Descriptive tasks (select at least one)

1. Electrolysis: the basics, the laws and examples of applications.

2. The phenomenon of adsorption and its implications for heterogeneous catalysis.

3. The uncertainty principle and its consequences.

4. Zeotropic and azeotropic mixtures.

5. Discuss aspects of quantum mechanics connected with the spin of electrons.

6. The notion of a statistical ensemble. Based on an arbitrarily selected ensemble describe the relationship between the statistical properties of the system with a corresponding thermodynamic potential.

7. Properties of molecules resulting from symmetry.

8. Tunneling, its role and examples in chemistry.

9. The notion of entropy.

10. Characteristics of matter in different spatial scales: from sub-atomic to cosmological. Describe the dominant interactions for each of these scales.

Useful constants: \( h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}; \ R=8.315 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}; \ k=1.38 \times 10^{-23} \text{ J}\cdot\text{K}^{-1}; \) electron mass \( = 9.11 \times 10^{-31} \text{ kg} \)
Short tasks:

1. Explain, which protective layer: silver or zinc is better in protecting a steel object against electrochemical corrosion, after the layer becomes locally damaged (e.g., scratched).

2. An iron wire weighing 4.5 g was immersed in a solution of copper(II) chloride. After some time, the wire was removed, washed with distilled water and weighed after drying. The mass, including the cooper layer, was 5.3 g. a) How many grams of copper was deposited on the wire; b) How many grams of iron dissolved into the solution? $M_{\text{Fe}} \approx 56 \text{ g/mol}, M_{\text{Cu}} \approx 64 \text{ g/mol}.$
3. What is the lattice enthalpy? Using the Born-Haber cycle and the values of standard enthalpies of the processes indicated below calculate the lattice enthalpy of an ionic NaCl crystal.

<table>
<thead>
<tr>
<th>Step</th>
<th>( \Delta H^\circ ) (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sublimation Na(s)</td>
<td>+107</td>
</tr>
<tr>
<td>Ionization Na(g)</td>
<td>+498</td>
</tr>
<tr>
<td>Dissociation Cl(_2)(g)</td>
<td>+244</td>
</tr>
<tr>
<td>Electron attachment to Cl(g)</td>
<td>-351</td>
</tr>
<tr>
<td>Formation of NaCl(s)</td>
<td>-411</td>
</tr>
</tbody>
</table>

4. A closed container was filled with hydrogen, iodide and hydrogen iodide in the following quantities: 0.30 mol of H\(_2\)(g), 0.40 mol of I\(_2\)(g), and 0.20 mol HI(g) at the temperature of 870 K and under the pressure of 1.00 bar. Calculate the amounts of components at equilibrium, knowing that the equilibrium constant of the reaction H\(_2\)(g) + I\(_2\)(g) \rightleftharpoons 2\text{HI(g)} is 870.
5. The standard free enthalpy ($\Delta G^\circ$) of a certain biological reaction at the temperature of 310 K is -200 kJ/mol, while for another reaction it is -100 kJ/mol. What is the ratio of the equilibrium constants?

6. Derive the dependence of the half-life on the concentration of the substrate A for a reaction that is zero-order with respect to A.
7. Determine the packing fraction for the fcc (face-centred cubic) structure.

8. A sphere of mass $m_k$, temperature $t_k$, and the specific heat $c_k$ falls into snow of temperature $t_s < 0$ and the specific heat $c_s$ with velocity $v$ and stops after being totally immersed. Both temperatures are in Celsius degrees, velocity in [m/s], and specific heats in [joule/kg/deg]. Calculate the mass of water formed after melting the snow assuming that the rest of snow will not change its temperature. The heat of melting for snow is $c_t$ (in [joule/kg]).
9. Consider a mixture of monoatomic perfect gases, consisting of \( N \) atoms of mass \( M \) and \( n \) atoms of mass \( m \). The mixture is at thermodynamic equilibrium and the temperature is \( T \). Calculate:
   a. Mean square velocity for the atoms of each sort
   b. Mean square velocity for all the atoms in the mixture.

   The mean square velocity is defined as \( \sqrt{<v \cdot v>} \), where \( <v \cdot v> \) denotes the average \( v \cdot v \), where \( v \) is the velocity vector.

10. 1 mol of a one-atomic perfect gas is maintained under the pressure of 1 bar. As the result of the heat delivered the gas increases its volume from 10 to 30 l. How much heat has been delivered?
11. Show that at constant temperature the internal energy $U$ of 1 mol of a gas fulfilling the equation of state:
\[ p = RT(V-b) \]
does not depend on the molar volume. What will be the dependence of $U$ on $V$ if the term $-a/V^2$ is added to the above equation of state? $R$, $a$, and $b$ are constants.

12. Consider one-dimensional electron moving in a box, where the potential is zero for $|x| \leq R$ while it is infinite for $|x| > R > 0$. Verify that (unnormalized) wave function
\[ \psi(x) = \sin\left(\frac{\pi(x+R)}{2R}\right) \quad \text{for} \quad |x| \leq R, \quad \psi(x)=0 \quad \text{for} \quad |x| > R \]
is an eigenfunction of this motion. Is it or is not the ground-state function? Why? Determine the corresponding eigenenergy.
13. For the motion considered in the previous problem, estimate the ground-state energy by means of the variation principle, applying the (unnormalized) trial function

\[ \phi_A(x) = A|x|^2 \quad \text{for} \quad |x| \leq R, \quad \phi_A(x) = 0 \quad \text{for} \quad |x| > R, \]

where \( A \) is a real constant. If the obtained result is inconsistent with the expected one, examine the validity of the trial function. Find the relative error of the final result.

Useful constant: \( \pi^2/8 \approx 1.234 \).

14. The operator of the orbital angular momentum of a particle is \( \mathbf{L} = \mathbf{r} \times \mathbf{p} \), where \( \mathbf{p} = -i \frac{\partial}{\partial \mathbf{r}} \) (in atomic units). Verify that its components satisfy the commutation rule \( [L_x, L_y] = i L_z \). 


15. Give the total number of vibrations in the following molecules. Will each of the molecules be active in the IR and Raman spectra?
(a) H$_2$O; (b) N$_2$; (c) CCl$_4$; (d) C$_6$H$_6$

16. To what speed must an electron be accelerated for it to have a wavelength of 3.0 cm$^{-1}$?