

CHEM103

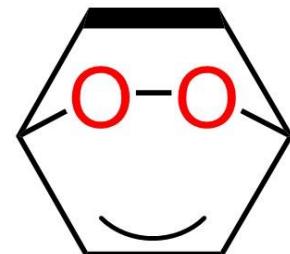
General Chemistry

Chapter 2: Atoms, Molecules, and Ions



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Assignment 1

Please either **print** the Answer Sheet or **use** your paper; **write down** your answers on your sheet/paper.

Please submit your assignments to me during the classes. Or you can submit your assignment to the folder **outside room 520, research building 1** (anytime you like).

Homework 1

Due date: 14 Sep. (Wed)

Review on Chapter 1

Chemistry: matter, its properties and changes

Classifications of Matter:

Atoms, Elements, Compounds, Mixture; State of Matter

Properties of Matter:

Physical & Chemical; Intensive & Extensive;
Separation of Mixtures

Measurement of Matter:

Units (SI, Prefix); Uncertainty (Exact vs. Inexact number; Precision and Accuracy; Significant Figures);
Dimensional Analysis

Outline of Chapter 2

Atoms:

Atomic Theory; Atomic Structure (nucleus, electron, proton & neutron); Atomic Weight (atomic number; isotopes); Periodic Table (periods & groups)

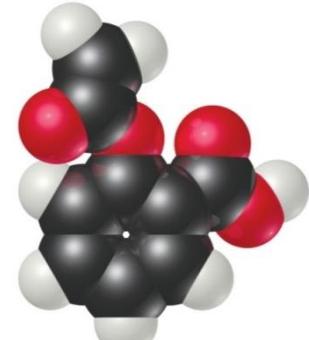
Molecules:

Compounds; Chemical formula and empirical formula

Ions:

Cations, anions, ionic bonds

Naming of Inorganic & Organic Compounds



All matter/material: composed of > 100 elements (>100 chemically different kinds of atoms).

Structure & behavior of atoms are keys to understand both physical & chemical properties of matter.

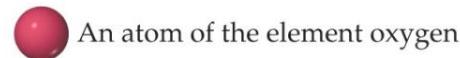
Any rules to combine different atoms? How do properties of a substance relate to the types of atoms?

Atomic Theory of Matter

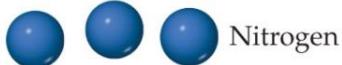
Atomic Theory of Matter

Dalton's Atomic Theory

1. Each element is composed of extremely small particles called atoms.



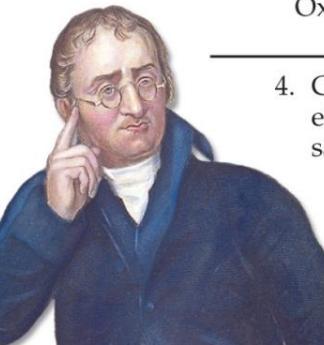
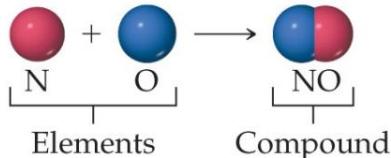
2. All atoms of a given element are identical, but the atoms of one element are different from the atoms of all other elements.



3. Atoms of one element cannot be changed into atoms of a different element by chemical reactions; atoms are neither created nor destroyed in chemical reactions.



4. Compounds are formed when atoms of more than one element combine; a given compound always has the same relative number and kind of atoms.



Atomos: Greek meaning of
“indivisible or uncuttable
(不能分割的)”

Atoms: fundamental building blocks of matter reemerged in the early 19th century, championed by John Dalton.

Dalton's Postulates (道尔顿的假说)

1. Each element is composed of an extremely small particle (粒子), so-called atom.



An atom of the element oxygen

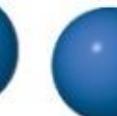


An atom of the element nitrogen

2. All atoms of the same element are same to one another in terms of mass and other properties. The atoms of one element are different from the atoms of all other elements.

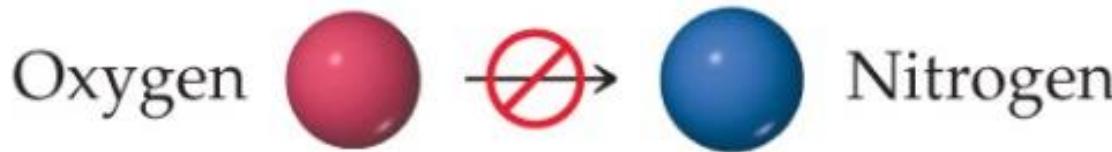


Oxygen

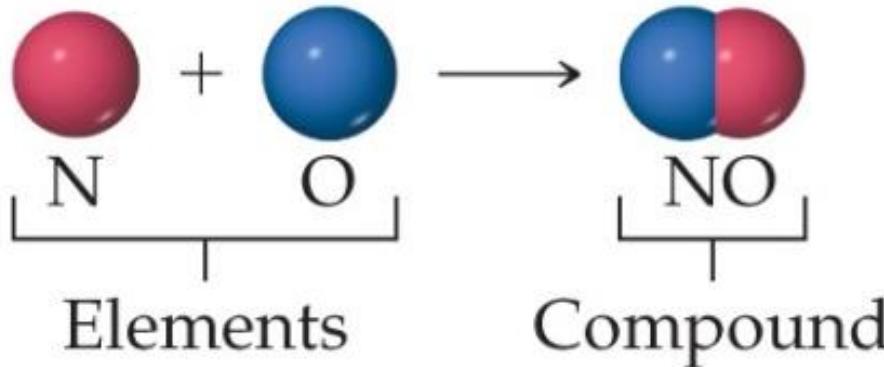


Nitrogen

3. Atoms of an element are **NOT changed** into atoms of a **different element** by chemical reactions. Atoms are neither created nor destroyed in chemical reactions.

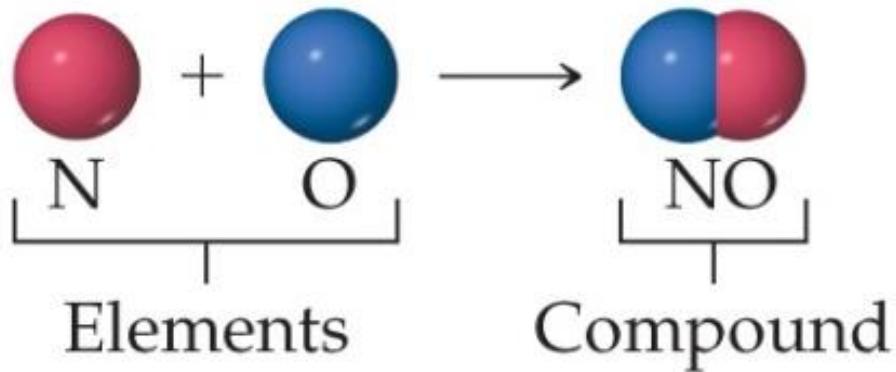


4. Compounds are formed when atoms of **more than one element** combine. A **same** compound always has the **same relative number and same kind of atoms**.



Law of Conservation of Mass (质量守恒定律)

The **total mass** of substances present **after** a chemical reaction is the **same** as the total mass of substances present **before** the reaction.



$$M(N) + M(O) = M(NO)$$

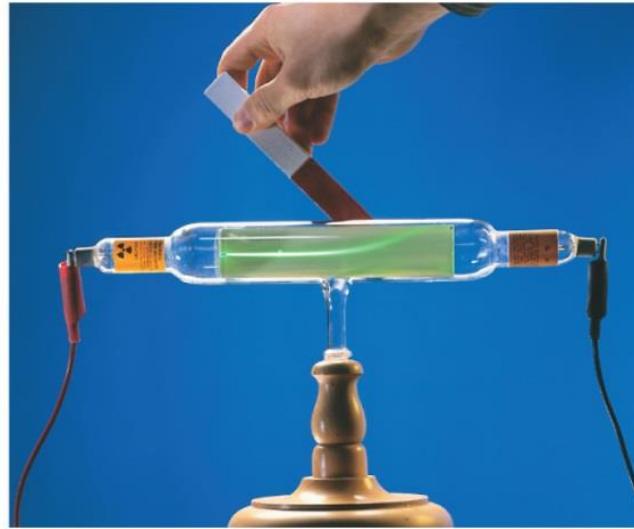
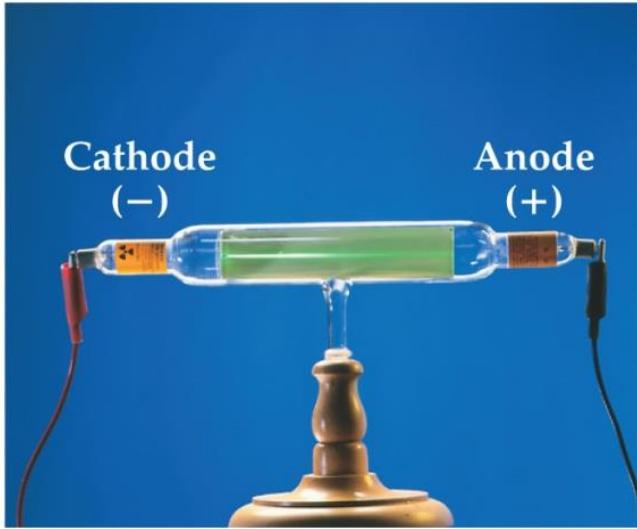
Beakers of silver nitrate (AgNO_3) and sodium chloride (NaCl) solutions before mixing (left) and after mixing (right).



The Discovery of Atomic Structure

Atoms,
Molecules,
and Ions

The Electron (e^-)

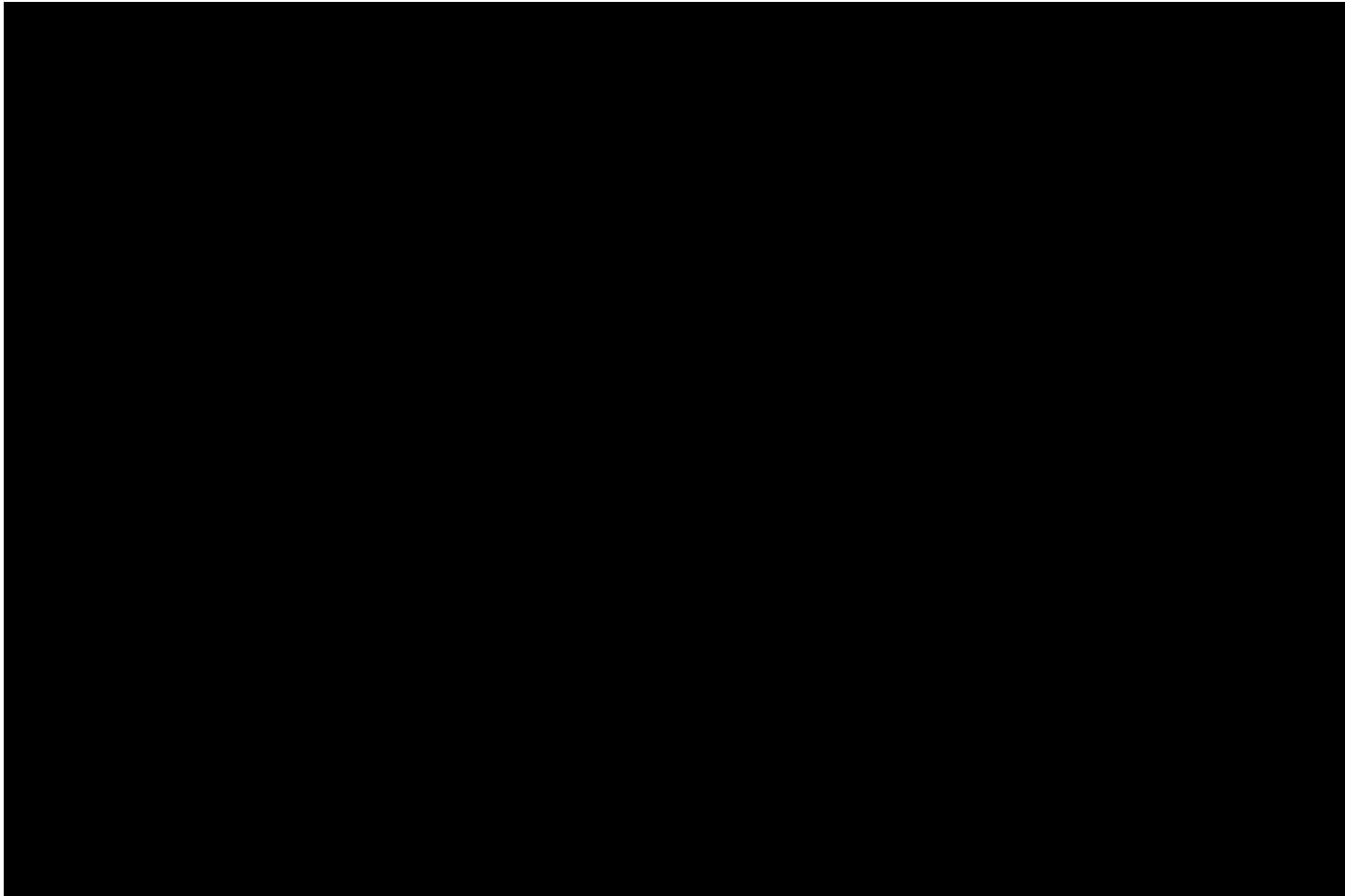


(a) Electrons move from the cathode (negative electrode) to the anode (positive electrode). The tube contains a glass screen (set diagonally to the electron beam) that fluoresces, showing the path of the cathode rays.

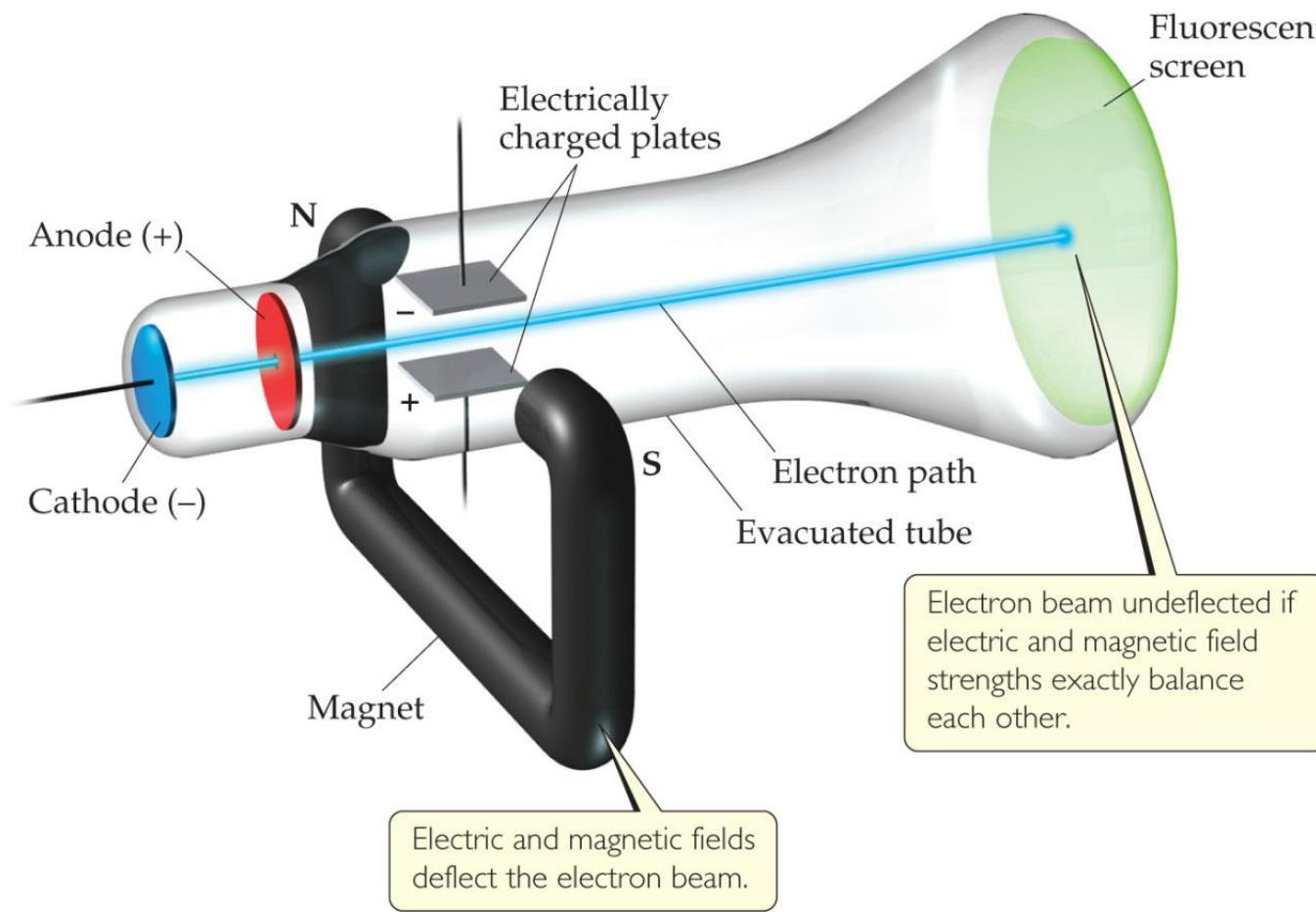
(b) The rays are deflected by a magnet.

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- Streams of **negatively charged particles** were found to emanate (发射) from negative cathode tubes (阴极射线管), causing fluorescence (荧光).
- J. J. Thomson is credited with their discovery (1897).

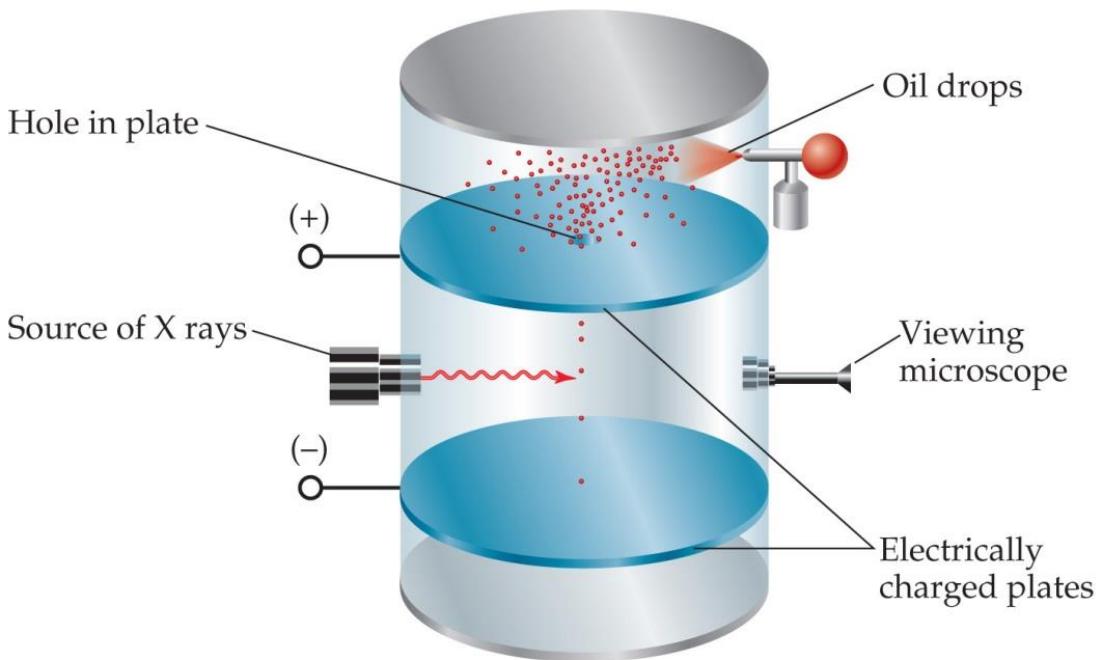


- Streams of negatively charged particles were found to emanate (发射) from cathode tubes (阴极射线管), causing fluorescence (荧光).



Thomson measured the **charge/mass ratio of the electron** to be 1.76×10^8 coulombs/gram (C/g).

Millikan Oil-Drop Experiment



As the charge/mass ratio of the electron was known (Thomson), determination of either the charge or the mass of an electron would be derived:

Charge → Mass

or

Mass → Charge

Robert Millikan determined the **charge on an electron** (1.602×10^{-19} C) in 1909. Then, **mass of an electron** = 1.602×10^{-19} C / 1.76×10^8 C/g = 9.10×10^{-28} g.

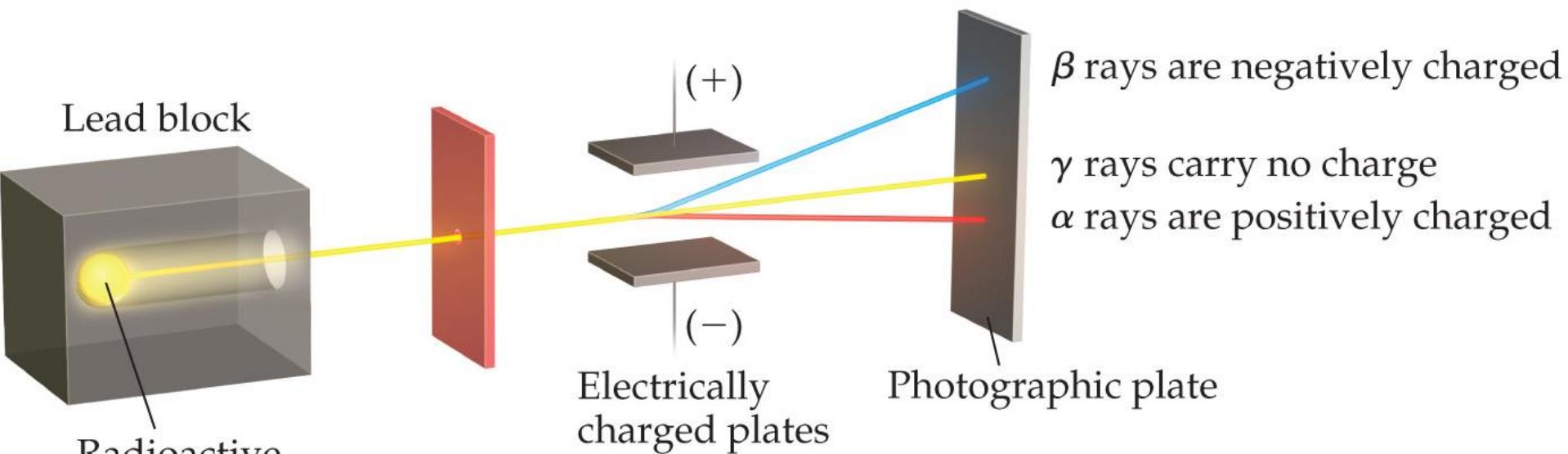
Millikan Oil Drop Experiment

Millikan's experiment showed that the charges were always integral multiples of 1.602×10^{-19} coulombs (C). Therefore, an electron mass = 9.10×10^{-28} g.

Radioactivity (放射性)

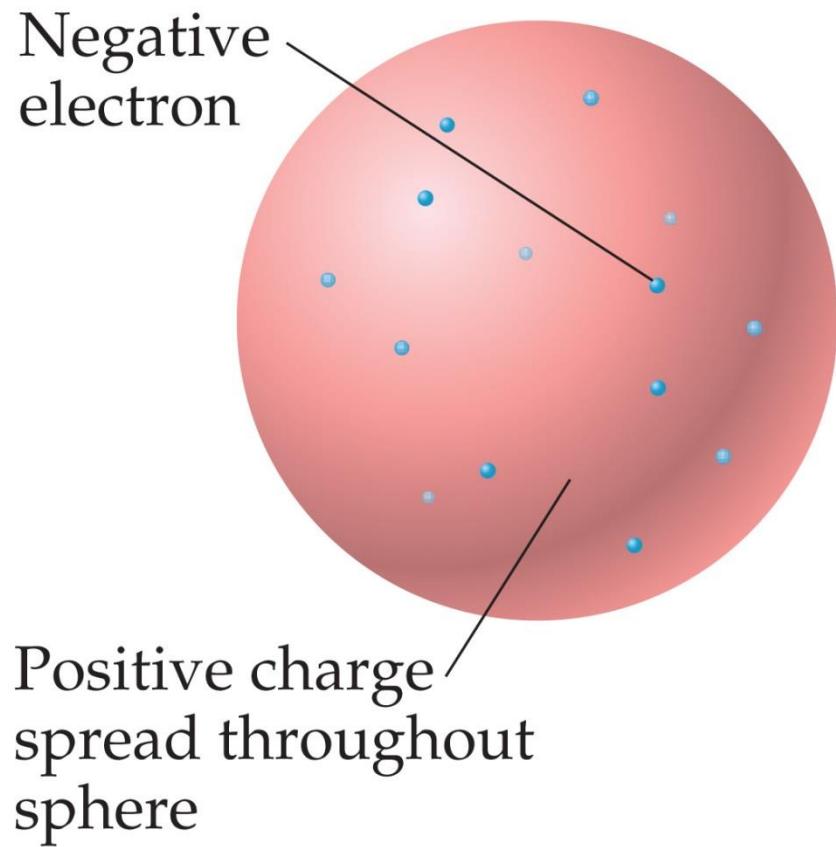
- Radioactivity: spontaneous (自发的) emission of radiation (辐射).
- First observed by Henri Becquerel (贝克勒尔) from a compound of uranium (U) in 1896.
- Becquerel (Bq) named after him is a measure of radioactivity. A quantity of radioactive material has an activity of 1 Bq, if one nucleus decays per second.
- Marie and Pierre Curie (居里) also studied and isolated it.

- Three types of radiation were discovered by Ernest Rutherford (卢瑟福):
 - α particles (positively-charged)
 - β particles (fast & negatively-charged)
 - γ rays (no charge)



Separation of Alpha, Beta, and Gamma Rays

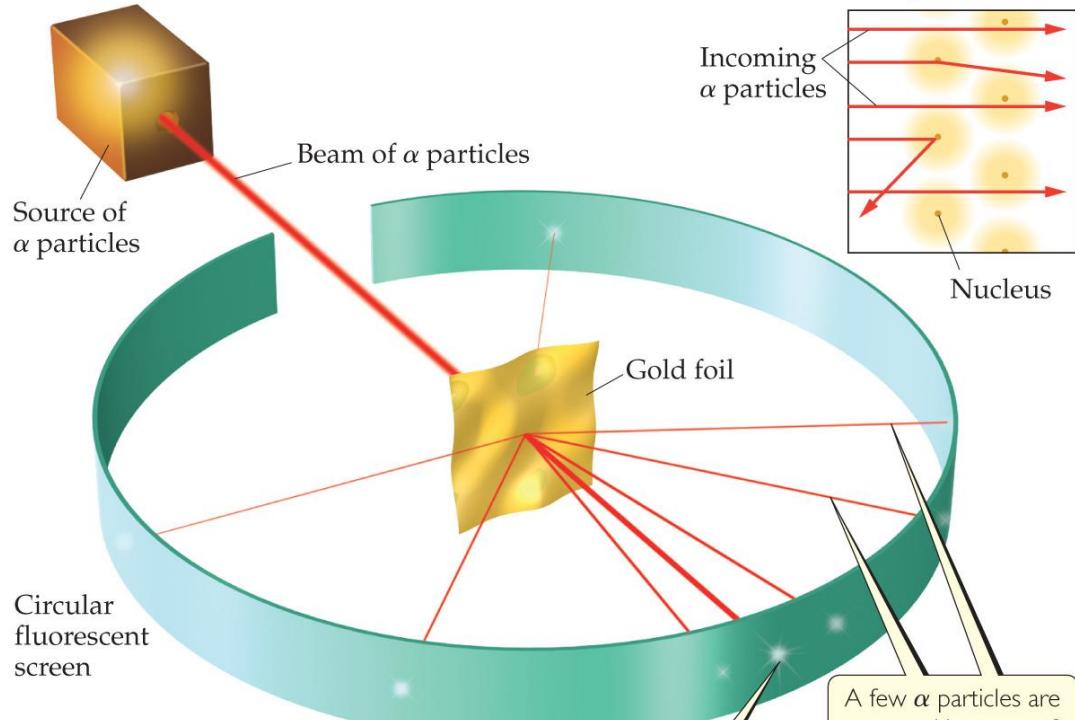
Thomson's Model of the Atom (~1900)



- The prevailing (流行) theory was the “plum pudding” (葡萄干布丁) model (by Thomson).
- Featured a uniform positive sphere of matter with negative electrons imbedded in it.

Discovery of the Nucleus (原子核)

Experiment



Interpretation

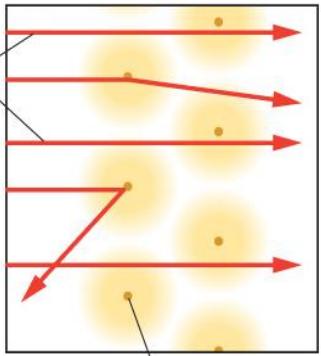
Incoming
 α particles

Nucleus

Circular
fluorescent
screen

Interpretation

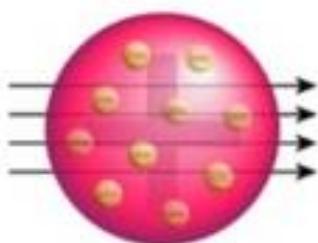
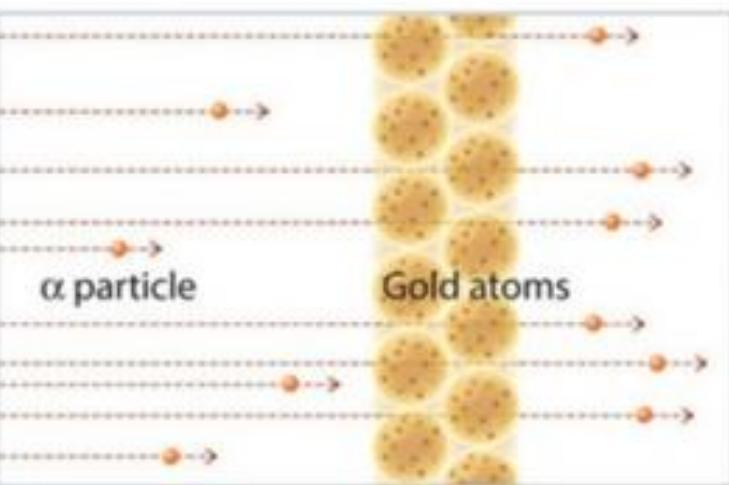
Incoming
 α particles



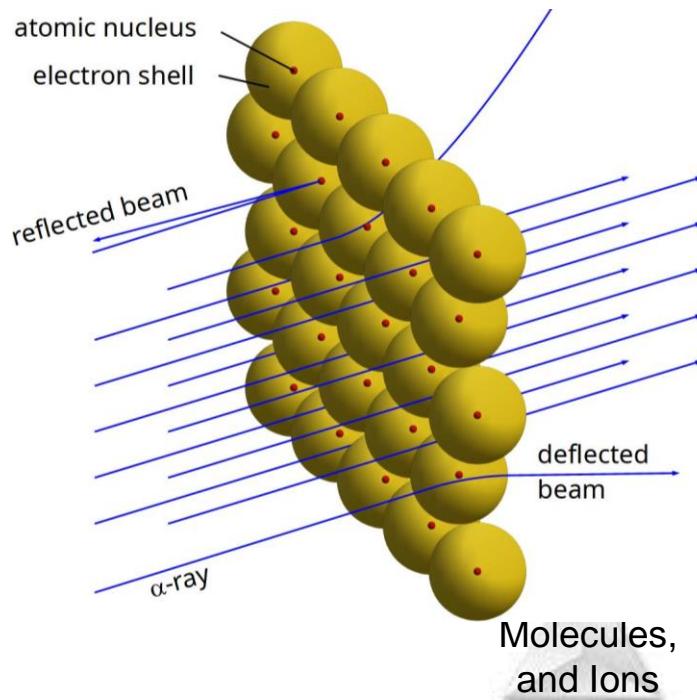
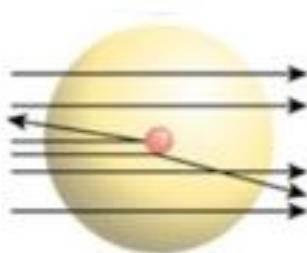
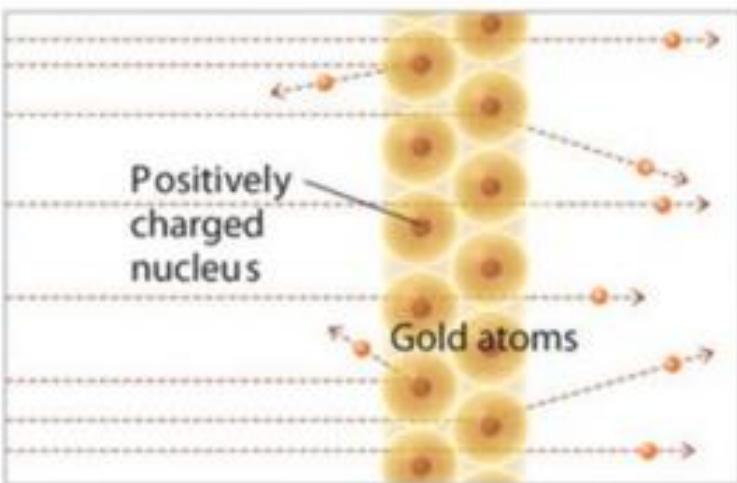
Nucleus

- Rutherford shot α particles at a thin sheet of gold foil, observed the pattern of **scatter of the particles & proposed nucleus**.

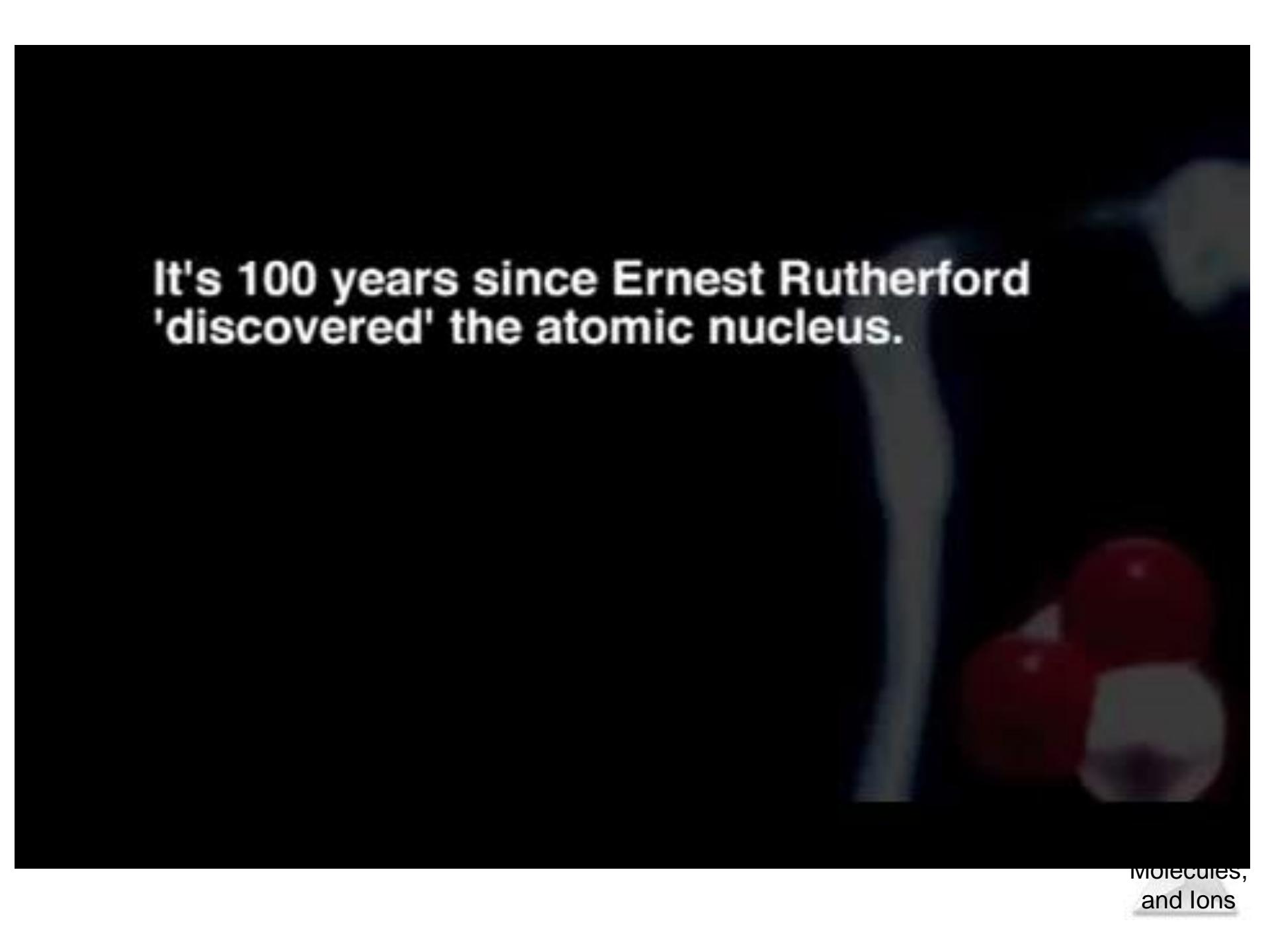
- As some particles were deflected (偏斜) at large angles, Thomson's model could not be correct.



(b) What Rutherford expected if Thomson's model were correct



(c) What Rutherford actually observed



**It's 100 years since Ernest Rutherford
'discovered' the atomic nucleus.**

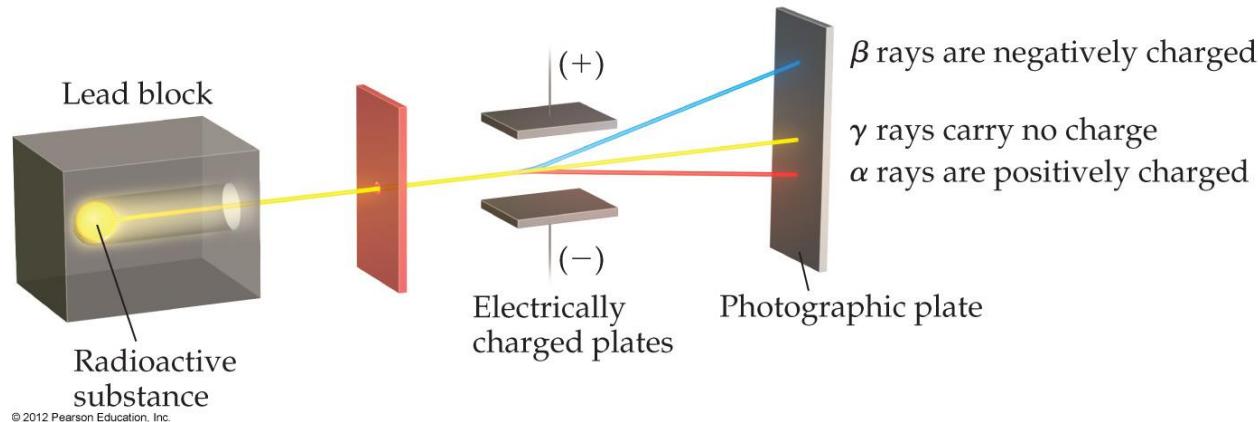
Which of the three kinds of radiation consists of electrons?

A. β

B. γ

C. α

D. (A) and (C)



Why more extend deflection of these rays?

A. β particles are negatively charged

B. α particles are positively charged

C. α particles are less massive than β particles

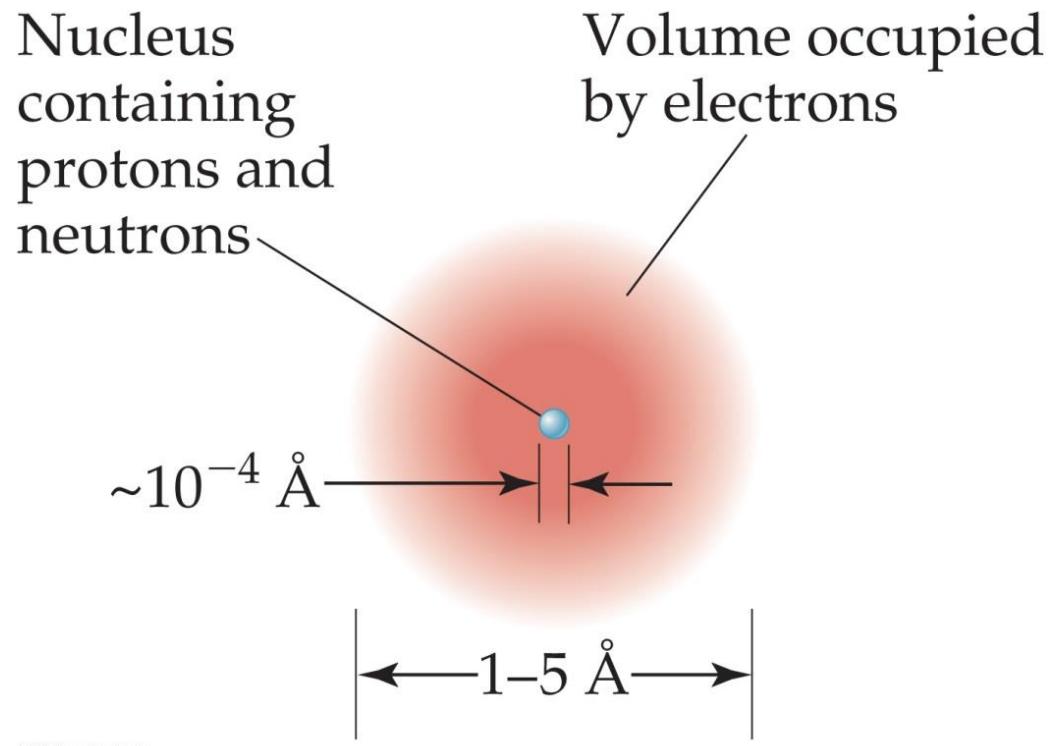
D. β particles are less massive than α particles

The Modern View of Atomic Structure

Atoms,
Molecules,
and Ions

The Structure of the Atom

- Rutherford postulated a **very small, dense nucleus** with the electrons around the outside of the atom.
- Most of the volume of the atom is **empty space**.
- The electrons play the major role in chemical reactions.

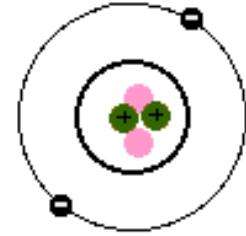


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$$1 \text{ \AA} = 1 \times 10^{-10} \text{ m}$$

$$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$$

Other Subatomic Particles



- Protons (质子) was discovered by Rutherford (1919); Neutrons (中子) was discovered by Chadwick (1932).
- **Protons & electrons:** the only particles that **have a charge** (but NOT neutrons).
- **Protons & neutrons:** essentially the **same mass**; whereas the mass of an electron is very small.

Particle	Charge	Atomic Mass Unit: (amu) Mass (amu)
Proton	Positive (1+)	1.0073
Neutron	None (neutral)	1.0087
Electron	Negative (1-)	5.486×10^{-4}

Symbols of Elements

Mass number (number of protons plus neutrons)



Atomic number (number of protons or electrons)

Symbol of element

read “Carbon-12”

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Elements are symbolized by one or two letters (e.g. C).

All atoms of the **same element** have the **same number of protons**, which is called the **atomic number**, Z (e.g. 6); **Different elements** have **different numbers of protons**.

The **mass of an atom (called mass number)** in atomic mass units (amu): the total number of protons & neutrons in the nucleus (e.g. 12).

Isotopes (同位素)

- **Isotopes:** atoms of the **same element** with **different masses**, due to **different numbers of neutrons**.

Symbol	Number of Protons	Number of Electrons	Number of Neutrons
^{11}C	6	6	5
^{12}C	6	6	6
^{13}C	6	6	7
^{14}C	6	6	8

*Almost 99% of the carbon found in nature is ^{12}C .

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- a.** If an atom has 15 protons, how many electrons does it have?
- b.** Where do the protons reside in an atom?

a.

- A. Cannot determine number of electrons without additional information.
- B. The atom has 30 electrons.
- C. The atom has 15 electrons.**
- D. The atom has no electrons unless it is charged.

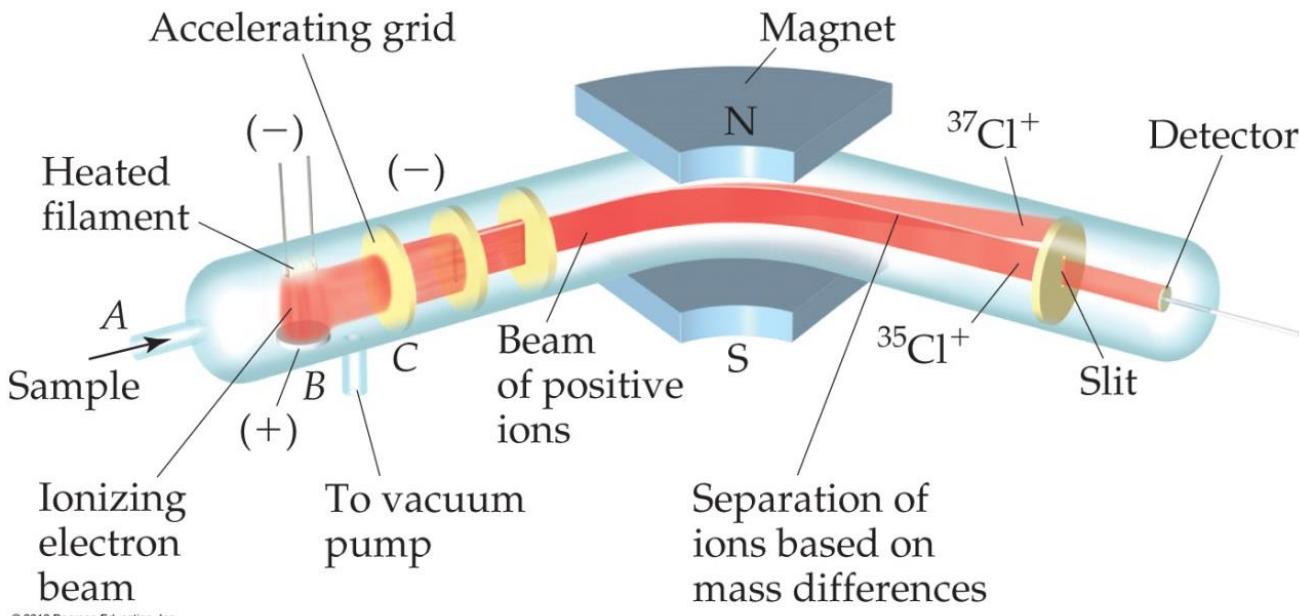
b.

- A. The protons reside in the nucleus of the atom.**
- B. The protons are evenly distributed throughout the atom.
- C. The protons are dispersed with the electrons around the nucleus.
- D. The protons reside in a shell just outside the nucleus

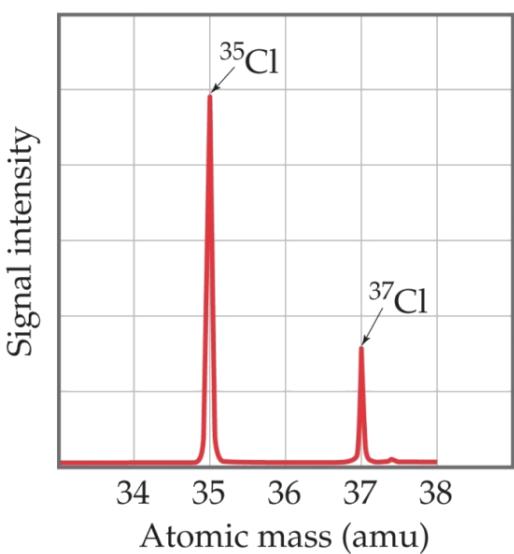
Atomic Weights

Atoms,
Molecules,
and Ions

Atomic Mass



Atomic & molecular masses can be measured with great accuracy by a mass spectrometer (MS, 质谱仪).



Exact atomic mass for ^{12}C : 12 amu
Atomic mass for ^1H : 1.0078 amu

Atomic Weight (Average Atomic Mass)

- **Atomic Weight** of an element is calculated from the isotopes of the element weighted by their relative abundances.

$$\text{Atomic weight} = \Sigma(\text{isotope mass})^*(\text{relative ratio})$$

Mg: $23.98504 * 0.7899 + 24.98584 * 0.1 + 25.98259 * 0.1101$

Isotope	Abundance	Atomic mass (amu)
^{24}Mg	78.99 %	23.98504
^{25}Mg	10.00 %	24.98584
^{26}Mg	11.01 %	25.98259

C: $12 * 0.9893 + 13.00335 * 0.0107 = 12.01 \text{ amu}$

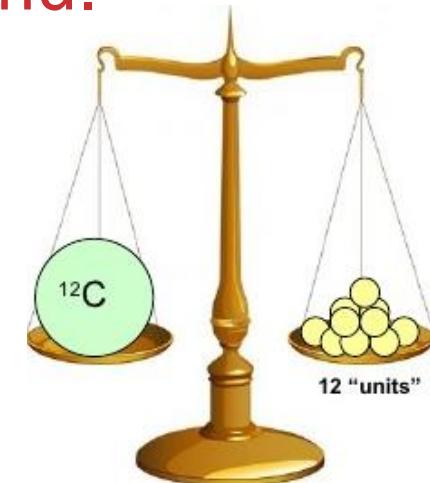
A particular atom of chromium has a mass of 52.94 amu, whereas the atomic weight of chromium is 51.99 amu. Explain the difference in the two masses.

- A. The 52.94 amu value and the 51.99 amu value represent two different isotopes of chromium.
- B. The atomic weight of chromium does not depend on the atom with a mass of 52.94 amu.
- C. The atomic weight of 51.99 amu is for a different isotope than the 52.94 amu mass.
- D. The atomic weight of chromium (51.99 amu) is an average atomic mass of all the naturally occurring isotopes of chromium.

(Relative) Atomic Mass (A.M.)

1 atomic mass unit (amu): 1/12 of the mass of a ^{12}C atom **exactly**; The **relative atomic mass (RAM)** of other elements is their mass relative to 1 amu.

$$\text{RAM} = \frac{\text{Mass of one atom of the element}}{\left(\frac{1}{12}\right) \text{Mass of one atom of carbon } \left(\text{C}^{12}\right)}$$



A.M. for proton & neutron: 1.0073 & 1.0087

$$\begin{aligned}\text{A.M. for } ^{12}\text{C} &= 12.0 \text{ (exact)} < 6*(1.0073 + 1.0087) \\ &= 12.096!\end{aligned}$$

Extra Info. (Not included in the exam): A.M. of atoms is reduced (“mass defect”), compared to their isolated nuclei, due to nuclear binding energy mass loss ($E = mc^2$).

The Periodic Table

(learn more from
Chapter 7)

Atoms,
Molecules,
and Ions

Periodic Table of the Elements

Periodic Table of the Elements																		
1 H Hydrogen 1.01																	18 He Helium 4.00	
2 Li Lithium 6.94	3 Be Beryllium 9.01																17 Ne Neon 20.18	
4 Mg Magnesium 24.31		5 Na Sodium 22.99	6 Ca Calcium 40.08	7 Sc Scandium 44.96	8 Ti Titanium 47.88	9 Cr Chromium 50.94	10 Mn Manganese 54.94	11 Fe Iron 55.85	12 Co Cobalt 58.93	13 Ni Nickel 58.69	14 Cu Copper 63.55	15 Zn Zinc 65.38	16 Al Aluminum 26.98	17 Si Silicon 28.09	18 P Phosphorus 30.97	19 S Sulfur 32.06	20 Cl Chlorine 35.45	21 Ar Argon 39.95
22 K Potassium 39.10	23 Ca Calcium 40.08	24 Sc Scandium 44.96	25 Ti Titanium 47.88	26 Cr Chromium 50.94	27 Mn Manganese 54.94	28 Fe Iron 55.85	29 Co Cobalt 58.93	30 Ni Nickel 58.69	31 Cu Copper 63.55	32 Zn Zinc 65.38	33 Al Aluminum 26.98	34 Si Silicon 28.09	35 P Phosphorus 30.97	36 S Sulfur 32.06	37 Cl Chlorine 35.45	38 Ar Argon 39.95		
39 Rb Rubidium 85.47	40 Sr Strontium 87.62	41 Y Yttrium 88.91	42 Zr Zirconium 91.22	43 Nb Niobium 92.91	44 Mo Molybdenum 95.95	45 Tc Technetium 98.91	46 Ru Ruthenium 101.07	47 Rh Rhodium 102.91	48 Pd Palladium 106.42	49 Ag Silver 107.87	50 Cd Cadmium 112.41	51 In Indium 114.82	52 Sn Tin 118.71	53 Sb Antimony 121.76	54 Te Tellurium 127.6	55 I Iodine 126.90	56 Xe Xenon 131.29	
57-71 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium [208.98]	85 At Astatine 209.98	86 Rn Radon 222.02	
87 Fr Francium 223.02	88 Ra Radium 226.03	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [263]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [293]	116 Lv Livermorium [294]	117 Ts Tennessine [294]	118 Og Oganesson [294]	

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

- The **periodic table**: a systematic catalog of elements.
 - Elements are arranged in order of atomic number.

Atoms, Molecules, and Ions

Periods

Periods - horizontal rows

1A
1
1
H
2A
2

	3 Li	4 Be
2		
3	11 Na	12 Mg
4		
5	19 K	20 Ca
6		
7	37 Rb	38 Sr
6	55 Cs	56 Ba
7	87 Fr	88 Ra

- Elements arranged in order of increasing atomic number

Steplike line divides ...
metals from nonmetals

Groups - vertical columns containing elements with similar properties

8A
18

2
He
10
Ne
18
Ar
36
Kr
54
Xe
86
Rn
118

3A 4A 5A

6 C	7 N
14	15

Si	P
32 Ge	33 As
50 Sn	51 Sb
82 Pb	83 Bi
114	115

67 Ho	68 Er
99 Es	100 Fm

- Metals
- Metalloids
- Nonmetals

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

- The rows on the periodic chart are **periods** (周期).
 - Columns are **groups** (族).
 - Elements in the **same group**: **similar** chemical properties generally.

Periodicity (周期性)

Atomic number	1	2	3	4	---	9	10	11	12	---	17	18	19	20	---
Symbol	H	He	Li	Be	---	F	Ne	Na	Mg	---	Cl	Ar	K	Ca	---
	Nonreactive gas		Soft, reactive metal			Nonreactive gas		Soft, reactive metal			Nonreactive gas		Soft, reactive metal		

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When one looks at the chemical properties of elements, one notices a repeating pattern of reactivities (活性).

Groups

Group	Name	Elements
1A	碱金属族	Alkali metals
2A	碱土金属族	Alkaline earth metals
6A	氧族	Chalcogens
7A	卤族	Halogens
8A	稀有气体族	Noble gases (or rare gases)

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These five groups are known by their names.

Periods - horizontal rows

1A
1
1 H 2A
2

Elements arranged in order of increasing atomic number

2
2 Li 4 Be

3
3 Na 12 Mg

4
4 K 20 Ca

5
5 Rb 38 Sr

6
6 Cs 56 Ba

7
7 Fr 88 Ra

3B 4B 5B 6B 7B

8 9 10

1B 2B

11 12

13 Al 14 Si 15 P 16 S 17 Cl 18 Ar

19 20 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 38 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 56 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 88 103 Lr 104 Rf 105 Db 106 Sg 107 Bh 108 Hs 109 Mt 110 Ds 111 Rg 112 Cn 113 114 115 116 117 118

Metals
Metalloids
Nonmetals

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

Groups - vertical columns containing elements with similar properties

8A
18
2 He

5 B 6 C 7 N 8 O 9 F 10 Ne

13 Al 14 Si 15 P 16 S 17 Cl 18 Ar

19 20 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 38 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 56 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 88 103 Lr 104 Rf 105 Db 106 Sg 107 Bh 108 Hs 109 Mt 110 Ds 111 Rg 112 Cn 113 114 115 116 117 118

Nonmetals: Right side (with the exception of H).

Metalloids (类金属): border the **stair-step line** (with the exception of Al, Po, and At).

Metals: Left side.

If F is a reactive nonmetal, which other element or elements shown here do you expect to also be a reactive nonmetal?

- A. He and Ar
- B. Be and Ca
- C. I and Cl
- D. Ne and Ar

Molecules and Molecular Compounds

Atoms,
Molecules,
and Ions

Chemical Formulas (方程式)



Hydrogen, H₂



Oxygen, O₂



Water, H₂O



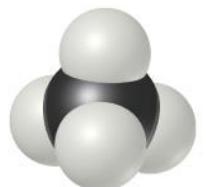
Hydrogen peroxide, H₂O₂



Carbon monoxide, CO



Carbon dioxide, CO₂



Methane, CH₄



Ethylene, C₂H₄

Molecular compounds are composed of molecules and almost always **contain only (two or more) nonmetals**.

The **subscript** (下标) to the right of the **symbol of an element**: the number (**integral**) of atoms of that element in one molecule of the compound (→ composition).
e.g. H₂ → 2 H atoms

Diatomeric Molecules (双原子分子)

- These seven elements occur naturally as molecules containing two atoms:

Hydrogen (H_2)

Nitrogen (N_2)

Oxygen (O_2)

Fluorine (F_2)

Chlorine (Cl_2)

Bromine (Br_2)

Iodine (I_2)



Hydrogen, H_2



Oxygen, O_2

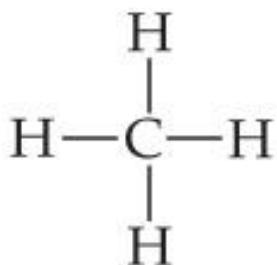
Types of Formulas

- **Empirical formulas** (实验式): the **lowest whole number ratio** (整数比) of atoms of each element in a compound (generally for **ionic and metallic compounds**).
- **Molecular formulas** (分子式): the **exact number** of atoms of each element in a **molecular compound** (generally **NOT for ionic and metallic compounds**).



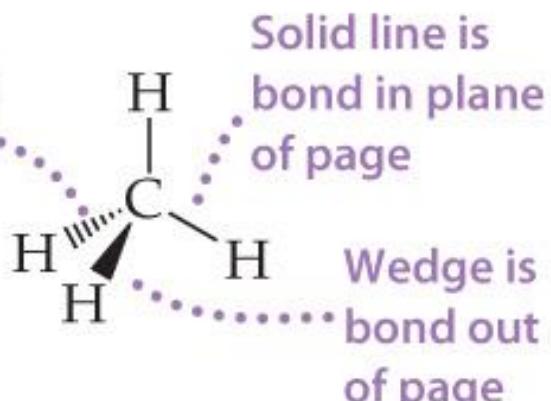


Molecular formula



Structural formula

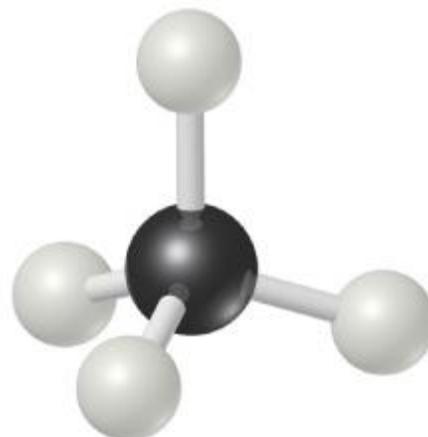
Dashed
wedge is bond
behind page



Perspective drawing

- **Structural formulas** show the order in which atoms are bonded.

- **Perspective drawings** show the 3-dimensional array of atoms in a compound.

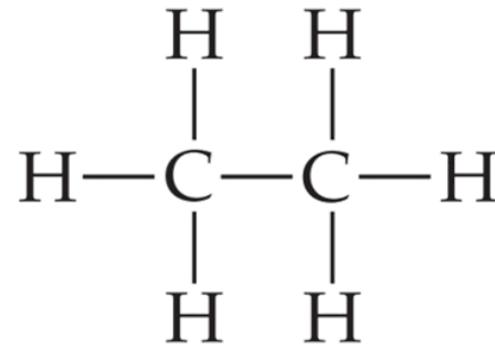


Ball-and-stick model



Space-filling model

The structural formula for ethane is



- a. What is the molecular formula for ethane?
- b. What is its empirical formula?
- c. Which kind of molecular model would most clearly show the angles between atoms?

a.

- A. CH
- B. CH_3
- C. CH_6
- D. C_2H_6

b.

- A. CH
- B. CH_3
- C. C_2H_2
- D. CH_6

c.

- A. perspective model
- B. visual depth model
- C. ball and stick model
- D. space-filling model

Ions and Ionic Compounds

Atoms,
Molecules,
and Ions

Cation

1A		2A													
H ⁺															
Li ⁺															
Na ⁺	Mg ²⁺														
K ⁺	Ca ²⁺														
Rb ⁺	Sr ²⁺														
Cs ⁺	Ba ²⁺														

Ions (离子)

Noble-gas
like ions (stable)

Transition metals

Anion

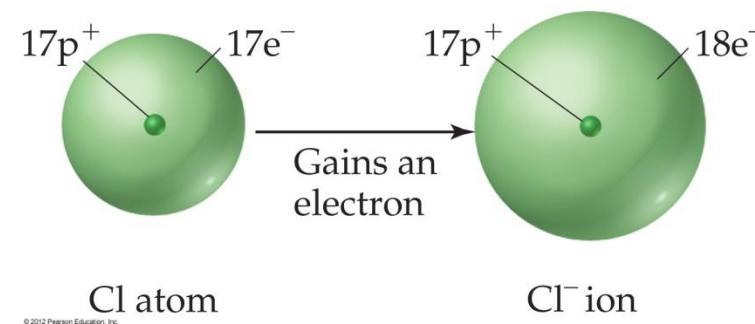
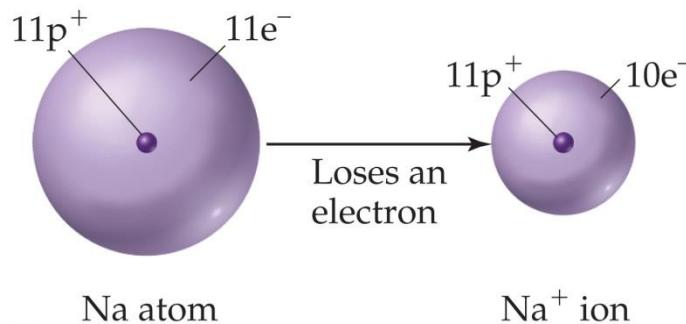
				7A	8A
				H ⁻	NOBLE GASES
			N ³⁻	O ²⁻	F ⁻
		Al ³⁺		S ²⁻	Cl ⁻
				Se ²⁻	Br ⁻
				Te ²⁻	I ⁻

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- When atoms **lose or gain electrons**, they become **ions (different chemical properties/behaviors** from neutral atoms).
 - Cations (loss): positive** & formed by elements on the **left side**.
 - Anions (gain): negative** & formed by elements on the **right side**.
- Molecules** → **polyatomic ions**

Ionic Bonds (via Electrostatic)

Ionic compounds (such as NaCl) are generally formed between metals (cation) & nonmetals (anion).



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A periodic table highlighting essential elements. The table is color-coded: red for the 6 most abundant essential elements (H, C, N, O, F, Ne), light blue for the 5 next most abundant essential elements (Li, Be, Na, Mg, Al, Si, P, S, Cl, Ar, Ga, Ge, As, Se, Br, Kr), and dark green for elements needed only in trace quantities (Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, In, Sn, Sb, Te, I, Xe, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd).

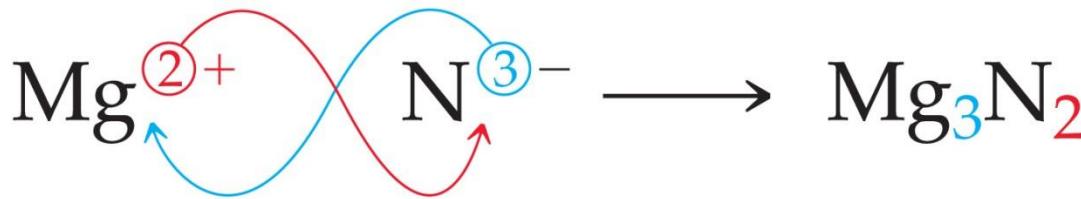
1A		8A																																	
H	He	2A																																	
Li	Be			3B			4B		5B		6B		7B		8B			1B			2B		3A			4A		5A		6A		7A		8A	
Na	Mg														8	9	10						B	C	N	O	F	He							
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn				Al	Si	P	S	Cl	Ar															
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe																		

6 most abundant essential elements

5 next most abundant essential elements

elements needed only in trace quantities

Writing Formulas



- As **compounds** are generally **electrically neutral**, one can determine the formula of a compound as follows:

- The **charge** on the **cation** becomes the **subscript** on the **anion**.
- The **charge** on the **anion** becomes the **subscript** on the **cation**.
- If these subscripts are not in the lowest whole-number ratio, divide them by the **greatest common factor** (no molecular formulas for ionic lattice: **empirical formulas**).

The elements found on the left side of the periodic table tend to _____ electrons.

- a. gain
- b. lose
- c. keep
- d. share

Why don't we write the formula for the compound formed by Ca^{2+} and O^{2-} as Ca_2O_2 ?

- A. The formula for calcium oxide is actually Ca_2O .
- B. The number of Ca^{2+} ions paired with O^{2-} ions in a compound can vary.
- C. Two Ca^{2+} ions can never be found in nature with an O^{2-} ion.
- D. Empirical formulas are used for ionic compounds.

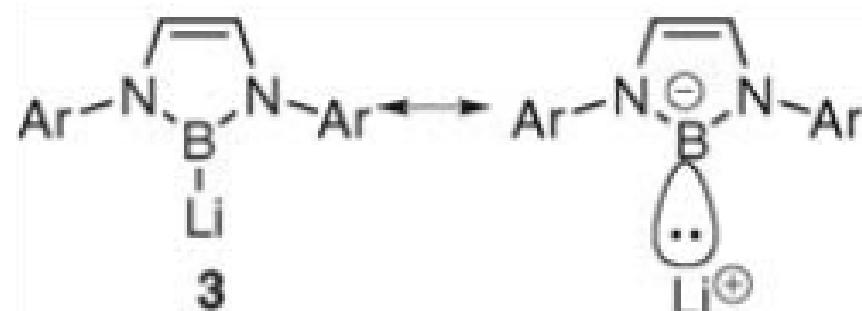
Isolation of a Boryl Anion (Extra Info.: Not included in the exam)

Boryllithium: Isolation, Characterization, and Reactivity as a Boryl Anion

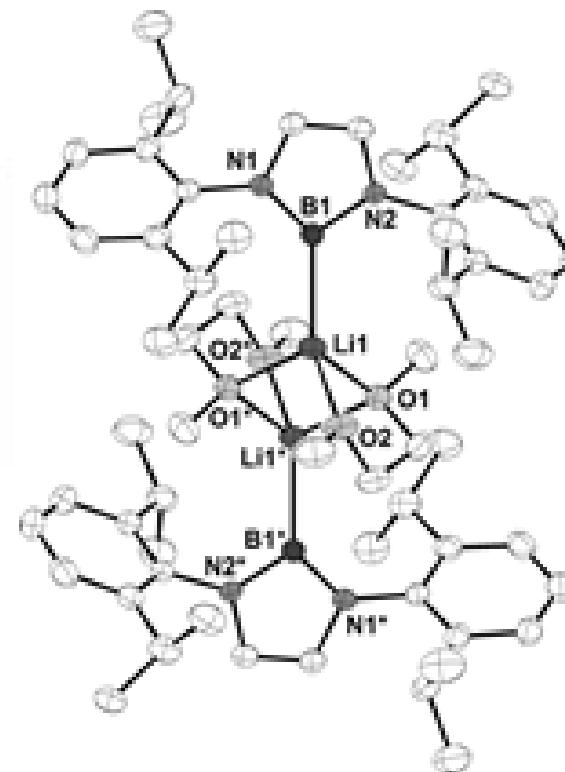
Yasutomo Segawa *et al.*

Science **314**, 113 (2006);

DOI: 10.1126/science.1131914



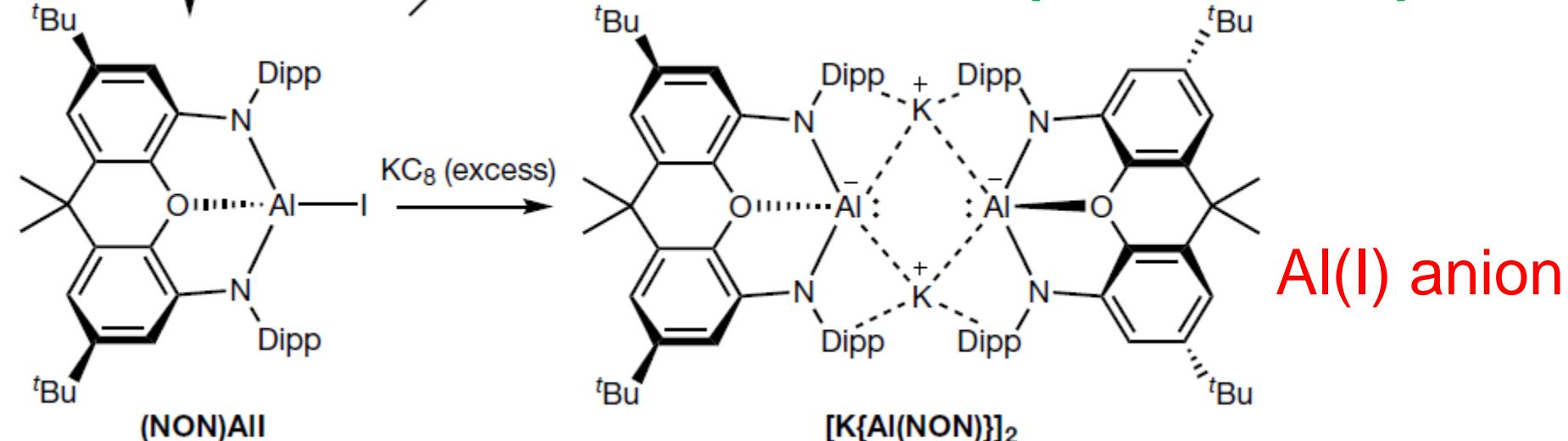
Boryl anion



Kyoko Nozaki
(Tokyo U)

Atoms,
Molecules,
and Ions

Isolation of a Al Anion (Extra Info.)

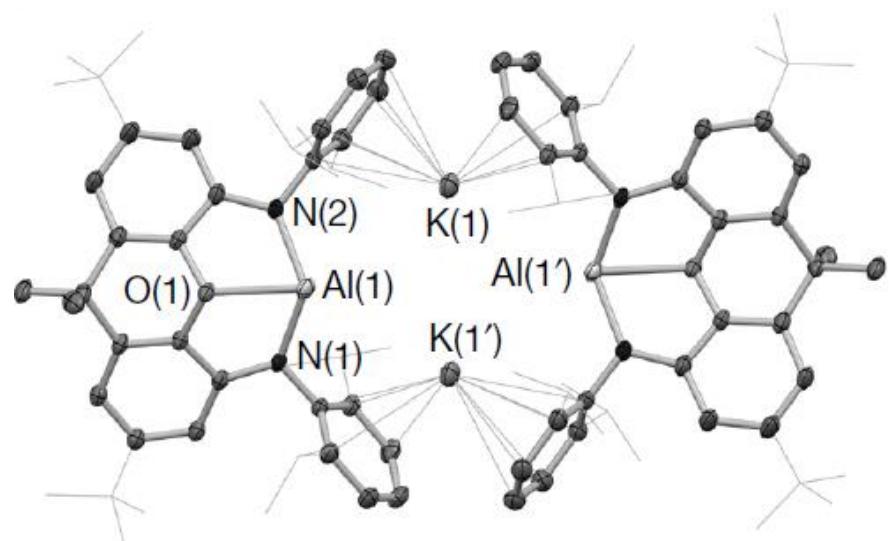


Al(I) anion

Synthesis, structure and reaction chemistry of a nucleophilic aluminyl anion

Jamie Hicks¹, Petra Vasko^{1,2}, Jose M. Goicoechea^{1*} & Simon Aldridge^{1*}

Simon Aldridge
(U of Oxford)



Naming of Inorganic Compounds

Atoms,
Molecules,
and Ions

Inorganic Nomenclature (命名)

1. Write the **name** of the **element** for the **metal cation**, e.g. iron, sodium; For **non-metal cation** (end in **-ium**): ammon**ium** ion (NH_4^+) and hydron**ium** ion (H_3O^+).

2. If the **cation** (e.g. **transition metals**) can have **more than one possible charge**, write the charge as a **Roman numeral** (罗马数字) **in parentheses** (括号).

FeSO_4 , Fe^{2+} and SO_4^{2-} Iron(II) sulfate (硫酸盐)

$\text{Fe}_2(\text{SO}_4)_3$, Fe^{3+} and SO_4^{2-} Iron(III) sulfate

3. For the **anion** of an **element**, change its ending to **-ide**. E.g.

Fe_2O_3 , Fe^{3+} and O^{2-} Iron(III) ox**ide**

Naming for Common Cations

Charge	Formula	Name	Formula	Name
1+	H ⁺ Li ⁺ Na ⁺ K ⁺ Cs ⁺ Ag ⁺	hydrogen ion lithium ion sodium ion potassium ion cesium ion silver ion	NH ₄ ⁺ Cu ⁺	ammonium ion copper(I) or cuprous ion
2+	Mg ²⁺ Ca ²⁺ Sr ²⁺ Ba ²⁺ Zn ²⁺ Cd ²⁺	magnesium ion calcium ion strontium ion barium ion zinc ion cadmium ion	Co ²⁺ Cu ²⁺ Fe ²⁺ Mn ²⁺ Hg ₂ ²⁺ Hg ²⁺ Ni ²⁺ Pb ²⁺ Sn ²⁺	cobalt(II) or cobaltous ion copper(II) or cupric ion iron(II) or ferrous ion manganese(II) or manganous ion mercury(I) or mercurous ion mercury(II) or mercuric ion nickel(II) or nickelous ion lead(II) or plumbous ion tin(II) or stannous ion
3+	Al ³⁺	aluminum ion	Cr ³⁺ Fe ³⁺	chromium(III) or chromic ion iron(III) or ferric ion

NH₄⁺: polyatomic ion
(多原子离子)

*The ions we use most often in this course are in boldface. Learn them first.

Patterns in Oxyanion Nomenclature

- When there are **two oxyanions** involving the **same element**:
 - Fewer** oxygens, ends in **-ite**.
 - More** oxygens, ends in **-ate**.

e.g.

- NO_2^- : nit**rite**; SO_3^{2-} : sulf**ite**
- NO_3^- : nit**rate**; SO_4^{2-} : sulf**ate**

HCO_3^- : **hydrogen** carbon**ate**

H_2PO_4^- : **dihydrogen** phosph**ate**

Simple
anion

_____ide
(chloride, Cl^-)

Four oxyanions

Oxyanions

per_____ate
(perchlorate, ClO_4^-)

_____ate
(chlorate, ClO_3^-)

_____ite
(chlorite, ClO_2^-)

hypo_____ite
(hypochlorite, ClO^-)

+O atom

-O atom

-O atom

Common or
representative
oxyanion

1. The second fewest oxygens, **ends** in **-ite**.
2. The second most oxygens, **ends** in **-ate**.
3. The fewest oxygens, add **prefix hypo-** and **ends** in **-ite**.
4. The most oxygens, add **prefix per-** and **ends** in **-ate**.

ClO_2^- : chlor**ite**; ClO_3^- : chlor**ate**

ClO^- : hypo**chlorite**; ClO_4^- : per**chlorate**

Naming for Common Anions

Charge	Formula	Name	Formula	Name
1−	H [−]	hydride ion	CH ₃ COO [−] (or C ₂ H ₃ O ₂ [−])	acetate ion
	F [−]	fluoride ion	ClO ₃ [−]	chlorate ion
	Cl [−]	chloride ion	ClO ₄ [−]	perchlorate ion
	Br [−]	bromide ion	NO ₃ [−]	nitrate ion
	I [−]	iodide ion	MnO ₄ [−]	permanganate ion
	CN [−]	cyanide ion		
	OH [−]	hydroxide ion		
2−	O ^{2−}	oxide ion	CO ₃ ^{2−}	carbonate ion
	O ₂ ^{2−}	peroxide ion	CrO ₄ ^{2−}	chromate ion
	S ^{2−}	sulfide ion	Cr ₂ O ₇ ^{2−}	dichromate ion
			SO ₄ ^{2−}	sulfate ion
3−	N ^{3−}	nitride ion	PO ₄ ^{3−}	phosphate ion

*The ions we use most often are in boldface. Learn them first.

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Maximum of 3 O atoms
in period 2.

Period 2

Period 3

Maximum of 4 O atoms
in period 3.

Group 4A	Group 5A	Group 6A	Group 7A
CO_3^{2-} Carbonate ion	NO_3^- Nitrate ion		
	PO_4^{3-} Phosphate ion	SO_4^{2-} Sulfate ion	ClO_4^- Perchlorate ion

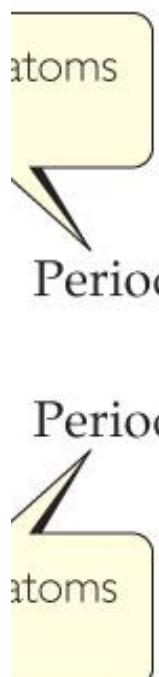
Charges increase right
to left.

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- Central atoms on the **second row** can form bonds with **at most three** oxygens; those on the **third row** can take up to **four oxygens**.
- **Negative charges increase** from *right* to *left*.

Predict the formulas for the borate ion and silicate ion, assuming they contain a single B and Si atom, respectively, and follow the trends shown in Figure 2.25.

- A. BO_4^{4-} and SiO_3^{3-}
- B. BO_3^{3-} and SiO_4^{4-}**
- C. BO_4^{3-} and SiO_3^{4-}
- D. BO_3^{4-} and SiO_4^{3-}



	Group 4A	Group 5A	Group 6A	Group 7A
Period 2	CO_3^{2-} Carbonate ion	NO_3^- Nitrate ion		
Period 3		PO_4^{3-} Phosphate ion	SO_4^{2-} Sulfate ion	ClO_4^- Perchlorate ion

Acid Nomenclature

Anion

ide
(chloride, Cl^-)

add H^+
ions

Acid

hydro_____ic acid
(hydrochloric acid, HCl)

- If the **anion** in the **acid ends** in **-ide**, change the ending to **-ic acid** and add the prefix **hydro-**.

HCl: hydrochloric acid

HBr: hydrobromic acid

HI: hydroiodic acid

ate
(chlorate, ClO_3^-)
(perchlorate, ClO_4^-)

add H^+
ions

 ic acid
(chloric acid, HClO_3)
(perchloric acid, HClO_4)

 ite
(chlorite, ClO_2^-)
(hypochlorite, ClO^-)

add H^+
ions

 ous acid
(chlorous acid, HClO_2)
(hypochlorous acid, HClO)

- If the anion in the acid ends in **-ate**, change the ending to **-ic acid**.

HClO_3 : chloric acid

HClO_4 : perchloric acid

- If the anion in the acid ends in **-ite**, change the ending to **-ous acid**.

HClO : hypochlorous acid

HClO_2 : chlorous acid

Nomenclature of Binary Compounds (with nonmetals)

TABLE 2.6 • Prefixes Used in Naming Binary Compounds Formed between Nonmetals

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

- The **less electronegative** (电负性) atom is usually named **first** (except NH₃).
- A **prefix** is used to denote the **number** of atoms of each element in the compound (**mono-** is **not used** on the first element listed, however). **Not usually used for ionic or metallic compounds.**

Atoms,
Molecules,
and Ions

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

- The name of the more electronegative element is changed to **-ide**.

CO_2 : carbon **dioxide**

CCl_4 : carbon **tetrachloride**

- If the prefix ends with **a** or **o** and the name of the element begins with a **vowel**, the two successive vowels are often changed into one.

CO : carbon **monoxide**

N_2O_5 : **dinitrogen pentoxide**

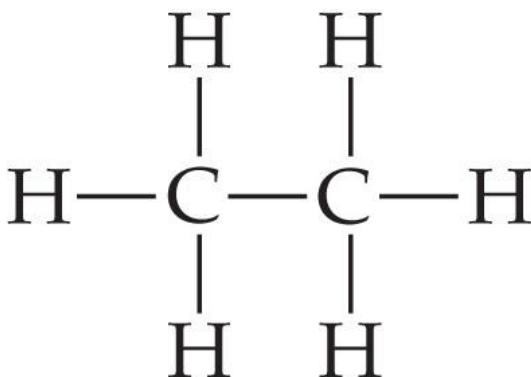
Naming of Simple Organic Compounds

Atoms,
Molecules,
and Ions

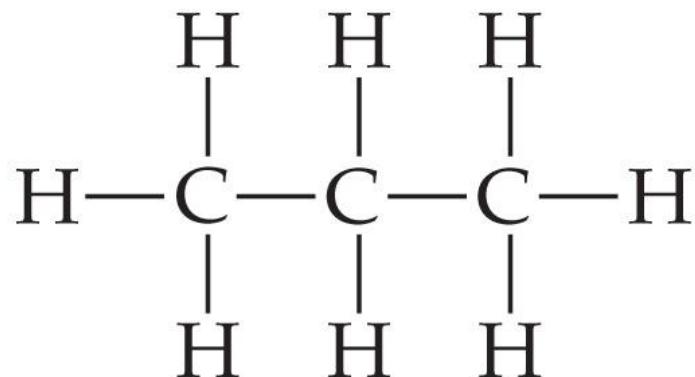
Nomenclature of Organic Compounds



Methane



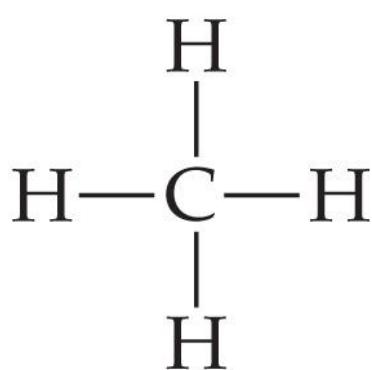
Ethane



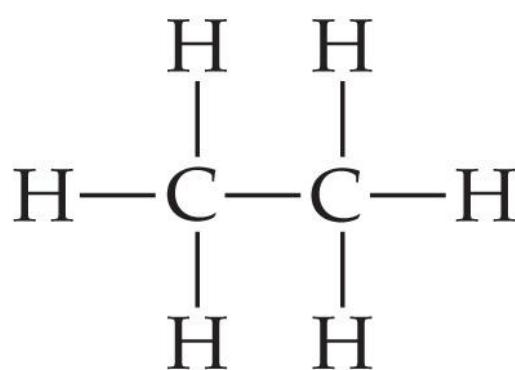
Propane

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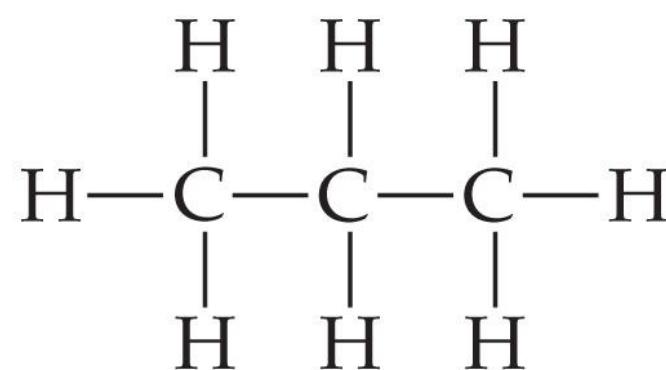
- **Organic chemistry:** the study of compounds containing **carbon**.
- Organic chemistry: its own system of nomenclature (different from inorganic chemistry).



Methane



Ethane



Propane

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The **simplest hydrocarbons** (compounds containing only carbon and hydrogen) are **alkanes**: each C atom connects with 4 other atoms.

The **first** part of the names: listed the **number (n)** of **carbons**. E.g.

$n = 1$: ***meth-***; $n = 2$: ***eth-***;

Penta-

5

$n = 3$: ***prop-***; $n = 4$: ***but-***.

Hexa-

6

For $n \Rightarrow 5$; use prefix (right table)

Hepta-

7

$n = 5$: **penta-** (pentane);

Octa-

8

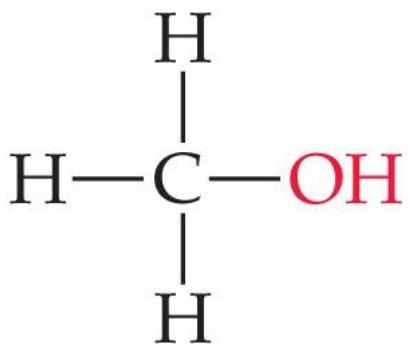
$n = 6$: **hexa-** (hexane); ... etc

Nona-

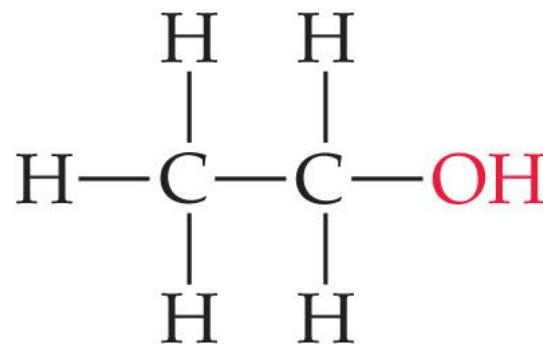
9

Deca-

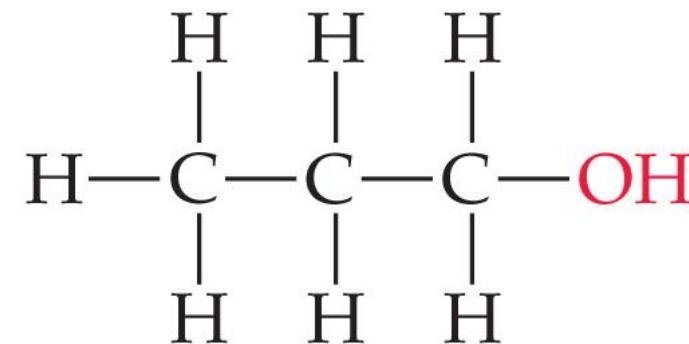
10



Methanol



Ethanol



1-Propanol

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- When a hydrogen in an alkane is replaced with something else (a **functional group**, like -OH), the name is derived from the name of the alkane.
- The ending denotes the type of a compound. E.g. an **alcohol** ends in **-ol**.

Methane → Methanol; Ethane → Ethanol;

Propane → 1-Propanol or 2-Propanol (**isomers**: same molecular formula & **different structures**)

NaOCl is named

- a. sodium chlorate.
- b. sodium chlorite.
- c. sodium perchlorate.
- d. sodium hypochlorite.

LiNO_3 is named

- a. lithium nitrate.
- b. lanthanum nitrate.
- c. lanthanum nitrite.
- d. lithium nitrite.

Fe_2O_3 is named

- a. diiron trioxide.
- b. iron(III) oxide.
- c. ferrous oxide.
- d. ironic oxide.

HIO_4 is named

- a. iodic acid.
- b. iodous acid.
- c. periodic acid.
- d. hydrogen iodate.

Cl_2O_7 is named

- a. chlorine(VII) oxide.
- b. dichlorine hexoxide.
- c. dichlorine heptoxide.
- d. bichlorine heptoxide.

C_3H_8 is named

- a. ethane.
- b. propane.
- c. propanol.
- d. pentane.

Key Summary

Atoms:

Atomic Theory; Atomic Structure (nucleus, electron, proton & neutron); Atomic Weight (atomic number; isotopes); Periodic Table (periods & groups)

Molecules:

Compounds; Chemical formula and empirical formula

Ions:

Cations, anions, ionic bonds

Naming of Inorganic & Organic Compounds

Atoms,
Molecules,
and Ions

**Thank You for Your
Attention!
Any Questions?**