

**3<sup>rd</sup>**



**International Chemistry Olympiad**

**6 theoretical problems  
2 practical problems**

# THE THIRD INTERNATIONAL CHEMISTRY OLYMPIAD

**BUDAPEST 1970  
HUNGARY**

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## THEORETICAL PROBLEMS

### PROBLEM 1

An amount of 23 g of gas (density  $\rho = 2.05 \text{ g dm}^{-3}$  at STP) when burned, gives 44 g of carbon dioxide and 27 g of water.

Problem:

What is the structural formula of the gas (compound)?

### SOLUTION

The unknown gas : X

$$\text{From the ideal gas law : } M(X) = \frac{\rho(X) R T}{p} = 46 \text{ g mol}^{-1}$$

$$n(X) = \frac{23 \text{ g}}{46 \text{ g mol}^{-1}} = 0.5 \text{ mol}$$

$$n(\text{CO}_2) = \frac{44 \text{ g}}{44 \text{ g mol}^{-1}} = 1 \text{ mol}$$

$$n(\text{C}) = 1 \text{ mol}$$

$$m(\text{C}) = 12 \text{ g}$$

$$n(\text{H}_2\text{O}) = \frac{27 \text{ g}}{18 \text{ g mol}^{-1}} = 1.5 \text{ mol}$$

$$n(\text{H}) = 3 \text{ mol}$$

$$m(\text{H}) = 3 \text{ g}$$

The compound contains also oxygen, since

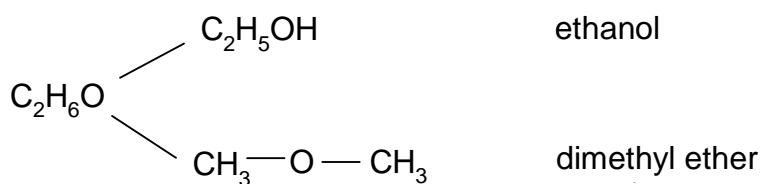
$$m(\text{C}) + m(\text{H}) = 12 \text{ g} + 3 \text{ g} = 15 \text{ g} < 23 \text{ g}$$

$$m(\text{O}) = 23 \text{ g} - 15 \text{ g} = 8 \text{ g}$$

$$n(\text{O}) = 0,5 \text{ mol}$$

$$n(\text{C}) : n(\text{H}) : n(\text{O}) = 1 : 3 : 0,5 = 2 : 6 : 1$$

The empirical formula of the compound is  $\text{C}_2\text{H}_6\text{O}$ .



Ethanol is liquid in the given conditions and therefore, the unknown gas is dimethyl ether.

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## PROBLEM 2

A sample of crystalline soda (**A**) with a mass of 1.287 g was allowed to react with an excess of hydrochloric acid and 100.8 cm<sup>3</sup> of a gas was liberated (measured at STP).

Another sample of different crystalline soda (**B**) with a mass of 0.715 g was decomposed by 50 cm<sup>3</sup> of 0.2 N sulphuric acid.

After total decomposition of soda, the excess of the sulphuric acid was neutralized which required 50 cm<sup>3</sup> of 0.1 N sodium hydroxide solution (by titration on methyl orange indicator).

Problems:

1. How many molecules of water in relation to one molecule of Na<sub>2</sub>CO<sub>3</sub> are contained in the first sample of soda?
2. Have both samples of soda the same composition?

Relative atomic masses:  $A_r(\text{Na}) = 23$ ;  $A_r(\text{H}) = 1$ ;  $A_r(\text{C}) = 12$ ;  $A_r(\text{O}) = 16$ .

## SOLUTION

Sample **A**:  $\text{Na}_2\text{CO}_3 \cdot x \text{H}_2\text{O}$

$$m(\text{A}) = 1.287 \text{ g}$$

$$n(\text{CO}_2) = \frac{pV}{RT} = 0.0045 \text{ mol} = n(\text{A})$$

$$M(\text{A}) = \frac{1.287 \text{ g}}{0.0045 \text{ mol}} = 286 \text{ g mol}^{-1}$$

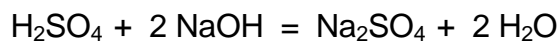
$$M(\text{A}) = M(\text{Na}_2\text{CO}_3) + x M(\text{H}_2\text{O})$$

$$x = \frac{M(\text{A}) - M(\text{Na}_2\text{CO}_3)}{M(\text{H}_2\text{O})} = \frac{(286 - 106) \text{ g mol}^{-1}}{18 \text{ g mol}^{-1}} = 10$$

Sample **A**:  $\text{Na}_2\text{CO}_3 \cdot 10 \text{H}_2\text{O}$

Sample **B**:  $\text{Na}_2\text{CO}_3 \cdot x \text{H}_2\text{O}$

$$m(\text{B}) = 0.715 \text{ g}$$



$$n(\text{NaOH}) = c V = 0.1 \text{ mol dm}^{-3} \times 0.05 \text{ dm}^3 = 0.005 \text{ mol}$$

Excess of  $\text{H}_2\text{SO}_4$ :  $n(\text{H}_2\text{SO}_4) = 0.0025 \text{ mol}$

Amount of substance combined with sample **B**:

$$n(\text{H}_2\text{SO}_4) = 0.0025 \text{ mol} = n(\text{B})$$

$$M(\text{B}) = \frac{0.715 \text{ g}}{0.0025 \text{ mol}} = 286 \text{ g mol}^{-1}$$

Sample **B**:  $\text{Na}_2\text{CO}_3 \cdot 10 \text{H}_2\text{O}$

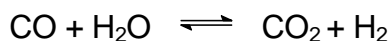
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### PROBLEM 3

Carbon monoxide was mixed with 1.5 times greater volume of water vapours.

What will be the composition (in mass as well as in volume %) of the gaseous mixture in the equilibrium state if 80 % of carbon monoxide is converted to carbon dioxide?

### SOLUTION



Assumption:

$$n(\text{CO}) = 1 \text{ mol}$$

$$n(\text{H}_2\text{O}) = 1.5 \text{ mol}$$

After reaction:

$$n(\text{CO}) = 0.2 \text{ mol}$$

$$n(\text{H}_2\text{O}) = 0.7 \text{ mol}$$

$$n(\text{CO}_2) = 0.8 \text{ mol}$$

$$n(\text{H}_2) = 0.8 \text{ mol}$$

$$\varphi(\text{CO}) = \frac{V(\text{CO})}{V} = \frac{0.2 \text{ mol}}{2.5 \text{ mol}} = 0.08 \text{ i.e. } 8 \text{ vol. \% of CO}$$

$$\varphi(\text{H}_2\text{O}) = \frac{V(\text{H}_2\text{O})}{V} = \frac{0.7 \text{ mol}}{2.5 \text{ mol}} = 0.28 \text{ i.e. } 28 \text{ vol. \% of H}_2\text{O}$$

$$\varphi(\text{CO}_2) = \frac{V(\text{CO}_2)}{V} = \frac{0.8 \text{ mol}}{2.5 \text{ mol}} = 0.32 \text{ i.e. } 32 \text{ vol. \% of CO}_2$$

$$\varphi(\text{H}_2) = \frac{V(\text{H}_2)}{V} = \frac{0.8 \text{ mol}}{2.5 \text{ mol}} = 0.32 \text{ i.e. } 32 \text{ vol. \% of H}_2$$

Before reaction:

$$m(\text{CO}) = n(\text{CO}) \times M(\text{CO}) = 1 \text{ mol} \times 28 \text{ g mol}^{-1} = 28 \text{ g}$$

$$m(\text{H}_2\text{O}) = 1.5 \text{ mol} \times 18 \text{ g mol}^{-1} = 27 \text{ g}$$

After reaction:

$$m(\text{CO}) = 0,2 \text{ mol} \times 28 \text{ g mol}^{-1} = 5.6 \text{ g}$$

$$m(\text{H}_2\text{O}) = 0.7 \text{ mol} \times 18 \text{ g mol}^{-1} = 12.6 \text{ g}$$

$$m(\text{CO}_2) = 0.8 \text{ mol} \times 44 \text{ g mol}^{-1} = 35.2 \text{ g}$$

$$m(\text{H}_2) = 0.8 \times 2 \text{ g mol}^{-1} = 1.6 \text{ g}$$

$$w(\text{CO}) = \frac{m(\text{CO})}{m} = \frac{5.6 \text{ g}}{55.0 \text{ g}} = 0.102 \text{ i.e. } 10.2 \text{ mass \% of CO}$$

$$w(\text{H}_2\text{O}) = \frac{m(\text{H}_2\text{O})}{m} = \frac{12.6 \text{ g}}{55.0 \text{ g}} = 0.229 \text{ i.e. } 22.9 \text{ mass \% of H}_2\text{O}$$

$$w(\text{CO}_2) = \frac{m(\text{CO}_2)}{m} = \frac{35.2 \text{ g}}{55.0 \text{ g}} = 0.640 \text{ i.e. } 64.0 \text{ mass \% of CO}_2$$

$$w(\text{H}_2) = \frac{m(\text{H}_2)}{m} = \frac{1.6 \text{ g}}{55.0 \text{ g}} = 0.029 \text{ i.e. } 2.9 \text{ mass \% of H}_2$$

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### PROBLEM 4

An alloy consists of rubidium and one of the other alkali metals. A sample of 4.6 g of the alloy when allowed to react with water, liberates 2.241 dm<sup>3</sup> of hydrogen at STP.

#### Problems:

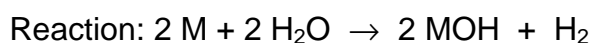
1. Which alkali metal is the component of the alloy?
2. What composition in % by mass has the alloy?

Relative atomic masses:

$$A_r(\text{Li}) = 7; \quad A_r(\text{Na}) = 23; \quad A_r(\text{K}) = 39; \quad A_r(\text{Rb}) = 85.5; \quad A_r(\text{Cs}) = 133$$

### SOLUTION

M - alkali metal



$$n(\text{H}_2) = 0.1 \text{ mol}$$

$$n(\text{M}) = 0.2 \text{ mol}$$

Mean molar mass:

$$M = \frac{4.6 \text{ g}}{0.2 \text{ mol}} = 23 \text{ g mol}^{-1}$$

Concerning the molar masses of alkali metals, only lithium can come into consideration, i.e. the alloy consists of rubidium and lithium.

$$n(\text{Rb}) + n(\text{Li}) = 0.2 \text{ mol}$$

$$m(\text{Rb}) + m(\text{Li}) = 4.6 \text{ g}$$

$$n(\text{Rb}) M(\text{Rb}) + n(\text{Li}) M(\text{Li}) = 4.6 \text{ g}$$

$$n(\text{Rb}) M(\text{Rb}) + (0.2 - n(\text{Rb})) M(\text{Li}) = 4.6$$

$$n(\text{Rb}) \cdot 85.5 + (0.2 - n(\text{Rb})) \times 7 = 4.6$$

$$n(\text{Rb}) = 0.0408 \text{ mol}$$

$$n(\text{Li}) = 0.1592 \text{ mol}$$

$$\% \text{ Rb} = \frac{0.0408 \text{ mol} \times 85.5 \text{ g mol}^{-1}}{4.6 \text{ g}} \times 100 = 76$$

$$\% \text{ Li} = \frac{0.1592 \text{ mol} \times 7 \text{ g mol}^{-1}}{4.6 \text{ g}} \times 100 = 24$$

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## PROBLEM 5

An amount of 20 g of copper (II) oxide was treated with a stoichiometric amount of a warm 20% sulphuric acid solution to produce a solution of copper (II) sulphate.

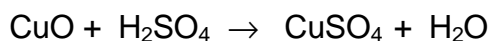
Problem:

1. How many grams of crystalline copper(II) sulphate ( $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ ) have crystallised when the solution is cooled to 20 °C?

Relative atomic masses:  $A_r(\text{Cu}) = 63.5$ ;  $A_r(\text{S}) = 32$ ;  $A_r(\text{O}) = 16$ ;  $A_r(\text{H}) = 1$

Solubility of  $\text{CuSO}_4$  at 20 °C:  $s = 20.9 \text{ g}$  of  $\text{CuSO}_4$  in 100 g of  $\text{H}_2\text{O}$ .

## SOLUTION



$$n(\text{CuO}) = \frac{m(\text{CuO})}{M(\text{CuO})} = \frac{20 \text{ g}}{79.5 \text{ g mol}^{-1}} = 0.2516 \text{ mol}$$

$$n(\text{H}_2\text{SO}_4) = n(\text{CuSO}_4) = 0.2516 \text{ mol}$$

Mass of the  $\text{CuSO}_4$  solution obtained by the reaction:

$$\begin{aligned} m(\text{solution CuSO}_4) &= m(\text{CuO}) + m(\text{solution H}_2\text{SO}_4) = \\ &= m(\text{CuO}) + \frac{n(\text{H}_2\text{SO}_4) \times M(\text{H}_2\text{SO}_4)}{w(\text{H}_2\text{SO}_4)} = 20 \text{ g} + \frac{0.2516 \text{ mol} \times 98 \text{ g mol}^{-1}}{0.20} \end{aligned}$$

$$m(\text{solution CuSO}_4) = 143.28 \text{ g}$$

Mass fraction of  $\text{CuSO}_4$ :

a) in the solution obtained:

$$w(\text{CuSO}_4) = \frac{m(\text{CuSO}_4)}{m(\text{solution CuSO}_4)} = \frac{n(\text{CuSO}_4) \times M(\text{CuSO}_4)}{m(\text{solution CuSO}_4)} = 0.28$$

b) in saturated solution of  $\text{CuSO}_4$  at 20°C:

$$w(\text{CuSO}_4) = \frac{20.9 \text{ g}}{120.9 \text{ g}} = 0.173$$

c) in crystalline  $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ :

$$w(\text{CuSO}_4) = \frac{M(\text{CuSO}_4)}{M(\text{CuSO}_4 \cdot 5\text{H}_2\text{O})} = 0.639$$

Mass balance equation for  $\text{CuSO}_4$ :

$$0.28 m = 0.639 m_1 + 0.173 m_2$$

$m$  - mass of the  $\text{CuSO}_4$  solution obtained by the reaction at a higher temperature.

$m_1$  - mass of the crystalline  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ .

$m_2$  - mass of the saturated solution of  $\text{CuSO}_4$  at  $20^\circ\text{C}$ .

$$0.28 \times 143.28 = 0.639 m_1 + 0.173 \times (143.28 - m_1)$$

$$m_1 = 32.9 \text{ g}$$

The yield of the crystallisation is 32.9 g of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ .

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## PROBLEM 6

Oxide of a certain metal contains 22.55 % of oxygen by mass. Another oxide of the same metal contains 50.48 mass % of oxygen.

Problem:

1. What is the relative atomic mass of the metal?

## SOLUTION

Oxide 1:  $M_2O_x$

$$2 : x = \frac{w(M)}{A_r(M)} : \frac{w(O)}{A_r(O)}$$

$$2 : x = \frac{0.7745}{A_r(M)} : \frac{0.2255}{16} = \frac{54.95}{A_r(M)} \quad (1)$$

Oxide 2:  $M_2O_y$

$$2 : y = \frac{w(M)}{A_r(M)} : \frac{w(O)}{A_r(O)}$$

$$2 : y = \frac{0.4952}{A_r(M)} : \frac{0.5048}{16} = \frac{15.695}{A_r(M)} \quad (2)$$

When (1) is divided by (2):

$$\frac{y}{x} = \frac{54.95}{15.695} = 3.5$$

$$\frac{y}{x} = \frac{7}{2}$$

By substituting  $x = 2$  into equation (1):

$$A_r(M) = 54.95$$

$$M = Mn$$

$$\text{Oxide 1} = MnO$$

$$\text{Oxide 2} = Mn_2O_7$$

## PRACTICAL PROBLEMS

### PROBLEM 1

An unknown sample is a mixture of 1.2-molar  $\text{H}_2\text{SO}_4$  and 1.47-molar  $\text{HCl}$ . By means of available solutions and facilities determine:

1. the total amount of substance (in mol) of the acid being present in  $1 \text{ dm}^3$  of the solution,
2. the mass of sulphuric acid as well as hydrochloric acid present in  $1 \text{ dm}^3$  of the sample.

### PROBLEM 2

By means of available reagents and facilities perform a qualitative analysis of the substances given in numbered test tubes and write down their chemical formulas.

Give 10 equations of the chemical reactions by which the substances were proved:

5 equations for reactions of precipitation,

2 equations for reactions connected with release of a gas,

3 equations for redox reactions.