Chemistry
Teach Yourself Series
Topic 7: Mole theory and stoichiometry

A: Level 14, 474 Flinders Street Melbourne VIC 3000
T: 1300 134 518 **W:** tssm.com.au **E:** info@tssm.com.au

Contents

Amounts in chemistry 3
Mole theory 3
As it appears in Units 1 & 2 3
Review questions 5
Review questions 6
Solutions 7
As it appears in Units 2 & 3 7
Review questions 8
Mole and gases 9
As it appears in Units 2 & 3 9
Review questions 9
Stoichiometry 10
As it appears in Units 2 & 3 10
Review questions 11
Solutions to Review Questions 12

Amounts in chemistry

Ever baked a cake? If you have, you will know that the exact ratio of each ingredient is important for the cake to be a good one. It is also costly to buy the same amount of each ingredient. This leads to considerable waste of sometimes costly ingredients.

The chemical industry is similar to the cake industry! All over the world, chemicals are produced in very large volumes. The cost is very high. Companies cannot afford to waste raw materials by not reacting chemicals in the correct amounts. Mole theory was instituted to ensure that scientists know exactly how much chemical they are dealing with.

Mole theory

As it appears in Units 1 & 2

Magnesium can react with sulfur to form magnesium sulfide.

$$Mg + S \rightarrow MgS$$

	Mg	+	S	→	MgS
	1 atom		1 atom		1 MgS
but	1 g.	+	1 g.		will lead to left over magnesium

This means that one atom of magnesium reacts with 1 atom of sulfur to form one magnesium sulfide. However, magnesium and sulfur have different masses, so 1 g. of magnesium is not a match for 1 g. of sulfur. This would be a considerable waste of magnesium.

Amounts					**Masses**		
Mg	**+**	**S**	**→**	**MgS**	**Mg**	**+**	**S**
1 atom	+	1 atom		1 MgS	24.3	:	32
10 atoms	+	10 atoms		10 MgS	10 x 24.3	:	10 x 32
1200 atoms	+	1200 atoms		1200 MgS	1200 x 24.3	:	1200 x 32
23400 atoms	+	23400 atoms		24300 MgS	23400 x24.3	:	23400 x 32

Conclusion:
For an exact ratio of magnesium to sulfur, the masses must be in the same ratio as the relative atomic masses.
Therefore, if you use the relative atomic masses you can predict equal amounts of magnesium and sulfur i.e. 24.3 g of magnesium will react with 32 g of sulfur or 48.6 g of magnesium reacts with 64 g of sulfur.

Mole theory uses masses that match the relative atomic masses from the Periodic Table. Carbon (^{12}C in fact is chosen as the standard)

> **1 mole** is the **amount** of substance that contains **6.023 x 10^{23}** particles.
>
> This value came from a choice of 12 g of ^{12}C as a standard (matching the relative atomic mass)

Mole = amount of substance: symbol n: unit ***mol***

6.023 x 10^{23} is known as Avogadro's number and has a symbol N_A

	number of particles	**mass, g**
1 mole of hydrogen atoms, H	6.023 x 10^{23} atoms of hydrogen	1
1 mole of hydrogen molecules, H_2	6.023 x 10^{23} molecules of H_2 2 x 6.023 x 10^{23} atoms of hydrogen	2
1 mole of magnesium atoms, Mg	6.023 x 10^{23} atoms of magnesium	24.3
1 mole of lead atoms, Pb	6.023 x 10^{23} atoms of lead	207
1 mole of water molecules, H_2O	6.023 x 10^{23} molecules of water, 3 x 6.023 x 10^{23} atoms	18
1 mole of magnesium sulfide, MgS	6.023 x 10^{23} atoms of magnesium and 6.023 x 10^{23} atoms of sulfur	56.3
2 mole of carbon atoms, C	2 x 6.023 x 10^{23} atoms of carbon	24
4 mole of carbon dioxide molecules, CO_2	4 x 6.023 x 10^{23} molecules of CO_2	176

Note: mole does not refer solely to atoms, it can refer to molecules or ions

Example

Calculate the number of

a. atoms in 6 mol of lithium
b. atoms in 0.2 mol of copper
c. molecules in 4 mol of oxygen gas, O_2
d. atoms in 4 mol of oxygen gas, O_2

Solution

a. 6 x 6.02 x 10^{23} = 3.61 x 10^{24}
b. 0.2 x 6.02 x 10^{23} = 1.20 x 10^{23}
c. 4 x 6.02 x 10^{23} = 2.41 x 10^{24}
d. 4 x 2 x 6.02 x 10^{23} = 4.82 x 10^{24}

Review questions

1. Calculate the number of
- **a**. atoms in 2 mol of lead ______________________
- **b**. atoms in 3 mol of magnesium ______________________
- **c**. molecules in 0.6 mol of nitrogen gas, N_2 ______________________
- **d**. atoms in 0.6 mol of nitrogen gas, N_2 ______________________
- **e**. atoms in 3.4 mol of water, H_2O ______________________

1 mole of sulfur contains 6.02×10^{23} atoms of sulfur. It has a mass of 32 g.
This is referred to as the **molar mass.**

Molar mass = mass of 1 mole, symbol M, unit g mol^{-1}

Molar mass of hydrogen atoms = 1 g mol^{-1}
Molar mass of hydrogen molecules, H_2 = 2 g mol^{-1}
Molar mass of water, H_2O = 2 x 1 + 16 = 18 g mol^{-1}
Molar mass of zinc oxide, ZnO = 65.4 + 16 = 82.4 g mol^{-1}

Calculating mole
12 g of carbon = 1 mol
=> 6 g of carbon = 0.5 mol
=> 36 g of carbon = 3 mol

$$n = \frac{m}{M} \qquad \text{or} \qquad m = n \times M$$

where n = mol, m = mass, M = molar mass

Example 1

Calculate the mass of
a. 1.4 mol of copper **b.** 0.48 mol of nitrogen gas **c.** 2.64 mol of NaCl

Solution
a. $m = n \times M = 1.4 \times 63.6 = 89 g$ **b**. $m = n \times M = 0.48 \times 28 = 13.4 g$ **c.** $m = n \times M = 2.64 \times 58.5 = 154\ g$

Example 2

Calculate the number of mole in
a. 50 g of magnesium **b.** 2.88 g of water **c.** 0.32 g of hydrogen gas

Solution

a. $n = \frac{m}{M} = \frac{50}{24.3} = 2.06 mol$ **b**. $n = \frac{m}{M} = \frac{2.88}{18} = 0.16 mol$ **c.** $n = \frac{m}{M} = \frac{0.32}{2} = 0.16 mol$

Review questions

2. Calculate the molar mass of

a. calcium

b. chlorine gas, Cl_2

c. hydrochloric acid, HCl

d. Na_2SO_4

3. Calculate the mass of

a. 2.4 mol of potassium

b. 5.56 mol of hydrogen gas

c. 0.36 mol of sodium fluoride, NaF

d. 1.12 mol of Na_2SO_4

4. Calculate the number of mole in

a. 20 g of silicon

b. 220 g of silicon dioxide, SiO_2

c. 0.88 g of Al_2S_3

5. Calculate the number of atoms in 100 g of water

6. Given 500 g of calcium carbonate, $CaCO_3$, calculate

a. the number of mole of $CaCO_3$

b. the number of mole of ions

c. the number of calcium ions

d. the number of oxygen atoms

Solutions

As it appears in Units 2 & 3

In a solution, the volume of water is also relevant. Calculations need to involve **concentration**.

A solution is likely to be **concentrated** if

- the **mass of solid added is high** and/or
- the **volume of water used is low**.

$$\boldsymbol{c = \frac{n}{V}} \qquad \textbf{or} \qquad \boldsymbol{n = c \times V}$$

where n = mol, c = concentration, V = volume
Unit for concentration is M for molarity.

(Again, mole should be used in this formula, not mass, because different substances weigh different amounts)

A 2.0 M solution of HCl contains 2 mole of HCl in every litre of solution.

Note: It is difficult to avoid confusion between the symbols m and M.
m = mass, but M can refer to the molar mass or to the concentration of a solution. The context of the question is needed to distinguish which quantity M is referring to.

Example 1
Calculate the concentration if
a. 0.24 mol of LiOH is dissolved in 400 mL
b. 1.2 mol of NaCl is dissolved in 10 L of water

Solution
a. $c = \frac{n}{V} = \frac{0.24}{0.4} = 0.6M$
b. $c = \frac{n}{V} = \frac{1.2}{10} = 0.12M$

Example 2
Calculate the number of mole in
a. 1.5 L of 0.4 M NaOH solution
b. 460 mL of 0.12 M HCl solution

Solution

a. $n = c \times V = 1.5 \times 0.4 = 0.6\ mol$

b. $n = c \times V = 0.12 \times 0.46 = 0.0552\ mol$

Example 3
Sometimes a question involves use of **both formulas**.
Technique: Establish which symbols are supplied and which symbol is asked for.

Calculate the concentration of a solution formed when 60 g of NaOH is added to 600 mL of water
c = ? m= 60 g V = 0.6 L

$c = \frac{n}{V}$ but n has to be found first using $n = \frac{m}{M}$

$n = \frac{m}{M} = \frac{60}{40} = 1.5 mol$ $c = \frac{n}{V} = \frac{1.5}{0.6} = 2.5 M$

Review questions

7. Calculate the concentrations of the following solutions
- **a.** 0.22 mol of NaCl in 356 mL
- **b.** 1.6 mol of HCl in 3.4 L of water

____

____

8. Calculate the number of mole in the following solutions:
- **a.** 500 mL of 2.5 M HCl
- **b.** 2.5 L of 0.2 M KI

____

____

9. Calculate the mass of KI in 240 mL of 0.6 M solution

____

____

Mole and gases

As it appears in Units 2 & 3

Mole theory is used with gases as well as with solutions. For gases

$$n = \frac{PV}{RT}$$

where n = mol, P = pressure (kPa), R = constant = 8.31, T = temperature K, V = volume, L

Since all gases behave the same, the identity of the gas does not affect the calculation

Example

A sample of nitrogen gas occupies a volume of 70 L at 200 kPa and 100 °C.
How many mole of nitrogen is present?

$$n = \frac{PV}{RT} = \frac{200x70}{8.31x373} = 4.52mol$$

Review questions

10. Calculate the number of mole of helium in a 6.6 L container that has a pressure of 120 kPa at 86 °C

____

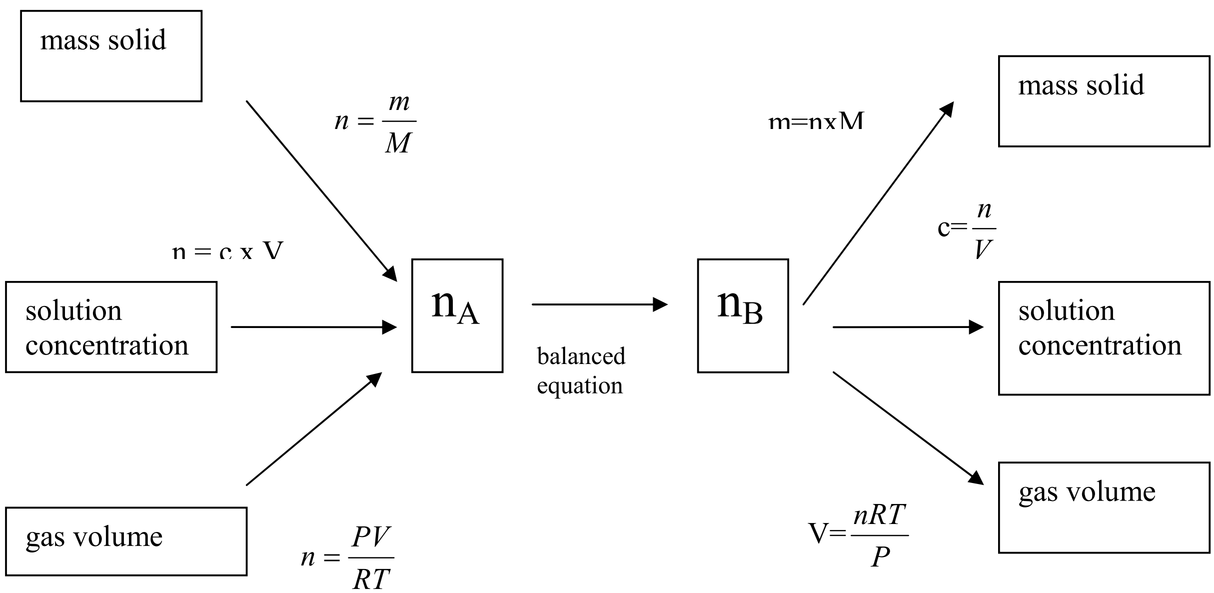
____

Stoichiometry

As it appears in Units 2 & 3

Correct calculation of amounts of product relies upon balanced equations and mole theory.

Most stoichiometry follows the outline below. The number of mole must be calculated, then the balanced equation is used to determine the mole ratio between substances.



Example
Calculate the mass of $AlCl_3$ formed from

- **a.** 50 g of Al
- **b.** 200 mL of 2.0 M HCl
- **c.** Calculate the volume of hydrogen gas produced at 100 kPa and 100 C from the 50 g of Al

Solution

a. a. $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$
m= 50 g m=?
This question matches the top section of the flowchart above.

$$n(Al) = \frac{m}{M} = \frac{50}{27} = 1.85mol$$

$$n(\text{AlCl}_3) = n(\text{Al}) = 1.85mol$$

$$mass(\text{AlCl}_3) = nxM = 1.85\text{x } 133.5 = 247\ g$$

b. $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

c=2 M, V=0.2 L m=?

Information this time is about a solution – the middle path of the flowchart is used.

$n(HCl) = c \times V = 2 \times 0.2 = 0.4$ mol

$n(AlCl_3) = 2/6 \times n(HCl) = 1/3 \times 0.4 = 0.133$ mol

$mass(AlCl_3) = n \times M = 0.133 \times 133.5 = 17.8\ g$

c. $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

m= 50 g V=

This time a gas calculation is required.

$n(Al) = 1.85\ mol$ from earlier

$n(H_2) = 3/2 \times n(Al) = 3/2 \times 1.85 = 2.78\ mol$

$$V = \frac{nRT}{P} = \frac{2.78 x 8.31 x 373}{100} = 86L$$

Review questions

11. The reaction between aluminium and oxygen is

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

a. Calculate the mass of Al_2O_3 that can be formed from 2.6 g of aluminium

b. Calculate the volume of oxygen gas required at 130 C and 101 kPa to produce 210 g of Al_2O_3

c. How many mole of Al_2O_3 can be formed from 0.112 g of oxygen gas?

Solutions to Review Questions

1. **a**. $2 \times 6.02 \times 10^{23} = 1.20 \times 10^{24}$
   b. $3 \times 6.02 \times 10^{23} = 1.81 \times 10^{24}$
   c. $0.6 \times 6.02 \times 10^{23} = 3.61 \times 10^{22}$
   d. $0.6 \times 2 \times 6.02 \times 10^{23} = 7.22 \times 10^{23}$
   e. $3.4 \times 3 \times 6.02 \times 10^{23} = 6.14 \times 10^{24}$

2. **a**. 40 g mol^{-1}
   b. 71 g mol^{-1}
   c. 36.5 g mol^{-1}
   d. $23 \times 2 + 32 + 64 = 142$ g mol^{-1}

3. **a**. m = 2.4 x 39.1 = 93.8 g
   b. m =5.56 x 2 = 11.12 g
   c. m = 0.36 x 42 = 15.1 g
   d. m= 1.12 x 142 = 159 g

4. **a.** $n = \frac{m}{M} = \frac{20}{28.1} = 0.71 mol$

   b. $n = \frac{m}{M} = \frac{220}{88.2} = 2.49 mol$

   c. $n = \frac{m}{M} = \frac{0.88}{150} = 0.0059 mol$

5. $n = \frac{m}{M} = \frac{100}{18} = 5.56 mol$

   Number of molecules = $5.56 \times 6.02 \times 10^{23}$
   As H_2O, each molecule has 3 atoms
   Number of atoms = $3 \times 5.56 \times 6.02 \times 10^{23} = 1.00 \times 10^{25}$

6. $n = \frac{m}{M} = \frac{500}{100} = 5 mol$

   a. 5
   b. 10 as $CaCO_3$ hastwo ions, Ca^{2+} and CO_3^{2-}
   c. $5 \times 6.02 \times 10^{23} = 3.01 \times 10^{24}$
   d. $5 \times 3 \times 6.02 \times 10^{23} = 9.03 \times 10^{24}$

7. **a.** $c = \frac{n}{V} = \frac{0.22}{0.356} = 0.62M$

b. $c = \frac{n}{V} = \frac{1.6}{3.4} = 0.47M$

8. **a.** $n = c \text{ x } V = 2.5 \text{ x } 0.5 = 1.25\ mol$
b. $n = c \text{ x } V = 2.5 \text{ x } 0.2 = 0.5\ mol$

9. $n = c \text{ x } V = 0.24 \text{ x } 0.6 = 0.144\ mol$

$m = n \text{ x } M = 0.144 \text{ x } 166 = 23.9\ g$

10. $n = \frac{PV}{RT} = \frac{120x6.6}{8.31x359} = 0.265mol$

11. The reaction between aluminium and oxygen is

$$4Al(s) + 3O(g) \rightarrow 2AlO(s)$$

a. $n = \frac{m}{M} = \frac{2.6}{27} = 0.096mol$ $n(Al_2O_3) = ½\ n(Al) = 0.048mol$
$m(Al_2O_3) = n \text{ x } M = 0.048 \text{ x } 102 = 4.90\ g$

b. $n(Al_2O_3) = 210/102 = 2.06\ mol$

$n(O_2) = 3/2 \text{ x } n(Al_2O_3)$

$V = \frac{nRT}{P} = \frac{3.09x8.31x403}{101} = 102.5L$

c. $n = \frac{m}{M} = \frac{0.112}{32} = 0.0035mol$

$n(Al_2O_3) = 2/3\ n(O_2) = 0.00233mol$