1. (20 marks)

(a) Hydrogen produced in the following reaction is collected over water when the barometric pressure is 98.93 kPa at 23 °C:

$$2\,Al\,(s) + 6\,HCl\,(aq) \rightarrow 2\,AlCl_3\,(aq) + 3H_2\,(g)$$

What volume of the hydrogen gas will be collected in the reaction of 2.50 g of Al (*s*) with excess HCl (*aq*)? (5%)
[The vapor pressure of water is 2.83 kPa at 23 °C; molar mass of Al is 26.98]

(b) Can you obtain precipitate of NaCl by adding 1 mL of concentrated HCl (12 M) to 4 mL of saturated NaCl solution (5.4 M)? Explain with explicit calculations. (5%)

(c) Calculate the mole fraction, molality, and molarity of CH_3CN in water when we mix 20.0 mL of CH_3CN and 80.0 mL of water. You can assume the conditions of ideal mixture in your calculations. [Density of CH_3CN is 786 mg/mL] (10%)

2. (20 marks) For the reaction $H_2(g)+I_2(g)\rightarrow 2HI(g)$, it has two elementary steps:

Fast $\quad I_2(g) \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} 2I(g)$

Slow $\quad 2I(g)+H_2(g) \xrightarrow{k_2} 2HI(g)$

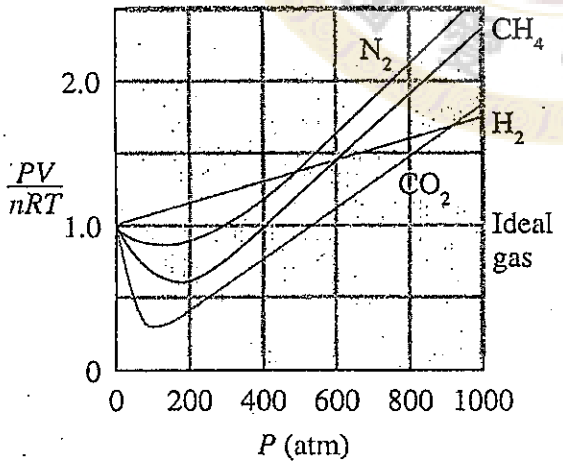
(a) Write down the rate law of the reaction.

(b) If the amount of I_2 is in excess, derive the half-life of the reaction. Define clearly all your variables such as rate constant and/or concentrations.

(c) If the activation energy is given as 40.6 kcal/mol and we assume the frequency factor is identical at different temperatures, determine the increase of the reaction rate when we increase the reaction temperature from 300 K to 310 K.

(d) In the perspective of chemistry, write down three meaningful statements about catalyst.

3. (20 marks) The following experimental data were obtained at 200 K. Based on the van der Waals equation, discuss the data trend of each gas with reference to the ideal gas behavior.



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4. (10 marks) A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Consider a fuel cell making use of the following reaction:

$C_3H_8\,(g) + 5\,O_2\,(g) \rightarrow 3\,CO_2\,(g) + 4\,H_2O\,(l)$

(a) For the complete reaction of one mole of C_3H_8, how many moles of electrons are transferred?

(b) Calculate the emf of the fuel cell based on the following data:

$\Delta G^0_f(CO_2) = -394.36$ kJ/mol

$\Delta G^0_f(C_3H_8) = -23.49$ kJ/mol

$\Delta G^0_f(H_2O) = -237.13$ kJ/mol

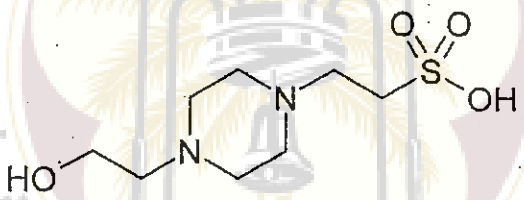
5. (10 marks)

(a) Consider a mineral salt known as hydroxyapatite, $Ca_5(PO_4)_3(OH)$. If some of the OH^- ions are substituted by CO_3^{2-}, explain whether or not some Ca^{2+} ions will also be lost.

(b) Assume that experimentally we obtain the compound of $Ca_x(PO_4)_3(OH)_y(CO_3)_{0.08}$. After some measurements, it is found that the ratio of Ca/P = 1.58. Determine x and y.

6. (20 marks)

(a) HEPES is widely used as a buffer in biology and it has the following formula:



Write down a possible structure for the zwitterion form of HEPES. （5%）

(b) It has been reported that HEPES has a pKa of 7.5 at room temperature. Based on the following generic formula, write down the structures of HA and A^- with reference to HEPES: （5%）

$HA \rightleftharpoons H^+ + A^-$

(c) Given a solution of 0.1 M HEPES in its fully protonated form, describe how you can prepare a 500 mL of 0.05 M HEPES buffer solution at pH 7.8? [Assume you have access to 1.0 M HCl, 1.0 M NaOH, and distilled water] （10 %）

You may or may not find the following constants useful:

Avogadro's number = 6.022×10^{23}

Boltzmann constant = 1.380×10^{-23} JK^{-1}

Elementary charge = 1.602×10^{-19} C

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