

THE MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
STATE HIGHER EDUCATIONAL INSTITUTION
«NATIONAL MINING UNIVERSITY»

O.Y. Svietkina, O.B Netyaga, G.V Tarasova

BASIC CONCEPTS AND LAWS OF CHEMISTRY.

Guidelines and objectives
for self-study courses

for students in all specialties

Dnipro
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FACULTY OF GEOLOGICAL PROSPECTING
Department of Chemistry

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Затверджено методичною комісією з галузі знань 10. Природничі науки за поданням кафедри хімії (протокол № 3 від 08.11.2016).

The theoretical themes of "Basic concepts and laws of chemistry", are examples of solving common tasks, in order to consolidate the material there are presented self-study tasks for solving.

Розглянуто теоретичні положення теми «Основні поняття й закони хімії», наведено приклади розв'язку типових задач з метою закріплення матеріалу, подано задачі для самостійного розв'язування.

Відповідальна за випуск завідувач кафедри хімії, д-р техн. наук, проф. О.Ю. Светкіна.

Introduction

Chemistry studies such form of substance motion which assumes qualitative change of matters i.e. transformation of one compounds into another. During chemical processes there is exchange of atoms between different matters, re-distribution of electrons between atoms, decay of one compounds and formation of new ones. As a result of chemical processes there happens formation of other substances with new chemical and physical qualities. To understand them it is necessary to know the composition of substances and laws of their transformation.

1. Basic Concept

All substances consist of atoms of chemical elements. For example, H₂O consists of such elements as hydrogen and oxygen.

Chemical element is a certain type of atoms characterized by the same nuclear charge.

Atom is the smallest particle of a chemical element that retains chemical properties.

Thus each chemical element corresponds with a particular type of an atom. Atoms of each element have the same properties.

The notion of mass of particular atoms of elements in the periodic table is within $10^{-22} - 10^{-24}$ g. Surely it is more reasonable to express atomic mass in atomic mass units (AMU)

Atomic mass unit is a very small unit which equals to 1/12 the mass of an atom of carbon.

12 grams of carbon ¹²C contains exactly $6,02 \cdot 10^{23}$ atoms, respectively

$$M_{\text{amu}} = \frac{12}{6,02 \cdot 10^{23}} \cdot \frac{1}{12} = \frac{1}{6,02 \cdot 10^{23}} = 1,67 \cdot 10^{-24} \text{ g/a.m.u.}$$

From the calculation we can see that 1 gram of the substance contains Avogadro number of atomic mass units.

A relative atom mass unit A_r is the ratio of atomic mass of the given element to the mass of 1 a.m.u. , i. e

$$A_r = \frac{m_a}{m_{\text{amu}}}$$

Relative atomic mass is expressed in a.m.u., accordingly atomic mass is expressed in grams, namely:

$$m_a = A_r m_{\text{amu}}$$

In the periodic table of D.I. Mandeleev there are shown relative atomic masses of elements, for instance, $A_r(\text{Fe}) = 55,84 \text{ a.m.u.}$; $A_r(\text{N}) = 14 \text{ a.m.u.}$

Examples of solving typical tasks

Task 1. Determine the mass of atoms of Calcium 5: 1) in atomic mass units; 2) in grams.

Solving. 1). The relative atomic mass of calcium $A_r(\text{Ca})$ is 40. a.m.u. (see. periodic system of elements). Mass of Calcium $m(\text{Ca})$ in a.m.u. is determined as follows:

$$m(\text{Ca}) = A_r(\text{Ca}) N,$$

where N – is amount of atoms of calcium.

$$m(\text{Ca}) = 40 \cdot 5 = 200 \text{ a.m.u.}$$

2) $m_{\text{amu}} = 1,67 \cdot 10^{-24} \text{ g/a.m.u.}$, then calculating the mass $m(\text{Ca})$ in grams is as follows:

$$m(\text{Ca}) = 200 \cdot 1,67 \cdot 10^{-24} = 3,34 \cdot 10^{-22} \text{ g.}$$

Molecule is the smallest particle of a single substance composed of identical or different atoms, it can exist independently and retain the chemical properties of the substance.

The molecules are single, double and polyatomic. They can be particles of simple and complex substances.

Simple stuff is a form of existence of chemical elements, its molecule contains atoms of one element.

There are more simple substances in nature than chemical elements, because the atoms of the same element can form several simple substances. This phenomenon is called Allotropy. For example, the Oxygen element creates two simple matters – ordinary oxygen O_2 and O_3 ozone.

Complex substances are formed of atoms of different elements. For example, molecule of potassium nitrate KNO_3 consists of atoms of potassium, nitrogen and oxygen. Any substance is characterized by a certain composition (nature and number of atoms in the molecule), structure (spatial arrangement of atoms in the molecule) specific chemical and physical properties.

Relative molecular mass of chemical compound M_r is a ratio of one molecule of the compound to the mass of 1 m_M well. ie

Relative molecular mass of chemical compound M_r is a ratio of mass of one molecule of the compound m_M to the mass of 1 a.m.u, ie

$$M_r = \frac{m_M}{m_{\text{amu}}}$$

The relative molecular mass is expressed in amu, respectively mass of molecules is in grams. The relative molecular mass of a substance is the sum of the values of relative atomic mass of elements that belong to it. Thus, the figure of sulfuric acid

$$M_r(\text{H}_2\text{SO}_4) = 2 \cdot 1 + 32 + 4 \cdot 16 = 98 \text{ a.m.u.}$$

Accordingly molecular mass is in grams m_M

$$m_M(\text{H}_2\text{SO}_4) = M_r(\text{H}_2\text{SO}_4) \cdot m_{\text{a.m.u.}} = 98 \cdot 1,67 \cdot 10^{-24} = 1,64 \cdot 10^{-22} \text{ g.}$$

Symbol M_r , proposed by the International Union of Pure and Applied Chemistry (IUPAC – International Union of Pure and Applied Chemistry), demonstrates the relative molecular mass (r - relative, that is relative).

The amount of substance is a number of structural elements in the system. The unit amount of the substance is considered to be a mole. When using the term "mole" it gives the name of particles which it belongs to, "mol of molecules", "mole of atoms" and so on.

Mole is the amount of substance that contains as many molecules, atoms, ions or other structural units, as atoms which are contained in 12 grams of carbon isotope ^{12}C .

The number of structural units included in one mole of any substance is called Avogadro constant (N_A) and is equal to $6,02 \cdot 10^{23}$

The mass of one mole of a substance called molar mass (M) for its measurement there are used g / mol or kg / mol.

Molar mass is numerically equal to the relative atomic or molecular mass.

For example, the molar mass of sulfuric acid is 98 g / mol, because the relative molecular mass of H_2SO_4 is 98 a.m.u.

The amount of substance $n(x)$ are from the ratio of the mass $m(x)$ of the substance to its molar mass $M(x)$, i. e

$$n(x) = \frac{m(x)}{M(x)}$$

Examples of solving typical tasks

Task 2. Calculate how many molecules fit in 40 g of nitric acid.

Solving. Molar mass of HNO_3 is equal to 63 g / mol. Find the number of moles contained in 40 grams of acid, such as:

$$n(\text{HNO}_3) = \frac{m(\text{HNO}_3)}{M(\text{HNO}_3)} = \frac{40}{63} = 0,63 \text{ mol.}$$

According to the law of Avogadro, one mole of nitric acid contains $6,02 \cdot 10^{23}$ molecules. So,

$$N(\text{HNO}_3) = n(\text{HNO}_3) \cdot N_A = 0,63 \cdot 6,02 \cdot 10^{23} = 3,79 \cdot 10^{23} \text{ molecules.}$$

Task 3. Determine the number of moles of carbon atoms in 60 grams of carbon.

Solving. Molar mass of carbon $M(\text{C}) = 12 \text{ g / mol}$, while

$$n(\text{C}) = \frac{m(\text{C})}{M(\text{C})} = \frac{60}{12} = 5 \text{ mol.}$$

Task 4. What should the mass of iron be so that it contains the same number of atoms as 3.2 g of sulfur?

Solving. The relative atomic mass of sulfur is 32 a.m.u., then its molar mass will be 32 g / mol. Calculate the number of moles of sulfur contained in 3,2 grams, namely:

$$n(\text{S}) = \frac{m(\text{S})}{M(\text{S})} = \frac{3,2}{32} = 0,1 \text{ mol.}$$

So to have the same number of atoms of Fe and S, it is necessary to have the same number of moles of Fe, i.e 0.1 mol. The relative atomic mass and Fe equal to 56. a.m.u, i.e. its molar mass is 56 g / mol and mass of 0.1 mol of Fe is found from this proportion:

$$\begin{array}{l} 1 \text{ mole Fe} \quad - \quad 56 \text{ g} \\ 0,1 \text{ mole Fe} \quad - \quad m(\text{Fe}); \end{array}$$

$$m(\text{Fe}) = 5,6 \text{ g.}$$

Task 5. Determine the amount of substance and mass $3,5 \cdot 10^{24}$ molecules of sodium carbonate.

Solving. The amount of sodium carbonate substance is determined by the following formula:

$$n(\text{Na}_2\text{CO}_3) = \frac{N(\text{Na}_2\text{CO}_3)}{N_A} = \frac{3,5 \cdot 10^{24}}{6,02 \cdot 10^{23}} = 5,81 \text{ mol}$$

Then calculate the molar mass of sodium carbonate, i. e

$$M(\text{Na}_2\text{CO}_3) = 2 \cdot 23 + 12 + 3 \cdot 16 = 106 \text{ g/mol.}$$

The mass of sodium carbonate is calculated as follows:

$$m(\text{Na}_2\text{CO}_3) = n(\text{Na}_2\text{CO}_3) \cdot M(\text{Na}_2\text{CO}_3) = 5,81 \cdot 106 = 615,86 \text{ g.}$$

In 1794 a German scientist I. Richter introduced the concept of equivalent. Currently **equivalent** is called a real or notional part of a substance that can replace, attach, release or in any other way be equivalent to one mole of ions of hydrogen in acid-base and ion-exchange reactions, or to be one electron in redox reactions.

Thus, **the equivalent of an element or chemical compound is the number of moles of substance which is combined (combined or replaced) with one mole of hydrogen or with one mole equivalent of any chemical.**

For example, in the compound HCl equivalent of chlorine there is 1 mole of Chlorine atoms; in H₂S equivalent Sulfur there is 1/2 mole Sulfur atoms; in H₂ equivalent of Oxygen there is 1/2 mole of Oxygen atoms.

Equivalent of an element can be calculated not only because of the hydrogen, for this you can use any other element, if the value of its equivalent is known. Thus, the equivalent of Oxygen atom is 1/2 mole. For example, sulfur dioxide SO₂, which contains 1 mole of Sulfur atoms and 2 moles of atoms of Oxygen, sulfur equivalent equal to 1/4 mole S, while trioxide SO₃ is 1/6 mole S.

The mass equivalent of one element or compound which is expressed in grams is called the molar mass equivalent and referred to as Me.

For example, the equivalent of HCl molar mass of Chlorine is 35.5 g / mol. The molar mass of equivalent of element M_e is easy to calculate if we divide the value of its molar mass of the atoms in the valence, i.e

$$M_e = \frac{M_{\text{atom}}}{B}.$$

For example, the value of molar mass of equivalent of phosphorus in compounds PCl₃ and PCl₅ respectively are as follows:

$$M_e(\text{P}) = \frac{31}{3} = 10,03 \text{ g/mol};$$

$$M_e(\text{P}) = \frac{31}{5} = 6,2 \text{ g/mol}.$$

The molar mass of complex substances equivalents is calculated by the following formula, namely:

Oxides:

$$M_e(\text{oxide}) = \frac{M \text{ oxide}}{\text{number of atoms of element} \cdot \text{valence}};$$

or

$$M_e(\text{oxide}) = M_e(\text{element}) + M_e(\text{oxygen}).$$

For example, $M_e(\text{Cr}_2\text{O}_3) = \frac{M(\text{Cr}_2\text{O}_3)}{2 \cdot 3} = \frac{152}{6} = 25,3 \text{ g/mol}$ or

$$M_e(\text{Cr}_2\text{O}_3) = M_e(\text{Cr}) + M_e(\text{O}) = \frac{52}{3} + \frac{16}{2} = 25,3 \text{ g/mol}.$$

Acids:

$$M_e(\text{acid}) = \frac{M \text{ acid}}{\text{basicity of acid}}.$$

Basicity of acid equals to the number of hydrogen ions that are replaced therein by metal cations.

For example, $M_e(\text{H}_2\text{SO}_4) = \frac{M(\text{H}_2\text{SO}_4)}{2} = \frac{98}{2} = 49 \text{ g/mol}$.

Bases:

$$M_e(\text{base}) = \frac{M \text{ base}}{\text{acidity of base}}.$$

Acidity of base is equal to the number of hydroxyl groups which are replaced in it by acid residue.

For example, $M_e(\text{Ca}(\text{OH})_2) = \frac{M(\text{Ca}(\text{OH})_2)}{2} = \frac{74}{2} = 37 \text{ g/mol}$.

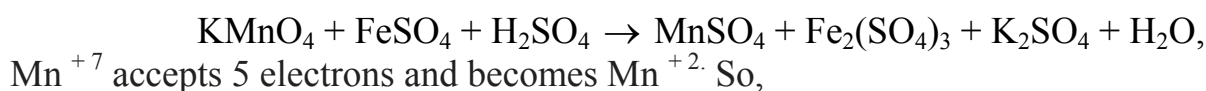
Salt:

$$M_e(\text{salt}) = \frac{M(\text{salt})}{\text{number of metal atoms} \cdot \text{valence of metal}}.$$

For example, $M_e(\text{Al}_2(\text{SO}_4)_3) = \frac{M_e(\text{Al}_2(\text{SO}_4)_3)}{2 \cdot 3} = \frac{342}{6} = 57 \text{ g/mol}$.

In redox reactions molar mass of equivalent of substance is determined by the number of electrons attached or committed atoms of elements in it.

For example, in the following reaction:



$$M_e(\text{KMnO}_4) = \frac{M(\text{KMnO}_4)}{5} = \frac{158}{5} = 31,6 \text{ g/mol.}$$

Often, instead of the term "molar equivalent weight" it is used the term "molar equivalent amount".

The molar equivalent amount of V_e is a volume that takes one equivalent of gaseous substances under normal conditions.

Thus, the equivalent of hydrogen is 1 mole, corresponding to 1/2 mol H_2 . Volume of one mole of hydrogen molecules under normal conditions is 22.4 liters. Consequently molar equivalent amount of H_2 is calculated as follows:

$$V_e(\text{H}_2) = 1/2 \cdot 22,4 = 11,2 \text{ l/mol.}$$

Similarly, the equivalent of oxygen atoms is 1/2 mole of O atoms corresponding to 1/4 mole of O_2 molecules, and the molar equivalent amount of O_2 .

$$V_e(\text{O}_2) = 1/4 \cdot 22,4 = 5,6 \text{ l/mol.}$$

Number of moles substance equivalents $n_e(x)$ are taken from the ratio of the mass $m(x)$ of the substance to its molar mass of equivalent, ie

$$n_e(x) = \frac{m(x)}{M_e(x)}.$$

Examples of solving typical tasks

Task 6. Determine the equivalent weight of 3.5 of ammonium nitrate.

Solving. Calculate the molar mass of equivalent NH_4NO_3 as follows:

$$M_e(\text{NH}_4\text{NO}_3) = \frac{M(\text{NH}_4\text{NO}_3)}{1 \cdot 1} = 80 \text{ g/mol.}$$

Then mass of 3.5 equivalents of ammonium nitrate(n_e)

$$m(\text{NH}_4\text{NO}_3) = M_e(\text{NH}_4\text{NO}_3) \cdot n_e(\text{NH}_4\text{NO}_3) = 80 \cdot 3,5 = 280 \text{ g.}$$

Task 7. How many equivalents are contained in 15 g of zinc hydroxide?

Solving. Molar mass of equivalent of $\text{Zn}(\text{OH})_2$

$$M_e(\text{Zn}(\text{OH})_2) = \frac{M(\text{Zn}(\text{OH})_2)}{2} = \frac{99}{2} = 49,5 \text{ g/mol.}$$

Then
$$n(\text{Zn}(\text{OH})_2) = \frac{m(\text{Zn}(\text{OH})_2)}{M_e(\text{Zn}(\text{OH})_2)} = \frac{15}{49,5} = 0,303 \text{ mol.}$$

Task 8. Determine the number of moles of equivalent contained in 12 liters of carbon (IV) oxide under normal conditions.

Solving. Number of moles of CO₂ equivalent we calculate using the following formula:

$$n_e(\text{CO}_2) = \frac{V(\text{CO}_2)}{V_e(\text{CO}_2)}$$

The equivalent amount of CO₂ is found so

$$V_e(\text{CO}_2) = \frac{V_M}{\text{number of atoms (C)} \cdot \text{valence (C)}} = \frac{22,4}{1 \cdot 4} = 5,6 \text{ l/mol.}$$

So,

$$n_e(\text{CO}_2) = \frac{12}{5,6} = 2,14 \text{ mol.}$$

2. Basic laws of Chemistry

At the end of XVIII – early XIX century there were discovered laws of conservation of mass, sustainability structure, multiple relations, law of equivalents and gas laws – the law of volumetric relationships of Gay-Lussac and Avogadro's law. As a result of the implementation of these laws in chemistry quantitative methods were well established. Chemistry Section, which examines quantitative composition of matter and quantitative relationships between the ones that react are called stoichiometry. According to the calculations of quantitative relationships between elements in compounds or between substances in chemical reactions are called stoichiometric calculations. The above laws are considered to be the basic laws of stoichiometry.

In 1748 M.V. Lomonosov had a hypothesis, according to which changes in nature occur so that when something is added to something, then at the same time it is subtracted from something else. And in 1756, studying chemical transformations of metals by heating, scientists experimentally demonstrated that by heating the substance in a sealed retort without air outside the total mass of metal and other materials remain unchanged.

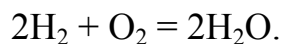
Thus, **the law of conservation of mass** was worded as follows: **weight substances entered into a reaction equal weight substances obtained from this reaction.**

For example, as a result of combustion of 24 g of magnesium 16 g of oxygen joins it and it is produced 40 g of magnesium oxide.

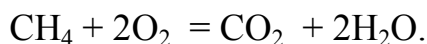
The composition of most inorganic materials (oxides, hydroxides, salts) is subjected to **the law of sustainability**, which was formulated by a French scientist Fl. Proust in 1801 based on chemical analysis of a large number of chemicals:

each chemically pure compound irrespective of the manner and conditions of getting has a steady number of members.

For example, if you burn a mixture of hydrogen and oxygen, water is formed by the following equation:



During the combustion of methane we also get water, that is,



So, qualitative and quantitative composition of water is always the same, regardless of how it is received.

In 1803 an eminent English chemist and physicist John. Dalton discovered the **law of multiple relationships** and formulated it this way:

if two elements form together several chemical compounds, the massive amount of one of the elements are included in the same mass number of the second element, relate to each other as a small integers.

For example, nitrogen and oxygen form five compounds: N_2O ; NO ; N_2O_3 ; NO_2 and N_2O_5 . In these compounds nitrogen accounts 0,57; 1,14; 1,71; 2,28 per unit mass and 2,85 units of Oxygen respectively.

The ratio of these numbers is the ratio of whole numbers, that is 0,57: 1,14: 1,71: 2,28: 2,85 = 1: 2: 3: 4: 5.

On the basis of this law, Dalton introduced the concept of relative atomic mass unit for which he received a lot of hydrogen. Currently, the relative atomic mass unit was made 1/12 of the mass of carbon atoms of the isotope ^{12}C .

Avogadro's Law (1811) is one of the basic in the science, in which

equal volumes of different gases under the same conditions (temperature and pressure) contain the same number of molecules.

The consequences of this law are:

1. Equal number of molecules of gaseous substances under the same conditions takes the same amount.

2. Mole of any gaseous substance occupies a volume of 22,4 liters at a temperature of 273 K and pressure of 101,325 kPa (normal conditions). It is accepted to call it as molar volume and has a mark symbol as V_M .

3. Stoichiometric reactions between gases show the relation between volumes of reacting and received gases.

Based on Avogadro's law and its consequences there can be made different calculations. For example, you can determine the volume which occupies 64 g of oxygen under normal conditions, namely:

$$M(\text{O}_2) = 32 \text{ g/mol},$$

$$n = \frac{m}{M} = \frac{64}{32} = 2 \text{ mol},$$

$$V = V_M \cdot n = 22,4 \cdot 2 = 44,8 \text{ l}.$$

Examples of solving typical tasks

Task 9. Determine the number of moles SO_2 , contained in 3 liters of gas (eg. In.).

Solving. Under Avogadro the law one mole of SO_2 in normal volume holds 22.4 liters (V_M), so the number of moles SO_2 is determined by the following formula:

$$n(\text{SO}_2) = \frac{V(\text{SO}_2)}{V_M} = \frac{3}{22,4} = 0,134 \text{ mol}.$$

Task 10. Determine the volume, which occupy $5,4 \cdot 10^{22}$ of oxygen molecules (eg. In.).

Solving. We calculate the volume O_2 according to the equivalent law, namely:

$$\frac{V(\text{O}_2)}{V_M} = \frac{N(\text{O}_2)}{N_A} \Rightarrow V(\text{O}_2) = \frac{V_M \cdot N(\text{O}_2)}{N_A} = \frac{22,4 \cdot 5,4 \cdot 10^{22}}{6,02 \cdot 10^{23}} = 2 \text{ l}.$$

In the transition from normal conditions to any other or vice versa it is used the equation of state of gas, which combines gas laws of Boyle - Mariotte and Gay-Lussac. This equation is called **the combined gas law** and it is recorded as follows:

$$\frac{PV}{T} = \frac{P_0 V_M}{T_0},$$

where V is the volume of gas at pressure P and temperature T ; V_0 is the volume of gas under normal conditions ($T_0 = 273 \text{ K}$, $P_0 = 101\,325 \text{ Pa}$).

Examples of solving typical tasks

Task 11. What volume occupies at 20°C and a pressure of 250 kPa of ammonia when its mass is equal to 51 grams ?

Solving. Determine the number of substance of ammonia as follows:

$$n(\text{NH}_3) = \frac{m(\text{NH}_3)}{M(\text{NH}_3)} = \frac{51}{17} = 3 \text{ mol}.$$

Volume of ammonia under normal conditions

$$V(\text{NH}_3) = V_M \cdot n(\text{NH}_3) = 22,4 \cdot 3 = 67,21.$$

Calculate the amount of ammonia under these conditions ($T = 273 + 20 = 293\text{K}$, $P = 250\text{ kPa}$) using combined gas law, that is,

$$\frac{PV}{T} = \frac{P_0 V_M}{T_0},$$

where

$$V(\text{NH}_3) = \frac{P_0 V_M T}{P T_0} = \frac{101,3 \cdot 293 \cdot 67,2}{250 \cdot 273} = 29,21.$$

To calculate the molar mass of gaseous substances you can use the equation of Clapeyron - Mendeleev, which is as follows:

$$PV = \frac{m}{M} RT,$$

where P – gas pressure Pa; V – gas volume, m^3 ; m – mass of gaseous substances, g; M – molar mass of gas, g/mol; **R - universal gas constant**, equal to $8,314\text{ J / mol} \cdot \text{K}$ (in SI); T - absolute temperature, K.

Often when determining the molar mass of gas it is used Common Units of pressure and volume. It is necessary to take appropriate value of universal gas constant.

Thus, if the volume of gas is measured in milliliters and the pressure is in mm Hg. c., the universal gas constant

$$R = 62360 \frac{\text{mm.Hg.c} \cdot \text{ml}}{\text{g/mol}}.$$

If the volume of gas is measured in liters and the pressure in the atmosphere,

$$R = 0,082 \frac{\text{l} \cdot \text{atm}}{\text{g/mol}}.$$

Examples of solving typical tasks

Task 12. Calculate the molar mass of benzene, if 600 ml of its mass vapor at 87°C and pressure of 83,2 kPa is 1,3 g

Solving. We express this problem in terms of the SI:

$P = 8,32 \cdot 10^4 \text{ Pa}$; $V = 6 \text{ m}^3 \cdot 10^{-4}$; $m = 1,30 \cdot 10^{-3} \text{ kg}$; $T = 360 \text{ K}$. Substitute the data into the equation of Clapeyron – Mendeleev, in which $PV = \frac{m}{M}RT$, and find the molar mass of benzene, namely:

$$M = \frac{mRT}{PV} = \frac{1,30 \cdot 10^{-3} \cdot 8,31 \cdot 360}{8,32 \cdot 10^4 \cdot 6 \cdot 10^{-4}} = 78,0 \cdot 10^{-3} \text{ kg/mol} = 78,0 \text{ g/mol}.$$

Task 13. Pressure of water vapor at 25°C is 3173 Pa . How many molecules are contained in 1 ml of this vapor?

Solving. Vapor is water in the gaseous state, so it can be used in gas laws. For equation Clapeyron – Mendeleev find the amount of substance gas (consider that $T = 273 + 25 = 298 \text{ K}$, and $V = 10^{-6} \text{ m}^3$) as follows:

$$n = \frac{PV}{RT} = \frac{3173 \cdot 10^{-6}}{8,31 \cdot 298} = 1,28 \cdot 10^{-6} \text{ mol}.$$

According to Avogadro's law we calculate the number of molecules in 1 ml of the vapor, namely:

$$N = n \cdot N_A = 1,28 \cdot 10^{-6} \cdot 6,02 \cdot 10^{23} = 7,71 \cdot 10^{17} \text{ molecules}.$$

Law equivalents (experimentally set in 1793 by German chemist Richter IV and James finally formulated by Dalton in 1803) are stated as follows:

Substances interact in mass quantities proportional to their masses of molar equivalents, i. e

$$\frac{m_1}{m_2} = \frac{M_{e1}}{M_{e2}}.$$

When one of the substances that interact with each other is gaseous, then under normal circumstances it is advisable to use the law of equivalents in the following form:

$$\frac{m_1}{V_2} = \frac{M_{e1}}{V_{e2}}.$$

Task 14. Determine the molar mass of equivalent and molar mass of trivalent metal, which forms $56,64$ grams of metal oxide at the combustion of 30 grams.

Solving: Calculate the mass of oxygen during the combustion of metal as follows:

$$m(\text{Me}) = m(\text{oxide}) - m(\text{O}) = 56,64 - 30 = 26,64 \text{ g}.$$

According to the law of equivalents: $\frac{m(\text{Me})}{m(\text{O}_2)} = \frac{M_e(\text{Me})}{M_e(\text{O}_2)}$,

find the equivalent weight of metal, namely:

$$M_e(\text{Me}) = m(\text{Me}) \cdot \frac{M_e(\text{O}_2)}{m(\text{O}_2)} = 30 \cdot \frac{8}{26,64} = 9 \text{ g/mol.}$$

Equivalent weight of metal

$$M_e(\text{Me}) = \frac{M(\text{Me})}{B},$$

then $M(\text{Me}) = M_e(\text{Me}) \cdot B = 9 \cdot 3 = 27 \text{ g/mol.}$

Task15. Calculate the molar mass of metal equivalent, knowing that its chloride contains 65,57 % of chlorine. Equivalent weight of chlorine is 35,45 g / mol.

Solving. Let's apply the following notation:

$$\% \text{ Cl} = m(\text{Cl}),$$

$$\% \text{ Me} = m(\text{Me}),$$

then $m(\text{Me}) = 100 - m(\text{Cl}) = 100 - 65,57 = 34,43 \text{ g.}$

According to the law of equivalents

$$\frac{m(\text{Cl})}{m(\text{Me})} = \frac{M_e(\text{Cl})}{M_e(\text{Me})};$$

$$M_e(\text{Me}) = \frac{m(\text{Me}) \cdot M_e(\text{Cl})}{m(\text{Cl})} = \frac{34,43 \cdot 35,45}{65,57} = 18,62 \text{ g/mol.}$$

Task 16. At the interaction of 5,2 g of metal with 3,5 g of Nitrogen there is formed nitride. What metal is it if its valence is 1 and valence of Nitrogen is 3?

Solving.
$$M_e(\text{N}) = \frac{M(\text{N})}{B} = \frac{14}{3} = 4,67 \text{ g/mol.}$$

According to the law of equivalents

$$\frac{m(\text{Me})}{m(\text{N})} = \frac{M_e(\text{Me})}{M_e(\text{N})};$$

$$M_e(\text{Me}) = \frac{m(\text{Me}) \cdot M_e(\text{N})}{m(\text{N})} = \frac{5,2 \cdot 4,67}{3,5} = 6,94 \text{ g/mol;}$$

$$M_e(\text{Me}) = \frac{M(\text{Me})}{B},$$

so, $M(\text{Me}) = M_e(\text{Me}) B$; $M(\text{Me}) = 6,94 \cdot 1 = 6,94 \text{ g/mol}$.

Unknown metal is lithium with molar mass of 6,94 g / mol.

Task 17. To dissolve 58 g of iron it took 7,3 grams of hydrochloric acid. What formula does formed salt have? What is the valence of iron and what formula formed the salt has?

Solving. According to the law of equivalents

$$\frac{m(\text{Fe})}{M_e(\text{Fe})} = \frac{m(\text{HCl})}{M_e(\text{HCl})},$$

so

$$M_e(\text{Fe}) = \frac{m(\text{Fe}) \cdot M_e(\text{HCl})}{m(\text{HCl})};$$

$M_e(\text{HCl}) = 36,5 \text{ g/mol}$;

$$M_e(\text{Fe}) = \frac{5,58 \cdot 36,5}{7,3} = 27,9 \text{ g/mol};$$

$$M_e(\text{Fe}) = \frac{M(\text{Fe})}{B(\text{Fe})}.$$

From here
$$B(\text{Fe}) = \frac{M(\text{Fe})}{M_e(\text{Fe})} = \frac{55,8}{27,9} = 2.$$

Formula of formed salt – FeCl_2 .

Questions for self-checking

1. Define the concepts of chemical elements, atoms, molecules, simple and complex matter. What is the primary particle – atom or molecule?
2. What are the relative atomic and molecular masses?
3. What the equivalent and molar mass of equivalent (equivalent weight) are
4. Give the formulas for the calculation of equivalents and their molar masses of simple and complex substances.
5. State the law equivalents.

6. State the basic laws of stoichiometry.

7. Why is Avogadro's law valid only for emissions? What impact does it have?

The tasks for independent solution

1. 0,56 liters of oxygen interact with 1,2 g of divalent metal. Calculate its equivalent and molar mass.

Answer: 12 g / mol, 24 g / mol.

2. Neutralization of 0,336 g of acid consumed 0,292 g of sodium hydroxide. Calculate the equivalent weight of acid.

Answer: 46 g / mol.

3. The same amount of metal reacts with oxygen 0,2 g and 3,2 g of halogen. Calculate the equivalent weight of halogen.

Answer: 128 g / mol.

4. The metal chloride contains 36 % of metal and 64 % of chlorine. Determine the equivalent weight of metal.

Answer: 19,97 g / mol.

5. Oxide of trivalent element contains 31,58 % of oxygen. Calculate the molar mass of the element.

Answer: 52 g / mol.

6. Determine the amount of 5,3 equivalents of oxygen under the normal conditions.

Answer: 29,68 l.

7. At the interaction 0,121 grams of metal with acid there was emitted 0,112 liters of hydrogen (eg. In.). Determine the equivalent weight of metal.

Answer: 12,1 g / mol.

8. What approximate volume (NC) will $2,41 \cdot 10^{25}$ chlorine molecules take and whether the number of molecules of carbon (IV) of oxide is the same?

Answer: 896,7 liters.

9. Sulfide of divalent metal contains 67,1 % of metal. Determine the molar mass of metal.

Answer: 65,26 g / mol.

10. Determine the amount of Hydrogen spent on restoration of 2,5 g of zinc oxide under normal conditions.

Answer: 0,69 liters.

11. The combustion of 1,534 g hexavalent metal took 280 ml of oxygen (eg. In.). Determine the molar mass of metal.
Answer: 184,08 g / mol.
12. Dissolving 16,8 grams of metal required 14,7 grams of sulfuric acid. Determine the equivalent weight of the metal and the amount of hydrogen released.
Answer: 56 g / mol; 3,36 liters.
13. Arsen sulfide contains 38 % of sulfur. The equivalent weight of sulfur is 16 g / mol. Calculate the equivalent weight and valence of arsenic.
Answer: 26,11 g / mol; 3.
14. Calculate the mass of 80 molecules of sodium silicate in grams and atomic mass units.
Answer: $1,63 \cdot 10^{-20}$ g; 9760 a.m.u.
15. Determine the amount of 20 equivalents of hydrogen under normal conditions.
Answer: 224 liters.
16. At the dissolution of 4,8 g of metal it was emitted 2,694 liters of hydrogen (eg. In.). Determine the equivalent weight of metal.
Answer: 19,96 g / mol.
17. The combustion of 0,511 g of trivalent metal took 100 ml of oxygen (eg. In.). Determine the molar mass of metal.
Answer: 85,84 g / mol.
18. What quantity of substance does sulfur (IV) oxide fit the same number of atoms of sulfur as pyrites FeS with weight of 24 grams?
Answer: 0,27 mol.
19. At the interaction of 5,6 g of iron with sulfur there was formed 8,8 g of iron (II) sulfide. Find the equivalent mass of iron, if the equivalent weight of sulfur is 16 g / mol.
Answer: 28 g / mol.
20. 1,355 g of iron (III) chloride reacts without reserve of 1 g of sodium hydroxide, which the equivalent weight is 40 g / mol. Determine the equivalent mass of iron.
Answer: 18,7 g / mol.
21. How many atoms of iodine fit in 50,8 g I₂?
Answer: $2,41 \cdot 10^{23}$ atoms.

22. What volume of nitrogen (II) oxide is formed by the interaction $5 \cdot 10^{20}$ molecules of nitrogen and oxygen?

Answer: 37, 21 liters.

23. What volume for NU do $2,7 \cdot 10^{22}$ molecules of gas occupy?

Answer: 0,99 liters.

24. Weight of $0,001 \text{ m}^3$ of gas (0°C , 101.33 kPa) is $1,25 \text{ g}$. Calculate the molar mass of gas and mass of its one molecule in grams.

Answer: $27,99 \text{ g / mol}$; $4,65 \cdot 10^{-23} \text{ g}$.

25. The volume of gas at a pressure of $98,7 \text{ kPa}$ and temperature of 91°C is 680 ml . Calculate the volume of gas under normal conditions.

Answer: $5 \cdot 10^{-4} \text{ m}^3$.

26. As a result of the interaction of $1,28 \text{ g}$ of metal with water at a temperature of 21°C and pressure of $104,5 \text{ kPa}$ there was formed 380 ml of hydrogen. Find the equivalent weight of metal.

Answer: $39,8 \text{ g / mol}$.

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ОСНОВНІ ПОНЯТТЯ Й ЗАКОНИ ХІМІЇ
МЕТОДИЧНІ РЕКОМЕНДАЦІЇ ТА ЗАВДАННЯ
до самостійного вивчення дисципліни
студентами всіх спеціальностей
(англійською мовою)

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