Chemistry and materials science: second-round sample tasks

Module 1. Entry-level questions with one correct answer (each correct answer is worth 2 points)

1.1 Calculate the calorie content of 450 g of a food product containing 50 percent of water, 30 percent of protein, 15 percent of fat, and 5 percent of carbohydrates.

To determine the caloric content of proteins, fats, and carbohydrates, use the table specific heat values of the complete oxidation of substances in the body:
conditional protein:17 kJ/g; conditional fat: 39KJ/g; carbohydrates: 17KJ/g.
A) 1267 kcal.
B) 1200 kcal.
C) 1367 kcal.
D) 1395 kcal

1.2 A first-order reaction is 20 percent complete within 50 minutes. Calculate the reaction rate at a reagent concentration of 0.001 mol/l.

A) 4.46×10^{-6}
B) 4.46×10^{-5}
C) 44.6×10^{-6}
D) 2.23×10^{-6}

1.3 For the reaction $2NO + O_2 \leftrightarrow 2NO_2$ at 950°C, the equilibrium constant is $K_P = 10.2$. Find the partial pressure of oxygen O_2 in the system if equilibrium has been established, and the ratio of partial pressures in the system $P_{NO2} / P_{NO} = 4$.
A) 10.2 atm.
B) 1.57 atm.
C) 0.392 atm.
D) 0.06 atm.

1.4 A first-order reaction has an activation energy of $E_a = 115$ kJ/mol, and the pre-exponential factor A in the equation $k = A\cdot e^{(-Ea/RT)}$ is $5\cdot10^{13}$. Which is the half-life of this reaction at 100°C?
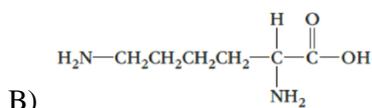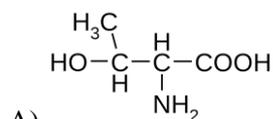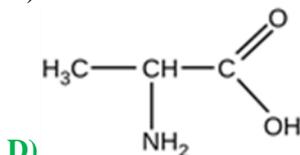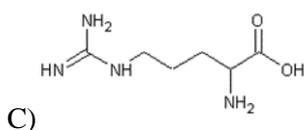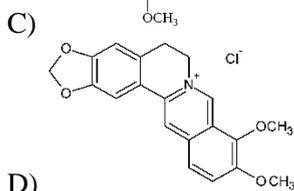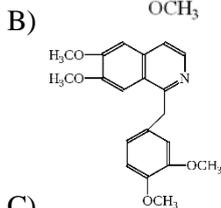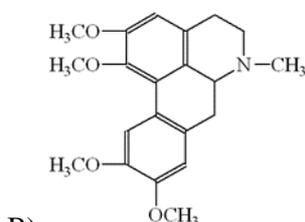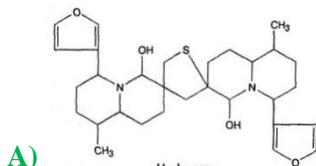A) 5 minutes
B) 100 minutes
C) 3 minutes
D) 5 seconds

1.5 The tetrapeptide taftsin, a regulator of the immune system, has the following structure: Thr-Lys-Pro-Arg. Which of the amino acids is not included in the structure of taftsin:

A)

B)

C)

D)

1.6 Which natural alkaloid is the quinolizidine cycle part of?

A)

B)

C)

D)

1.7 Phase transitions of the first order include:

A) melting and condensation of matter;
B) transition of a metal or alloy to a superconducting state;
C) transition of liquid helium to a superfluid state;
D) the transformation of a magnetic alloy from a ferromagnetic state to a paramagnetic state.

1.8 How do the lattice period and the number of atoms per elementary cell change depending on the concentration of the solid solution during the formation of an interstitial solid solution?

A) the lattice period remains unchanged, and the number of atoms per elementary cell increases;
B) the lattice period increases, and the number of atoms per elementary cell rises;
C) the lattice period increases, and the number of atoms per elementary cell remains unchanged;
D) the lattice period decreases, and the number of atoms per elementary cell increases.

1.9 Which of the following is the term for the uniformity of properties regardless of the direction of measurement?

A) allotropy
B) isotropy
C) anisotropy
D) polymorphism

1.10 Which method is used to determine the hardness of thin layers?
A) the Brinell hardness test
B) the Vickers hardness test
C) the Rockwell hardness test
D) the microhardness test

Module 2. Multiple-answer tasks (each is worth 7 points)

2.1 A solution contains lead nitrate and potassium iodide. Which substances should be added in small quantities to this solution so that the surface of the formed solid phase is negatively charged?

1) calcium nitrate
2) potassium chloride
3) barium iodide
4) sodium iodide
Points awarded:
7 points for two correct answers
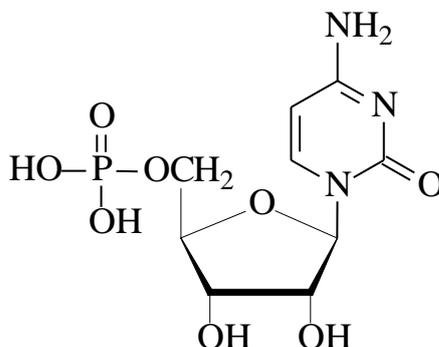2 points for one correct answer

2.2 The dependence of the electrolyte activity on its molar concentration is expressed by the formula $a = \gamma_{\pm} \cdot m$. For which THREE substances is this expression true?
A) KCl
B) K_3PO_4
C) CuSO$_4$
D) $CuBr_2$
E) NaBr
F) K_2SO_4
Points awarded:
7 points for three correct answers
4 points for two correct answers
2 points for one correct answer

2.3 Which THREE compounds are formed by the complete hydrolysis of the compound whose formula is shown below in an acidic environment?

A. D-ribose
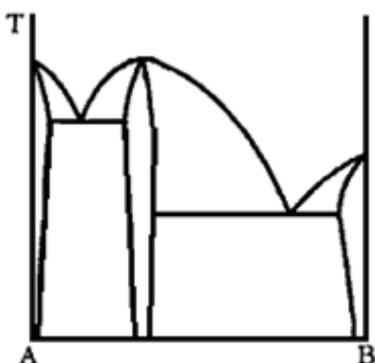**B. cytosine**
C. Phosphate
D. Timin
E. Phosphoric acid
Points awarded:
7 points for three correct answers
4 points for two correct answers
2 points for one correct answer

2.4 Which THREE statements are true for the system shown in the phase diagram?

A)   There is no solid solubility in the system.
B) There is a limited solubility in the liquid state in the system.
C) Substances A and B are partially miscible in a solid state.
D) Substances A and B do not form chemical compounds.
E) Formation of a stable non-stoichiometric chemical compound is possible in the system.
F) Substances A and B are miscible in a liquid state.
Points awarded:
7 points for three correct answers
4 points for two correct answers
2 points for one correct answer

2.5 Which THREE characteristics can be obtained after tensile tests at room temperature?
A) endurance limit
B) tensile strength
C) yield stress
D) creep limit
E) elastic limit
F) ultimate strength
Points awarded:
7 points for three correct answers
4 points for two correct answers
2 points for one correct answer

Module 3. Tasks with a detailed answer (the maximum possible score is 15 points)

3.1 Basic bismuth nitrate has an enveloping, anti-inflammatory effect and is included in complex medicines as a gastroprotective agent. Basic bismuth nitrate (dihydroxyvismuth (III) nitrate) is practically insoluble in water. The substance was calcined to a constant mass to convert the powder to a soluble state. Dilute nitric acid was added to the resulting yellow residue until fully dissolved. When drops of potassium iodide

solution were added to the resulting solution, a black precipitate was formed, whose mass differed from the mass of the solid residue after calcination by 14.3 g. Determine the mass of the basic bismuth nitrate and calculate what minimum mass of a 20 percent potassium iodide solution is required for the complete dissolution of the resulting black precipitate with the formation of potassium tetraiodovismutate (III).

SOLUTION:

Assessment criteria (other formulations are possible, as long as the answer is correct)	Points
4Bi(OH)2NO3 (t0) → 2Bi2O3 + 4NO2 + 4H2O + O2 Bi2O3 + 6HNO3 → 2Bi(NO3)3 + 3H2O Bi(NO3)3 + 3KI → BiI3 + 3KNO3 BiI3 + KI → K[BiI4]	**5**
Let v (Bi (OH)2NO3) = x mol m(Bi2O3) = 466·0,5x = 233x m(BiI3) = 590x 590x – 233x =14,3 x = 0.04	**5**
m (Bi (OH)2NO3) = 305·0.04 = 12.2 g v (KI) = 0.04 mol m (KI)solution = 0.04·166/0, 2 = 33.2 g	**5**

3.2 The vapor pressure of H_2O over a mixture of $MgSO_4 \bullet 7H_2O$ and $MgSO_4 \bullet 6H_2O$ crystalline hydrates is 0.0151 atm. at 25°C and 0.0222 atm. at 30°C. Calculate ΔH_0, ΔS_0, ΔG_0 of the dehydration reaction at 30°C.

$MgSO_4 \cdot 7H_2O \leftrightarrow MgSO_4 \cdot 6H_2O + H_2O$

0.2 grams of $MgSO_4 \bullet 7H_2O$ was placed in a sealed container with dry argon; the volume of salt is negligible. The tank maintains the constant pressure P_{total} = 0.5 atm. and a temperature of 30 °C. What was the volume of the container, and how much argon was in it by mass, if the mass of the salt after equilibrium was decreased by 5 percent?

Solution:
The dehydration reaction constant can be expressed by the following expression:
$K_p = p_{H_2O}$ (1 point for the correctly expressed equilibrium constant)
Since the temperature change is small, we use the equation of the isobar of a chemical reaction in the integral form to find ΔH^0:
$$\lg \frac{K_{p2}}{K_{p1}} = \frac{\Delta H^0 (T_2 - T_1)}{2{,}303 \cdot R \cdot T_1 \cdot T_2}$$
Thus $\Delta H^0 = \dfrac{\lg \frac{0{,}0222}{0{,}0151} \cdot 8{,}31 \cdot 2{,}303 \cdot 298 \cdot 303}{(303 - 298)}$ = 57846 J/mol (2 points for the correct ΔH^0 value)
The relationship between the Gibbs energy and the equilibrium is as follows:
$\Delta G^0 = -RT \cdot \ln K_p$

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Thus, $\Delta G^0 = -8.31 \cdot 303 \cdot 0{,}0222 = $ = -55.90 J/mol (2 points for the correct ΔG^0 value)

The entropy of the reaction can be found from the expression:

$\Delta G = \Delta H - T \cdot \Delta S$

$\Delta S^0 = \frac{(-55{,}90 - 57846)}{-303} = $ 191,10 J/(mol·K) (2 points for the correct ΔS^0 value)

The mass of the salt decreases due to the release of water vapor during the decomposition of $MgSO_4 \cdot 7H_2O$.

m(H_2O) = m($MgSO_4 \cdot 7H_2O$) * 5% = 0.2 grams * 5% = 0.01 g

The partial pressure of H_2O at equilibrium is 0.0222 atm. (1 point for the correct P_{H2O} value);

the partial pressure of Ar will be P_{Ar} = P_{total} - P_{H2O} = 0.5 – 0.0222 = 0.4778 atm. (1 point for the correct P_{Ar} value)

Since the partial pressure of H_2O is known, we can find the volume of the vessel, using the Mendeleev-Clapeyron equation.

V = m(H_2O)/M(H_2O)*R*T/P_{H2O} = 0.01/18*8.31*303/(0.022*1.01325·10^5) = 0.000628 m^3 = 0.628 liters. (3 points for the correct vessel volume)

The amount of argon can be found based on the volume of the vessel, .

m(Ar) = P(Ar)*V*M(Ar)/(R*T) = 0.4778*1.01325·10^5*0.000628*40/(8.31*303) = 0.48300 grams. (3 points for the correct mass of Ar)

3.3 Calculate the impact strength of material after pendulum impact testing using the standard method. The square cross-section of the samples is 10*10 mm; the depth of the incision is 2 mm; the fracture work is A = 200 J.

Solution: The impact strength in this test scheme is calculated by the formula

CS = A/F, the units are J/cm^2

where F is the cross-sectional area of the sample at the incision site before the test.

The cross-sectional area is 1 cm*0.8 cm = 0.8 cm^2

Impact strength CS = 200/0.8 = 250 J/cm2

Answer: The impact strength of the material is 250 J/cm^2

Assessment criteria:

6 points for writing down the formula for determining the impact strength.

4 points for calculating the working cross-section of the sample in cm^2.

5 points for obtaining the numerical value of the impact strength.