Section A: (5 marks for each question)

1. What is the oxidation number of Mn in MnO_4^-?

   A. +5 B. +7 C. -5 D. -7

2. If the half life of a reaction with respect to a reactant concentration is $\frac{0.693}{k}$, what is the reaction order of the reactant?

   A. First order B. Second order C. Third order D. Zero order

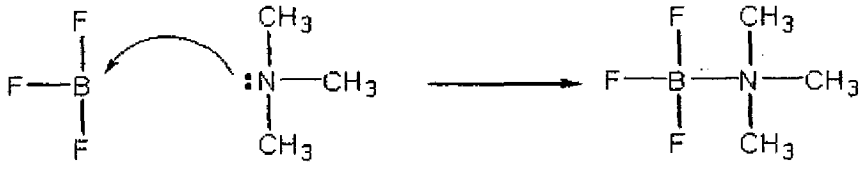
3. Which of the following is an extensive property?

   A. Temperature B. Volume C. Molar heat capacity
   D. Specific heat capacity

4. For any spontaneous chemical reactions in a beaker at constant temperature, which of the following condition must be satisfied?

   A. $\Delta S_{system} \geq 0$ B. $\Delta H - T\Delta S_{system} < 0$
   C. $\Delta G \geq 0$ D. $\Delta S_{universe} < 0$

5. Which one of the following reactants and product is a Lewis acid?



   A. BF_3 B. $N(CH_3)_3$ C. BF_3-$N(CH_3)_3$ D. None of them

6. Consider a mineral salt perovskite $MgSiO_3$. If some of the Si atoms are substituted by Al, determine the value x for the resultant non-stoichiometric perovskite compound $MgSi_{0.95}Al_{0.05}O_x$.

   A. 2.9 B. 2.95 C. 2.975 D. 3

7. Given that a saturated NaCl solution has a concentration of 5.4 M, which of the following condition will cause NaCl to crystallize?
   [NaCl (molar mass 58.44); $NaNO_3$ (molar mass 85.00)]

   A. Addition of 1 M $NaNO_3$ solution to 5.4 M NaCl solution.
   B. Addition of 10 g of NaCl crystals to 100 ml of 3 M NaCl solution
   C. Addition of 6 M $NaNO_3$ solution to saturated NaCl solution
   D. Addition of 1.0 g of $NaNO_3$ crystals to 10.0 ml of 4.4 M NaCl solution

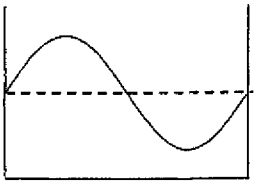
8. The compound 2-germaacetic acid (GeH_3COOH), is an unstable weak acid. At 25°C, a 0.050 M solution of 2-germaacetic acid has a pH of 2.42. Determine the K_a of 2-germaacetic acid.

   A. 3.12×10^{-4} B. 3.80×10^{-3} C. 2.42 D. 0.38

9. The amino acid glycine, $H_2N\text{-}CH_2\text{-}COOH$, can undergo the following equilibria in water:
   $H_2N\text{-}CH_2\text{-}COOH + H_2O \leftrightarrow H_2N\text{-}CH_2\text{-}COO^- + H_3O^+$ $K_a = 4.3 \times 10^{-3}$
   $H_2N\text{-}CH_2\text{-}COOH + H_2O \leftrightarrow {}^+H_3N\text{-}CH_2\text{-}COOH + OH^-$ $K_b = 6.0 \times 10^{-5}$
   What is the equilibrium constant for the intramolecular proton transfer to form a zwitterion?
   $H_2N\text{-}CH_2\text{-}COOH \leftrightarrow {}^+H_3N\text{-}CH_2\text{-}COO^-$

   A. 2.6×10^{7} B. 2.58×10^{-7} C. 0.014 D. 2.18×10^{-3}

10. Referring to the following wavefunction calculated for a particle in a one-dimensional box.



The probability that a particle will appear in the middle of the box will be

A. 0.0 B. 1.0 C. 0.5 D. 0.25

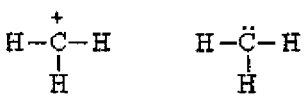
Section B: (10 marks for each question)

1. (a) Assign formal charges to the atoms (except hydrogen) in each of the following resonance forms and determine which species is the major resonance contributor:

   $[CH_3\text{-}CH\text{-}CN]^-$ $\leftrightarrow$ $[CH_3\text{-}CH{=}C{=}N]^-$

   (b) Draw all the possible structural isomers of C_4H_9Br.

   (c) Indicate the molecular geometry of carbon in each of the following molecules:



   (d) Determine the hybridization states of each of the carbon atoms in
   $H_3C - CH = C = O$

2. Write down the orbital diagram of a silicon atom. Sketch the shapes of p_y, d_{z^2}, d_{xz} and $d_{x^2-y^2}$ orbitals (indicate the signs of the lobes).

3. Mass spectrometry is a powerful analytical technique that is used to quantify the amount of molecules with different molecular masses. For the mass spectrum of a hypothetical molecule C_{120}, calculate the relative population of the following species observed in the spectrum (Take the most populated species as 100 %). Given: The natural abundance of ^{13}C and ^{12}C is 1.1 % and 98.9 %, respectively.

Mass	1440	1441	1442	1443	1444	1445	1446
Relative Population							

4. The following reduction potentials have been measured for the oxidation states of copper:

$Cu^{2+}(aq) + e^- \rightarrow Cu^+(aq)$ $\quad E^0 = 0.153$ V

$Cu^+(aq) + e^- \rightarrow Cu(s)$ $\quad E^0 = 0.521$ V

Comment on the stability of $Cu^+(aq)$. Calculate the standard free energy change and equilibrium constant at 298 K for the disproportionation of $Cu^+(aq)$.

5. Consider the following real hydrogenlike wavefunctions:

$$\psi_{2s} = \frac{1}{4\sqrt{2\pi}}\left(\frac{Z}{a}\right)^{\frac{3}{2}}\left(2-\frac{Zr}{a}\right)e^{-Zr/2a}$$

$$\psi_{3s} = \frac{1}{81\sqrt{3\pi}}\left(\frac{Z}{a}\right)^{\frac{3}{2}}\left(27-18\frac{Zr}{a}+2\frac{Z^2r^2}{a^2}\right)e^{-Zr/3a}$$

Calculate the nodal positions of the above two wavefunctions (ignore the case of $r \rightarrow \infty$).