

Chemistry and Materials Sciences: Second-round Sample Tasks for the Open Doors Undergraduate Track

The variant includes 42 tasks, 25 of which are entry level tasks with one correct answer (a correctly completed task is 1 point), 13 are intermediate level tasks with several correct answers (a correctly completed task is 1-3 points), 4 are advanced level tasks with a detailed answer (the correctly completed task is 1-9 points).

In test tasks, correct answers are highlighted in bold.

For complex tasks with a detailed answer, assessment criteria and a standard answer are provided.

1. Inorganic and nuclear chemistry

Task 1 Entry level (1 point)

Select the substance the aqueous solution of which will have a $\text{pH} < 7$

- 1) NaOH
- 2) Na_2SO_3
- 3) NaCl
- 4) CH_3COONa
- 5) **CuSO_4**

Answer: 5

Task 2 Entry level (1 point)

The industrial method of ammonia production is based on the direct interaction of hydrogen and nitrogen. What volume (normal conditions) of ammonia (in liters) can be obtained from 20 liters of nitrogen?

- 1) 10 l
- 2) 20 l
- 3) 30 l
- 4) **40 l**
- 5) 50 l

Answer: 4

Task 3 Average level (3 points)

Among the proposed formulas/names of substances located in the numbered cells, choose the formulas/names of: A) divalent acid B) amphoteric hydroxide C) acid oxide

1	BeO	2	H_3PO_4	3	N_2O
4	H_2PO_3	5	$\text{Ca}(\text{OH})_2$	6	silane

7	Mn_2O_7	8	carbon monoxide	9	$Be(OH)_2$
---	-----------	---	--------------------	---	------------

Write the numbers in your answer, putting them in the order corresponding to the letters:

A	B	C
4	9	7

Answer: 4, 9, 7

Task 4
Average level (3 points)

Solution Y was added to a test tube with salt X. As a result of the reaction, X dissolved and gas was observed. From the proposed list, select the substances X and Y that can enter into the described reaction

1. $CrCl_3$
2. $CaSO_4$
- 3. HCl**
4. $NaOH$
- 5. $CaCO_3$**

Write the numbers in your answer, putting them in the order corresponding to the letters X and Y.

X	Y
5	3

Answer: 5, 3.

Task 5
Average level (3 points)

Match the formula of a substance with the reagents the substance can interact with. For each position indicated by a letter, match the corresponding position indicated by a number:

Formula of the substance	Reagents
A) Cl_2	1) HNO_3 , O_2 , CuO
B) P_4	2) Cu , KI , $NaOH$
C) NH_3	3) $Ba(NO_3)_2$, $NaOH$, Na_2S
D) $CuSO_4$	4) $BaCO_3$, S , Fe_2O_3
	5) $NaOH$, O_2 , HNO_3

Write the numbers in the answer in the order corresponding to the letters: A, B, C, D.

A	B	C	D
2	5	1	3

Answer: A – 2, B – 5, C – 1, D – 3.

Task 6

Advanced level (9 points)

In the laboratory, a student discovered a jar containing an unknown substance, A. Upon introducing this substance into a burner flame, the flame turned purple. When concentrated sulfuric acid was added to solid A, a colorless gas, B, with a pungent odor was released. Passing this gas through a sodium hydroxide solution, which had been previously treated with a few drops of litmus, resulted in a color change from blue to violet. When gas B was passed through a hydrochloric acid solution, also treated with litmus, no visible changes occurred. Additionally, when gas B was passed through a silver nitrate solution, a white curd-like precipitate, C, was formed, containing 75.26% silver.

1. Identify **A**, **B**, **C**. Explain your answer.
2. Write the equations of the described reactions.
3. Determine the volume (normal conditions) of gas **B** that will be released when 6 g of substance **A** interacts with 11 ml of 18.34 M sulfuric acid.

Note: the assessment takes into account the progress of the solution; writing the answer only is not enough for getting points.

Solution:

1. A - colors the flame violet, therefore, it contains potassium ions;
 $A + H_2SO_4 \rightarrow B \uparrow$ (colorless, pungent odor, acidic environment, as it neutralizes alkali and does not react with acid);

$B + AgNO_3 \rightarrow C \downarrow$ (white, curdled, $\omega(Ag) = 75,26\%$).

Let the composition of the salt be AgX

$M(X) = 108 \cdot 24.74 / 75.26 = 35.5 \text{ g/mol}$

Fits the description $AgCl$.

A	B	C
KCl	HCl	AgCl

2. $KCl + H_2SO_4 = KHSO_4 + HCl$ (if K_2SO_4 is written count as the correct answer)

$HCl + NaOH = NaCl + H_2O$

$HCl + AgNO_3 = AgCl + HNO_3$

3. $n(H_2SO_4) = C \cdot V = 18.34 \cdot 0.011 = 0.2 \text{ mol}$

$n(KCl) = m/M = 6/74.5 = 0.08 \text{ mol}$

H_2SO_4 in excess, therefore an acidic salt is formed:

$KCl + H_2SO_4 = KHSO_4 + HCl$

$n(HCl) = n(KCl) = 0.08 \text{ mol}$

$V(HCl) = n \cdot V_m = 0.08 \cdot 22.4 = 1.792 \text{ L}$

Answer : $V(HCl) = 1.792 \text{ л}$

Assessment criteria:

Criteria 1 – Substances A, B, C are identified, appropriate explanations are given – **3 points**.

Criteria 2 – All necessary reactions are recorded – **3 points**.

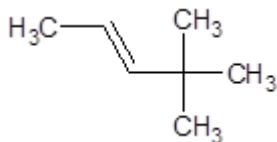
Criteria 3 – The calculation was carried out, the correct result was obtained – **3 points**.

2. Organic chemistry:

ONE CLICK TO OPEN ALL DOORS

Task 1
Entry level (1 point)

The structural formula of an organic substance is shown in the figure. Select the isomer for this substance.



- 1) 3,3-dimethylbutene-1
- 2) 2,4,4-trimethylpentene-2
- 3) 4-methylpentene-2
- 4) **2,4-dimethylpentene-2**

Answer: 4

Task 2
Entry level (1 point)

What hydrocarbon can be produced by the interaction of bromoethane and sodium?

- 1) ethylene
- 2) **butane**
- 3) ethane
- 4) dibromoethane

Answer: 2

Task 3
Average level (3 points)

Name of the organic compound according to IUPAC nomenclature 2,5-dimethylhexen-1-ol-3.
How many primary carbon atoms does this compound contain?

Answer: 4 (the reference answer is an integer)

Average level (3 points)

An unsaturated hydrocarbon (class of alkenes) was chlorinated and then subjected to alkaline hydrolysis with NaOH, yielding 2-methylbutanediol-2,3. Determine the formula of the starting alkene. (The name of the hydrocarbon should be in accordance with IUPAC nomenclature).

Answer: 2-methylbutene-2 (the reference answer is a word)

Task 5
Average level (3 points)

Which substances can enter into an electrophilic substitution reaction with chlorobenzene?

ONE CLICK TO OPEN ALL DOORS

- 1) Cl₂
- 2) H₂
- 3) Mg
- 4) H₂SO₄ conc.
- 5) H₂O

Answer: 1, 4

(1 correct answer – 1 point; 2 correct answers – 3 points)

Task 6
Advanced level (9 points)

Cracking of saturated hydrocarbon X with molecular weight 128 g/mol occurs according to the reaction equation:



1) Determine the simplest formula of substance X. Think of 2 different isomers of substance X. Draw the structural formulae of these isomers and name them according to IUPAC nomenclature.

2) Determine the structure of substances Y and Z, if it is known that substance Z can be obtained from Y according to the following scheme:



3) The structural formula of substance X contains 5 primary carbon atoms. Determine the structure of substance X. Name substances X, Y, Z according to IUPAC nomenclature.

Note: the assessment takes into account the progress of the solution; writing the answer only is not enough for getting points.

Solution:

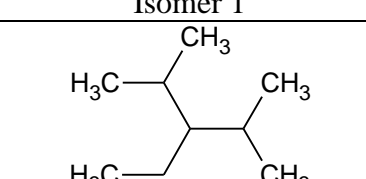
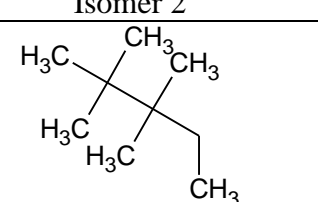
1) The general formula of all alkanes is C_nH_{2n+2}. If the molecular weight is known, we can find n and the empirical formula.

$$12 \cdot n + (2 \cdot n + 2) = 128$$

$$14n = 128 - 2 = 126$$

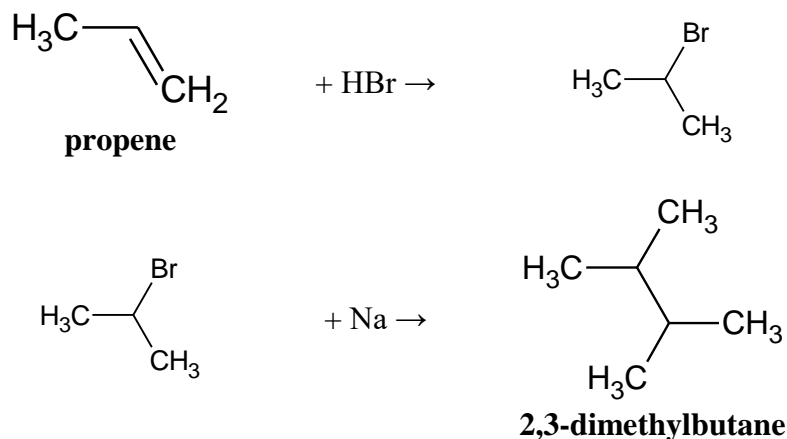
$$n = 126 / 14 = 9$$

The simplest formula for substance X is C₉H₂₀

Isomer 1	Isomer 2
 <p>3-ethyl-2,4-dimethylpentane</p>	 <p>2,2,3,3-tetramethylpentane</p>

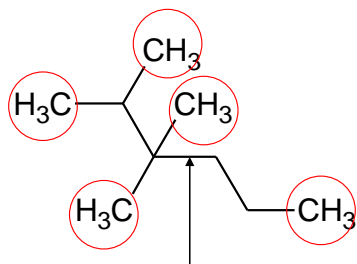
Criteria 1:	The simplest formula of substance X is correctly found	1 point
	Structural formulas and names of isomers are given correctly. (1 point for structural formula and name of one compound)	2 points

2) Alkenes are able to attach HBr, so **Y** is an alkene. The number of carbon atoms in **Y** must be 2 times less than in **Z**. So **Y** is a propene.



Criteria 2:	The structural formulas of substances Y and Z are correctly established. (1 point for the structural formula of one compound)	2 points
-------------	--	-----------------

3) The structural formula of **X** satisfying the conditions of the problem is shown in the figure. Red circles indicate primary carbon atoms. The arrow is the bond that is broken by cracking.



Name of substances:
X – 2,3,3- trimethylhexane
Y – propene
Z – 2,3- dimethylbutane

Criteria 3:	The structural formula of substance X is correctly found.	1 point
	Correctly named substances X , Y , Z . (1 point for naming one substance)	3 points

3. Physical chemistry:

Task 1 Entry level (1 point)

What is the standard enthalpy of formation of barium oxide – BaO in kJ/mol, if 111.62 kJ of heat is released during the oxidation of 0.2 mol of barium?

1) -1116.2

ONE CLICK TO OPEN ALL DOORS

- 2) – 558.1
 3) 2232.4
 4) -22.324
 5) 558.1

Answer: 2

Task 2
Entry level (1 point)

The equilibrium temperature for a reversible reaction under standard conditions, if $\Delta H_p^0 = 260.3$ kJ, $\Delta S_p^0 = 282$ J/K, is equal to

- 1) 1083 K
 2) 1.08 K
3) 923 K
 4) 0.92 K
 5) 542.3 K

Answer: 3

Task 3
Average level (3 points)

At 253°C, the reaction ends in 20 seconds. How long will it take for this reaction at 293°C if $\gamma = 3$:

- 1) 0.25 sec.**
 2) 1260 sec.
 3) 0.74 sec.
 4) 0.17 sec.
 5) 6 sec.

Answer: 1

Task 4
Average level (3 points)

Under what conditions will the reaction $\text{FeO}(c) + \text{H}_2(g) = \text{Fe}(k) + \text{H}_2\text{O}(g)$ occur if $\Delta S^0_{298} = 0.027$ kJ/K?

Substance	ΔH^0_{298} , kJ/mol	ΔG^0_{298} , kJ/mol
FeO(c)	-264.8	-244.3
H ₂ O(g)	-241.8	-228.6

- 1) under standard conditions
2) at T > 851.85 K
 3) at T > 298 K
4) at T = 1000 K
 5) at T = 581.48 K

Answer: 2, 4

Task 5
Average level (3 points)

Under what conditions will the equilibrium shift towards the direct reaction $\text{CH}_4(\text{g}) + \text{CO}_2(\text{g}) \leftrightarrow \text{CO}(\text{g}) + \text{H}_2$; $\Delta H > 0$?

- 1) with increasing temperature
- 2) with increasing pressure
- 3) when the temperature decreases
- 4) when pressure decreases
- 5) when the CH_4 concentration decreases

Answer: 1, 4

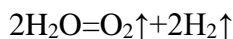
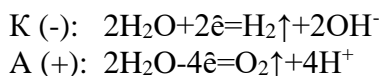
Task 6
Advanced level (9 points)

An electric current was passed through an electrolyzer containing 500 ml of 4.6% NaOH solution ($\rho = 1.05 \text{ g/cm}^3$). After a few minutes, the mass fraction of sodium hydroxide became equal to 10%. Determine the volumes of gases released at the electrodes.

Note: the assessment takes into account the progress of the solution; writing the answer only is not enough for getting points.

Solution:

- 1) Find the mass of a 4.6% NaOH solution:
 $m_{4.6\% \text{ sol.}} = 500 \text{ ml} \cdot 1.05 \text{ g/ml} = 525 \text{ g}$
- 2) Find the mass of dissolved NaOH in 525 g of solution:
 $M_{\text{sol. subs.}} = 525 \text{ g} \cdot 0.046 = 24.15 \text{ g}$
- 3) Electrolysis scheme:
 $\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-$



Criteria 1 – **6 points**.

- 4) Find the mass of a 10% NaOH solution after electrolysis:
 $m_{10\% \text{ sol.}} = 24.15 \text{ g} : 0.1 = 241.5 \text{ g}$
Criteria 2 – **1 point**
- 5) Find the mass of water that has undergone electrolysis:
 $m_{\text{aq}} = 525 \text{ g} - 241.5 \text{ g} = 283.5 \text{ g}$
- 6) Let's find how many liters of H_2 and O_2 are released:
 $v(\text{H}_2\text{O}) = 283.5 \text{ g} : 18 \text{ g/mol} = 15.75 \text{ mol}$
 $v(\text{O}_2) = 15.75 \text{ mol} : 2 = 7.875 \text{ mol}$
 $v(\text{H}_2) = 283.5 \text{ g} : 18 \text{ g/mol} = 15.75 \text{ mol}$

$$V(\text{O}_2) = 7.875 \text{ mol} \cdot 22.4 \text{ L/mol} = \mathbf{176.4 \text{ L}}$$

$$V(\text{H}_2) = 15.75 \text{ mol} \cdot 22.4 \text{ L/mol} = \mathbf{352.8 \text{ L}}$$

Criteria 3 – **2 points**

Answer: 176 liters of oxygen and 352.8 liters of hydrogen were released.

Evaluation criteria:

Criterion 1 – The electrolysis scheme has been drawn up correctly. The mass of the 4.6% solution and the mass of NaOH dissolved in the solution were calculated. – **6 points**.

Criterion 2 – The mass of a 10% NaOH solution after electrolysis and the mass of water subjected to electrolysis are calculated – **1 point**.

Criterion 3 – Calculated volumes of released gases – **2 points**.

Scientific field 4: Analytical chemistry

Task 1

Entry level (1 point)

A mixture of NaCl and CuSO₄ salts was dissolved in distilled water. Which reagent can be used to detect copper ions in the solution?

- 1) AgNO₃
- 2) BaCl₂
- 3) Cu
- 4) **Na₂S**
- 5) N₂

Answer: 4

Task 2

Entry level (1 point)

When titrating 10 mL of HNO₃ solution, 5.2 mL of Na₂CO₃ solution was consumed. Determine the initial concentration of HNO₃ in the solution if the concentration of Na₂CO₃ is 0.15 mol/L

- 1) 0.52 mol/L
- 2) **0.156 mol/L**
- 3) 52 %
- 4) 0.333 mol/L
- 5) 0.001 mol/L

Answer: 2

Task 3

Average level (3 points)

An alkaline solution is titrated with an acid solution in the presence of phenolphthalein. Which substance is the titrant?

- 1) Water

- 2) Acid solution
- 3) Alkali solution
- 4) phenolphthalein
- 5) glassware

Answer: 2

Task 4
Average level (3 points)

The solution contains the following ions: Ag^+ , Al^{3+} , Pb^{2+} , Ni^{2+} and Cu^{2+} . The solution under study is acidified ($\text{pH} = 0.5$) and then H_2S is added. Determine which ions remain in the solution after these operations.

- 1) Ag^+
- 2) Al^{3+}
- 3) Cu^{2+}
- 4) Ni^{2+}
- 5) Pb^{2+}

Answer: 2, 4

(1 correct answer – 1 point; 2 correct answers – 3 points)

Task 5
Entry level (3 points)

A solution of FeCl_3 is available in the laboratory. An excess of NH_4OH was added to the solution until the precipitate was completely precipitated. The washed precipitate was calcined in a muffle furnace. After all operations, the mass of the precipitate was 1.35 g. Determine the mass of FeCl_3 in the initial solution. (Express your answer in grams and round to hundredths).

Answer: 2.74 g (**2.60 – 2.88 g**) (reference answer – number, range).

(1 point if the answer is rounded to tenths or whole numbers)

Task 6
Advanced level (9 points)

The laboratory received a sample of an alloy. It is known that the alloy contains 2 metals. To determine the chemical composition of the alloy, the following experiments were performed.

Experiment 1 - An alloy sample was placed in an excess of HCl solution and heated. After the reaction, which proceeded with outgassing, a colorless solution and an insoluble precipitate were obtained. The precipitate was separated from the solution.

Experiment 2 - The precipitate from experiment 1 was completely dissolved in concentrated nitric acid, brown gas was released, and the solution turned blue. When the blue NaOH solution is neutralized, a blue precipitate falls out.

Experiment 3 - Part of the solution from experiment 1 was treated with excess NaOH and a white precipitate precipitated. When exposed to H_2O_2 , the precipitate turns brown.

Task:

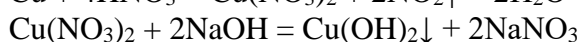
- 1) Determine which element was discovered in experiment 1. Justify your answer with equations of chemical reactions.
- 2) Determine which element was discovered in experiment 2. Justify your answer with chemical reaction equations.
- 3) Determine the mass fraction of elements in the alloy if it is known that interaction of 300 mg of the alloy with excess HCl produces 42.8 ml of gas under normal conditions.

Note: the assessment takes into account the progress of the solution; writing the answer only is not enough.

Solution:

Justification: **experience 1**

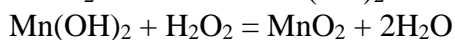
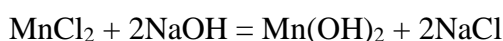
- 1) Copper dissolves in concentrated nitric acid to form a blue solution. When alkali acts on copper salts, a blue precipitate precipitates.



Criteria 1:	correctly written reaction equations (1 point per reaction).	2 points
	Specifies the attributes by which an element can be identified	1 point

Justification: **experience 2**

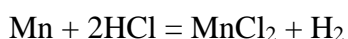
- 1) Manganese salts form a white precipitate when exposed to NaOH, which turns brown when exposed to H₂O₂



Criteria 2:	correctly written reaction equations (1 point per reaction).	2 points
	Specifies the attributes by which an element can be identified	1 point

Determination of **mass fractions of elements** in the alloy.

Of the two alloy components, manganese is able to react with hydrochloric acid



$$v(\text{Mn}) = v(\text{H}_2) = V(\text{H}_2)/V_m = 42.8 \cdot 10^{-3} / 22.4 = 0.00191 \text{ mol}$$

$$m(\text{Mn}) = v(\text{Mn}) \cdot M(\text{Mn}) = 0.00191 \cdot 54.9 = 0.105 \text{ gram} = 105 \text{ mg}$$

$$\omega(\text{Mn}) = m(\text{Mn})/m(\text{alloy}) = 105/300 \cdot 100\% = \mathbf{35\%}$$

$$\omega(\text{Cu}) = 100\% - \omega(\text{Mn}) = \mathbf{65\%}$$

Criteria 3:	correctly written reaction equations	1 point
	The calculation of the mass fractions of metals in the alloy is correct.	2 points

5: Crystallography**Task 1**

Entry level (1 point)

A crystal lattice is called primitive if

- 1) **nodes are located only in the vertices of the cell**
- 2) nodes are located in the vertices of the cell and on faces perpendicular to the Z-axis.
- 3) nodes are located in the vertices of the cell and on the faces parallel to the Z axis
- 4) nodes are located at the vertices of the cell and in the center of all other faces
- 5) nodes are located at the vertices of the cell and in the volume of the lattice

Answer: 1

Task 2
Entry level (1 point)

A polyhedron having 6 faces is called

- 1) tetrahedron
- 2) octahedron
- 3) **cube**
- 4) icosahedron
- 5) dodecahedron

Answer: 3

Task 3
Entry level (1 point)

Open symmetry elements include

- 1) rotation axis
- 2) mirror plane
- 3) rotoinversion axis
- 4) mirror-rotating axis
- 5) **screw axis**

Answer: 5

Task 4
Entry level (1 point)

The unit cell parameters $a=b=c$, $\alpha = \beta = \gamma = 90^\circ$ correspond to

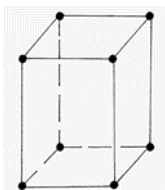
- 1) monoclinic syngony
- 2) rhombic syngony
- 3) tetragonal syngony
- 4) hexagonal syngony
- 5) **cubic syngony**

Answer: 5

Task 5

Entry level (1 point)

The number of formula units corresponds to the number of atoms per unit cell. Calculate the number of formula units in the following unit cell:



- 1) 1
- 2) 2
- 3) 3
- 4) 4
- 5) 8

Answer: 1

Task 6
Average level (3 points)

Lower category crystals may have:

- 1) **second-order axes**
- 2) third-order axes
- 3) **plane of symmetry**
- 4) fifth order axes
- 5) **center of symmetry**

Answer: 1,3,5

(one correct answer – 1 point; two correct answers – 2 points; three correct answers – 3 points)

6. Testing in materials sciences

Task 1
Entry level (1 point)

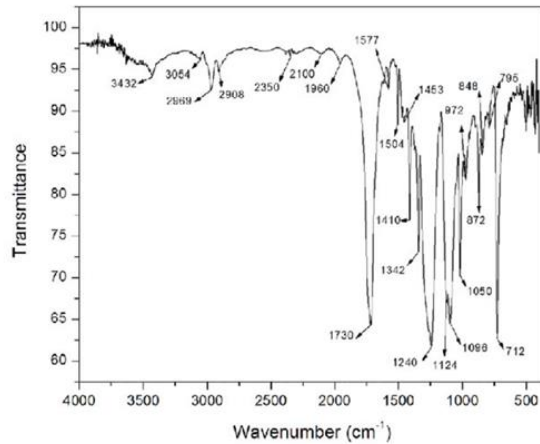
The ultimate result of the gas-phase fluorination of polyethylene with F_2 will be the production of

- 1) polyvinyl chloride $(C_2H_3Cl)_n$
- 2) **polytetrafluoroethylene $(C_2F_4)_n$**
- 3) polytrifluoroethylene $(CF_2-CFCl)_n$
- 4) polypropylene $(C_3H_6)_n$

Answer: 2

Task 2
Entry level (1 point)

The above infrared spectrum refers to...



- 1) tetrahydrofuran C_4H_8O
- 2) polystyrene $(C_8H_8)_n$
- 3) copolymer of acrylonitrile, butadiene and styrene $(C_3H_5)_x \cdot (C_4H_6)_y \cdot (C_6H_5)_z$
- 4) polyethylene terephthalate $(C_{10}H_8O_4)_n$**

Answer: 4

Task 3 Entry level (1 point)

The hardness of polymers is determined by the depth of indentation of the indenter, using one of the following methods:

- 1) the Rockwell method**
- 2) the Brinell method
- 3) the Vickers method
- 4) all answers are incorrect

Answer: 1

Task 4 Entry level (1 point)

If the number of observations exceeds 20, a criterion used to evaluate gross errors is:

- 1) Romanovsky
- 2) Kashpirovsky
- 3) three sigma**
- 4) preferred num

Answer: 3

Task 5 Entry level (1 point)

The initial stage of the biofouling process of polymers by microscopic fungi, also known as micromycetes, is mainly due to

ONE CLICK TO OPEN ALL DOORS

- 1) the adhesion of micromycetes to the polymer surface.
- 2) the method of obtaining the polymer.
- 3) operating conditions of the polymer.
- 4) the duration and storage conditions of the polymer.

Answer: 1

Task 6
Average level (3 points)

Correlate the scientific equipment with the measurement results obtained when using it:

Equipment	Measurement results
1 – Kruss DSA100	A – Identification of the polymer (IR spectrum)
2-Shimadzu IRTracer-100 FTIR Spectrophotometer	B – Topology and chemical composition of the polymer surface (SEM image)
3 – ZEISS Axio Imager 2 MAT	C – Physico-mechanical properties of the polymer (tensile strength and other parameters)
4 – Zwick Roell Z0.5	D – Topology of the polymer surface (optical imaging)
5 – JEOL JSM-7500	E – Contact angle, surface energy calculation, polar and dispersion components

Answer:

- 1 – E;
- 2 – A
- 3 – D
- 4 – C
- 5 – B

(Correspondence 3 out of 5 – 1 point; 3 out of 4 – 2 points, 5 out of 5 – 3 points)

7: Metallurgy

Task 1
Entry level (1 point)

Which of the following metals belong to the alkali metal group?

- 1) sodium and platinum
- 2) potassium and copper
- 3) rubidium and cesium
- 4) nickel and zinc
- 5) cobalt and silver

Answer: 3

Task 2
Entry level (1 point)

What type of syngony does magnetite (Fe₃O₄) belong to?

- 1) **Cubic**
- 2) Rhombic
- 3) Triclinic
- 4) Monoclinic
- 5) Octahedral

Answer: 1

Task 3
Entry level (1 point)

What are the main elements in brass?

- 1) **Copper and zinc**
- 2) Copper and nickel
- 3) Copper and platinum
- 4) Copper and tin
- 5) Copper and silver

Answer: 1

Task 4
Entry level (1 point)

What are the main advantages of titanium alloys?

- 1) Cost-effectiveness and plasticity
- 2) High electrical conductivity and moisture resistance
- 3) Low melting point and high thermal conductivity
- 4) **High specific strength and corrosion resistance**
- 5) High wear resistance and plasticity

Answer: 4

Task 5
Entry level (1 point)

What is characteristic of a substance in a crystalline state?

- 1) Increased electrical conductivity
- 2) **Anisotropy of properties**
- 3) High plasticity
- 4) High corrosion resistance
- 5) High thermal conductivity

Answer: 2

Task 6
Average level (3 points)

Which methods can be used to determine shrinkage of non-ferrous casting alloys?

- 1) Rietveld method
- 2) **Hydrostatic weighing method**
- 3) Adsorption-structural analysis
- 4) **Pycnometric method**
- 5) Scanning electron microscopy

Answer: 2,4

(one correct answer – 1 point; two correct answers – 3 points)