Chapter 3: Calculations with Chemical Formula and Equations

3.4 Avogadro's Number

Mole : SI-Unit to measure amount of substance

Kg ------- mass
ml ------- vol
mole------ atoms & molecules

1 mole atoms = 6.022×10^{23} atom
1 mole molecules = 6.022×10^{23} molecule (Note: 1Kg water= 1000g water, etc...)
1 mole ions = 6.022×10^{23} ions

6.022×10^{23} = Avogadro's Number (N_A)

Atomic Mass (M.wt) & Molar Mass (MM): (From Periodic Table)

Σ Atoms-----give molecule
H, H, O atoms give H_2O molecule

** Atomic Mass (M.wt): for atoms
Unit of M.wt is (amu or g/mol)

Ex. M.wt for Carbon atom (C) in the Periodic Table is 12 amu (g/mol of atom)

** Molar Mass (MM): for molecules
Unit of M.wt is (g element/mol of compound) = g/mol

Ex. MM for $C_6H_{12}O_6$ molecule is
(12x6) + (1x12) + (16x6) = 180g/mol

Q: Find atomic mass (M.wt) and molar mass (MM) of each of the following?

1- S
2- As
3- CH_3CH_2OH
4- $HClO_4$

*** **Mole Calculations:**

$$\text{mole} = \frac{\text{mass}}{\text{molar mass}}$$

$$n = \frac{m}{MM \text{ or } M.wt}$$

Note:
Always deal with moles not with grams

Ex: How many moles are there in 62.5 grams of $NaHCO_3$ Solution?

Soln:

$M.wt(NaHCO_3) = 23 + 1 + 12 + (3\times16) = 84$ g/mol

$$n = \frac{m}{M.wt}$$

$$n = \frac{62.5\ g}{84\ g/mol} = 0.744 \text{ mol}$$

Note:
A molar mass can also be called a molecular mass or formula weight

Ex: How many atoms are there in 46 grams of carbon?

Soln:

$$n = \frac{46 \text{ g carbon}}{12 \text{ g/mol carbon}} = 3.83 \text{ mol}$$

Now, $1 \text{ mol} \longrightarrow 6.022\times10^{23}$ atom

$3.83 \text{ mol} \longrightarrow X$ atoms

$$\therefore X = \frac{(6.022\times10^{23} \text{ atom})(3.83 \text{ mol})}{1 \text{ mol}} = 2.3\times10^{24} \text{ atom}$$

Note:
We can solve these questions by these Laws:

1) no. of atoms = n X N_A

2) no. of molecules = n X N_A

3) no. of atoms in molecules = n X N_A X no. of atoms

*** Solve the last examples given with these laws .....

Ex.1: How many oxygen atoms are in 0.25 mol of $Ca(NO_3)_2$?

Soln: by law (3):
no. of O atoms in $Ca(NO_3)_2$ = 0.25 X 6.022×10^{23} X 6
= 9.03×10^{23} atom

Ex.2: How many molecules of ethane (C_2H_6) are present in 0.334 g of C_2H_6?
Soln: by law (2):
no. of molecules = n x N_A
= 0.011 x 6.022×10^{23}
= 6.70×10^{21}

n = m/M.wt
=0.334/(12x2+1x6) = 0.011

Ex.3: The density of water is 1.00 g/mL at 48° C. How many water molecules are present in 2.56 mL of water at this temperature?
Soln:

d = mass/volume(L)
» m = d x V
= 1g/ml x 2.56 ml = 2.56 g of H_2O

»»» n = mass/M.wt
= 2.56g/18g/mol = 0.142 mol

Now,
By law (2)
no. of molecules = n x N_A
= 0.142 x 6.022×10^{23}
= 8.56×10^{22}

Note:
Molarity (M) = n/vol

If he asked you about molarity find n from no. of molecules as above then find the molarity...

Law (2): no. of molecules = n x N.A
» n = no. of molecules/N.A

»»» M = n/vol. (he give you the volume or from V = m/d)

Questions:
1) Calculate the number of O atoms in 1.50 g of glucose ($C_6H_{12}O_6$)?
Ans: 3.01×10^{22}

2) $C_{19}H_{38}O$ is about 1.0×10^{-12} g. How many molecules are in this quantity?
Ans: 2.1×10^{9}

3) What is the mass of 22 molecules (CH_3CO_2H) ?(Hint: begin with law 2)
Ans: 2.19×10^{-21}

4) What is the volume of 6.2×10^{22} molecules $CHBr_3$ (MM=253g/mol)? (d=3.92g/ml)
Ans: 6.65ml

***** Remember *****

$$A + B \longrightarrow C$$

Reactants Product

Physical state of all reactants and products are indicated using subscripts:

(s) = solid (l) = liquid (g) = gas (aq) = aqueous (ions or compounds in solutions)

How to Balance ...?

- Write the unbalanced equation, including the correct formulas, for all reactants and products.
- Compare the number of atoms on the reactants and product(s) sides.
- Balance the elements by changing the number of molecules or ions with coefficients (the numbers placed before formulas, i.e., Number of moles of a substance), *only these coefficients can be changed when balancing an equation; the formulas themselves can't be changed.* Do not change the molecules or ions.

Add these *mefficients* to balance the equation

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

$$H_2 + O_2 \longrightarrow H_2O_2$$

NOT ALLOWED! When this subscript is added, we get a completely different reaction.

* Always balance the heavier atoms (C,O,N,...) before trying to balance lighter ones such as (H).
- If necessary, continue to rebalance and recheck.
- Consider reducing the coefficients so that the smallest possible whole numbers are used. Fractions can be used for oxygen gas.

Ex. Balance the equation: $CH_4 + O_2 \longrightarrow CO_2 + H_2O$

1- Identify the number of atoms:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

#C	1	1
#O	2	3
#H	4	2

2- Balance the oxygen

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

#C	1	1
#O	4	4
#H	4	4

3- Recheck (notice that the hydrogen is automatically balanced in this example):

Ans: $CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$

Q: balance the equations:

1) $C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$

2) $KClO_3 + C_{12}H_{22}O_{11} \longrightarrow KCl + CO_2 + H_2O$

3) $HCl_{(aq)} + CaCO_{3(s)} \longrightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$

** Treat polyatomic as ONE UNIT-Do not breaks them up into atoms

4) $Al_2(SO_4)_{3(aq)} + Ba(NO_3)_{2(aq)} \longrightarrow BaSO_{4(s)} + Al(NO_3)_{3(l)}$

3.6 Quantitative Information of Balanced Equation

Stoichiometry: establishes the quantities of reactants (used) and products (obtained) based on a balanced chemical equation.

With a balanced equation, you can compare reactants and products, and determine the amount of products formed or the amount or reactants needed to produce a certain amount of a product.

- when comparing different compounds in a reaction, you must always compare in moles (i.e. coefficients)

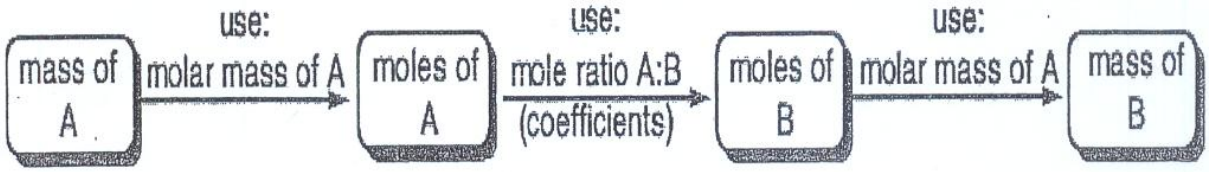
Ex. Show the Stoichiometry for this rxn.?

$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$

Ans:

1mol 2mol ⟶ 1mol 2mol

** How to calculate amount of reactants or products using "mole method"



Ex: How many grams of water are produced when 24.3 g of methane is reacted with excess oxygen?

$$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$$

Ans: 1) Write equation contains only the two compounds that he talks about:
2) Find n (moles) of reactants
3) do the calculations by " mole method "

$$CH_4 \longrightarrow 2\ H_2O$$

$$n = \frac{m}{M.wt}$$

$$= \frac{24.3\ g}{(12+4\times1)\ g/mol}$$

$$= 1.52\ mol$$

Now,

$$1\ mol \longrightarrow 2\ mol$$

$$1.52\ mol \longrightarrow X\ (mols\ H_2O)$$ [you can use mole ratio which is easy]

$$x = \left(\frac{2}{1}\right) \times 1.52 = 3.04\ mol$$

$$moles\ C = \left(\frac{c}{a}\right) \times moles\ A$$

$$x = \left(\frac{2}{1}\right) \times 1.52 = 3.04\ mol$$

$$\therefore\ mass\ H_2O = n \times M.wt$$

$$= 3.04 \times 18 = 54.72\ g$$

Ex: In one reaction, 0.507 mole of $SiCl_4$ is produced. How many grams of chlorine (Cl_2) were used in the reaction?

$$Si_{(s)} + 2Cl_{2(g)} \longrightarrow SiCl_{4(l)}$$

Ans:

$$2mol\ Cl_2 \longrightarrow 1mol\ SiCl_4$$
$$X \longrightarrow 0.507\ mol$$

$X = (2/1)\times(0.507) = 1.014$ mol

» $m\ (Cl_2) = n \times M.wt$

$= 1.014\ g \times 71\ g/mol = 71.994\ g$

Q. given the equation: $KCN_{(aq)} + HCl_{(aq)} \longrightarrow KCl_{(aq)} + HCN_{(g)}$

If a sample of 0.140 g of KCN is treated with an excess of HCl, calculate the amount of HCN formed, in grams:

Ans: 0.0581 g

3.7 Limiting Reactant (L.R)

» The reagent that is consumed first in a reaction is called "limiting reactant or reagent". In previous examples, the assumption was that one reactant was in excess and the other was the limiting reactant.

» Method of finding the limiting reactant is calculating the amount of product that could be formed from each reactant. The reactant that produces the least amount (moles) is limiting reagent.

Ex1: Identify the limiting reactant and how much ammonia gas can be produced when 8 g of nitrogen gas reacts with 8 g of hydrogen gas by:

$$3H_2 + N_2 \longrightarrow 2NH_3$$

Ans:

$n = \frac{m}{M.wt}$ $n = \frac{m}{M.wt}$

$= \frac{8}{1x2}$ $= \frac{8}{14x2}$

$= 4$ mol $= 0.286$ mol

» Find L.R. by dividing each moles on the coefficient (least »» L.R.):

» 4/3 0.286/1

=1.3 =0.286 (L.R.)

»» Now, Find the amount of product with respect to L.R.

» 1mol N_2 ⟶ 2mol NH_3

0.286mol ⟶ X

↓

(Before dividing on coefficient)

» X = (2/1) x 0.286 = 0.572 mol

» m = n x M.wt

= 0.572 x (14+1x3) =9.724 g

Q1: Nitric oxide (NO) reacts with oxygen gas to form nitrogen dioxide (NO_2), a dark-brown gas:

$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$

In one experiment 0.886 mole of NO is mixed with 0.503 mole of O_2. Calculate the number of moles of NO_2 produced?

Ans: 0.886 mol

Q2: Consider the reaction $MnO_2 + 4HCl \longrightarrow MnCl_2 + Cl_2 + 2H_2O$

If 0.86 mole of MnO_2 and 48.2 g of HCl react, how many grams of Cl_2 will be produced?

Ans: 23.4 g

>>> Excess Reagent

$$\text{n. Excess (remained)} = \left[\text{n. total(excess)}\right] - \left[\text{n. reacted (excess)}\right]$$

$\Longrightarrow$ mass Excess = n.(excess) x Mwt.

Ex. In the example 1 (page 10) calculate the mass of excess in g ?

Since H_2 is excess,

n. H_2 = n.total H_2 – n. H_2 reacted (L.R.)

= 4 mol - [(3/1) x 0.286]

= 4 – 0.858

= 3.142 mol

$\Longrightarrow$ m. excess = 3.142 mol x 2 g/mol(H_2) = 6.284 g

Q. Assume that 10g of K_2PtCl_4 and 10g of NH_3 are allowed to react, how many grams of the excess reactant are consumed, and how many grams remain?

$$K_2PtCl_4 + 2NH_3 \longrightarrow Pt(NH_3)Cl_2 + 2KCl$$

Ans.:

NH_3 is excess

Grams of NH_3 consumed =0.819 g

Grams of NH_3 not consumed =9.2 g

ent Yield (% Yield)

centage yield is a ratio of the actual yield (Experimentally) of a product over the d one, known as the theoretical yield (Calculations).

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

=--
l yield < Theoretical yield

From the Ex1, what is the percent yield, if only 8.2 g of ammonia is produced?

$$\text{ield} = \frac{8.2}{9.724} \times 100$$
$$= 84.33\ \%$$

= How you can differentiate between actual & theoretical yield in the question ...?

he said words such as:
oduced ... gram, the amount of product was _ gram, the yield is _ g, found to be ... ım .
it means Actual yield

Years Questions

1) What is the mass in gram of $1x10^{12}$ lead (Pb) atoms?

A. 3.44×10^{-10} g B. 1.27×10^{-6} g C. 3.20×10^{7} g D. 4.12×10^{9} cm

2) Given the reaction:

$$CaF_2 + H_2SO_4 \longrightarrow CaSO_4 + 2HF$$

In one process 6.00 kg of CaF_2 are treated with an excess of H_2SO_4 and yield 2.86 kg of HF. Calculate the percent yield of HF?

A. 70.7 % B. 82.6 % C. 93.0 % D. 97.1 %

3) Given the reaction:

$$2\,NH_{3(g)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(aq)}$$

How many kilograms (kg) of NH3 are needed to produce 1×10^5 kg of $(NH_4)_2SO_4$

A. 2.58×10^{-4} kg B. 2.58×10^{2} kg C. 2.58×10^{7} kg D. 2.58×10^{4} kg

4) Given the reaction:

$$FeTiO_3 + H_2SO_4 \longrightarrow TiO_2 + FeSO_4 + H_2O$$

$8x10^3$ kg of $FeTiO_3$ yielded $3.67x10^3$ kg of TiO_2. What is the percent yield?

A. 87.1 B. 64.0 C. 75.5 D. 89.4

5) Ethylene (C_2H_4) can be prepared by heating hexane (C_6H_{14}) at 800°C:

$$C_6H_{14} \longrightarrow C_2H_4 + \text{other products}$$

If the yield of ethylene production is 42.5%, what mass of hexane (C_6H_{14}) must be reacted to produce 481 g of ethylene?

A. 5.6×10^4 g B. 2.2×10^2 g C. 3.5×10^3 g D. 7.8×10^2 g

6) Ozone (O_3) reacts with nitric oxide (NO), the reaction is

$$O_3 + NO \longrightarrow O_2 + NO_2$$

If 0.740 g of O_3 reacts with 0.670 g of NO, how many grams of NO_2 will be produced?

A. 0.71 g B. 7.4 g C. 2.5 g D. 0.94 g

Students Answers Sheet

Question No.	Answer
1	
2	
3	
4	
5	
6	

The Solution

Question No.	Answer
1	A
2	C
3	D
4	A
5	C
6	A

#خطوة_عزيزة

فريق الإرشاد الأكاديميّ 2014

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