Class №4 The theme: «Solutions. Solutions of electrolytes. Acid and base theories. Colligative properties of solutions».

1. Questions:

1. Unsaturated, saturated, and supersaturated solutions. Dissolution mechanism of solid ionic and nonionic compounds. Thermodynamics of dissolution.
2. Solubility. Factors effecting solubility.
3. Solubility of gases in liquids. Henry's law (statement and mathematical expression) and Sechenov's law, their biological roles.
4. Solutions of electrolytes. Ionization and dissociation.
5. Weak electrolyte solutions properties. Dissociation constant and dissociation degree (α). Ostwald dilution law.
6. Properties of the strong electrolyte solutions. Debye-Hüchel strong electrolytes theory.
7. Solubility product (K_{sp}).
8. Electrolytes in human organism.
9. Diffusion. Factors effecting diffusion.
10. Colligative properties of nonelectrolyte and electrolyte solutions. Van't Hoff factor.
11. Lowering of vapor pressure of solvent above solution. Raoult's law.
12. Boiling-point elevation and freezing-point depression of the solutions.
13. Osmosis, osmotic pressure.
14. Hypotonic, hypertonic and isotonic solutions. Plasmolysis and hemolysis. Osmotic pressure of blood.
15. Medical and biological role of osmosis and diffusion.

2. Familiarize with teaching tasks:

№	Content of the task:
1	Calculate the solubility of nitrogen in water from air at 0.78 atm if the solubility of nitrogen at 1 atm is 6.8×10^{-4} M.
	Solution: According to the Henry's law: $C(N_2) = K \times P$ $K = \frac{C_1(N_2)}{P_1} = \frac{6.8\times10^{-4}}{1} = 6.8\times10^{-4}\ mol/(L\cdot atm)$ $C_2(N_2) = K \times P_2 = 6.8\times10^{-4}\times0.78 = 5.3\times10^{-3}\ mol/L$
2	Calculate the concentration of acetate ions in 0.2 M CH_3COOH acid solution ($K_a=1.8\times10^{-5}$).
	Solution: $CH_3COOH \leftrightarrow CH_3COO^- + H^+$ (dissociation of acetic acid) $K = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]}$ As CH_3COO^- and H^+ are formed in 1:1 mole ratio, $[CH_3COO^-] = [H^+] = \mathbf{x}$ mol/L As only a slight amount of acid dissociates into ions in such weak acid solution, the concentration of undissociated weak acid is approximately equal to the initial concentration of the acid. $[CH_3COOH] \sim C(CH_3COOH) = 0.2$ mol/L Therefore, dissociation constant equation can be written as under: $K = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]} \approx \frac{x\cdot x}{C(CH_3COOH)}$ $x \approx \sqrt{K\cdot C(CH_3COOH)} = \sqrt{1.8\cdot10^{-5}\cdot0.2} = \sqrt{0.36\cdot10^{-5}} = 1.9\cdot10^{-3}$ mol/L

	Answer: $[CH_3COO^-] = 1.9\times10^{-3}$ mol/L
3	Calculate the solubility of silver carbonate. K_{sp} of Ag_2CO_3 is 8.9×10^{-12}.
	Solution: Suppose the solubility of Ag_2CO_3 is S mol/L, S 2S S $Ag_2CO_3 \leftrightarrow 2Ag^+ + CO_3^{2-}$ (dissociation of insoluble salt) $K_{sp}(Ag_2CO_3) = [Ag^+]^2\cdot[CO_3^{2-}] = (2S)^2\cdot S = 4S^3$ $4S^3 = K_{sp} \Rightarrow S = \sqrt[3]{\frac{K_{SP}}{4}} = \sqrt[3]{\frac{8.9\times10^{-12}}{4}} = 1.3\times10^{-4}$ mol/L Answer: $S(Ag_2CO_3) = 1.3\times10^{-4}$ mol/L
4	Calculate the ionic strength of 0.1 M sodium sulfate solution.
	Solution: Sodium sulfate is strong electrolyte ($\alpha_{\%} = 100\%$) $Na_2SO_4 \leftrightarrow 2Na^+ + SO_4^{2-}$ As ionic strength is a half-sum of the mathematical product of the concentration of all ions in the solution and the square of their charges: $I = \frac{1}{2}\cdot\sum C\cdot Z^2$ $C(Na^+) = 2C(Na_2SO_4) = 2\times0.1 = 0.2$ mol/L $C(SO_4^{2-}) = C(Na_2SO_4) = 0.1$ mol/L $I = \frac{1}{2}\times(0.2\times1^2 + 0.1\times(-2)^2) = \frac{1}{2}\times0.6 = 0.3$ Answer: I = 0.3.
5	10 g of the paraffin $C_{20}H_{42}$, a nonvolatile solute, was dissolved in 50 g of chloroform, $CHCl_3$. At 20 °C, the vapor pressure of pure chloroform is 156 mmHg. What is the vapor pressure of the solution at this temperature?
	Solution: According to the first Raoult's law for dilute nonelectrolytes solutions, the vapor pressure of the solution is: $P_{solution} = P^o_{solvent}\cdot\chi_{solvent}$ To calculate the vapor pressure of the solution, it is necessary to calculate the mole fraction of solvent. The first thing to do therefore is to calculate the number of moles of each component. The molar mass of $C_{20}H_{42}$ is 282 g/mol, and the molar mass of $CHCl_3$ is 119.5 g/mol. The moles of paraffin: $n(C_{20}H_{42}) = \frac{m}{Mr} = \frac{10}{282} = 0.0355\,mol$ The moles of chloroform: $n(CHCl_3) = \frac{m}{Mr} = \frac{50}{119.5} = 0.418\,mol$ The mole fraction, χ, of chloroform in solution: $\chi(CHCl_3) = \frac{n(CHCl_3)}{n(CHCl_3)+n(C_{20}H_{42})} = \frac{0.418}{0.418+0.0355} = 0.922$ The vapor pressure of the solution is: $P_{solution} = P^o(CHCl_3)\cdot\chi(CHCl_3) = 156\times0.922 = 143.8\,mmHg$

6	What is the freezing-point of an aqueous solution containing 40% by mass of ethanol, C_2H_5OH? K(H_2O) = 1.86 ºC/m.
	Solution: According to the second Raoult's law for dilute nonelectrolytes solutions, the freezing-point lowering is $\Delta t_f = K \cdot C_m$ For 100 g of 40% solution: the mass of solute, C_2H_5OH, is 40 g and the mass of water is 60 g or 0.06 kg. $C_m = \frac{m_{solute}}{Mr \times m_{H2O\,(\kappa g)}} = \frac{40}{46 \times 0.06} = 14.49\, mol/\kappa g \Rightarrow$ $\Delta t_f = K \cdot C_m = 1.86 \times 14.49 = 27\,^{o}C$ $t_f = 0 - 27 = -27^{o}\,C$
7	Calculate the osmotic pressure at 37 °C of an aqueous solution containing 8.9 g of sodium chloride in 500 mL of solution. What will happen to blood cells that are placed in this solution?
	Solution: According to the Van't Hoff's law for electrolytes solutions: $\pi = i \cdot C \cdot R \cdot T$ NaCl ↔ Na^+ + Cl^- $i \approx 2$ $C = \frac{n}{V} = \frac{m}{Mr \cdot V} = \frac{8.9}{58.5 \times 0.5} = 0.3\, mol/L$ $\pi = 2 \times 0.3 \times 8.31 \times 310 = 1545.7\ \kappa Pa$ Solution is hypertonic to blood ($\pi_{solution} > \pi_{blood}$). Blood cells will undergo plasmolysis (the shrinkage of protoplasm away from the cell walls).
8	An aqueous solution contains 5% of glucose by mass. The density of this solution is 1.05 g/ml. Calculate the osmotic pressure of this solution at 37 °C. Is this solution isotonic to blood?
	Solution: According to the Van't Hoff's law for dilute nonelectrolytes solutions $\pi = C \cdot R \cdot T$ $C = \frac{\omega\% \cdot 10 \cdot \rho}{M} = \frac{5 \times 10 \times 1.05}{180} = 0.29\ mol \cdot l^{-}$ (conversion formula) $\pi = 0.29 \times 8.31 \times 310 = 751\, \kappa Pa$ Solution is isotonic to blood.

3. Answer the multiple-choice test questions (in written form):

1 What is the type of bond between atoms in the water molecule:

A Covalent nonpolar

B Ionic bond

C Hydrogen bond

D Covalent polar

2 What is the kind of bond between water molecules?

A Covalent nonpolar
B Ionic bond
C Hydrogen bond
D Covalent polar

3 What substances are partly soluble at room temperature:

A Water and methanol
B Water and phenol
C Benzene and toluene
D Water and acetic acid

4 At what temperature the concentration of oxygen in solution is the greatest?

A 5ºC
B 10ºC
C 15ºC
D 20ºC

5 What gas doesn't follow Henry's law?

A NH_3
B H_2
C O_2
D CH_4

6 What is the reason of decompression (caisson) disease?

A Decreasing of the solubility of gas in blood due to the pressure reduction
B Sharp change of blood temperature
C Increasing of the solubility of gas in blood due to the pressure reduction
D Lack of oxygen in respiratory mixture

7 What is the reason of mountain (altitude) disease?

A Decreasing of nitrogen partial pressure
B Increasing of nitrogen partial pressure
C Increasing of oxygen partial pressure
D Decreasing of oxygen partial pressure

8 What law describes the solubility of gases in solutions with presence of electrolyte?

A Henry's law
B Dalton's law
C Sechenov's law
D $C = kP$

9 In what solution the solubility of nitrogen gas is greater:

A In blood
B In water
C In 20% NaCl solution
D In 10% NaCl solution

10 The strong electrolyte is a substance with dissociation degree (α):

A $\alpha < 3\%$
B $\alpha > 30\%$
C $3\% < \alpha < 30\%$

11 What substance dissociates gradually (step by step) from the following?

A $C_{12}H_{22}O_{11}$

B CH_3COOH

C Na_2SO_4;

D H_3PO_4.

12 Choose the weak electrolyte from the following:

A $C_6H_{12}O_6$

B CH_3COOH

C HCl

D H_2SO_4

13 The expression of dissociation constant of H_3PO_4 is:

A $$K_a = \frac{[H^+]^3 \cdot [PO_4{}^{3-}]}{[H_3PO_4]}$$

B $$K_a = \frac{[3H] \cdot [PO_4{}^{3-}]}{[H_3PO_4]}$$

C $$K_a = \frac{[H_3PO_4]}{[H^+]^3 \cdot [PO_4{}^{3-}]}$$

D $$K_a = \frac{[H^+]^3 \cdot [P] \cdot [O_4{}^{2-}]}{[H_3PO_4]}$$

14 What constant characterizes the solubility of insoluble salts?

A Hydrolysis constant

B Dissociation degree

C Solubility product

D Rate constant

15 What is the K_{sp} expression for calcium phosphate?

A $K_{sp} = [Ca^{2+}]^3 \cdot [PO_4{}^{3-}]^2$

B $K_{sp} = [Ca^{2+}]^2 \cdot [PO_4{}^{3-}]$

C $$K_{sp} = \frac{[Ca^{2+}]^3 \cdot [PO_4{}^{3-}]^{3-}}{[Ca_3(PO_4)_2]}$$

D $K_{sp} = [Ca^{2+}] \cdot [PO_4{}^{3-}]$

16 What ions cannot simultaneously be in solution:

A NH_4^+ and NO_3^-

B Ba^{2+} and Cl^-

C Na^+ and CO_3^{2-}

D Zn^{2+} and CO_3^{2-}

17 Indicate the colligative property:

A Solubility

B Index of refraction

C Diffusion

D Elevation of boiling point

18 What is an isotonic coefficient (Van't Hoff's factor) of calcium chloride if it dissociates completely in water medium:

A i = 1
B i = 2
C i = 3
D i = 4

19 For what solution the isotonic coefficient is the biggest:

A C(NaCl) = 0.1 mol/L
B C(NaCl) = 0.0001 mol/L
C C(NaCl) = 0.01 mol/L
D C(NaCl) = 0.001 mol/L

20 For what electrolyte solution the isotonic coefficient is the biggest:

A C(NaCl) = 0.01 mol/L
B C(K_2SO_4) = 0.01 mol/L
C C(KCl) = 0.01 mol/L
D C ($MgSO_4$) = 0.01 mol/L

21 For which from NaCl solutions the osmotic pressure is the biggest:

A C(NaCl) = 0.1 mol/L
B C(NaCl) = 0.0001 mol/L
C C(NaCl) = 0.01 mol/L
D C(NaCl) = 0.001 mol/L

22 What osmotic pressure the solutions which are used in medical practice as isotonic must have:

A 500-600 kPa
B 740-800 kPa
C 800-900 kPa
D 400-500 kPa

23 Which of the following NaCl solutions is an isotonic to blood?

A ω (NaCl) = 0.009
B ω (NaCl) = 0.9
C ω (NaCl) = 0.00009
D ω (NaCl) = 0.09

24 The blood cell undergoes plasmolysis if it is placed in:

A 0.9 % NaCl solution
B 10 % NaCl solution
C water
D 0.1 % NaCl solution

4. Tasks for an independent work (in written form):

1. Calculate the solubility of oxygen in water from air at 2.5 atm if the solubility of oxygen at 1 atm is 1.263×10^{-4} M.

2. Calculate the solubility of $CaSO_4$ in water if $K_{sp} = 6.26 \times 10^{-5}$.

3. The vapor pressure of benzene is 100.0 mmHg at 26.1°C. Calculate the vapor pressure of a solution containing 24.6 g of camphor ($C_{10}H_{16}O$) dissolved in 98.5 g of benzene.

4. Calculate the boiling point elevation of 0.12 kg of water containing 50 g of $Al_2(SO_4)_3$, assuming complete dissociation of this electrolyte. $K_b(H_2O) = 0.512$ °C/m.

5. Calculate the freezing-point depression of 350 g of water containing 115 g of sucrose.
   $K_f(H_2O) = 1.86$ °C/m.

6. The osmotic pressure of solution containing 14.0 g of insulin per liter is 6.12 kPa at 25°C. What is the molecular weight of insulin?

7. Calculate the osmotic pressure of a sodium chloride solution with concentration 7.5 % by mass (density is 1.05 g/ml) at 37°C. What will happen to blood cells that are placed in this solution?

Laboratory work: «Solutions and solubility. Solutions of electrolytes».

1. Effect of temperature on the solubility of salts.

Pour 2 ml of distilled water in a test-tube. Add certain amount of sodium carbonate until it stops dissolving. Heat the test-tube stirring it from time to time. Cool the test-tube putting it into running water. Note the changes accompanying these processes. Make a conclusion about the effect of temperature on solubility of solid compounds.

2. Heat effects of dissolving processes.

To observe heat effects of a dissolving process, prepare solutions of the following salts: sodium hydroxide, potassium thiocyanide, and sodium chloride. For this add 7 ml of distilled water to 3 g of each compound. Measure the change in temperature (with help of digital millimeter) accompanying the dissolving of salts. Note the changes and make a conclusion.

3. Precipitation of insoluble salts.

Fill two test-tubes with 3 ml of the following solutions: 1 – barium chloride, 2 – sodium chloride. Add 2 ml of saturated solution of sodium sulfate in each test-tube. Observe the changes accompanying these processes and write down formula (molecular), ionic and net ionic equations for the reactions.