SECTION A

Answer **ALL** questions, using the **AL(C)** Answer Book.

1 (a)

An experiment was carried out at 298 K to study the acid-catalyzed hydrolysis of sucrose:

$$C_{12}H_{22}O_{11}(aq) + H_2O(l) \xrightarrow{HCl(aq)} C_6H_{12}O_6(aq) + C_6H_{12}O_6(aq)$$

Sucrose Glucose Fructose

The table below lists the concentration of sucrose, in arbitrary units, at different times.

Time / minutes	0	60	120	180	240
$[C_{12}H_{22}O_{11}(aq)]$	100.0	81.3	66.3	54.0	44.1

(i) Suggest a method that can be used to monitor the progress of the hydrolysis.

(ii) By plotting a suitable graph, show that the hydrolysis is first order with respect to sucrose. That is, the rate equation of the hydrolysis can be represented by:

$$\text{Rate of reaction} = k' [C_{12}H_{22}O_{11}(aq)]$$

(iii) Using your graph, determine k' at 298 K.

(iv) Suggest how you would show experimentally that the rate of the hydrolysis is also first order with respect to hydrochloric acid.

(8 marks)

1 (b)

Given the standard reduction potentials listed below:

	$E^{\ominus}$ / V
$Cr^{2+}(aq) + 2e^- \rightleftharpoons Cr(s)$	– 0.91
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	– 0.76
$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(s)$	– 0.40
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+ 1.23
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+ 1.33

Predict, with explanation, any chemical change(s) involving chromium that would occur

(i) When excess chromium granules are added to deoxygenated dilute hydrochloric acid at room temperature.

(ii) When the solution obtained in (i) is acidified and is then allowed to stand in air.

(iii) When excess zinc granules are added to the solution obtained in (ii).

(6 marks)

1 (c)

A buffer solution is prepared by mixing 0.10 M $CH_3CH_2COOH(aq)$ and 0.20 M $CH_3CH_2COONa(aq)$ in a volume ratio of 6 : 4.

(i) Calculate the pH of the buffer solution at 298 K.
(K_a of $CH_3CH_2COOH(aq)$ is 1.30×10^{-5} mol dm^{-3} at 298 K.)

(ii) Briefly describe how this buffer solution works.

(iii) Suggest one application of buffer solutions in daily life.

(6 marks)

2 (a)

At 298 K, the equilibrium constants, K_c, for reactions (1) and (2) below are 1.8×10^{7} mol^{-2} dm^{6} and 2.0×10^{-10} mol^{2} dm^{-6} respectively.

$$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) \qquad (1)$$

$$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq) \qquad (2)$$

(i) For each of the reactions (1) and (2), write an expression for its K_c.

(ii) Calculate the K_c at 298 K for the following reaction:

$$AgCl(s) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) + Cl^-(aq)$$

(iii) Using your result, calculate the solubility, in mol dm^{-3}, of AgCl(s) in 0.10 M $NH_3(aq)$ at 298 K.

(7 marks)

2 (b)

Give two examples to illustrate the statement:
'Some lithium compounds differ in their chemical properties from corresponding compounds of other Group I elements.'

(4 marks)

2 (c)

Sulphur dioxide can act as an oxidizing agent and as a reducing agent. Using equations, give two examples of each action of sulphur dioxide.

(4 marks)

3 (a)

Compare the oxidizing power of fluorine, chlorine and bromine. Illustrate your answer with appropriate examples.

(3 marks)

3 (b)

Suggest a method to remove stains of colloidal sulphur in a conical flask. State the chemistry involved.

(2 marks)

3 (c)

Element **X** is a silvery-grey metal. Its relative atomic mass is smaller than 110. All isotopes of **X** are radioactive. **X** exhibits variable oxidation states, including +4, +5 and +7 in its compounds, and its highest possible oxidation state is +7.

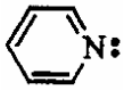
(i) Referring to the Periodic Table, deduce what element **X** may be.

(ii) Many radioisotopes, including some isotopes of **X**, are used in nuclear medicine as radioactive tracers.
Suggest one criterion for choosing a radioisotope as a tracer in the human body.

(3 marks)

4 (a)

Pyridine can act as a ligand in complex formation.



Pyridine

(i) Give hybridization state of nitrogen in pyridine.

(ii) A six-coordinate iron complex has the formula $[Fe(py)_4Cl_2]$, where py represents pyridine.
What is the oxidation state of iron in this complex?

(iii) Draw all possible three-dimensional structures of this complex.

(4 marks)

4 (b)

(i) What is 'disproportionation'?

(ii) State the expected observation when water is added to copper(I) sulphate(VI), a white solid. Write a balanced equation for the reaction involved.

(3 marks)

4 (c)

(i) What is the standard enthalpy change of formation of a compound?

(ii) 0.10 g of magnesium was added to an excess of dilute hydrochloric acid in a polystyrene foam cup with negligible heat capacity. The maximum rise in temperature of the mixture was found to be 4.3°C.

Given that the heat capacity of the acid used is 494 J K^{-1}, calculate the molar enthalpy change for the reaction:

$$Mg(s) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

(iii) In a similar experiment, the molar enthalpy change for the reaction of magnesium carbonate with hydrochloric acid was found to be –90 kJ.

In addition, given that the standard enthalpy change of formation of $H_2O(l)$ is –285 kJ mol^{-3} and that of $CO_2(g)$ is –393 kJ mol^{-3}, estimate the enthalpy change of formation of $MgCO_3(s)$ under the conditions of the experiment.

(7 marks)

4 (d)

A gaseous compound **A** has the following composition by mass:

N 21.6%, O 49.2% and F 29.2%

(i) Deduce the empirical formula of **A**.

(ii) At 298 K and 1.01 x 10^5 N m^{-2}, the density of A is 2.65 g dm^{-3}. Assuming that A behaves as an ideal gas, calculate the molar mass of A and hence deduce its molecular formula.

(3 marks)

END OF SECTION A

SECTION B

Answer **ALL** questions, using the **AL(E)** Answer Book.

5 (a)

Plastic wastes can be used as a source of energy. Incineration of plastic wastes can produce energy for heating and for generation of electricity. The table below lists the calorific values of two plastics.

Plastics	**Calorific value / kJ kg^{-1}**
Polystyrene	46 000
Polyvinyl chloride	18 900

(i) Suggest two reasons why the calorific value of polystyrene is greater than that of polyvinyl chloride.

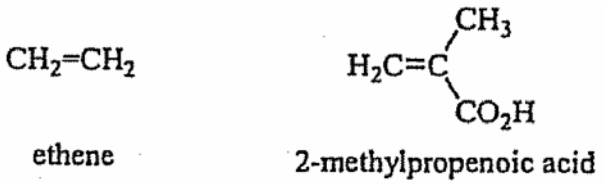
(2 marks)

(ii) What is the main chemical ingredient of rubbing alcohol for disinfection? Write an equation to show the industrial synthesis of this chemical.

(2 marks)

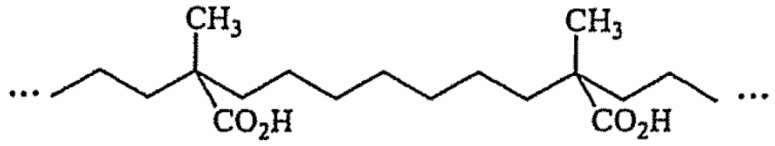
5 (b)

Ethene and 2-methylpropenoic acid react in the presence of benzoyl peroxide to give polymer **N** which does not have a definite repeating unit.



ethene 2-methylpropenoic acid

A portion of the structure of A/is shown below:



(i) Name the type of polymerization involved in the formation of **N**.

(ii) State, with explanation, whether or not **N** is a thermosetting polymer.

(iii) Explain why the strength of **N** obtained depends on the relative amounts of ethene and 2-methylpropenoic acid used in the polymerization.

(iv) **N** reacts with excess sodium hydroxide to give another polymer **P**.

(1) Draw the structure of **P** which corresponds to the portion of the structure shown above.

(2) Compare the strengths of **N** and **P**. Explain your answer.

(7 marks)

5 (c)

A mixture of 2.8 g of butane-1,4-diol and 6.3 g of benzene-1,3-dicarbonyl chloride was heated at 215°C for 30 minutes to give 6.4 g of a polymer **M**.

Butane-1,4-diol Benzene-1,3-dicarbonyl chloride

(i) Draw the repeating unit of **M**.

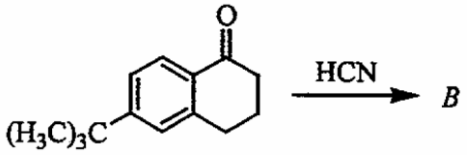
(ii) What type of polymerization is involved in the formation of **M**?

(iii) Calculate the percentage yield of **M**.

(5 marks)

6 (a)

Consider the following reaction:



(i) Give the structure of the major organic product ***B***, labeling all chiral centres with asterisks.

(ii) Outline a mechanism of the reaction.

(iii) Will the product obtained rotate the plane of polarization of a beam of plane polarized light? Explain.

(5 marks)

6 (b)

CO_2 and SiO_2 are oxides of Group IV elements.

(i) Account for the fact that CO_2 is a gas while SiO_2 is a high melting solid under room temperature and atmospheric pressure.

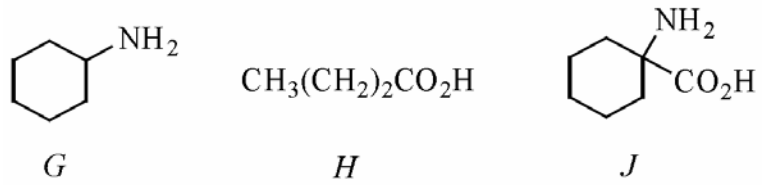
(ii) Give the hybridization state of carbon in CO_2 and of silicon in SiO_2.

(3 marks)

6 (c)

Based on the fact that the pK_a of carboxylic acids (RCOOH) is about 5 and that the pK_b of amines (RNH_2) is about 10, answer the questions below:

(i) For each of the compounds ***G***, ***H*** and ***J*** below,



G *H* *J*

(1) Draw the structure of the predominant species in a pH 3 buffer solution.

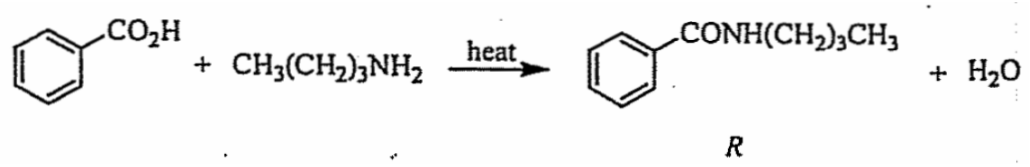
(2) Draw the structure of the predominant species in a pH 11 buffer solution.

(ii) Two electrodes are dipped into an aqueous solution of ***G***, ***H*** and ***J*** maintained at pH 7 are connected to the two poles of a battery. Which of these compounds, under such conditions, will remain almost stationary? Explain your answer.

(6 marks)

7 (a)

The equation below shows the reaction of benzoic acid with butan-1-amine at elevated temperatures to give compound **R**:



(i) Give the systematic name of **R**.

(ii) Name the type of reaction involved.

(iii) The reaction of benzoic acid with butan-1-amine at room temperature gives another product **S**. Give the structure of **S**.

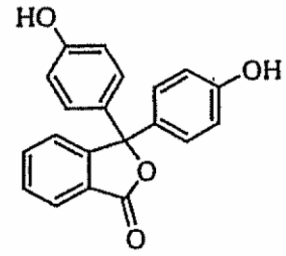
(iv) Suggest why high temperature can facilitate the formation of **R**.

(v) Using benzoic acid as the starting material, devise another route for the synthesis of **R**, which does not involves reactions that take place at temperatures much higher than room temperature.

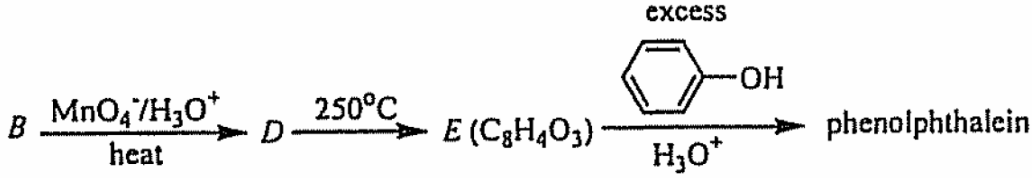
(6 marks)

7 (b)

Phenolphthalein is an acid-base indicator with the following structure:



It can be synthesized from compound ***B*** (C_8H_{10}) via the following reaction pathway:



Under acidic conditions, ***D*** reacts with butan-1-ol to give compound ***F*** ($C_{16}H_{22}O_4$).

Suggest structures for compounds ***B***, ***D***, ***E*** and ***F***.

(4 marks)

END OF PAPER