# Chemistry and Materials Science: Second-round Sample Tasks for the Open Doors Postgraduate Track

You will be asked to complete 35 tasks, including:
- 21 entry-level tasks, each correct answer worth 1 point;
- 5 intermediate-level multiple-response tasks, each worth 3–4 points, if answered correctly;
- 6 intermediate-level single-response tasks, each worth 3 points, if answered correctly;
- 3 advanced tasks (constructed response), each correctly completed task valued at 15 points.

Evaluation criteria and standard answers are provided for the advanced tasks requiring constructed responses.

## Inorganic and Nuclear Chemistry

### Task 1
### Entry level (1 point)

Which substance is a double salt?

a) $Na_2IO_3(NO_3)$
b) PbFCl
c) $K_3Fe(CN)_6$
d) $K_2Mg(SO_4)_2 \cdot 6H_2O$

**Answer: d.**

### Task 2
### Entry level (1 point)

Which of the five aqueous saturated solutions of poorly soluble compounds will have the minimum concentration of anion?

a) silver iodide ($Ks = 8.3 \cdot 10^{-17}$)
b) thallium chloride (I) ($Ks = 1.7 \cdot 10^{-4}$)
c) calcium sulfate ($Ks = 2.5 \cdot 10^{-5}$)
d) barium carbonate ($Ks = 4.0 \cdot 10^{-10}$)

**Answer: a.**

### Task 3
### Entry level (1 point)

The interaction of sulfur (IV) oxide and chlorine in the light produces

a) sulfuryl chloride
b) thionyl chloride
c) sulfuric acid
d) chlorosulfonic acid

**Answer: a.**

## Task 4
## Intermediate level (3 points)

The ionization constant of ammonia in solution is $1.74 \cdot 10^{-5}$. To 100 ml of a 0.5 M ammonia solution, 5.35 g of ammonium chloride is added. Calculate by how many times the concentration of hydroxonium ions has increased in the solution. Neglect any change in the volume of the solution when the salt is added. Enter your answer as an integer.

**Answer: 340.**

## Task 5
## Intermediate level (3 points)

The hydrochloric acid solution has a mass of 433 g. The number of chlorine atoms in the solution is 10 times less than the number of oxygen atoms. 32.5 g of zinc granules were added to the solution and kept until the reaction stopped. Calculate the mass of the 20% sodium hydroxide solution that must be added to the resulting solution to ensure all reactions stop. Enter your answer as an integer.

**Answer: 600.**

## Task 6
## Advanced level (15 points)

The content of sodium thiosulfate pentahydrate in the preparation is quantitatively determined by direct iodometric titration: A sample of the drug weighing 0.345 g is dissolved in 25 ml of water, transferred to a 100.0 ml volumetric flask and the volume of the solution is brought to the mark with water. For titration, a 10.0 ml sample is taken, an indicator is added and titrated with 0.05 M iodine solution until the color changes. 1.35 ml of titrant solution was used for titration. Calculate the mass fraction (in %) of the crystallohydrate in the preparation.

**Please note** that the evaluation will consider your problem-solving process; providing only the final answer is not sufficient.

**Solution:**

| | |
|---|---|
| $2Na_2S_2O_3 + I_2 \rightarrow Na_2S_4O_6 + 2\ NaI$ | 3 |
| Mass of sodium thiosulfate in the sample (aliquot fraction):<br>$m\ (Na_2S_2O_3) = M(Na_2S_2O_3) \cdot 2 \cdot C\ (I_2) \cdot V\ (I_2)$<br>$m\ (Na_2S_2O_3) = 158 \cdot 2 \cdot 0.05 \cdot 0.00135 = 0.02133$ g | 3 |
| Mass of sodium thiosulfate in solution:<br>$m\ (Na_2S_2O_3) = 0.02133 \cdot 100/10 = 0.2133$g | 3 |
| Weight of sodium thiosulfate crystallohydrate:<br>$m\ (Na_2S_2O_3 \cdot 5H_2O) = 248 \cdot 0.2133/\ 158 = 0.3348$ g | 3 |

| | |
|---|---|
| Mass fraction:<br>ω ($Na_2S_2O_3 \cdot 5H_2O$) = (0.3348 / 0.345)·100% = 97.1% | 3 |

**Answer: 97.1**

# Organic Chemistry

## Task 7
## Entry level (1 point)

Which compound exhibits the strongest acidic properties?

a) phenol
b) 4-aminophenol
c) 3-aminophenol
d) 2,4-dinitrophenol

**Answer: d.**

## Task 8
## Entry level (1 point)

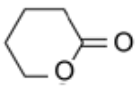
In which compound is a glycoside bond present?

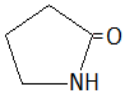
a) glucose
b) fructose
c) maltose
d) Mannose

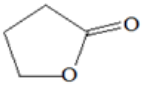
**Answer: c.**

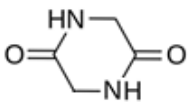
## Task 9
## Entry level (1 point)

Which of the following represents diketopiperazine?

a) 


b) 


c) 


d) 


**Answer: d.**

## Task 10
## Intermediate level (3 points)

Acetaldehyde was divided into two equal parts. The first part underwent croton condensation, and, with a yield of 70%, 12.25 g of croton aldehyde (butene-2-al) was obtained. Upon oxidation of the second part of the aldehyde, carboxylic acid was produced. The resulting acid reacted with a yield

of 60% with monatomic alcohol (in the presence of sulfuric acid), so that 30.6 g of organic product was formed. Determine the alcohol formula. In the answer, specify its molecular weight as integer number.

**Answer: 60.**

### Task 11
### Intermediate level (3 points)

A mixture of adenine and cytosine was burned in excess of oxygen. The combustion products were passed through an excess of calcium hydroxide solution. The sediment mass was 220 g. The volume of unabsorbed gas is equal to the volume of gas formed by the interaction of sodium cyanide weighing 93.1 g with sodium hypochlorite in an aqueous solution. Determine the mass of adenosine-5-monophosphate, from which the adenine included in the initial mixture was isolated. Round your answer to one decimal place.

**Answer: 69.4.**

## Analytical Chemistry

### Task 12
### Entry level (1 point)

Calculate the solubility (in mol/L) and concentration of $Ba^{2+}$ ions (in g-ion/L) in a solution of $Ba_3(PO_4)_2$ (solubility product = $6 \cdot 10^{-39}$).

a) $2.76 \cdot 10^{-6}$ mol/L, $1.8 \cdot 10^{-8}$ g-ion/L
b) $2.76 \cdot 10^{-6}$ mol/L, $2.7 \cdot 10^{-8}$ g-ion/L
c) $0.89 \cdot 10^{-8}$ mol/L, $2.7 \cdot 10^{-8}$ g-ion/L
d) $0.69 \cdot 10^{-6}$ mol/L, $0.89 \cdot 10^{-8}$ g-ion/L

**Answer: c.**

### Task 13
### Entry level (1 point)

The dissociation constant of formic acid HCOOH, which dissociates according to the equation:
$HCOOH = H^+ + COOH^-$
is $2.1 \cdot 10^{-4}$. Calculate the degree of dissociation α and the concentration of $[H^+]$ for a 0.3M solution of this acid.

a) $6.96 \cdot 10^{-4}$, $5.3 \cdot 10^{-3}$ g-ion/L
b) $2.64 \cdot 10^{-2}$ , $7.9 \cdot 10^{-3}$ g-ion/L
c) $1.17 \cdot 10^{-2}$, $7.9 \cdot 10^{-3}$ g-ion/L
d) $2.64 \cdot 10^{-2}$, $1.25 \cdot 10^{-2}$ g-ion/L

**Answer: b.**

### Task 14
### Entry level (1 point)

Calculate the concentration of ions $Ag^+$ in a 0.1M solution $[Ag(NH_3)_2]NO_3$, containing an excess of 1 mole of ammonia. Instability constant of ion $[Ag(NH_3)_2]^+$ is $5.7 \cdot 10^{-8}$.

a) $0.5 \cdot 10^{-8}$ g-ion/L
b) $0.4 \cdot 10^{-6}$ g-ion/L
c) $0.6 \cdot 10^{-7}$ g-ion/L
d) $0.6 \cdot 10^{-8}$ g-ion/L

**Answer: d.**

## Task 15
## Intermediate level (3 points)

A transparent pink solution was submitted to a laboratory for testing. While studying the solution, a laboratory assistant conducted a series tests with separate portions of the solution, yielding the following results:

a) Adding sodium hydroxide resulted in a mixture of white, blue, and pink colors.
b) Adding sulfuric acid and hydrogen peroxide solutions caused a portion of the solution to turn yellow-orange.
c) Adding ammonium thiocyanate solution in the presence of isoamyl alcohol caused the upper layer to turn bright blue.
d) Adding barium chloride solution produced a white precipitate.

Which ions do the unknown solution contain?

a) $Ni^{2+}$
b) $Fe^{3+}$
c) $Ti^{4+}$
d) $Cr^{3+}$
e) $Co^{2+}$
f) $SO_4^{2-}$

**Answer: c, e, f.**

## Task 16
## Intermediate level (3 points)

A sample containing iron was submitted to a laboratory for testing. To determine the total iron, a 1 g sample was dissolved in concentrated hydrochloric acid and reduced with metallic zinc. Then, the resulting solution was diluted with distilled water in a measuring flask to a volume of 100 ml. An aliquot of 5 ml was taken from the resulting solution and transferred to a 100 ml conical flask. A mixture of sulfuric and phosphoric acids, 2-3 drops of diphenylamine indicator were added to the flask, and titration was carried out with a 0.01 mol/l potassium dichromate solution until the indicator turned blue-violet. A total of 10.25 ml of titrant was spent on the titration of the sample. Calculate the mass fraction of total iron (%) in the sample (assume Mr(Fe) = 56). Provide your answer as an integer.

**Answer: 69.**

# Physical Chemistry

## Task 17
## Entry level (1 point)

The change in enthalpy for the reaction is -145 kJ/mol. Calculate the equilibrium constant of the reaction at 700 K, given that the equilibrium constant at 650 K is 1000.

a) 147
b) 0.045
c) 6800
d) 3.5

**Answer: a.**

## Task 18
## Entry level (1 point)

Carbon tetrachloride boils at 76.8 °C. At this temperature, the enthalpy of evaporation at constant pressure is 29.82 kJ/mol. Calculate the entropy change by 1 mol at the boiling point of carbon tetrachloride.

a) 5.5 kJ /(K·mol)
b) 85.2 J/(K mol)
c) -16.5 J/(K·mol)
d) 32 J/(K·mol)

**Answer: b.**

## Task 19
## Entry level (1 point)

Calculate the Gibbs energy change for the isothermal compression of 0.003 m³ of methane at 25°C, when the pressure is increased from 0.5 ·$10^5$ Pa to 2.0 × $10^5$ Pa. Assume methane is an ideal gas.

a) 103 J
b) 206 J
c) 10.3 J
d) 20.6 J

**Answer: b.**

## Task 20
## Intermediate level (3 points)

Which THREE statements are true for 0.25 molal NaCl solution in water?

a) This is a solution of a strong electrolyte.
b)The freezing point of the solution is lower than the freezing point of the pure solvent.
c) The numerical value of the ionic strength of the solution is 0.25.

d) The NaCl solution conducts electric current less effectively than the solvent.

e) The NaCl activity coefficient for the specified solution is 0.

f) When diluted, the value of the solution's specific electrical conductivity will decrease.

**Answer: a, c, f.**

## Task 21
## Intermediate level (3 points)

Which THREE statements are true for a 0.1 molar solution of acetic acid in water?

a) This is a solution of a strong electrolyte.

b) If the resistivity of 0.1 molar acetic acid solution in water at 298 K is 1960 ohm cm, the molar electrical conductivity of the solution is 5 $10^{-4}$ Cm · $cm^2$/mol.

c) If the value of the limiting mobility of acetic acid ions is $\lambda_{H^+ = 350 S \cdot sm^2/mol}$, $\lambda_{CH_3COO^- = 40{,}9 S \cdot sm^2/mol}$, the degree of dissociation of 0.1 molar solution is 0.013.

d) The dissociation degree of acetic acid solutions does not depend on the degree of dilution.

e) The electrical conductivity of 0.1 molar acetic acid solution increases with increasing temperature.

f) The dissociation constant of 0.1 molar acetic acid solution is 1.71 $10^{-5}$.

**Answer: c, e, f.**

## Task 22
## Advanced level (15 points)

The following reaction takes place in a galvanic cell:

$$2FeCl_3 + Sn \leftrightarrow SnCl_2 + 2FeCl_2$$

1) Draw a diagram of the galvanic cell. Specify the electrode processes taking place in this galvanic cell.

2) Calculate the standard EMF, ΔG°, and the reaction equilibrium constant at 25 °C.

$E_{Sn^{2+}}$ = -0.140 B, $E_{Fe^{3+}Fe^{2+}}$ = 0.771 V.

3) Find the concentration of the $SnCl_2$ solution in a cell if the galvanic cell shows an EMF equal to 0.967 V, and the concentrations of $FeCl_3$ and $FeCl_2$ in another cell are both equal to 0.005 mol / L. (ion activity can be replaced with appropriate concentrations).

**Please note** that the evaluation will consider your problem-solving process; providing only the final answer is not sufficient.

**Solution:**

GE scheme:

$Sn \mid Sn^{2+} \parallel Fe^{3+}, Fe^{2+} \mid Pt$ 2 points

Electrode processes:

Left electrode (anode): $Sn - 2e \rightarrow Sn^{2+}$ (oxidation) 2 points

The right electrode (cathode): $Fe^{3+} + e \rightarrow Fe^{2+}$ (restoration) 2 points

Calculation of the standard EMF.

$E^\circ = E_{right}^{\ 0} - E_{left}^{\ 0} = 0.771 - (-0.140) = 0.911$ V 1 point

$\Delta G^0 = -zFE^\circ = -2 \cdot 96485 \cdot 1.021 = -175796$ J 2 points

$\ln K = E^\circ \cdot z \cdot F/(R \cdot T) = 0.911 \cdot 2 \cdot 96485/(8.31 \cdot 298) = 71.0$

$K = e^{\wedge}79.6 = 6.76\ 10^{30}$ 2 points

$E_{right} = E_{right}^{\ 0} - 8.31 \cdot 298/1/96485 \cdot \ln(0.005/0.005) = 0.771$ V

$E_{left} = E_{right} - E = 0.771 - 0.967 = -0.196$ V

$\ln(C(Sn^{2+})) = (E_{left} - E_{left}^{\ 0}) \cdot z \cdot F/R/T = (-0.196 - (-0.140)) \cdot 2 \cdot 96485/8.31/298 = -4.36$

$C(Sn^{2+}) = 0.013$ mol / L 4 points

# Crystallography

## Task 23
## Entry level (1 point)

Indicate the ratios of angles and translations in the unit cell of an orthorhombic crystal.

a) a=b=c, α=β=γ= 90°
b) a=b≠c, α=β=γ= 90°
c) a≠b≠c, α=β=γ≠ 90°
d) a≠b≠c, α=β=γ= 90°

**Answer: d.**

## Task 24
## Entry level (1 point)

The RbCl crystal belongs to the B2 (Pm3m) structure type. How many atoms are there per unit cell in this crystal?

a) 2
b) 4
c) 6
d) 8

**Answer: a.**

## Task 25
## Entry level (1 point)

Which symmetry class does a crystal with the space group $I4_1/amd$ belong to?

a) 4mm
b) 4/m
c) $\frac{4}{m}\frac{2}{m}\frac{2}{m}$
d) $\frac{4}{m}3\frac{2}{m}$

**Answer: c.**

## Task 26
## Intermediate level (3 points)

What is the lattice parameter of Ni (Fm3m) if its atomic radius is 1.245 Å? The answer should be rounded to the format X.XX.

**Answer: 3.52.**

# Metallurgy and Metallurgical Engineering

### Task 27
### Entry level (1 point)

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.

**Answer: a.**

### Task 28
### Entry level (1 point)

Which of the following is the packing density of a BCC crystal?

a) 0.52
b) 0.74
c) 0.68
d) 0.34

**Answer: c.**

### Task 29
### Entry level (1 point)

Which of the following denotes transition from a liquid state to a solid state?

a) recrystallization
b) melting
c) amorphization
d) crystallization

**Answer: d.**

### Task 30
### Intermediate level (3 points)

Due to the dimensional effect, the solubility of nanoparticles of a certain substance is higher than its bulk phase. Which of the following characteristics should be known to evaluate the solubility of these nanoparticles at a certain temperature, if their radius is known?

a) bulk phase solubility
b) specific enthalpy of bulk phase melting

c) molar volume of the substance
d) surface tension of the substance at the solid–liquid boundary
e) surface tension of the substance at the solid–gaseous boundary
f) surface tension of the substance at the liquid–gaseous boundary

**Answer: a, c, d.**

### Task 31
### Advanced level (15 points)

Determine the number of atoms per an elementary cell of Au (structural type A1), given that its density is $\rho = 19.32$ g/cm$^3$, lattice period is $a = 4.078$ Å, $A_{Au} = 196.97$, and $1\ u = 1.66 \cdot 10^{-24}$ g.

**Please note** that the evaluation will consider your problem-solving process; providing only the final answer is not sufficient.

**Solution.** Density $\rho = m / V$, where m is the mass of the unit cell, and V is the volume of the unit cell.

$m = N \cdot m_{av}$, where N is the number of atoms per unit cell, $m_{av}$ is the average mass of a particle ($m_{av} = A \cdot 1.66 \cdot 10^{-24}$ (A is atomic mass))

Structural type A1 has the cubic cell, therefore the volume of the unit cell is $V = a^3$.

Therefore:

$$\rho = (N \cdot A \cdot 1.66 \cdot 10^{-24}) / a^3;\ N = \rho \cdot a^3 / (A \cdot 1.66 \cdot 10^{-24}) = 19.32 \cdot (4.078 \cdot 10^{-8})^3 / 196.97 \cdot 1.66 \cdot 10^{-24} = 4$$

**Answer: 4 atoms**

**Assessment system**

Writing the formula for density through mass and volume is worth 3 points.
Writing the formula for the mass of the elementary cell in terms of the number of atoms and their mass is worth 2 points.
Writing the expression for the average mass of the particle earns 2 points.
Writing the formula for the volume of the elementary cell, for a given structural type is worth 2 points.
Derivation of the final formula for the number of atoms per elementary cell is worth 3 points.
Substitution of numerical values into the formula earns 1 point.
Recording the answer correctly (as an integer) is worth 2 points.

## Materials Science: Evaluation and Testing

### Task 32
### Entry level (1 point)

Which of the following denotes the difference in properties depending on the direction of mechanical testing?

a) allotropy

b) isotropy
c) anisotropy
d) polymorphism

**Answer: c.**

**Task 33**
**Entry level (1 point)**

Which method of determining the hardness number uses the following formula?

$$HB = P / D^2 \left[ \frac{2 / \pi}{1 - \sqrt{1 - (d / D)^2}} \right]$$

a) Brinell hardness
b) Vickers hardness
c) Rockwell hardness
d) micro hardness

**Answer: a.**

**Task 34**
**Entry level (1 point)**

Phase transitions of the first kind are the processes in which:

a) the first derivatives of the specific thermodynamic potentials for different phases are the same, and the second derivatives are different.

b) the first derivatives of specific thermodynamic potentials for different phases are not equal.

c) there is an abrupt change in heat capacity, temperature coefficient of expansion, and compressibility of the substance.

d) the mass of the first phase decreases, and that of the second remains unchanged.

**Answer: b.**

**Task 35**
**Intermediate level (4 points)**

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

**Answer: b, c, e**