The Structure of the atom

Dalton's Atomic Theory

Elements are composed of extremely small particles called atoms. All atoms of same element are alike.

The separation of atoms and union of atoms occur in chemical reactions.
In these reactions, no atom is created or destroyed, and no one atom of one element is converted into an atom of another element.

A chemical compound is the result of the combination of atoms of two or more elements in a simple numerical ratio.

The structure of the atom

Atoms are made up of the following particles:

	mass
Electrons: negatively charged	9.1095×10^{-31} kg
Protons: positively charged	1.67252×10^{-27} kg
Neutrons: neutral	1.67495×10^{-27} kg

The atom

neutrons and protons form what we call the nucleus

the mass of the nucleus constitute most of the mass of the atom

the atom is neutral in charge

elements are represented by symbols and numbers

$$^{A}_{Z}Symbol$$

A
the mass number = number of protons + number of neutrons

Z
the atomic number = number of protons =number of electrons

the number of neutrons can be calculated as
N = A –Z

Nuclides that have identical Z and different A (i.e. differ in number of neutrons) are: *isotopes*

Example $^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

All three are isotopes of hydrogen

The periodic table

Metals

Non-metals

MAIN-GROUP ELEMENTS | TRANSITION ELEMENTS | MAIN-GROUP ELEMENTS

Period	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	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** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.70	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	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** 95.94	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** 183.9	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 **Unq** (261)	105 **Unp** (262)	106 **Unh** (263)	107 **Uns** (262)	108 **Uno** (265)	109 **Une** (267)									

INNER TRANSITION ELEMENTS

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** 173.0	71 **Lu** 175.0
7	Actinides	90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (244)	94 **Pu** (242)	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** (260)

A molecule is formed from two or more atoms

H_2O **Cl_2** **NH_3**

Ions bear negative or positive charges

Na^+ **Al^{3+}** **O^{2-}**

Example

Determine the number of electrons, protons, and neutrons for

K^+, Br-, Ar, Al^{3+}

	Electrons	Neutrons	protons
$^{39}_{19}K^{+}$	**18**	**20**	**19**
$^{80}_{35}Br^{-}$	**36**	**45**	**35**
$^{40}_{18}Ar$	**18**	**22**	**18**
$^{27}_{13}Al^{3+}$	**10**	**14**	**13**

Atomic mass

The mass of an atom is related to the number of electrons , protons , and neutrons it has.

One cannot weigh a single atom, but it is possible to determine the mass of one atom relative to another experimentally.

By international agreement, an atom of the carbon isotope ^{12}C has a mass of exactly *12 atomic mass units (amu)*

Average Atomic mass

Most naturally occurring elements have more than one isotope. This means that the reported mass in the tables is the average mass of the naturally occurring mixture of isotopes.

Example:
The natural abundances of ^{12}C and ^{13}C are 98.89% and 1.11% respectively

The average atomic mass of carbon =
(0.9889)(12.0000amu) + (0.0110)(13.0335amu)
=12.01amu

Molar mass and Avogadro's number

The mole
The amount of substance that contain as many elementary entities (atoms, molecules……)
as there are atoms in exactly 12 grams of the ^{12}C isotope.

This number is determined experimentally,
the current accepted value is
1 mole = 6.022045×10^{23} particles

This number is called Avogadro's number

we have seen that
1 mole of ^{12}C has a mass of exactly 12 g
and contains 6.022×10^{23} atoms
this mass of ^{12}C is its ***molar mass***

Molar Mass
the mass of one mole of units

Numerically:
molar mass of ^{12}C in grams = atomic mass of ^{12}C in amu

the atomic mass of Na = 22.99 amu
the molar mass of Na = 22.99 g

Example:
How many grams of Mn are there in 0.356 mol of Mn

Molar mass of Mn = 54.94 g

1 mol Mn ≡ 54.94 g Mn
0.356 mol Mn ≡ x g Mn

$$x = \frac{0.356\ mol \times 54.94\ g}{1 mol} = 19.6\ g$$

Example:

How many atoms of Zn are there in 0.356 mol of Zn?

Molar mass of Zn = 65.39 g

1 mol Zn ≡ 6.022×10^{23} atoms

0.356 mol Zn ≡ x atoms

$$x = \frac{0.356 mol \times 6.022\times10^{23} atoms}{1 mol} = 2.14\times10^{23} atoms$$

Example:

Calculate the mass of one S atom.

Molar mass of S = 32.07 g

32.07 g ≡ 6.022×10^{23} atoms

x g ≡ 1 atom

$$x = \frac{1 atoms \times 32.07\ g}{6.022 \times 10^{23}\ atoms} = 5.325 \times 10^{-23}\ g$$

Naming Compounds

Ionic compounds consist of positive ions (cations) and Negative ions (anions)
Cations names are similar to that of the element

Cation	Name
Na^{+}	Sodium ion
K^{+}	Potassium ion
NH_4^{+}	Ammonium ion
Mg^{2+}	Magnesium ion
Fe^{2+}	Iron (II) or ferrous
Fe^{3+}	Iron (III) or ferric

Anions named by adding “ide” to the element’s name

Cl^-	Chloride	OH^-	Hydroxide
I^-	Iodide	NO_3^-	Nitrate
CO_3^{2-}	Carbonate	O^{2-}	Oxide
CN^-	Cyanide	SO_4^{2-}	Sulfate
		PO_4^{3-}	Phosphate

Ionic compounds names start with the positive ion followed by the negative ion

NaCl	Sodium Chloride
KI	Potassium Iodide
Na_2CO_3	Sodium Carbonate
KCN	Potassium Cyanide

$Mg(NO_3)_2$	Magnesium Nitrate
$CaSO_4$	Calcium Sulfate
$(NH_4)_3PO_4$	Ammonium Phosphate

Non-ionic compounds

HCl	Hydrogen chloride
HBr	Hydrogen bromide
CO	Carbon monoxide
CO_2	Carbon dioxide

Chemical Formulas

Simple formula(empirical formula)

The formula that is written using the simplest whole-number ratio

Molecular formula

Shows the exact number of atoms of each element in the smallest unit of a substance

Water

Simple formula: H_2O

Molecular formula: H_2O

Hydrogen peroxide

Simple formula: HO

Molecular formula: H_2O_2

Molecular weight of molecules (molar mass)

The sum of the atomic molar masses of atoms in the molecule.

Example

What is the molecular weight of CH_4?

Molecular weight of CH_4 = 12.01+4(1.008) = 16.04 g

This means that one mole of CH_4 weighs 16.04 g

Example:

How many moles are there in 6.07g of CH_4?

1 mol $CH_4 \equiv$ 16.04 g

x mol $CH_4 \equiv$ 6.07g

$$x = \frac{6.07\ g \times 1mol}{16.04\ g} = 0.378\ mol$$

Example

Determine the molecular formula of a compound that has a simple formula of P_2O_5 and a molecular weight of 284g/mol.

Molar mass of the simple formula = (31×2)+(16×5)=142g

The ratio between the two formulas = $\frac{284\ g}{142\ g} = 2$

The molecular formula of the compound =

$P_{(2x2)}O_{(5x2)} = P_4O_{10}$

Percent composition of a compound

The percent composition by mass is the percent by mass of each element the compound contains.

Example

The percent composition of H_2O is calculated as follows:

$$\%H = \frac{2 \times 1.008\, g}{18.016} \times 100 = 11.19\%$$

$$\%O = \frac{16.0\, g}{18.016} \times 100 = 88.8\%$$

Problem:

Calculate the percent composition of H_2O_2.

Example:

Vitamin C is composed of 40.92% carbon (c), 4.58% hydrogen (H), and 54.5% oxygen (O). determine the empirical formula of vitamin C.

Because the sum of the percentages is 100 it is appropriate to consider 100 grams of vitamin C

In a 100g of Vitamin C there will be:
40.92gC
4.58g H
54.50gO

using the molar mass of the elements we can find out number of moles:

$$n_C = \frac{40.92g}{12.01g/mol} = 3.407mol$$

$$n_H = \frac{4.58g}{1.008g/mol} = 4.54mol$$

$$n_O = \frac{54.50\,g}{16.00\,g\;/\,mol} = 3.406\,mol$$

the formula that gives the ratios of the atoms in vitamin C is $\mathbf{C_{3.407}H_{4.54}O_{3.406}}$

To arrive to the simple formula we have to convert these numbers to whole numbers by dividing all subscripts by the smallest one

C: $$\frac{3.407}{3.406} = 1$$

H: $$\frac{4.54}{3.406} = 1.33$$

O: $$\frac{3.406}{3.406} = 1$$

Now the formula is : $C_1H_{1.33}O_1$

We still need to convert 1.33 to an integer

This can be done by trial and error:

$1 \times 1.33 = 1.33$
$2 \times 1.33 = 2.66$
$3 \times 1.33 = 3.99 \approx 4$

so we have to multiply all subscripts by 3 to get the smallest whole numbers in the formula

$C_{1x3}H_{3x1.33}O_{3x1}$
The simple formula of vitamin C is $C_3H_4O_3$