2nd

ICHO

International Chemistry Olympiad

4 theoretical problems
2 practical problems

THE SECOND
INTERNATIONAL CHEMISTRY OLYMPIAD
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THEORETICAL PROBLEMS

PROBLEM 1

An amount of 20 g of potassium sulphate was dissolved in 150 cm^3 of water. The solution was then electrolysed. After electrolysis, the content of potassium sulphate in the solution was 15 % by mass.

Problem:

What volumes of hydrogen and oxygen were obtained at a temperature of 20 °C and a pressure of 101 325 Pa?

SOLUTION

On electrolysis, only water is decomposed and the total amount of potassium sulphate in the electrolyte solution is constant. The mass of water in the solution:

1.1 Before electrolysis (on the assumption that ρ = 1 g cm^{-3}): $m(H_2O)$ = 150 g

1.2 After electrolysis:

$$m(H_2O) = m(\text{solution}) - m(K_2SO_4) = \frac{20\text{ g}}{0.15} - 20\text{ g} = 113.3\text{ g}$$

The mass of water decomposed on electrolysis:

$m(H_2O)$ = 150 – 113.3 = 36.7 g, i. e.

$n(H_2O)$ = 2.04 mol

Since, $2\,H_2O \rightarrow 2\,H_2 + O_2$

thus, $n(H_2)$ = 2.04 mol

$n(O_2)$ = 1.02 mol

$$V(H_2) = \frac{n(H_2)RT}{p} = \frac{2.04\ \text{mol} \times 8.314\ \text{J mol}^{-1}\ \text{K}^{-1} \times 293.15\ \text{K}}{101325\ \text{Pa}}$$

$\approx$ 0.049 m^3, resp. 49 dm^3

$V(O_2)$ = ½ $V(H_2) \approx 0.0245\ m^3 \approx 24.5\ dm^3$

PROBLEM 2

A compound **A** contains 38.67 % of potassium, 13.85 % of nitrogen, and 47.48 % of oxygen. On heating, it is converted to a compound **B** containing 45.85 % of potassium, 16.47 % of nitrogen, and 37.66 % of oxygen.

Problem:

2.1 What are the stoichiometric formulas of the compounds?

2.2 Write the corresponding chemical equation.

SOLUTION

2.1 Compound **A**:

$K_xN_yO_z$ $$x : y : z = \frac{38.67}{39.1} = \frac{13.85}{14} = \frac{47.48}{16} = 0.989 : 0.989 : 2.968 = 1 : 1 : 3$$

A : KNO_3

Compound **B**:

$K_pN_qO_r$ $$p : q : r = \frac{45.85}{39.1} = \frac{16.47}{14} = \frac{37.66}{16} = 1.173 : 1.176 : 2.354 = 1 : 1 : 2$$

B : KNO_2

2.2 Equation: $2\ KNO_3 \rightarrow 2\ KNO_2 + O_2$

PROBLEM 3

A 10 cm^3 sample of an unknown gaseous hydrocarbon was mixed with 70 cm^3 of oxygen and the mixture was set on fire by means of an electric spark. When the reaction was over and water vapours were liquefied, the final volume of gases decreased to 65 cm^3. This mixture then reacted with a potassium hydroxide solution and the volume of gases decreased to 45 cm^3.

Problem:

What is the molecular formula of the unknown hydrocarbon if volumes of gases were measured at standard temperature and pressure (STP) conditions?

SOLUTION

The unknown gaseous hydrocarbon has the general formula: C_xH_y

$$n(C_xH_y) = \frac{0.010\ dm^3}{22.4\ dm^3\ mol^{-1}} = \frac{0.010}{22.4}\ mol$$

Balance of oxygen:

- Before the reaction: 70 cm^3, i. e. $\frac{0.070}{22.4}$ mol
- After the reaction: 45 cm^3, i. e. $\frac{0.045}{22.4}$ mol

Consumed in the reaction: $\frac{0.025}{22.4}$ mol of O_2

According to the equation:

$$C_xH_y + (x + \frac{y}{4})\ O_2 = x\ CO_2 + \frac{y}{2}\ H_2O$$

Hence, $\frac{0.020}{22.4}$ mol of O_2 reacted with carbon and $\frac{0.020}{22.4}$ mol of CO_2 was formed ($C + O_2 = CO_2$),

$\frac{0.005}{22.4}$ mol O_2 combined with hydrogen and $\frac{0.010}{22.4}$ mol of water was obtained ($2\ H_2 + O_2 = 2\ H_2O$).

$3\ n(\text{C}) = n(\text{CO}_2) = \dfrac{0.020}{22.4}\ \text{mol}$

$n(\text{H}_2) = 2\ n(\text{H}_2\text{O}) = \dfrac{0.020}{22.4}\ \text{mol}$

x : y = n(C) : n(H_2) = 0.020 : 0.020 = 1 : 1

From the possible solutions C_2H_2, C_3H_3, C_4H_4, C_5H_5.only C_2H_2 satisfies to the conditions given in the task, i. e. the unknown hydrocarbon is acetylene.

PROBLEM 4

Calcium carbide and water are the basic raw materials in the production of:

a) ethanol

b) acetic acid

c) ethylene and polyethylene

d) vinyl chloride

e) benzene

Problem:

Give basic chemical equations for each reaction by which the above mentioned compounds can be obtained.

SOLUTION

Basic reaction: $CaC_2 + 2\,H_2O = Ca(OH)_2 + C_2H_2$

From acetylene can be obtained:

a) ethanol

$$CH{\equiv}CH + H_2O \xrightarrow[\text{diluted } H_2SO_4]{HgSO_4 \text{ (catalyst)}} \underset{\text{vinyl alcohol}}{CH_2{=}CH{-}OH} \longrightarrow$$

$$\xrightarrow{\text{rearrangement}} \underset{\text{acetaldehyde}}{CH_3{-}CH{=}O} \xrightarrow{\text{reduction}} \underset{\text{ethanol}}{CH_3{-}CH_2{-}OH}$$

b) acetic acid

$$CH{\equiv}CH + H_2O \xrightarrow[\text{diluted } H_2SO_4]{HgSO_4 \text{ (catalyst)}} \underset{\text{vinyl alcohol}}{CH_2{=}CH{-}OH} \longrightarrow$$

$$\xrightarrow{\text{rearrangement}} \underset{\text{acetaldehyde}}{CH_3{-}CH{=}O} \xrightarrow{\text{oxidation}} \underset{\text{acetic acid}}{CH_3{-}COOH}$$

c) ethylene, polyethylene

$$CH\equiv CH + H_2O \xrightarrow{\text{catalyst}} CH_2{=}CH_2$$

ethylene

$$CH_2{=}CH_2 \xrightarrow[\text{catalyst}]{\text{pressure, temperature}} (-CH_2-CH_2-)_n$$

polyethylene

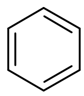
d) vinyl chloride

$$CH\equiv CH + HCl \longrightarrow CH_2{=}CH-Cl$$

vinyl chloride

e) benzene

$$3\ CH\equiv CH \xrightarrow{400-500\ ^\circ C}$$



PRACTICAL PROBLEMS

PROBLEM 1 (Practical)

a) Three numbered test-tubes (1-3) contain mixtures of two substances from the following pairs (4 variants):

1.	$ZnSO_4$ - NaBr	NaCl - $Ca(NO_3)_2$	$MgSO_4$ - NH_4Cl
2.	$AlCl_3$ - KBr	$CaCl_2$ - $NaNO_3$	$ZnCl_2$ - $(NH_4)_2SO_4$
3.	KNO_3 - Na_2CO_3	KCl - $MgSO_4$	NH_4Cl - $Ba(NO_3)_2$
4.	$MgCl_2$ - KNO_3	K_2CO_3 - $ZnSO_4$	$Al(NO_3)_3$ - NaCl

b) Each of the test-tubes numbered 4 and 5 contains one of the following substances: glucose, saccharose, urea, sodium acetate, oxalic acid.

Problem:

By means of reagents that are available on the laboratory desk determine the content of the individual test-tubes. Give reasons for both the tests performed and your answers and write the chemical equations of the corresponding reactions.

Note:

For the identification of substances given in the above task, the following reagents were available to competing pupils: 1 N HCl, 3 N HCl, 1 N H_2SO_4, concentrated H_2SO_4, $FeSO_4$, 2 N NaOH, 20 % NaOH, 2 N NH_4Cl, 2 N $CuSO_4$, 2 N $BaCl_2$, 0,1 N $AgNO_3$, 0,1 % $KMnO_4$, distilled water, phenolphtalein, methyl orange. In addition, further laboratory facilities, such as platinum wire, cobalt glass, etc., were available.

PROBLEM 2 (Practical)

Allow to react 10 cm^3 of a 3 N HCl solution with the metal sample (competing pupils were given precisely weighed samples of magnesium, zinc or aluminium) and collect the hydrogen evolved in the reaction in a measuring cylinder above water. Perform the task by means of available device and procedure.

In order to simplify the problem, calculate the mass of your metal sample from the volume of hydrogen on the assumption that it was measured at STP conditions.