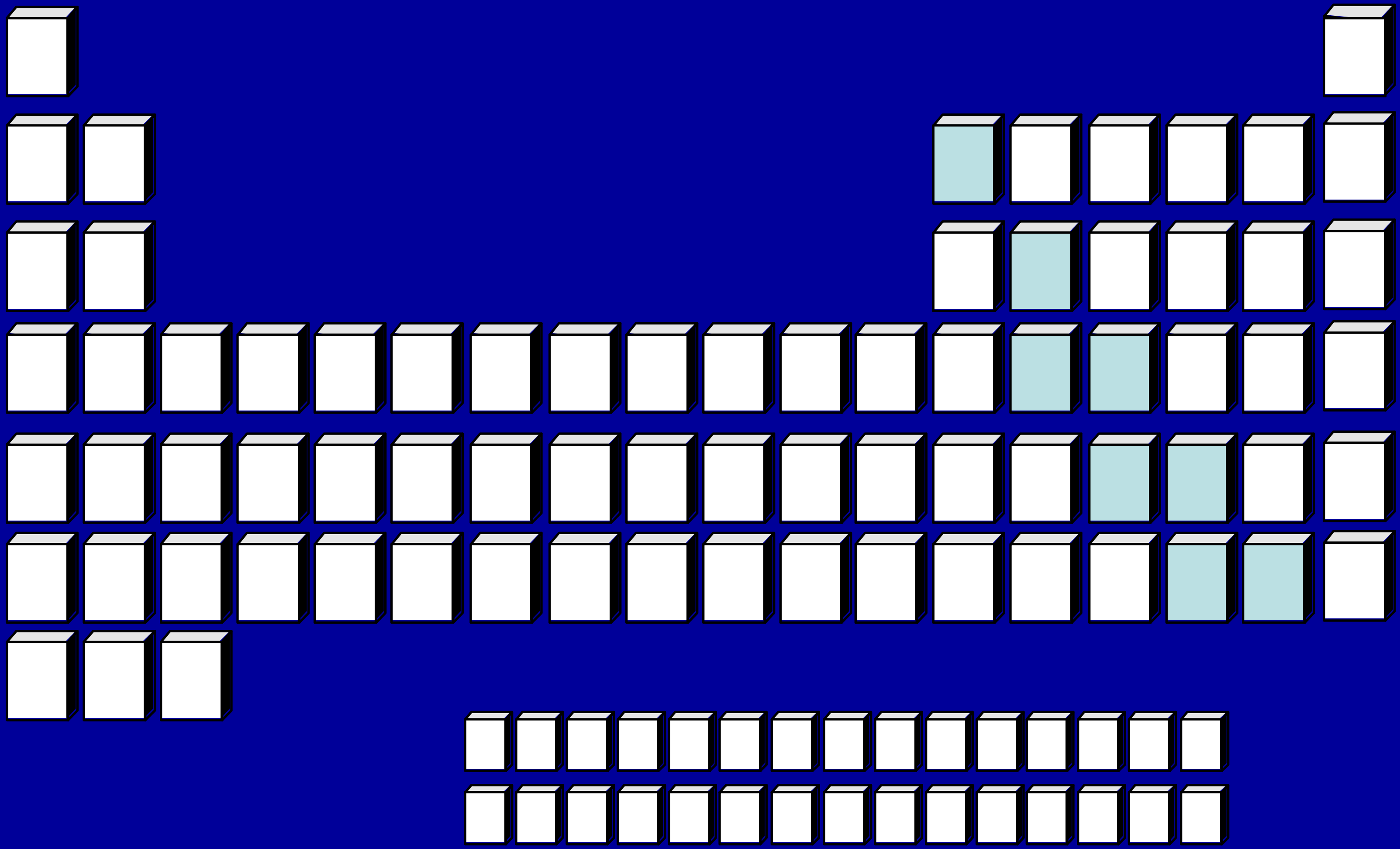


Nonmetals

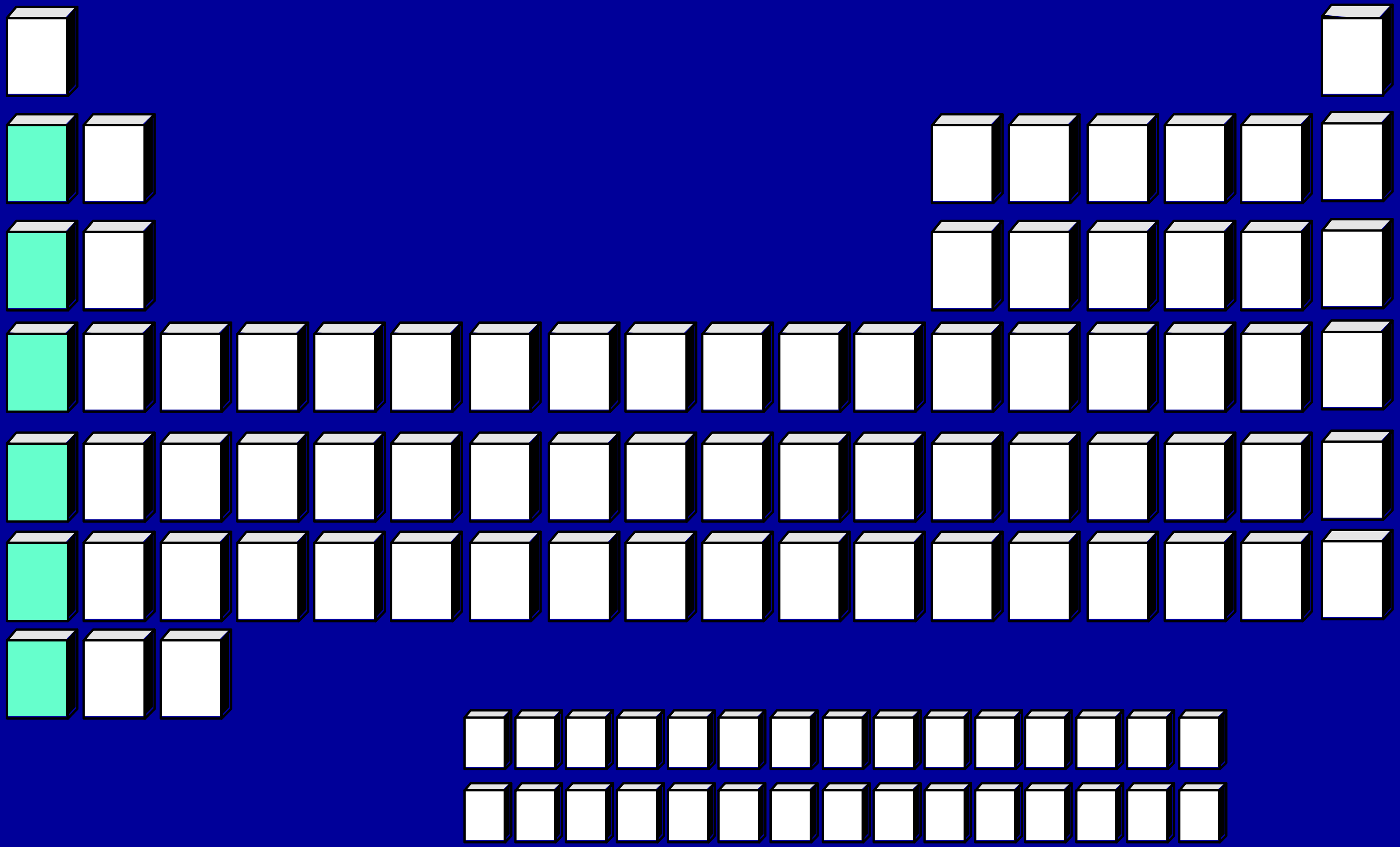
- **Brittle**
- **Gain electrons**
- **Covalent bonds**



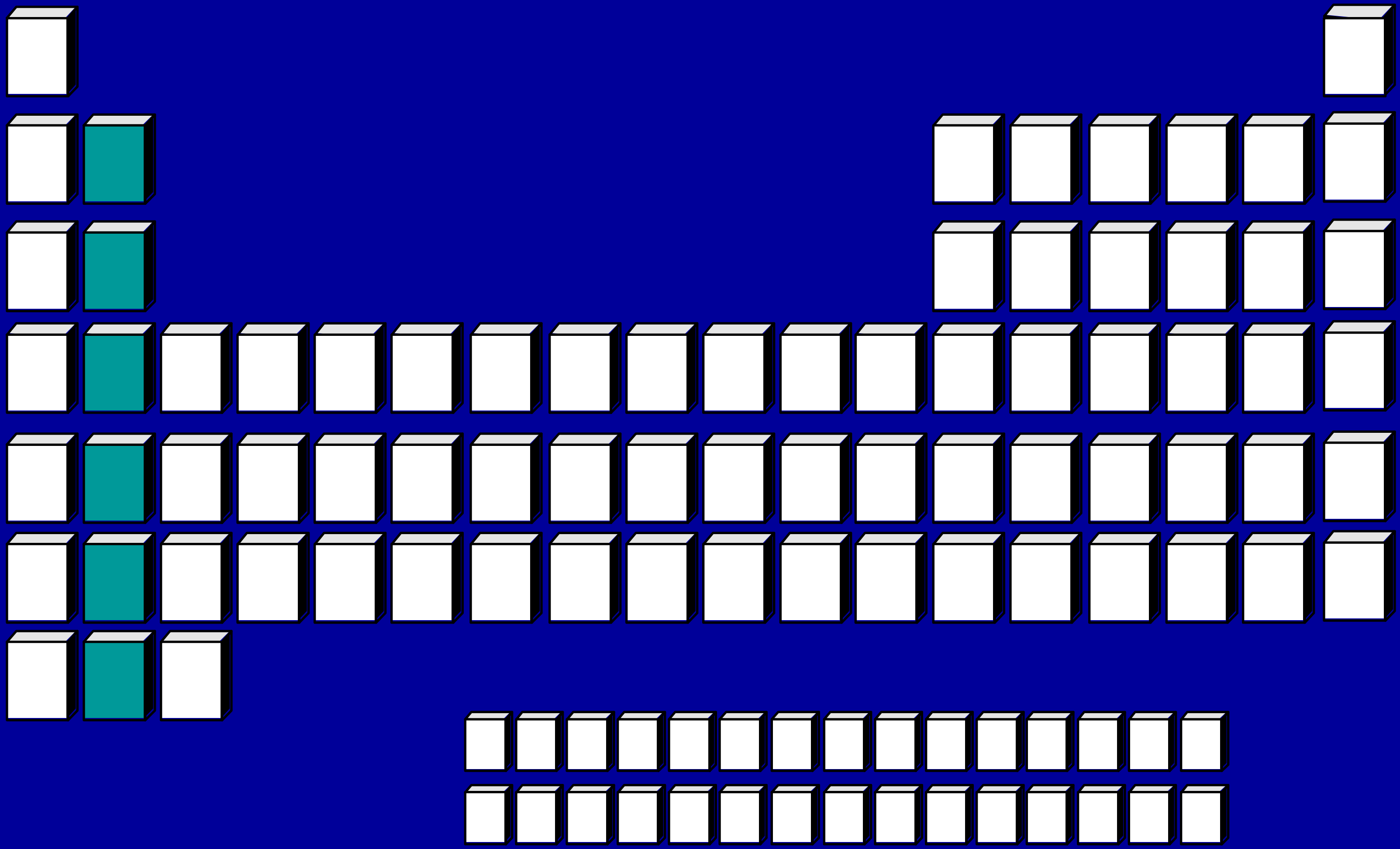
Semi-metals or Metalloids



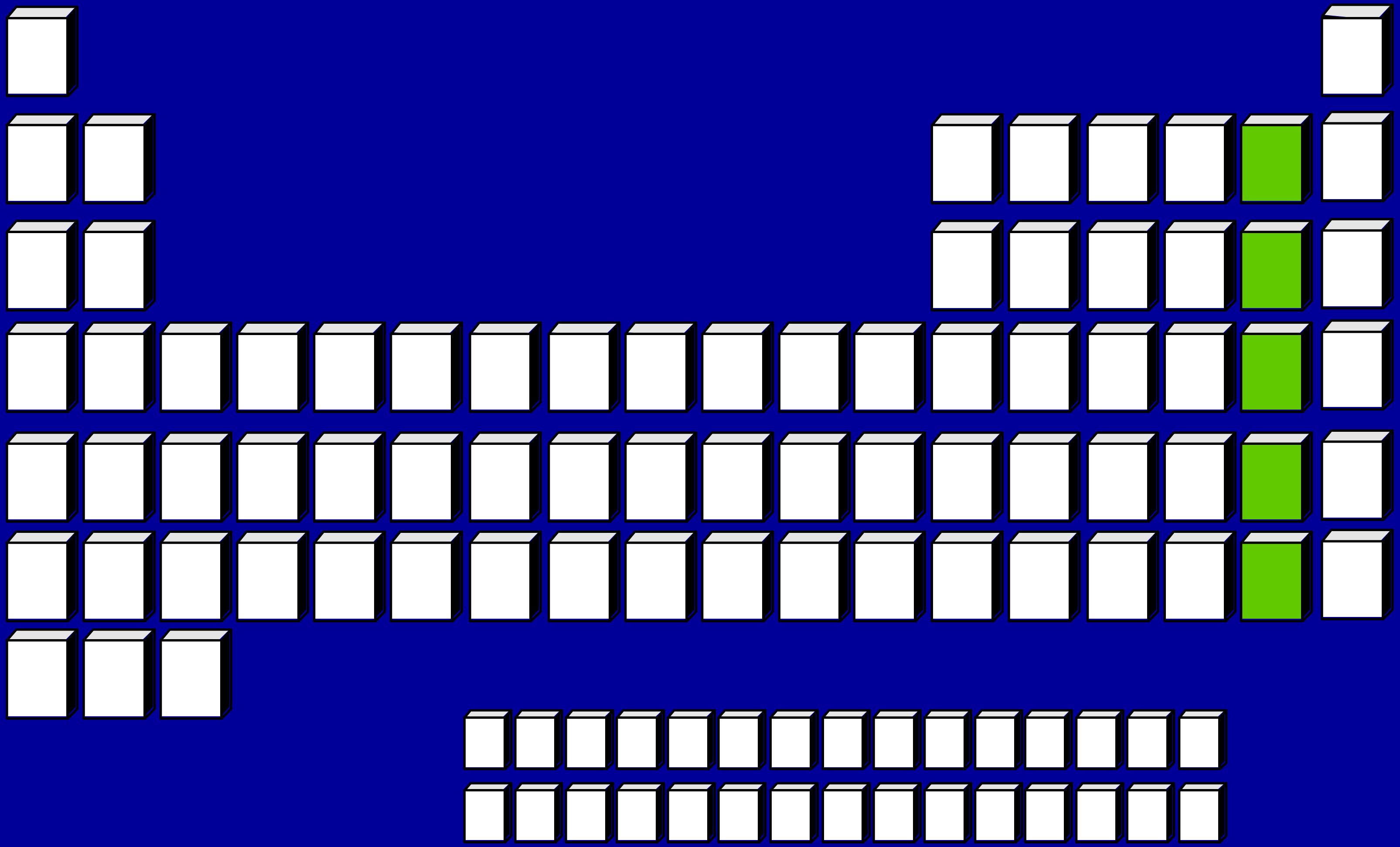
Alkali Metals



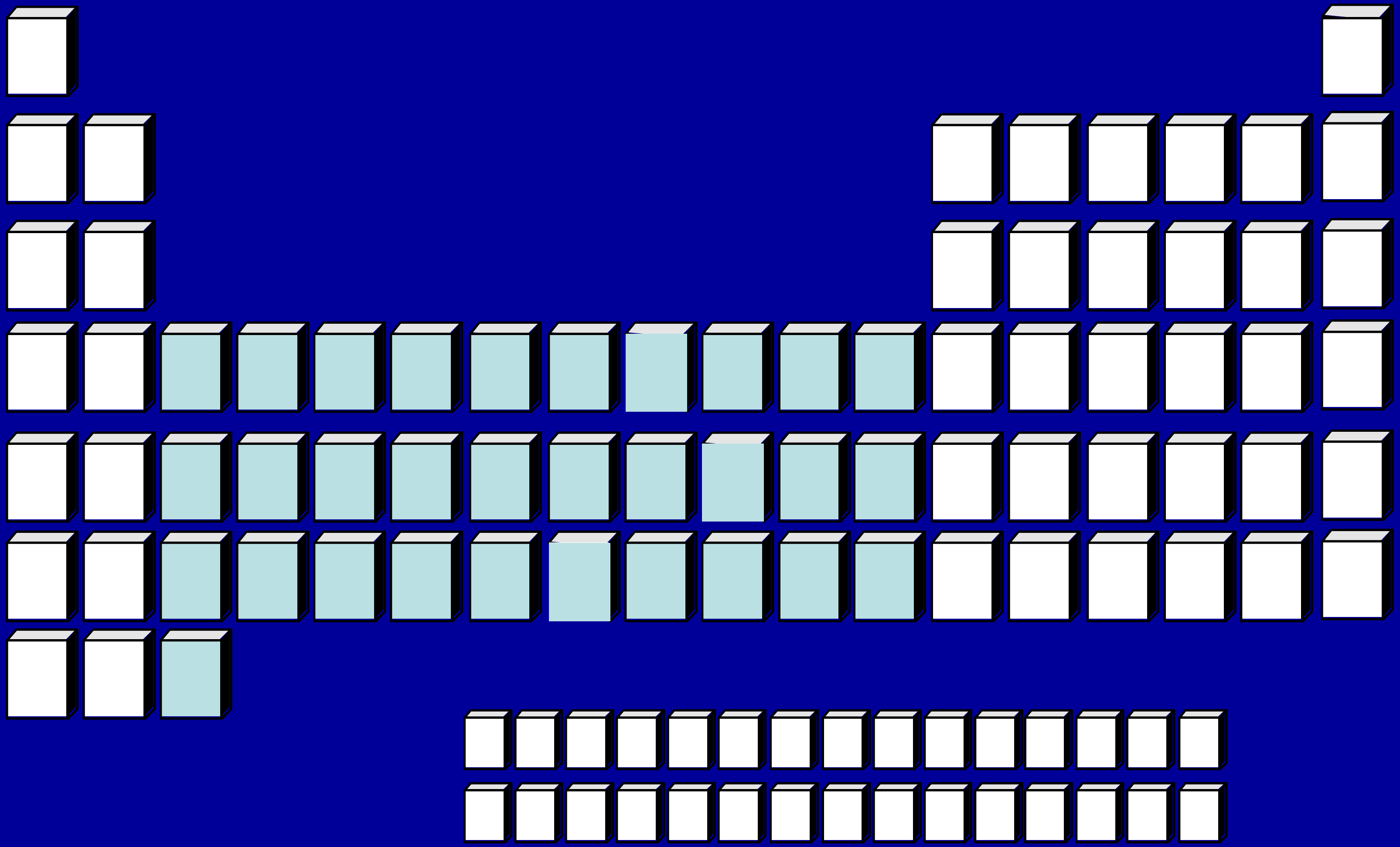
Alkaline Earth Metals



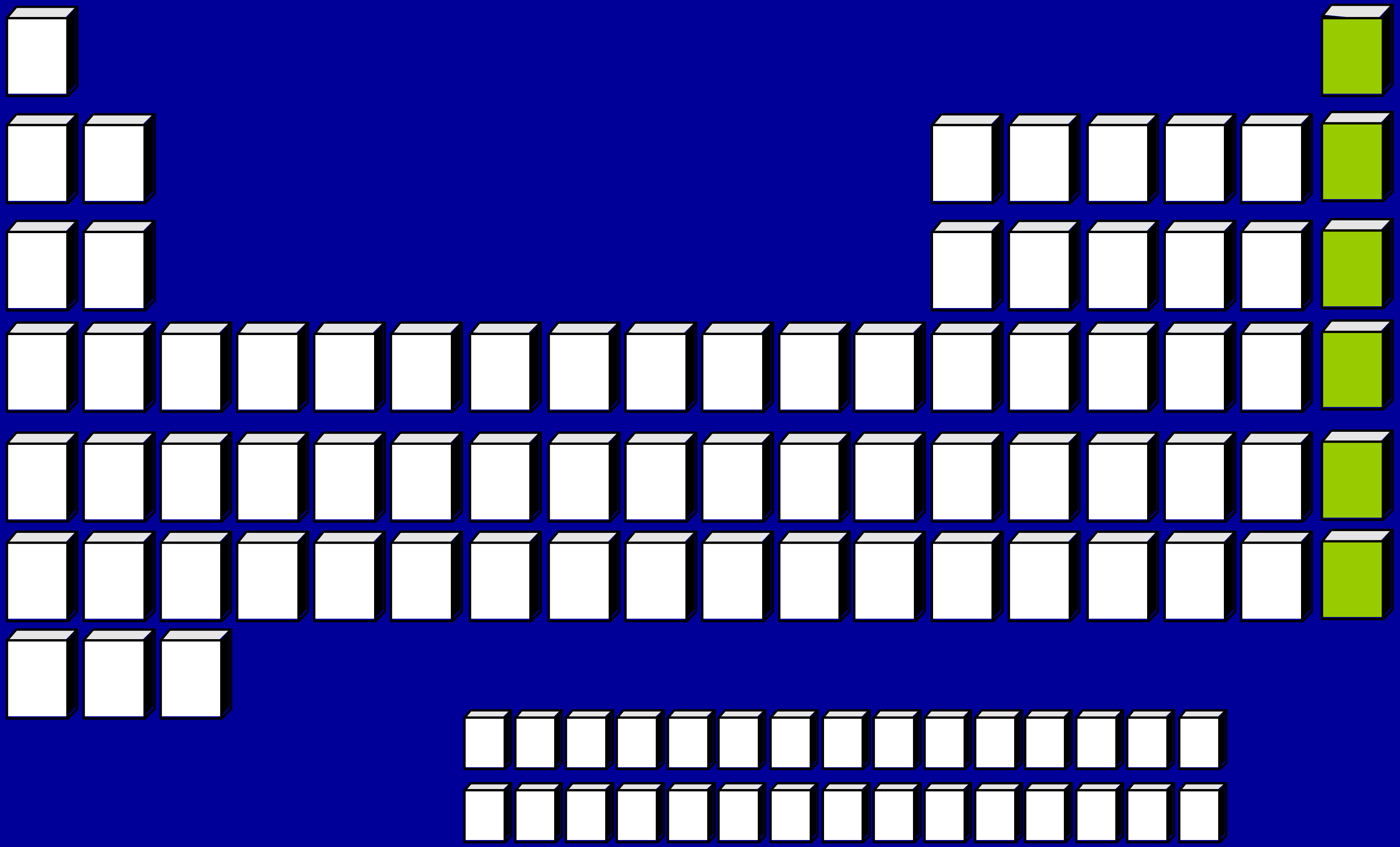
Halogens



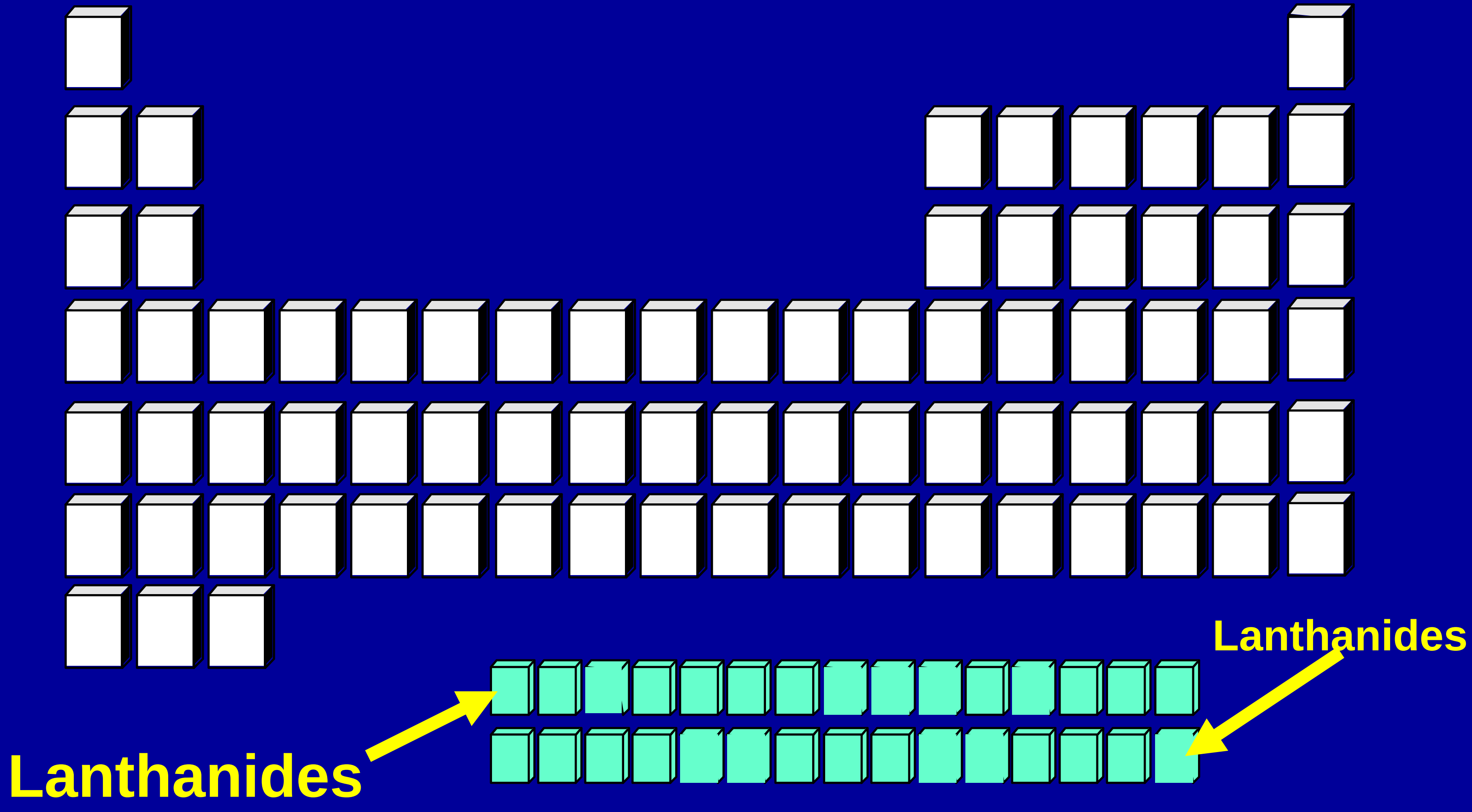
Transition metals



Noble Gases



Inner Transition Metals



Select an element

(🔗 = Internet link)

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 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									

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

1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
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	71 Lu	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	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112		114		116		

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
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

Metals

Metalloids

Nonmetals

2.5 The Atomic Mass Scale and Average atomic Mass

- ***Atomic mass*** **is the mass of the atom in atomic mass units (amu)**
- ***Atomic mass unit*** **is defined as a mass exactly equal to one-twelfth the mass of one carbon-12 atom**
- **Carbon-12 (12 amu) provides the standard for measuring the atomic mass of the other elements**

- **Average atomic mass**
  - **Masses on the periodic table are not whole numbers.**
  - **Mass spectrometer provides information about percentages of different isotopes of each element.**
  - **Periodic table mass is the weighted average of all of the isotopes of each element**

- Oxygen is the most abundant element both in the Earth's crust and in the human body

- atomic masses of its three stable isotopes, ^{16}O (99.757%), ^{17}O (0.038%), and ^{18}O (0.205%), are 15.9949 amu, 16.9999 amu, and 17.9999amu, respectively. Calculate the average atomic mass of oxygen using the relative abundances given in parentheses.

Steps:

1. **Convert each % into decimal abundance. (divide by 100)**
2. **Multiply mass of each isotope by its fractional abundance.**
3. **Add the contributions together.**

(0.99757)(15.9949 amu) +
(0.00038)(16.9999 amu) +
(0.00205)(17.9999) = 15.999 amu.

*__To four significant figures, this is the same as the mass given in the periodic table in the book: 16.00__

Example

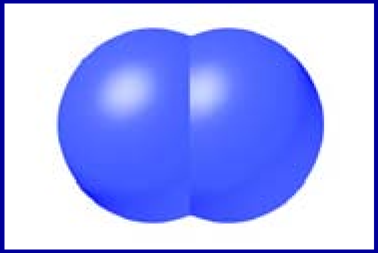
The atomic masses of the two stable isotopes of copper, ^{63}Cu (69.17%) and ^{65}Cu (30.83%), are 62.929599 amu and 64.927793 amu, respectively. Calculate the average atomic mass of copper.

(0.6917)(62.929599 amu) +
(0.3083)(64.927793 amu) +
= 63.55 amu.

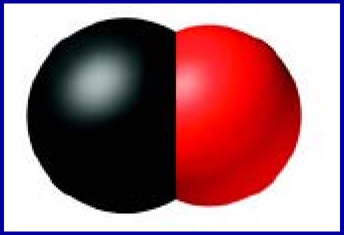
2.6 Molecules and Molecular Compounds

- *Molecule* - combination of at least two atoms in a specific arrangement held together by *chemical bonds*
  - May be an element or a compound
  - H_2, hydrogen gas, is an element
  - H_2O, water, is a compound

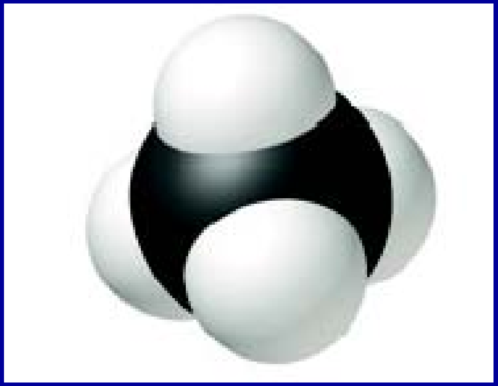
- **Diatomic molecules**:
  - Homonuclear (2 of the same atoms)
    - Examples: H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2



  - **Heteronuclear** (2 different atoms)
    - Examples: CO and HCl

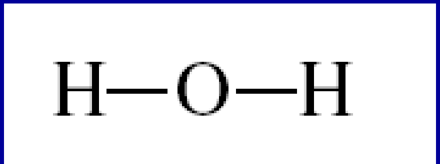


- **Polyatomic molecules**:
  - Contain more than 2 atoms
  - Most molecules
  - May contain more than one element
  - Examples: ozone, O_3; white phosphorus, P_4; water, H_2O, and methane (CH_4)



- ***Molecular formula*** **- shows exact number of atoms of each element in a molecule**
  - **Subscripts indicate number of atoms of each element present in the formula.**
  - **Example: $C_{12}H_{22}O_{11}$**

- ***Allotrope*** **- one of two or more distinct forms of an element**
  - **Examples: oxygen, O_2 and ozone, O_3; diamond and graphite (allotropic forms of carbon)**
- ***Structural formula*** **- shows the general arrangement of atoms within the molecule.**



- **Naming molecular compounds**
  - **Binary Molecular compounds**
    - **Composed of two nonmetals**
    - **Name the first element**
    - **Name the second element changing ending to "-ide"**
    - **Use prefixes to indicate number of atoms of each element**

TABLE 2.2 Greek Prefixes

Prefix	Meaning	Prefix	Meaning
Mono-	1	Hexa-	6
Di-	2	Hepta-	7
Tri-	3	Octa-	8
Tetra-	4	Nona-	9
Penta-	5	Deca-	10

TABLE 2.3 Some Compounds Named Using Greek Prefixes

Compound	Name	Compound	Name
CO	Carbon monoxide	SO_3	Sulfur trioxide
CO_2	Carbon dioxide	NO_2	Nitrogen dioxide
SO_2	Sulfur dioxide	N_2O_5	Dinitrogen pentoxide

Name the following:

NO_2

nitrogen dioxide

N_2O_4

dinitrogen tetraoxide

Write formulas for the following:

Diphosphorus pentoxide

P_2O_5

Sulfur hexafluoride

SF_6

Common Names

B_2H_6 diborane

SiH_4 silane

NH_3 ammonia

PH_3 phosphine

H_2O water

H_2S hydrogen sulfide

- ***Acid*** **- a substance that produces hydrogen ions (H^+) when dissolved in water**
- **Binary acids:**
  - **Many have 2 names. It is composed of :**
    - **Pure substance**
    - **Aqueous solution**
  - **Example: HCl, hydrogen chloride, when dissolved in water it is called hydrochloric acid**

- **Naming binary acids**
  - **Remove the "–gen" ending from hydrogen (leaving hydro–)**
  - **Change the "–ide" ending on the second element to "–ic"**
  - **Combine the two words and add the word "acid."**

Name the following:

HBr

hydrogen bromide   hydrobromic acid

H_2S

hydrogen sulfide   hydrosulfuric acid

Write formulas for the following:

Hydrochloric acid

HCl(aq)

Hydrofluoric acid

HF(aq)

- ***Organic compounds*** **- contain carbon and hydrogen (sometimes with oxygen, nitrogen, sulfur and the halogens.)**
  - ***Hydrocarbons*** **- contain only carbon and hydrogen**
  - ***Alkanes*** **- simplest examples of hydrocarbons**
  - **Many derivatives of alkanes are derived by replacing a hydrogen with one of the *functional groups.***
    - **Functional group determines chemical properties**

TABLE 2.5 Formulas, Names, and Models of Some Simple Alkanes

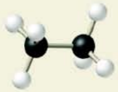
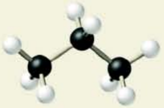
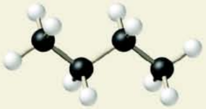
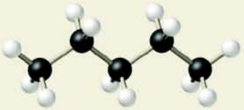
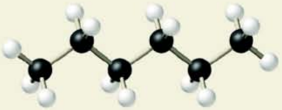
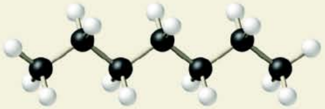
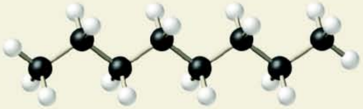
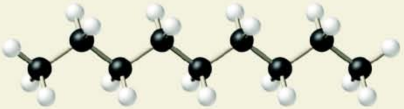
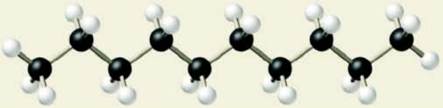
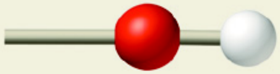
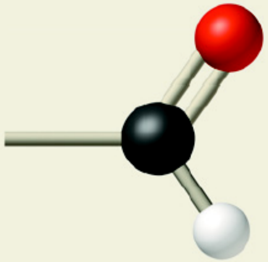
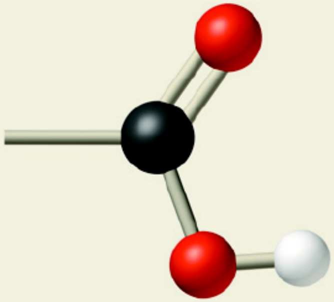
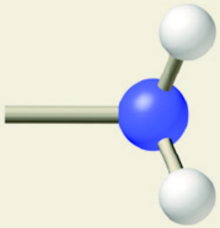
Formula	Name	Model
CH_4	Methane	
C_2H_6	Ethane	
C_3H_8	Propane	
C_4H_{10}	Butane	
C_5H_{12}	Pentane	
C_6H_{14}	Hexane	
C_7H_{16}	Heptane	
C_8H_{18}	Octane	
C_9H_{20}	Nonane	
$C_{10}H_{22}$	Decane	

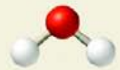
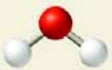
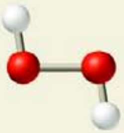
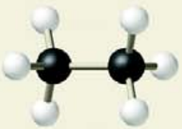
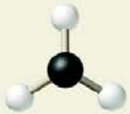
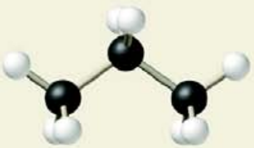
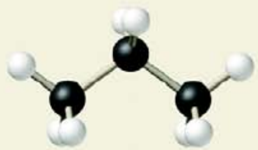
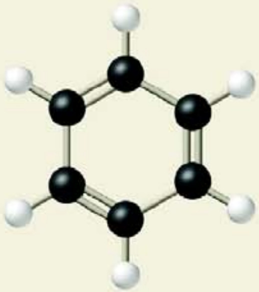
TABLE 2.6 Organic Functional Groups

Name	Functional Group	Model
Alcohol	$-OH$	
Aldehyde	$-CHO$	
Carboxylic acid	$-COOH$	
Amine	$-NH_2$	

- ***Empirical (simplest) formulas reveal the*** **elements present and in what whole-number ratio they are combined.**

<u>**Molecular(explicit)**</u>	<u>**Empirical(simplest)**</u>
H_2O_2	HO
N_2H_4	NH_2
H_2O	H_2O

TABLE 2.7 Molecular and Empirical Formulas

Compound	Molecular Formula	Model	Empirical Formula	Model
Water	H_2O		H_2O	
Hydrogen peroxide	H_2O_2		HO	
Ethane	C_2H_6		CH_3	
Propane	C_3H_8		C_3H_8	
Acetylene	C_2H_2		CH	
Benzene	C_6H_6		CH	

2.7 Ions and Ionic Compounds

- ***Ion*** - an atom or *group* of atoms that has a net positive or negative charge
- ***Monatomic ion*** - *one* atom with a positive or negative charge
- ***Cation*** **-** ion with a net *positive* charge due to the loss of one or more electrons
- ***Anion -*** ion with a net *negative* charge due the gain of one or more electrons

Common Monatomic Ions

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

- **Naming ions**
  - **Cations from A group metals**
    - **Name the element and add the word "ion"**
    - **Example: Na^+, sodium ion**
  - **Cations from transition metals with some exceptions**
    - **Name element**
    - **Indicate charge of metal with Roman numeral**
    - **Add word "ion"**
    - **Example: Cu^{2+} ,copper(II) ion**

– Anions

- Name the element and modify the ending to "-ide"
- Example: Cl^-, chloride

- *Polyatomic ions* - ions that are a combination of two or more atoms
  - Notice similarities - number of oxygen atoms and endings for oxoanions
    - Nitrate, NO_3^- and nitrite, NO_2^-

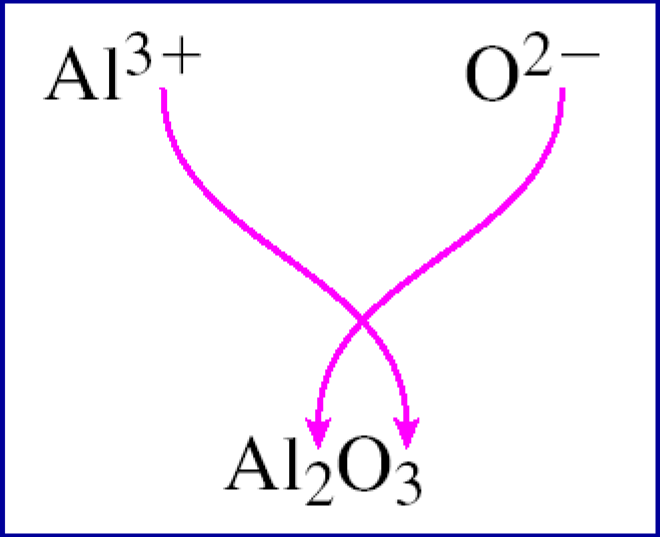
TABLE 2.9 Common Polyatomic Ions

Name	Formula/Charge
Cations	
Ammonium	NH_4^+
Hydronium	H_3O^+
Mercury(I)	Hg_2^{2+}
Anions	
Azide	N_3^-
Carbonate	CO_3^{2-}
Chlorate	ClO_3^-
Chlorite	ClO_2^-
Chromate	CrO_4^{2-}
Cyanide	CN^-
Dichromate	$Cr_2O_7^{2-}$
Dihydrogen phosphate	$H_2PO_4^-$
Hydrogen carbonate or bicarbonate	HCO_3^-
Hydrogen phosphate	HPO_4^{2-}
Hydrogen sulfate or bisulfate	HSO_4^-
Hydroxide	OH^-
Hypochlorite	ClO^-
Nitrate	NO_3^-
Nitrite	NO_2^-
Oxalate	$C_2O_4^{2-}$
Perchlorate	ClO_4^-
Permanganate	MnO_4^-
Peroxide	O_2^{2-}
Phosphate	PO_4^{3-}
Phosphite	PO_3^{3-}
Sulfate	SO_4^{2-}
Sulfite	SO_3^{2-}
Thiocyanate	SCN^-

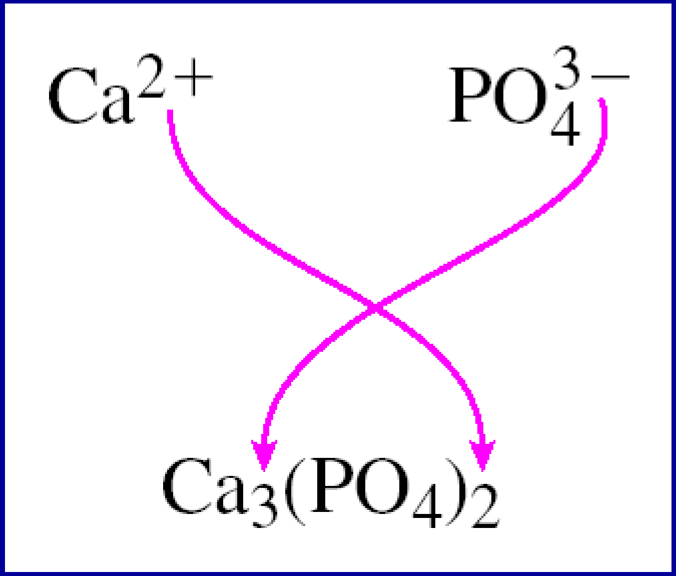
- **Ionic compounds** - represented by empirical formulas
  - Compound formed is **electrically neutral**
  - **Sum of the charges on the cation(s) and anion(s) in each formula unit must be zero**
  - Examples:

Al^{3+} and O^{2-} Al_2O_3

Ca^{2+} and PO_4^{3-} $Ca_3(PO_4)_2$

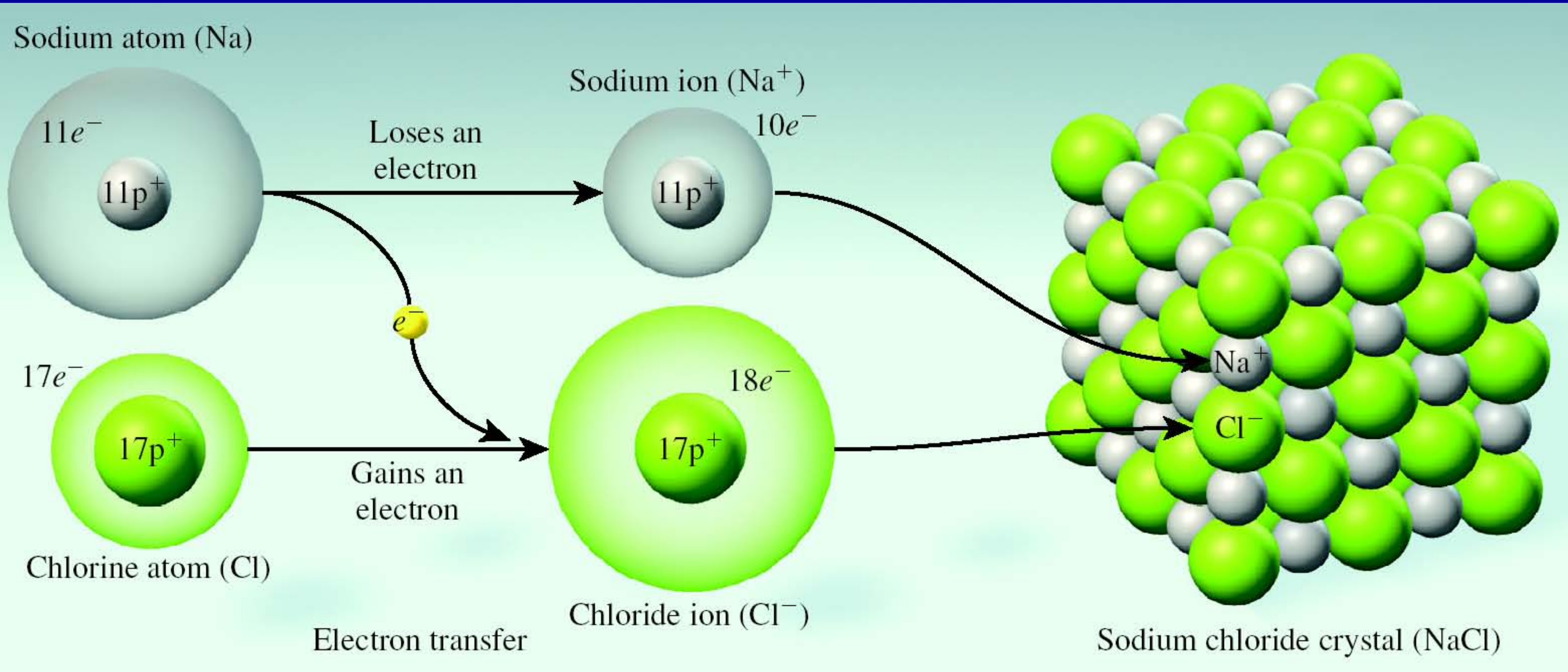


Al^{3+}
O^{2-}
Al_2O_3



Ca^{2+}
PO_4^{3-}
$Ca_3(PO_4)_2$

Formation of an Ionic Compound



Write empirical formulas for

- **Aluminum and bromide**

  $AlBr_3$

- **barium and phosphate**

  $Ba_3(PO_4)_2$

- **Magnesium and nitrate**

  $Mg(NO_3)_2$

- **Ammonium and sulfate**

  $(NH_4)_2SO_4$

- **Naming ionic compounds**
  - **Name the cation**
  - **Name the anion**
  - **Check the name of cation**
    - **If it is an A group metal you are finished**
    - **If it is a transition metal, with some exceptions, add the appropriate Roman numeral to indicate the positive ionic charge**

Write names for the following:

- $KMnO_4$

  potassium permanganate
- $Sr_3(PO_4)_2$

  strontium phosphate
- $Co(NO_3)_2$

  cobalt(II) nitrate
- $FeSO_4$

  iron(II) sulfate

- **Oxoacids**
  - **When writing formulas, add the number of H^+ ions necessary to balance the corresponding oxoanion's negative charge**
  - **Naming formulas**
    - **If the anion ends in "-ite" the acid ends with "-ous" acid**
    - **If the anion ends in "-ate" the acid ends in "-ic" acid**

Name the following:

- **H_2SO_3**

  sulfurous acid

- **HClO**

  hypochlorous acid

- **H_3PO_4**

  phosphoric acid

Write formulas for the following:

- **Perchloric acid**

  $HClO_4$

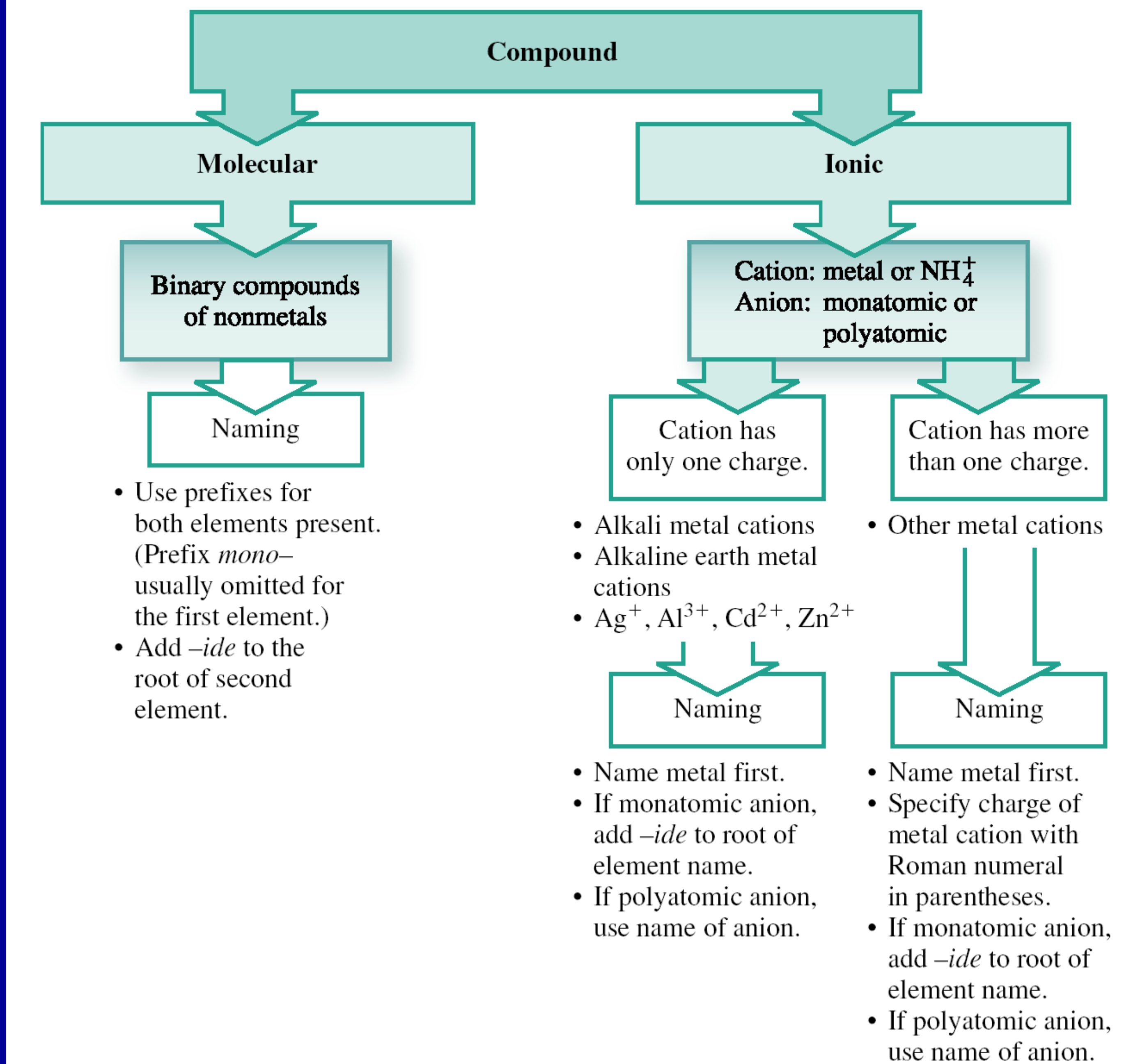
- **Nitric acid**

  HNO_3

- *Hydrates* - compounds that have a specific number of water molecules within their solid structure
  - Hydrated compounds may be heated to remove the water forming an anhydrous compound
  - Name the compound and add the word hydrate. Indicate the number of water molecules with a prefix on hydrate.
    - Example: $CuSO_4 \cdot 5\ H_2O$
      - Copper (II) sulfate pentahydrate

TABLE 2.10 Common and Systematic Names of Some Familiar Inorganic Compounds

Formula	Common Name	Systematic Name
H_2O	Water	Dihydrogen monoxide
NH_3	Ammonia	Trihydrogen nitride
CO_2	Dry ice	Solid carbon dioxide
$NaCl$	Salt	Sodium chloride
N_2O	Laughing gas	Dinitrogen monoxide
$CaCO_3$	Marble, chalk, limestone	Calcium carbonate
$NaHCO_3$	Baking soda	Sodium hydrogen carbonate
$MgSO_4 \cdot 7H_2O$	Epsom salt	Magnesium sulfate heptahydrate
$Mg(OH)_2$	Milk of magnesia	Magnesium hydroxide


Compound
Molecular
Ionic
Binary compounds of nonmetals
Cation: metal or NH_4^+
Anion: monatomic or polyatomic
Naming
• Use prefixes for both elements present. (Prefix *mono–* usually omitted for the first element.)
• Add *–ide* to the root of second element.
Cation has only one charge.
Cation has more than one charge.
• Alkali metal cations
• Alkaline earth metal cations
• Ag^+, Al^{3+}, Cd^{2+}, Zn^{2+}
• Other metal cations
Naming
Naming
• Name metal first.
• If monatomic anion, add *–ide* to root of element name.
• If polyatomic anion, use name of anion.
• Name metal first.
• Specify charge of metal cation with Roman numeral in parentheses.
• If monatomic anion, add *–ide* to root of element name.
• If polyatomic anion, use name of anion.

Learning outcomes

- Atomic theory - parts of the atom; theories; laws
- Types of radiation
- Atomic number and mass number
- Isotopes
- Periodic table; families and periods; metals, nonmetals and metalloids

Learning outcomes

- Average atomic mass
- Naming and writing formulas for
  - Binary molecular compounds
  - Binary acids
  - Ionic compounds
  - Oxoacids
  - Hydrates