Chemistry and Materials Sciences: Second-round Sample Tasks for the Open Doors Bachelor's Track

This sample test comprises 42 tasks, including 25 entry-level tasks with a single correct answer (each correct answer is assigned 1 point), 13 intermediate-level tasks with multiple correct answers (the correct answer is assigned 1 – 3 points), and 4 advanced-level tasks requiring a detailed answer (the answer is assigned 1 – 9 points depending on its correctness and completeness).

For advanced-level tasks requiring a detailed answer, assessment criteria and a standard answer are provided.

Field of Science 1. Inorganic and Nuclear Chemistry

Task 1
Entry level (1 point)

Select the substance the aqueous solution of which will have a 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
Intermediate level (3 points)

Among the proposed formulae/names of substances located in the numbered cells, choose the formulae/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	$Ca(OH)_2$	6	silane

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

Write down the numbers in the answer, arranging them in the order corresponding to the letters:

A	B	C
4	9	7

Answer: 4, 9, 7

Task 4
Intermediate level (3 points)

Solution Y was added to a test tube with salt X. As a result of the reaction, X dissolved, and the release of 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 down the numbers in your answer, putting them in the order corresponding to letters X and Y.

X	Y
5	3

Answer: 5, 3.

Task 5
Intermediate level (3 points)

Match the formula of a substance with the reagents the substance can interact with. For each position indicated by a letter, select 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 down the numbers in the answer, arranging them 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 found 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 substance 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 curdled 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: A complete solution must include your method and reasoning. Providing the final answer alone will not suffice.

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
$M(X) = 108 \cdot 24.74/75.26 = 35.5$ g/mol
AgCl fits the description.

A	***B***	***C***
KCl	***HCl***	***AgCl***

2. $KCl + H_2SO_4 = KHSO_4 + HCl$ (K_2SO_4 counts as the correct answer)
$HCl + NaOH = NaCl + H_2O$
$HCl + AgNO_3 = AgCl + HNO_3$

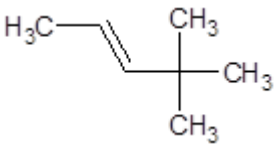
3. $n(H_2SO_4) = C \cdot V = 18.34 \cdot 0.011 = 0.2$ mol
$n(KCl) = m/M = 6/74.5 = 0.08$ mol
H_2SO_4 in excess, therefore an acidic salt is formed:
$KCl + H_2SO_4 = KHSO_4 + HCl$
$n(HCl) = n(KCl) = 0.08$ mol
$V(HCl) = n \cdot Vm = 0.08 \cdot 22.4 = 1.792$ L

Answer : V(HCl) = 1.792 L
Assessment criteria:
Criteria 1 – Substances A, B, C are identified, appropriate explanations are given – **3 points**.
Criteria 2 – All necessary reactions are written down – **3 points**.
Criteria 3 – The calculation was carried out and the correct result was obtained – **3 points**.

Field of Science 2. Organic Chemistry

Task 7
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 8
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 9
Intermediate level (3 points)

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

Answer: 4 (the reference answer is an integer)

Task 10
Intermediate level (3 points)

An unsaturated hydrocarbon (class of alkenes) was chlorinated and then subjected to alkaline hydrolysis with NaOH, yielding 2-methylbutanediol-2,3. Find the formula of the starting alkene (use IUPAC nomenclature for the name of the hydrocarbon).

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

Task 11
Intermediate level (3 points)

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

1) Cl_2
2) H_2
3) Mg
4) H_2SO_4 conc.
5) H_2O

Answer: 1, 4
(1 correct answer – 1 point; 2 correct answers – 3 points)

Task 12
Advanced level (9 points)

Cracking of saturated hydrocarbon X with molecular weight 128 g/mol occurs according to the reaction equation:
X → Y + Z.
1) Determine the simplest formula for substance **X**. Find 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**, given that substance **Z** can be obtained from **Y** according to the following scheme:

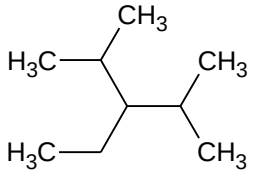
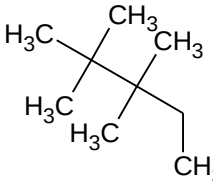
$$\mathbf{Y} \xrightarrow{HBr} \mathbf{N} \xrightarrow{Na} \mathbf{Z}$$

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: A complete solution must include your method and reasoning. Providing the final answer alone will not suffice.

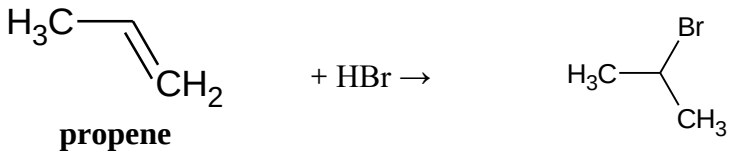
Solution:
1) The general formula of all alkanes is C_nH_{2n+2}. If the molecular weight is known, we can find n and the empirical formula.

$12 \cdot n + (2-n+2) = 128$
$14n = 128-2 = 126$
$n = 126/14 = 9$
*The simplest formula for substance **X** is **C_9H_{20}***

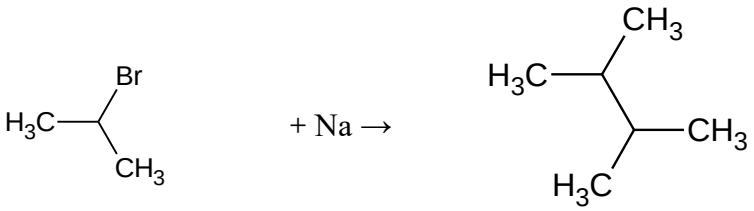
Isomer 1	Isomer 2
 3-ethyl-2,4-dimethylpentane	 2,2,3,3-tetramethylpentane

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

2) *Alkenes are capable of adding HBr, therefore* ***Y*** *is an alkene. The number of carbon atoms in* ***Y*** *must be 2 times as small as in* ***Z****. Therefore,* ***Y*** *is a propene.*



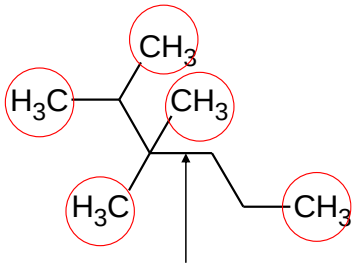
propene



2,3-dimethylbutane

Criteria 2:	The structural formulae of substances Y and Z are correctly done. (1 point for the structural formula of one compound)	**2 points**

3) The structural formula of ***X*** *which satisfies the condition 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**
	Substances **X**, **Y**, **Z are named correctly**. (1 point for naming one substance)	**3 points**

Field of Science 3. Physical Chemistry

Task 13
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
2) – 558.1
3) 2232.4
4) -22.324
5) 558.1

Answer: 2

Task 14
Entry level (1 point)

The equilibrium temperature for a reversible reaction under standard conditions, if ΔH_p^0=260.3 kJ, ΔS_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 15
Intermediate level (3 points)

At 253ºC, the reaction ends in 20 seconds. How long will it take for this reaction at 293ºC if γ=3:

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

Answer: 1

Task 16
Intermediate level (3 points)

Under what conditions will the reaction $FeO(c)+H_2(g)=Fe(k)+H_2O(g)$ occur if ΔS^o_{298}=0.027 kJ/K?

Substance	ΔH^o_{298}, kJ/mol	ΔG^o_{298}, kJ/mol
$FeO_{(c)}$	-264.8	-244.3
$H_2O_{(g)}$	-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 17
Intermediate level (3 points)

Under what conditions will the equilibrium shift towards the direct reaction $CH_4(g) + CO_2(g) \leftrightarrow CO(g) + H_2$; $\Delta H > 0$?

1) with increasing temperature
2) with increasing pressure
3) with decreasing temperature
4) with decreasing pressure
5) with decreasing concentration of CH_4

Answer: 1, 4

Task 18
Advanced level (9 points)

An electric current was passed through an electrolyzer containing 500 ml of 4.6% NaOH solution (ρ=1.05 g/cm3). After a few minutes, the mass fraction of sodium hydroxide became equal to 10%. Find the volumes of gases released at the electrodes.

Note: A complete solution must include your method and reasoning. Providing the final answer alone will not suffice.

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

K (-): $2H_2O+2\hat{e}=H_2\uparrow+2OH^-$
A (+): $2H_2O-4\hat{e}=O_2\uparrow+4H^+$

$2H_2O=O_2\uparrow+2H_2\uparrow$
Criterion 1 – **6 points**.

4) Find the mass of a 10% NaOH solution after electrolysis:
$m_{10\%\ sol.}=24.15g:0.1=241.5g$
Criterion 2 – **1 point**
5) Find the mass of water that has undergone electrolysis:
$m_{aq} = 525g-241.5g=283.5\ g$
6) Find how many liters of H_2 and O_2 are released:
$v(H_2O) = 283.5g:18g/mol=15.75mol$
$v(O_2) = 15.75mol:2=7.875mol$

$v(H_2)$ = 283.5g:18g/mol=15.75mol
*$V(O_2)$ = 7.875mol·22.4L/mol=**176.4 L***
*$V(H_2)$ = 15.75mol·22.4L/mol=**352.8 L***
Criterion 3 – **2 points**

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

Assessment criteria:
Criterion 1 – The electrolysis scheme is done correctly. The mass of the 4.6% solution and the mass of NaOH dissolved in the solution are calculated correctly. **– 6 points**.
Criterion 2 – The mass of a 10% NaOH solution after electrolysis and the mass of water subjected to electrolysis are calculated correctly – **1 point**.
Criterion 3 – Volumes of the released gases are calculated correctly – **2 points**.

Field of Science 4. Analytical Chemistry

Task 19
Entry level (1 point)

A mixture of NaCl and $CuSO_4$ salts was dissolved in distilled water. Which reagent can be used to detect copper ions in the solution?

1) $AgNO_3$
2) $BaCl_2$
3) Cu
4) Na_2S
5) N_2

Answer: 4

Task 20
Entry level (1 point)

When titrating 10 mL of HNO_3 solution, 5.2 mL of Na_2CO_3 solution was consumed. Find the initial concentration of HNO_3 if the concentration of Na_2CO_3 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 21
Intermediate 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) Phenophthalein
5) Glassware

Answer: 2

Task 22
Intermediate level (3 points)

The solution contains the following ions: Ag+, Al3+, Pb2+, Ni2+, and Cu2+. The solution in question is acidified (pH = 0.5) and then H2S is added. Find 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 23
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 complete precipitation. The washed precipitate was calcined in a muffle furnace. After all operations, the mass of the precipitate was 1.35 g. Find the mass of $FeCl_3$ in the initial solution. (Express your answer in grams and round to the nearest hundredth).

Answer: 2.74 g **(2.60 – 2.88 g)** (reference answer – a number, a range).
(1 point if the answer is rounded to tenths or whole numbers)

Task 24
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 with the release of gas, 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 forms.

Experiment 3 - Part of the solution from Experiment 1 was treated with excess NaOH and a white precipitate formed. 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) Find the mass fraction of the elements in the alloy given that interaction of 300 mg of the alloy with excess HCl produces 42.8 ml of gas under normal conditions.

Note: A complete solution must include your method and reasoning. Providing the final answer alone will not suffice.

Solution:

Justification: **Experiment 1**

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

$Cu + 4HNO_3 = Cu(NO_3)_2 + 2NO_2\uparrow + 2H_2O$
$Cu(NO_3)_2 + 2NaOH = Cu(OH)_2\downarrow + 2NaNO_3$

Criterion 1:	Reaction equations are written correctly (1 point per reaction).	**2 points**
	Identifying characteristics of an element are given	**1 point**

Justification: **Experiment 2**

1) When exposed to NaOH, manganese salts form a white precipitate which turns brown when exposed to H_2O_2

$MnCl_2 + 2NaOH = Mn(OH)_2 + 2NaCl$
$Mn(OH)_2 + H_2O_2 = MnO_2 + 2H_2O$

Criterion 2:	Reaction equations are written correctly (1 point per reaction).	**2 points**
	Identifying characteristics of an element are given	**1 point**

*Finding the **mass fractions of elements** in the alloy.*
Of the two alloy components, only manganese is able to react with hydrochloric acid

$Mn + 2HCl = MnCl_2 + H_2$

$\nu(Mn) = \nu(H_2) = V(H_2)/V_m = 42.8 \cdot 10^{-3} / 22.4 = 0.00191$ mol
$m(Mn) = \nu(Mn) \cdot M(Mn) = 0.00191 \cdot 54.9 = 0.105$ gram $= 105$ mg
$\omega(Mn) = m(Mn)/m(alloy) = 105/300 \cdot 100\% =$ **35%**
$\omega(Cu) = 100\% - \omega(Mn) =$ **65%**

Criterion 3:	Reaction equations are written correctly	**1 point**
	The calculation of the mass fractions of metals in the alloy is correct.	**2 points**

Field of Science 5. Crystallography

Task 25
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 26
Entry level (1 point)

A polyhedron with 6 faces is called

1) a tetrahedron
2) an octahedron
3) a cube
4) an icosahedron
5) a dodecahedron

Answer: 3

Task 27
Entry level (1 point)

Open symmetry elements include

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

Answer: 5

Task 28
Entry level (1 point)

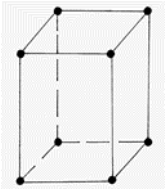
The unit cell parameters a=b=c, $\alpha = \beta = \gamma = 90°$ correspond to

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

Answer: 5

Task 29
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 30
Intermediate 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)

Field of Science 6. Testing in Materials Sciences

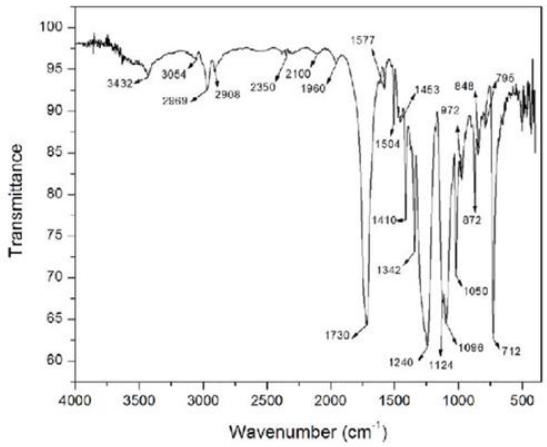
Task 31
Entry level (1 point)

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 $(CF_2\text{-}CFCl)_n$
4) polypropylene $(C_3H_6)_n$

Answer: 2

Task 32
Entry level (1 point)

The given infrared spectrum refers to...



1) tetrahydrofuran C_4H_8O
2) polystyrene $(C_8H_8)_n$
3) copolymer of acrylonitrile, butadiene and styrene $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$
4) polyethylene terephthalate $(C_{10}H_8O_4)_n$

Answer: 4

Task 33
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 34
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 numbers

Answer: 3

Task 35
Entry level (1 point)

The initial stage of the biofouling process of polymers by microscopic fungi, also known as micromycetes, is mainly due to
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 36
Intermediate level (3 points)

Match the scientific equipment and 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
(3 matches out of 5 – 1 point; 3 matches out of 4 – 2 points, 5 matches out of 5 – 3 points)

Field of Science 7. Metallurgy

Task 37
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 38
Entry level (1 point)

What type of syngony does magnetite (Fe_3O_4) belong to?

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

Answer: 1

Task 39
Entry level (1 point)

What are the main elements that make up brass?

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

Answer: 1

Task 40
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 41
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 42
Intermediate level (3 points)

Which of the following 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)