1 a) Show how can you calculate the displacement equilibrium, where a metal such as Fe dipped in CuSO$_4$ solution, with estimation of $a_{Fe^{2+}}/a_{Cu^{2+}}$ concentration at equilibrium.

b) What is meant by electrode potential, discuss the structure of the electrical double layer of electrode immersed in solution?

2 a) Write the composition of the concentration cell without diffusion, referring to cell reactions and its potential.

b) Calculate the E.M.F. and and $\Delta G^\circ$ of the cell:

\[ Sn / Sn^{2+} (a = 0.8) // Pd^{2+} (a = 0.4), Pd \]

\[ e_{Sn/Sn^{2+}}^0 = -0.14 \text{Volt}, \quad e_{Pd/Pd^{2+}}^0 = -0.126 \text{Volt}. \]

c) The alkaline strong battery may be represented as the following:

\[ \text{Fe/FeO(s)/KOH}_{aq} / \text{NiO}_2(s)/\text{Ni}_2\text{O}_3(s)/\text{Ni} \]

Write the chemical reaction of the cell and derive an equation to estimate the potential of both negative and positive electrodes.

3 a) HBr gas absorbs IR radiations at 4.08 nm. How can you calculate the chemical bond strength of that gas molecule?

b) What is the expected type of the electronic spectra of the following compounds? In which region could be the spectra expected? Which one of them is colored and why?

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{CH} = \text{CHCOOH} \]

4 a) What are the advantages and limitations of rotational spectra?
4 b) How can you calculate the bond length of HBr (g) molecule at 25 °C according to the rotational spectra in which the molecule absorbs at 3.0 cm\(^{-1}\) from energy level J = 0 to J = 1 transition. [21 marks]

5 a) Select All the correct answers (Justify your answer): [30 marks]

i. What is the eigenvalue of the momentum operator \( \hat{P}_x = -i\hbar \frac{\partial}{\partial x} \) with eigenfunction \( e^{ikx} \)?
   A. \( ik \)  B. \( -ikh \)  C. \( kh \)  D. \( ikx \)  E. \( e^{ikx} \)[6 marks]

ii. If the wave function \( \psi(x) \) satisfies the equation \( \int_{-\infty}^{\infty} \psi^*(x)\psi(x)dx = \frac{2\pi}{3} \), which of the following wave functions is normalized?
   A. \( \sqrt{\frac{2\pi}{3}}\psi(x) \)  B. \( \sqrt{\frac{3}{2\pi}}\psi(x) \)  C. \( \psi(x) \)  D. \( \frac{2\pi}{3}\psi(x) \)  E. \( \frac{3}{2\pi}\psi(x) \)[6 marks]

iii. What are the properties of stationary state wave function?
   A. Finite  B. Continuous  C. Single Valued  D. Hermitian  E. Real Valued [6 marks]

iv. An electron moves in a one-dimensional square well with size \( L \), where the potential energy is zero in the interior and infinite potential energy at the walls, has a ground state energy \( E_0 \). If the size is decreases to \( L/2 \) what is the new ground state energy?
   A. Zero  B. \( E_0/2 \)  C. \( E_0/4 \)  D. \( E_0 \)  E. \( 4E_0 \)[6 marks]

v. What does De Broglie relation state?
   A. \( \lambda = \frac{h}{mc} = \frac{h}{mv} \)  B. \( \lambda = \frac{ch}{m} = \frac{vh}{m} \)  C. \( \lambda = \frac{mc}{h} = \frac{mv}{h} \)  D. \( \lambda = \frac{h}{c} = \frac{(n+1)}{P} \)  E. \( \lambda = \frac{h}{P} = \frac{(n+1)}{P} \)[6 marks]

b) For the particle in a ring in ground state, if the particle vector extending from \( \varphi=0 \) to \( \varphi=2\pi \). What is the probability of finding the particle in half of the ring? [12 marks]

6 a) Using secular determinant, calculate the energy of the \( \pi \) molecular orbitals of allyl cation (\( CH_2 \equiv \dot{C} \equiv H = CH_2 \)). Sketch the molecular orbital diagram. [20 marks]

b) If the C-C bond stabilization energy is -230 kJ/mole, calculate the delocalization energy in 1,3-butadiene molecule relative to ethene molecule. [22 marks]