1st

ICHO

International Chemistry Olympiad

4 theoretical problems
2 practical problems

THE FIRST
INTERNATIONAL CHEMISTRY OLYMPIAD
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THEORETICAL PROBLEMS

PROBLEM 1

A mixture of hydrogen and chlorine kept in a closed flask at a constant temperature was irradiated by scattered light. After a certain time the chlorine content decreased by 20 % compared with that of the starting mixture and the resulting mixture had the composition as follows: 60 volume % of chlorine, 10 volume % of hydrogen, and 30 volume % of hydrogen chloride.

Problems:

1.1 What is the composition of the initial gaseous mixture?

1.2 How chlorine, hydrogen, and hydrogen chloride are produced?

SOLUTION

1.1 $H_2 + Cl_2 \rightarrow 2\ HCl$

30 volume parts of hydrogen chloride could only be formed by the reaction of 15 volume parts of hydrogen and 15 volume parts of chlorine. Hence, the initial composition of the mixture had to be:

Cl_2: 60 + 15 = 75 %

H_2: 10 + 15 = 25 %

1.2 Chlorine and hydrogen are produced by electrolysis of aqueous solutions of NaCl: $NaCl(aq) \rightarrow Na^+(aq) + Cl^-(aq)$

anode: $2\ Cl^- - 2\ e \rightarrow Cl_2$

cathode: $2\ Na^+ + 2\ e \rightarrow 2\ Na$

$$2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2$$

Hydrogen chloride is produced by the reaction of hydrogen with chlorine.

PROBLEM 2

Write down equations for the following reactions:

2.1 Oxidation of chromium(III) chloride with bromine in alkaline solution (KOH).

2.2 Oxidation of potassium nitrite with potassium permanganate in acid solution (H_2SO_4).

2.3 Action of chlorine on lime water ($Ca(OH)_2$) in a cold reaction mixture.

SOLUTION

2.1 $2\ CrCl_3 + 3\ Br_2 + 16\ KOH \rightarrow 2\ K_2CrO_4 + 6\ KBr + 6\ KCl + 8\ H_2O$

2.2 $5\ KNO_2 + 2\ KMnO_4 + 3\ H_2SO_4 \rightarrow 2\ MnSO_4 + K_2SO_4 + 5\ KNO_3 + 3\ H_2O$

2.3. $Cl_2 + Ca(OH)_2 \rightarrow CaOCl_2 + H_2O$

PROBLEM 3

The gas escaping from a blast furnace has the following composition:

12.0 volume % of CO_2 28.0 volume % of CO

3.0 volume % of H_2 0.6 volume % of CH_4

0.2 volume % of C_2H_4 56.2 volume % of N_2

Problems:

3.1 Calculate the theoretical consumption of air (in m^3) which is necessary for a total combustion of 200 m^3 of the above gas if both the gas and air are measured at the same temperature. (Oxygen content in the air is about 20 % by volume).

3.2 Determine the composition of combustion products if the gas is burned in a 20 % excess of air.

SOLUTION

	O_2
3.1 $2\,CO + O_2 \rightarrow 2\,CO_2$	14
$2\,H_2 + O_2 \rightarrow 2\,H_2O$	1.5
$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$	1.2
$C_2H_4 + 3\,O_2 \rightarrow 2\,CO_2 + 2\,H_2O$	0.6
	17.3 parts x 5 = 86.5 parts of the air

200 m^3 of the gas .... 2 x 86.5 = 173.0 m^3 of the air

+ 20 % 34.6 m^3

207.6 m^3 of the air

3.2 207.6 **:** 5 = 41.52 parts of O_2 **:** 2 = 20.76 parts of O_2 for 100 m^3 of the gas

20.76 x 4 = 83.04 parts of N_2 for 100 m^3 of the gas

Balance:	CO_2	H_2O	N_2	O_2
(volume parts)	12.00	3.00	56.20	20.76
	28.00	1.20	83.04	- 17.30
	0.60	0.40		
	0.40			
	41.00	4.60	139.24	3.46

Total: 41.00 + 4.60 + 139.24 + 3.46 = 188.30 of volume parts of the gaseous components.

$$\% \, H_2O = \frac{4.60}{188.30} \times 100 = 2.44$$

$$\% \, N_2 = \frac{139.24}{188.30} \times 100 = 73.95$$

$$\% \, O_2 = \frac{3.46}{188.30} \times 100 = 1.84$$

PROBLEM 4

A volume of 31.7 cm^3 of a 0.1-normal NaOH is required for the neutralization of 0.19 g of an organic acid whose vapour is thirty times as dense as gaseous hydrogen.

Problem:

4.1 Give the name and structural formula of the acid.

(The acid concerned is a common organic acid.)

SOLUTION

4.1

a) The supposed acid may be: HA, H_2A, H_3A, etc.

$n(\text{NaOH}) = c\,V = 0.1 \text{ mol dm}^{-3} \times 0.0317 \text{ dm}^3 = 3.17 \times 10^{-3} \text{ mol}$

$$n(\text{acid}) = \frac{3.17 \times 10^{-3}}{v} \text{ mol}$$

where v = 1, 2, 3,......

$$n(\text{acid}) = \frac{m(\text{acid})}{M(\text{acid})}$$

$$M(\text{acid}) = v \times \frac{0.19 \text{ g}}{3.17 \times 10^{-3} \text{ mol}} = v \times 60 \text{ g mol}^{-1} \qquad (1)$$

b) From the ideal gas law we can obtain:

$$\frac{\rho_1}{\rho_2} = \frac{M_1}{M_2}$$

$M(H_2) = 2 \text{ g mol}^{-1}$

$M(\text{acid}) = 30 \times 2 = 60 \text{ g mol}^{-1}$

By comparing with (1): $v = 1$

The acid concerned is a monoprotic acid and its molar mass is 60 g mol^{-1}.

The acid is <u>acetic acid:</u> CH_3–COOH

PRACTICAL PROBLEMS

PROBLEM 1 (Practical)

There are ten test tubes in the rack at your disposal (1 – 10) and each test tube contains one of aqueous solutions of the following salts: Na_2SO_4, $AgNO_3$, KI, $Ba(OH)_2$, NH_4Cl, Ag_2SO_4, $Pb(NO_3)_2$, NaOH, NH_4I, KCl.

For identification of the particular test tubes you can use mutual reactions of the solutions in the test tubes only.

Determine in which order the solutions of the salts in your rack are and write chemical equations of the reactions you used for identification of the salts.

PROBLEM 2 (Practical)

Each of the six test tubes (A – F) in the rack contains one of the following substances:

benzoic acid, salicylic acid, citric acid, tartaric acid, oxalic acid and glucose.

Determine the order in which the substances in the test tubes are placed in your rack and give chemical reactions you used for identification of the substances.

For identification of the substances the following aqueous solutions are at your disposal: HCl, H_2SO_4, NaOH, NH_4OH, $CuSO_4$, $KMnO_4$, $FeCl_3$, KCl, and distilled water.