**Ministry of Health of the Republic of Belarus**
**Educational institution**
**"Gomel State Medical University"**

Department of General and Bioorganic Chemistry

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# METHODOLOGICAL MANUAL

for conducting the laboratory class with the first-year students
of the Faculty of International Students
studying in the specialty 7-07-0911-01 "Medical business" (FIS)
English-speaking students
in the discipline "Medical chemistry"

## Topic 1: **CHEMISTRY AND MEDICINE. THE DOCTRINE OF THE CHEMICAL EQUIVALENT. METHODS OF EXPRESSING THE COMPOSITION OF SOLUTIONS**

Time: 2 hours

Gomel, 2023

## THE TRAINING AND EDUCATIONAL GOALS, MOTIVATION TO STUDY THE TOPIC

**The purpose of the class:**

1. To familiarize students with the task of the laboratory workshop, its content and organization, as well as the rules of work in the chemical laboratory and safety techniques, to develop skills of working with measuring laboratory glassware.

2. To teach students to perform calculations and prepare solutions of a given concentration using individual substances or more concentrated solutions.

**The tasks of the class:**

As a result of the class, the student ***must know:***

1) the content, organization, goals and objectives of the workshop on medical chemistry;

2) the rules of work in the chemical laboratory and safety rules;

3) the concept of the chemical equivalent and the equivalent molar mass;

4) formulas for calculating the molar masses of chemical equivalents of simple and complex substances;

5) definition of the Equivalent Law and its mathematical expression;

6) the concept of solutions and ways of expressing the composition of solutions:

a) percent by mass (mass percent, mass fraction);

b) mole fraction (mole percent);

c) molarity (molar concentration);

d) molality;

e) normality (molar concentration of the equivalent);

f) titer.

The student ***must be able to:***

1) calculate the equivalence factor and the equivalent molar mass;

2) perform typical calculations involving the Equivalent Law;

3) find the concentration of solute in a certain volume or mass of solution or solvent;

4) perform calculations for the preparation of solutions of a given concentration.

**Motivation to study the topic:**

The concept of chemical equivalent is widely used in chemistry to perform quantitative calculations. This is the basis of one of the laws of chemistry – the Equivalent Law. Chemical amounts of solutes are used to express the concentration of solutions.

A general practitioner should have knowledge of the basis of the modern theory of solutions, since the important biochemical processes in the tissues of living organisms are running in solutions, and most medicines are absorbed only in the dissolved state. In addition, the modern theory of electrolytes serves as a scientific basis for studying the electrolyte balance of the human body under normal and pathological conditions.

## NECESSARY EQUIPMENT

1. Methodological manual for students on the topic "Chemistry and medicine. The doctrine of the chemical equivalent. Methods of expressing the composition of solutions".

2. Reference materials of physico-chemical constants for the 1$^{st}$ year education international students.

3. Chemical reagents and equipment necessary for laboratory work.

## CONTROL QUESTIONS ON THE TOPIC OF THE CLASS

1. The concept of a chemical equivalent. The equivalence factor. The Equivalent Law.
2. Concentration units used for expressing the composition of solutions:
a) percent by mass (mass percent, mass fraction);
b) mole fraction (mole percent);
c) molarity (molar concentration);
d) molality;
e) normality (molar concentration of the equivalent);
f) titer.

## COURSE OF THE CLASS

**The theoretical part**

### 1. THE CONCEPT OF A CHEMICAL EQUIVALENT. THE EQUIVALENCE FACTOR. THE EQUIVALENT LAW

**Chemical equivalent** is a real or hypothetical particle of a substance that is equivalent (chemically identical) to one proton in acid-base reactions or one electron in redox reactions. A real particle is an atom, molecule or ion, a hypothetical particle is a part of a real particle (½ part, ⅓ part, etc.).

Let's consider the following reactions:

a) $H^+ + OH^- \rightarrow H_2O$;
b) $2H^+ + S^{2-} \rightarrow H_2S$;
c) $H_2 - 2e^- \rightarrow 2H^+$;
d) $Al^{3+} + 3e^- \rightarrow Al^0$.

In acid-base reactions (a, b) 1 $H^+$ is equivalent to 1 $OH^-$, ½ $S^{2-}$. In redox reactions, (c, d), ½ of the $H_2$ molecule, ⅓ of the $Al^{3+}$ are equivalent to 1 electron. The listed particles are considered as chemical equivalents of the substances involved in these reactions.

From another point of view, **a chemical equivalent** is a real or hypothetical particle that is equivalent to 1 elementary charge in the particular ion-exchange or oxidation-reduction reaction [2,3].

For example, in the reaction: $H_3PO_4 + OH^- \rightarrow H_2PO_4^- + H_2O$, the equivalent corresponds to one $H_3PO_4$ molecule, since it reacts with one $OH^-$.

And in the reaction: $H_3PO_4 + 2OH^- \rightarrow HPO_4^{2-} + 2H_2O$, the $H_3PO_4$ molecule reacts with two $OH^-$, thus the equivalent of phosphoric acid is equal to ½ of $H_3PO_4$ molecule.

The mass of one mole of a substance is defined as molar mass (M), g/mol.
For example: $M(H_2O)$ = 18 g/mol; M(HCl) = 36.5 g/mol; M(NaOH) = 40 g/mol.

The mass of one mole of chemical equivalent of a substance is defined as **equivalent molar mass ($M_e$)**, g/mol. The equivalent molar mass relates to the molar mass of a substance as follows: $\boldsymbol{M_e(X) = f_e(X) \times M(X)}$, where $f_e(X)$ — an equivalence factor.

**The equivalence factor $\boldsymbol{f_e(X)}$** is the number which indicates what part of the real particle of substance X is equivalent to one hydrogen ion in the given acid-base reaction or to one electron in the redox reaction.

**The equivalence factors for individual substances** may be calculated according to following formulas:

*a) for acids:* $f_e = \frac{1}{a\ number\ of\ H\ atoms\ in\ a\ molecule}$;

For example: $f_e\ (HCl) = 1$; $f_e\ (H_2SO_4) = ½$, $f_e\ (H_3PO_4) = ⅓$

*b) for bases:* $f_e = \frac{1}{a\ number\ of\ OH-groups\ in\ a\ molecule}$;

For example: $f_e\ (NaOH) = 1$; $f_e\ (Ca(OH)_2) = ½$; $f_e\ (Al(OH)_3) = ⅓$

*c) for salts:* $f_e = \frac{1}{a\ number\ of\ Me\ atoms \times Me\ oxidation\ number}$;

For example: $f_e\ (NaCl) = 1$; $f_e\ (Na_2SO_4) = ½$; $f_e\ (Ca_3(PO_4)_2) = ⅙$.

**For substances involved in ion-exchange or oxidation-reduction reactions** the equivalence factors can be calculated according to following formula:

$$f_e = \frac{1}{Z} \le 1,$$

*Z* is the total charge of ions exchanging in 1 molecule (for ion-exchange reactions) or the number of electrons which 1 molecule (or ion) gains or losses (for redox reactions).

Z has always a positive value and the equivalence factor is less or equal to 1.

Let's consider the following reactions:

a) $Na_2CO_3 + HCl \rightarrow NaHCO_3 + NaCl$ $\quad f_e\ (Na_2CO_3) = 1$

b) $Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2\uparrow$ $\quad f_e\ (Na_2CO_3) = ½$

c) $5Na_2SO_3 + 2KMnO_4 + 3H_2SO_4 \rightarrow 5Na_2SO_4 + 2MnSO_4 + 3H_2O + K_2SO_4$
$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$ $\quad f_e\ (KMnO_4) = ⅕$

d) $3Na_2SO_3 + 2KMnO_4 + H_2O \rightarrow 3Na_2SO_4 + 2MnO_2 + 2KOH$
$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2 + 4OH^-$ $\quad f_e\ (KMnO_4) = ⅓$

e) $Na_2SO_3 + 2KMnO_4 + 2KOH \rightarrow Na_2SO_4 + 2K_2MnO_4 + H_2O$
$MnO_4^- + e^- \rightarrow MnO_4^{2-}$ $\quad f_e\ (KMnO_4) = 1$

The amount of substance (in moles) where particles are equivalents is called **the amount of equivalent of substance.** It's obvious that: $n_e(X) = m(X)/M(X) \times f_e(X)$

**The Equivalent Law:** the number moles of equivalents for reactants are equal to the number moles of equivalents for products (or the amounts of equivalents for reactants and products are identical) [1-4].

For a hypothetical reaction: $aA + bB \rightarrow cC + dD$ the Equivalent Law may be represented as:

$$\mathbf{n_e(A) = n_e(B) = n_e(C) = n_e(D)}$$

$n_e = \frac{m}{M_e}$ is the number moles of equivalent of substance (the amount of equivalents of substance), mol.

***Problem 1.*** The equal volumes of hydrogen gas were released from an acid as a result of its interaction with 0.69 g of Ca and 1.13 g of Zn. Calculate $M_e$ of zinc when $M_e$ of calcium is 20 g/mol.

***Solution:***

*Write the Equivalent Law for a given chemical reaction:*

$n_e(Ca) = n_e(Zn;$ $\quad \frac{m(Ca)}{M_e(Ca)} = \frac{m(Zn)}{M_e(Zn)}$

*From this equation we can derive that:*

$$M_e\,(Zn) = \frac{m(Zn)\times M_e(Ca)}{m(Ca)} = \frac{1.13\times 20}{0.69} = 32.7\ g/mol$$

***Answer:*** $M_e\,(Zn) = 32.7\ g/mol$

***Problem 2.*** An acid with mass of 9 g was neutralized by 8 g of sodium hydroxide NaOH. Calculate the equivalent molar mass of an acid.

***Solution:***

*Write the Equivalent Law for a given chemical reaction:*

$n_e(acid) = n_e(NaOH)$

$$\frac{m(acid)}{M_e(acid)} = \frac{m(NaOH)}{M_e(NaOH)};\quad M_e\,(NaOH) = M\,(NaOH)\times f_e = 40\ g/mol$$

*From this equation we can derive that:*

$$M_e\,(acid) = \frac{m(acid)\times M_e(NaOH)}{m(NaOH)} = \frac{9\times 40}{8} = 45\ g/mol$$

***Answer:*** $M_e\,(acid) = 45\ g/mol$

## 2. CONCENTRATION UNITS USED FOR EXPRESSING THE COMPOSITION OF SOLUTIONS

**Concentration** is a general term that represent the amount of solute contained in a given amount of solution (solvent). Various ways of expressing concentration are in use, each of which has advantages as well as limitations [1, 3, 4].

We will use the next types of solution concentration units to quantitatively describe the amounts of the solute(s) and the solvent:

**a) percent by mass** or **mass percent** or **mass fraction (ω)** is the mass of solute present in 100 g of solution:

$$\omega(X) = \frac{m(X)}{m(solution)}\times 100\%;$$ ***X — solute***

The percent by mass has no units because it is a ratio of two similar quantities.

**b) mole fraction** or **mole percent (χ)** is the ratio of the number of moles of a single component of a solution to the total number of moles present in the solution:

$$\chi(X)=\frac{n(X)}{n(X)+n(solvent)}\times 100\,\%;$$

The mole fraction has no units, since it too is a ratio of two similar quantities.

**c) molality ($C_m$)** is the number of moles of solute present in 1 kg of solvent:

$$C_m(X)=\frac{n(X)}{m(solvent)}, \quad [mol/kg];$$

**d) molarity** or **molar concentration ($C_M$)** is the number of moles of solute present in 1 liter of solution:

$$C_M(X)=\frac{n(X)}{V(solution)}, \quad [mol/l];\ \textbf{(1M)}$$

**e) normality** or **molar concentration of the equivalent ($C_N$)** is the number moles equivalents of solute present in 1 liter of a solution:

$$C_N(X)=\frac{n_e(X)}{V(solution)}, \quad [mol/l];\ \textbf{(1N)}$$

**f) titer (T)** is the mass of solute present in 1 milliliter of solution:

$$T(X)=\frac{m(X)}{V(solution)}, \quad [g/ml].$$

***Formulas for the relation of concentration units:***

**a)** $C_M(X)=\frac{\omega(X),\,\%\times\rho(solution)\times 10}{M(X)}$; $C_N(X)=\frac{\omega(X),\,\%\times\rho(solution)\times 10}{M_e(X)}$;

**b)** $C_M(X) = f_e \times C_N(X)$; $C_N(X)=\frac{C_M(X)}{f_e(X)}$

**c)** $C_M(X)=\frac{T(X)\times 1000}{M(X)}$; $C_N(X)=\frac{T(X)\times 1000}{M_e(X)}$.

**The practical part**

Safety instructions before laboratory work.

LABORATORY WORK

*Preparation of a less concentrated solution from a more concentrated solution*

*Task:* to prepare 100 ml of 6 % by mass NaCl solution using more concentrated stock solution.

Carry out an experiment in the following sequence of operations:

1) determine a density of the initial (more concentrated) solution using a set of areometers (densitometers);

2) find percent by mass of NaCl in the solution using a reference book;

3) calculate a volume of the initial (more concentrated) solution required for the less concentrated solution preparing;

4) prepare the dilute solution and determine its density;

5) calculate an absolute (D) and a relative ($D_o$) errors of the experiment:

$$D = \rho^{(exp)} - \rho^{(table)} =$$

$$D_o = \frac{|D|}{\rho^{(table)}} \times 100\ \% =$$

**Control over the assimilation of the topic**

It is conducted in the form of an oral conversation with students.

## QUESTIONS FOR SELF-CONTROL OF KNOWLEDGE

1. The concept of a chemical equivalent. The equivalence factor. The Equivalent Law.
2. General concept of solutions.
3. Concentration units used for expressing the composition of solutions:

a) percent by mass (mass percent, mass fraction);
b) mole fraction (mole percent);
c) molarity (molar concentration);
d) molality;
e) normality (molar concentration of the equivalent);
f) titer.

***Exercises for the self – control***

**1.** Calculate $f_e$ and $M_e$ for $H_3PO_4$ in the following reactions:

$H_3PO_4 + NaOH \rightarrow NaH_2PO_4 + H_2O$
$H_3PO_4 + 2NaOH \rightarrow Na_2HPO_4 + 2H_2O$

**2.** Calculate $f_e$ and $M_e$ for $Fe(OH)_3$ in the following reactions:

$Fe(OH)_3 + HCl \rightarrow Fe(OH)_2Cl + H_2O$
$Fe(OH)_3 + 3HCl \rightarrow FeCl_3 + 3H_2O$

**3.** Interaction of 5.95 g of a substance and 2.75 g of hydrochloric acid gives 4.4 g of a salt. Calculate the equivalent molar mass of a given substance and an obtained salt.

*Answer: 79 g/mol; 59 g/mol*

**4.** The reduction of 2.32 g of a tungsten oxide runs with 0.54 g of water elimination. Calculate the equivalent molar mass of a given oxide.

*Answer: 38.7 g/mol*

**5.** Calculate the percent by mass of the solute in each of the following aqueous solutions: a) 5.5 g of NaBr in 78.2 g of solution; b) 31 g of KCl in 152 g of water.

*Answer: 7 %; 17 %*

**6.** A solution is prepared by mixing 62.6 ml of benzene ($C_6H_6$) with 80.3 ml of toluene ($C_7H_8$). Calculate the mole fractions of these two components. The densities are: benzene – 0.879 g/cm$^3$; toluene – 0.867 g/cm$^3$.

*Answer: 48 %; 52 %*

**7.** Calculate the molality of each of the following solutions:

a) 14.3 g of sucrose ($C_{12}H_{22}O_{11}$) in 676 g of water;

b) 7.2 mole of ethylene glycol ($C_2H_6O_2$) in 3546 g of water.

*Answer: a) 0.061 mol/kg; b) 2.03 mol/kg*

**8.** What volume of 38 % by mass hydrochloric acid solution (density of the solution is 1.19 g/ml) should be taken to prepare 1 liter of 2N solution? Calculate the titer of the prepared solution.

*Answer: 161.4 ml; $7.3\times10^{-2}$ g/ml*

## QUESTIONS FOR INDEPENDENT WORK OF STUDENTS (IWS)

1. The role of medical chemistry in the process of formation of professional qualities of students of institutions of higher medical education.
2. Physical and chemical properties of water, which determine its role in the processes of vital activity.

## LIST OF SOURCES USED

1. Medical chemistry : textbook for students of higher education establishments – med. univ., inst. and acad. / V.O. Kalibabchuk, V.I. Halynska, L.I. Hryshchenko et al. ; ed. by V.O. Kalibabchuk. – 6th ed., corr. – Kyiv : AUS Medicine Publishing, 2018. – P. 58-60.

2. Основы химии для иностранных студентов = Essential chemistry for foreign students : учебно-методическое пособие / С. В. Ткачёв [и др.]. – 5-е изд. – Минск : БГМУ, 2018. – 168 с. – Режим доступа: http://rep.bsmu.by:8080/handle/BSMU/21054.

3. Филиппова, В. А. Общая химия : учеб. пособие для студентов лечеб. фак-та, обуч. на англ. яз. : в 2 ч. = General Chemistry : Educational guaidance for students medical department in English medium / В. А. Филиппова, А. В. Лысенкова, Л. В. Чернышева. – Гомель : ГомГМУ, 2009. – Ч. 1. – 192 с. URI: https://elib.gsmu.by/handle/GomSMU/2679.

4. Chang, Raymond. Chemistry / R. Chang. – 4th ed. – USA : University Science Books, 1991. – 1065 p.