THE UNIVERSITY OF ZAMBIA
SCHOOL OF NATURAL SCIENCES

2017/2018 ACADEMIC YEAR
FINAL EXAMINATIONS

CHE1000: INTRODUCTION TO CHEMISTRY

TIME: THREE (3) HOURS

INSTRUCTIONS TO THE CANDIDATES

1. Indicate your **student ID number** and **TG number** on **ALL** your answer booklets.
2. This examination paper consists of two (**2**) sections: **A** and **B**
3. Section **A** has ten **(10)** short answer questions. Questions carry equal marks. (Total marks = **40**).

   ANSWER ALL QUESTIONS IN SECTION A IN THE MAIN ANSWER BOOKLET
4. Section **B** has five **(5)** long answer questions. Questions carry equal marks. (Total marks = **60**).

   ANSWER QUESTION B1 and ANY THREE QUESTIONS, EACH QUESTION IN A SEPARATE ANSWER BOOKLET.
6. **YOU ARE REMINDED OF THE NEED TO ORGANISE AND PRESENT YOUR WORK CLEARLY AND LOGICALLY.**
7. **ENSURE** that you have eight (8) printed pages containing questions A1 to A10 and B1 to B5.

ADDITIONAL INFORMATION TO THE CANDIDATES:

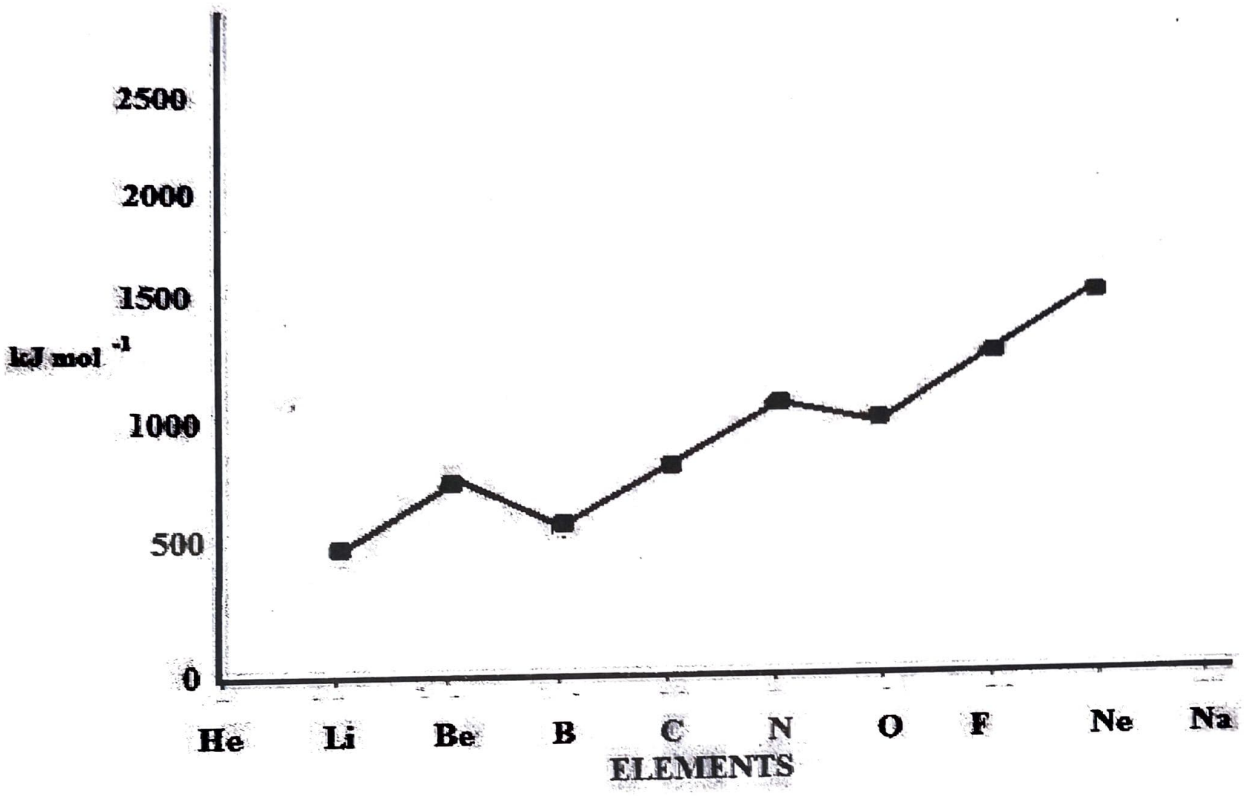
Useful data is provided on page 9.
Periodic Table of Elements is on last page.

SECTION A
ANSWER ALL QUESTIONS IN THE MAIN BOOKLET

Question A1

(a) Differentiate between an orbit and an orbital.

(b) Explain in brief the discontinuities in ionization energy of the elements in the second period as evidenced in the diagram below in going across a period



[4]

Question A2

(a) Define the photoelectric effect and state one condition that must be fulfilled for the photoelectric effect to be observed.

(b) The threshold frequency ν_0 for a metal is $6.0 \times 10^{13}\ s^{-1}$. Calculate the kinetic energy of an electron when the radiation of frequency $\nu = 1.0 \times 10^{14}\ s^{-1}$ hits the metal.

[4]

Question A3

Consider the following data:

Half equation	*E* /V
$Fe^{3+}(aq) + 3e^- \rightleftharpoons Fe(s)$	– 0.04
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	– 0.44

Use the data above to construct a redox equation for the reaction between Fe^{3+} (aq) and Fe(s), and whether or not this reaction is feasible. Show your work. **[4]**

Question A4

Nitrogen monoxide reacts with hydrogen gas to produce nitrogen gas and water. The mechanism is believed to be:

Step 1: $2NO \rightarrow N_2O_2$

Step 2: $N_2O_2 + H_2 \rightarrow N_2O + H_2O$

Step 3: $N_2O + H_2 \rightarrow N_2 + H_2O$

(a) What is the molecularity of Step 2?

(b) What is the balanced net reaction?

(c) Identify any reaction intermediate(s).

[4]

Question A5

Consider the following gaseous reaction:

$$SO_2Cl_2(g) \rightarrow SO_2(g) + Cl_2(g)$$

Experiment	Initial Concentration (mol dm^{-3})	Initial rate of formation of SO_2, R_0 (mol $dm^{-3}s^{-1}$)
1	0.100	2.2×10^{-6}
2	0.200	4.4×10^{-6}
3	0.300	6.6×10^{-6}

(a) Determine the rate Law for the reaction

(b) Calculate the rate constant for the reaction solution.

[4]

Question A6

Calculate the enthalpy change, ΔH_R, for the reaction

$$2NH_3(g) + CO_2(g) \rightarrow NH_2CONH_2(s) + H_2O(l)$$

Substance	Enthalpies of formation ΔH_f / kJ mol^{-1}
$NH_3(g)$	−46.2
$CO_2(g)$	−393.5
$NH_2CONH_2(s)$	−632.2
$H_2O(l)$	−285.8

[4]

Question A7

What is the vapour pressure of a solution at 298 K containing 68 g of glucose (M_r 180 g/mol) in 600 g of water? The vapor pressure of pure water at 298 K is 0.03173 bar. **[4]**

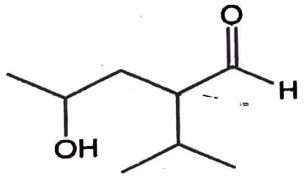
Question A8

Calculate ΔH_{vap} for ethanol, given vapor pressure at 313 K = 0.19999 bar. The normal boiling point for ethanol is 351 K.

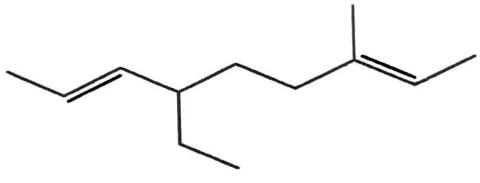
Question A9

Provide the IUPAC name for each of the following compounds:

(a)



(b)



[4]

Question A10

(a) Write the line formula for 4-aminobutanoic acid.

(b) Describe the highlighted carbon oxygen double bond of the ketene, $CH_2 = \mathbf{C= O}$.

(c) Provide the stereochemical structure for the C*is*-alkene, C_4H_8, which has two vinylic and six allylic hydrogens. **[4]**

SECTION B
ANSWER QUESTION B1 AND ANY THREE QUESTIONS EACH IN A SEPARATE BOOKLET

Question B1

(a) The reaction of concentrated sulphuric acid with water is highly exothermic. Describe in one sentence how to dilute the acid. *[1]*

(b) In the laboratory, redox titration was performed involving the following reaction:

$$MnO_4^-(aq) + 5Fe^{2+}(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$$

The reduction reaction takes place in an acidic medium (H^+). In the experiment sulphuric acid was added to Fe^{2+} solution in the conical flask. At the stoichiometric point or equivalent point, Fe^{2+} completely reacted with potassium permanganate.
The same redox reaction above can be used in a galvanic cell under condition of dynamic equilibrium.

(i) Describe in one sentence, in terms of number of moles, the effect of adding sulphuric acid to Fe^{2+} solution in the conical flask. *[2]*

(ii) Name the indicator in the titration and how the end-point is detected? *[2]*

(iii) List three chemicals in the half cell reduction reaction below, required for the half cell to be in dynamic equilibrium. *[2]*

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$$

(c) The experiment on the effect of temperature on the rate of reaction was performed in the laboratory. The rate law for the reaction is given below:

$$\frac{\text{constant}}{t} = k[H^+]^m[S_2SO_3^{2-}(aq)]^n$$

(i) In the rate law equation, what is the name of the term on the left hand side of the equation. [1]

(ii) What mathematical rule or manipulation is done on the rate law to obtain a linear equation with y = -ln t and x = 1/T? [2]

(iii) Write the Arrhenius equation. [2]

(iv) Given that $E_a = 3.801 \times 10^4$ Jmol^{-1}
Calculate the slope b in the linear equation. [3]

Question B2

(a) State Grahams Law using the formula format.

(b) Nickel forms a gaseous compound of the formula Ni(CO)x . If methane (CH_4) effuses 3.3 times faster than the compound, under the same conditions of temperature and pressure, calculate the value of x. **[4]**

(c) A flammable gas made up only of carbon and hydrogen is found to effuse through a porous barrier in 1.50 min. Under the same conditions of temperature and pressure, it takes an equal volume of bromine vapor 4.73 min to effuse through the same barrier. **[5]**

(i) Calculate the molar mass of the unknown gas. **[5]**

(ii) Suggest the name of this gas. **[1]**

Question B3

(a) Write an equilibrium reaction equation for the ionization of acetic acid (CH_3COOH) in water and identify the conjugate acid-base pairs. **[2]**

(b) Some solid sodium acetate (CH_3COONa) is dissolved in 1 mol dm^{-3} solution of acetic acid.

(i) Write the equilibrium reaction. **[1]**

(ii) Explain the effect on the pH of the 1 mol dm^{-3} solution of acetic acid when the sodium acetate is dissolved. **[4]**

(c) Consider the reversible gas phase reaction:

$$SO_2Cl_2(g) \rightarrow SO_2(g) + Cl_2(g)$$

At 380 K, the equilibrium constant $K_p = 2.5$ bar

(i) Write the expression for K_p for the equilibrium. **[2]**

(ii) A sample of SO_2Cl_2 is introduced in an evacuated reaction vessel and brought to equilibrium at 380 K. If the sample and vessel are of such size that $p_{SO_2Cl_2} = 0.1$ bar at equilibrium; calculate the equilibrium values of p_{SO_2} and p_{Cl_2}. What is total gas pressure in the vessel? **[6]**

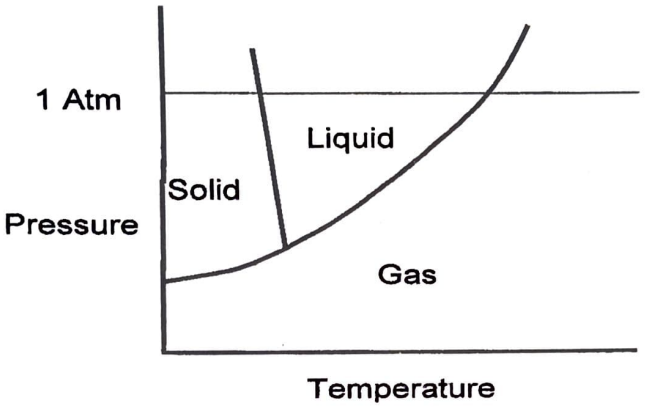
Question B4

(a) Calculate the ionisation energy of a hydrogen atom in its ground state i.e. when the hydrogen's electron is at level 1.

(b) (i) Draw the Lewis structure for the water H_2O molecule and use VSEPR theory to sketch the arrangement of electron pair in space. Name the geometrical shape illustrated.

(ii) For the molecule described in b (i) above show whether the molecule is polar or non-polar. Justify your answer.

(c) The diagram below shows a simplified phase diagram for water. Reproduce the phase diagram for water in your answer booklet and the answer the questions that follow.



(i) Indicate the triple point with the letter **A** and critical temperature **B.**

(ii) On the same diagram show the lines for the phase changes when a solute is added to water. Indicate the triple point for the solution as **C** and critical temperature **D**

Indicate on the diagram the position (temperature axis) ΔT_f and ΔT_b

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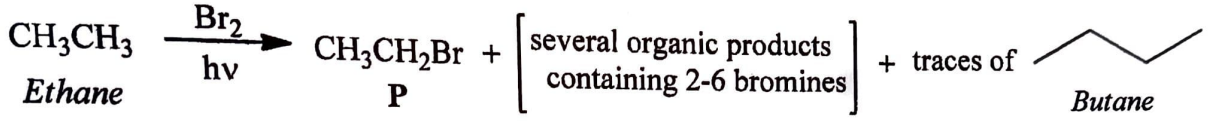
Question B5

(a) Consider the following reaction:



(i) Name the type of reaction. [1]

(ii) Provide detailed reaction mechanisms for formation of **P** from ethane. [6]

(iii) Propose a possible mechanism to account for the traces of butane found in the reaction mixture. [2]

(b) Consider a compound **X**, with molecular formula, C_3H_6O;

(i) Calculate the IHD (also called DBE and DU) of **X** and interpret it. [2]

(ii) Write any two (2) possible structures (line formulae) for **X**. [2]

(iii) Given that compound **X** is a primary alcohol which has 3 vinylic hydrogens, identify **X**, give line formula and IUPAC name. [2]

END OF EXAMINATION

USEFUL DATA

Physical contants

Avogadro constant, N_A	6.022×10^{23} mol^{-1}
Acceleration due to gravity	9.8 m s^{-2}
Faraday's constant, F	96485 C mol^{-1}
Mass of electron, m_e	9.11×10^{-31} kg
Planck's constant, h	6.626×10^{-34} J s
Rydberg constant, R_H	1.097×10^{7} m^{-1}
Speed of light, c	3.00×10^{8} m s^{-1}
Universal gas constant, R	8.3145 J mol^{-1} K^{-1}
	0.083145 L bar mol^{-1} K^{-1}
	0.08206 L atm mol^{-1} K^{-1}
	62.364 L torr mol^{-1} K^{-1}
	62.364 L mmHg mol^{-1} K^{-1}

Pressure conversions

1 atm $= 1.01325 \times 10^5$ Pa $= 1.01325 \times 10^5$ N m^{-2} = 760 torr = 760 mmHg = 1.01325 bar

1 bar $= 1.00000 \times 10^5$ Pa
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Other conversion factors

V= J C^{-1} 1 eV $= 1.602 \times 10^{-19}$ J

1 J = 1 kg m^{2}s^{-2}

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ADDITIONAL INFORMATION TO THE CANDIDATES:

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SECTION A

ANSWER ALL QUESTIONS IN THIS SECTION IN THE MAIN BOOKLET

Question A1

Hemoglobin is the protein that transports oxygen through the blood from the lungs. In doing so, each molecule of haemoglobin combines with four molecules of oxygen. If 1.00 g of haemoglobin combines with 1.53×10^{-6} m^3 of O_2 at 310 K and 99059 Pa, what is the molar mass of haemoglobin?

[4 Marks]

Question A2

(a) Two factors can determine the size (radius) of an atom. State any one of them and explain in *three lines or less*, how it influences the size of an atom.

(b) Is it more difficult to remove a valence electron from a magnesium atom or a chlorine atom? Explain in *three lines or less*.

[4 Marks]

Question A3

The following standard electrode potentials are needed for this question:

	E°/V
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2 + H_2O$	+ 0.81
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+ 0.34

Calculate the standard cell emf for the reaction between copper and nitric acid and derive the balanced reaction equation.

[4 Marks]

Question A4

Consider the reaction known to be zero order in A and have a rate constant of 5.0×10^{-2} M s^{-1} at 25 °C. An experiment was run at 25 °C, where $[A]_0 = 1.0 \times 10^{-3}$ M .

(a) Write the integrated rate law for this reaction.

(b) Calculate the half-life for this reaction.

(c) Find the concentration after 1.0×10^{-3} s has elapsed.

[4 Marks]

Question A5

A solution contains 1.0×10^{-5} mol dm^{-3} of Na_3PO_4 . What is the required concentration of $AgNO_3$ that would cause precipitation of Ag_3PO_4 ($K_{sp} = 1.8 \times 10^{-18}$)?

[4 Marks]

Question A6

(a) The enthalpy of formation of NH_3 is - 46 kJ/mol. Calculate the enthalpy change for the reaction $2NH_3\ (g) \rightarrow N_2\ (g) + 3H_2\ (g)$

(b) When 285 J of heat is added to 33.6 g of hexane, (M_r. 86.06 g/mol), the temperature increases by 3.74°C. Calculate the molar heat capacity of hexane.

[4 Marks]

Question A7

(a) The vapor pressure above a solution of a nonvolatile solute at 25.0 °C is 19.3 mm Hg. What is the mole fraction of the solute? (The vapor pressure of pure water is 23.8 torr at 25.0 °C.)

(b) List the following molecules in order of increasing surface tension: C_3H_8, CH_4, CH_3COOH and C_2H_6.

(c) Which substance has the higher vapor pressure: $C_{20}H_{42}$ or $C_{30}H_{62}$?

[4 Marks]

Question A8

(a) Identify the strongest intermolecular force present in the following molecules:

(i) CH_3CH_2OH

(ii) CH_3CH_2Cl

(b) Predict which will have the higher boiling point: ICl or Br_2. Explain your answer in not more than two lines.

[4 Marks]

Question A9

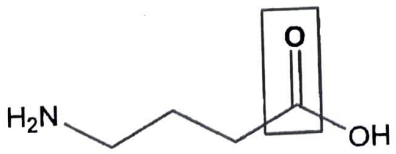
(a) For compound **A**, 5-isopropyl-2,3-dimethyloct-2-ene:

(i) Draw a line-bond formula.

(ii) Give molecular formula.

(iii) State the number of allylic hydrogens in **A**.

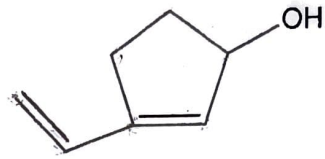
(b) Classify the molecule shown below and describe the bonding of the group in the box.



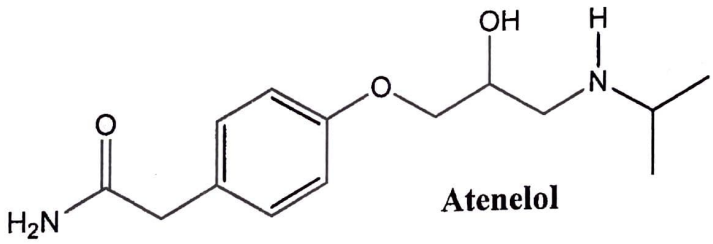
[4 Marks]

Question A10

(a) Give the **IUPAC** name for the molecule shown below:



(b) Identify all functional groups in the drug atenolol, used for treatment of hypertension (high blood pressure), shown below:



Atenelol

[4 Marks]

SECTION B

ANSWER QUESTION B1 AND ANY THREE QUESTIONS EACH IN A SEPARATE BOOKLET

Question B1

A CHE1000 Student, Lydia, trying to determine the concentration of HCl by titrating it with 0.525 mol dm^{-3} NaOH. It takes 83 mL of a 0.525 mol dm^{-3} NaOH solution to neutralize 235 mL of an HCl solution.

(a) Another student, Joseph, carefully pipettes 10.0 mL of 0.525 mol dm^{-3} NaOH into a test tube. He places the test tube into a small beaker and then pipettes 7.50 mL of 0.355 mol dm^{-3} HCl into another test tube. He accidentally knocked the test tubes, while placing, contents combined in the beaker.

(i) Is the solution formed from the contents of the two test tubes acidic or basic?

(ii) If he added few drops of Methyl Orange indicator what would be the colour of the solution? **(7 marks)**

(b) You are carrying out an acid base titration to determine the concentration of the acid. The endpoint of the neutralization is reached but the stopcock on the burette sticks slightly and allows a few more drops of acid to fall into the solution. Will this small amount of acid ~~base~~ have any effect on the determined value for the concentration of the acid? If so, how is it affected (***Not more than 4 lines***)? **(4 marks)**

(c) A few small drops of water are left in a burette that is then used to titrate a base into an acid solution to determine the concentration of the acid. Will this small amount of water have any effect on the determined value for the concentration of the acid? If so, how is it affected (***Not more than 4 lines***)? **(4 marks)**

[TOTAL: 15 Marks]

Question B2

(a) The active agent in many hair bleaches is hydrogen peroxide. The amount of hydrogen peroxide in 15.8 g hair bleach was determined by titration with a standard potassium permanganate solution:

$$2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \rightarrow 5O_2(g) + 2Mn^{2+}(aq) + 8H_2O(l)$$

(i) How many moles of MnO_4^- were required for the titration if 43.2 ml of 0.015 M $KMnO_4$ was needed to reach the end point? **(1 mark)**

(ii) How many moles of H_2O_2 were present in the 15.8 g of hair bleach? **(2 marks)**

(iii) How many grams of H_2O_2 were present in the hair bleach? **(1 mark)**

(iv) What is the mass percent H_2O_2 in the hair bleach? **(2 marks)**

(v) What is the reducing agent in the redox reaction? **(1 mark)**

(b) Consider the following precipitation reaction:

$$Hg_2(NO_3)_2(aq) + 2KI(aq) \rightarrow Hg_2I_2(s) + 2KNO_3(aq)$$

(i) Balance the reaction. **(2 marks)**

(ii) Write the **net** ionic reaction. **(2 marks)**

(iii) Identify the spectator ions. **(2 marks)**

(c) Determine the oxidation number of the underline atom in each of the following:

(i) $H_2\underline{S}O_4$ (ii) $\underline{Sb}Cl_3$ **(2 marks)**

[TOTAL: 15 Marks]

Question B3

(a) Use standard electrode potential, E°, data to calculate the cell potential for the following reaction:

$$Cl_2 + 2OH^- \leftrightharpoons Cl^- + ClO^- + H_2O$$ **(2 marks)**

(b) The chlorate(I) ion is unstable and decomposes when heated as shown.

$$3ClO^- \rightleftharpoons 2Cl^-(aq) + ClO_3^-(aq)$$

(i) Calculate the oxidation number of chlorine in each species. **(3 marks)**

(ii) In terms of electron transfer, state what happens to chlorine in the reaction. **(1 marks)**

(c) A half-equation involving bromate(V) ions, BrO_3^-, and bromide ions is shown.

$$BrO_3^-(aq) + 3H_2O(l) + 6e^- \rightleftharpoons Br^-(aq) + 6OH^-(aq) \quad E^0 = +0.58\ V$$

(i) An alkaline solution of chlorate (I), ClO^-, can be used to oxidise bromide ions to bromated (V) ions. Write the equation for the spontaneous reaction. **(2 marks)**

(ii) Draw a cell in which this reaction will occur and label all the parts. **(5 marks)**

(iii) Write the shorthand notation for the cell. **(2 marks)**

[TOTAL: 15 Marks]

Question B4

(a) Calculate the maximum Kinetic Energy (in joules) and velocity (3 significant figures) of an electron ejected from zinc by a 275 nm photon. The threshold energy or work function for Zn = 4.31eV. **(3 marks)**

(b) (i) The nitrogen atom in ammonium ion is sp^3 hybridized. Use a suitable hybridization scheme to show the hybridization on the nitrogen atom. **(3 marks)**

(ii) Show using a sketch diagram that NH_3 is a polar molecule. **(3 marks)**

(c) Ethene is a planar shaped molecule. Draw a fully labelled diagram showing the bonding (σ - sigma and π - pie) in the molecule. **(3 marks)**

(d) (i) How would you expect the first ionization energy to change as you go across a period in the periodic table. **(1 mark)**

(ii) State any two factors that influence the ease of removing an electron from an element. **(2 marks)**

[TOTAL: 15 Marks]

Question B5

(a) Several constitutional isomers can be written for molecular formula C_4H_7OCl.

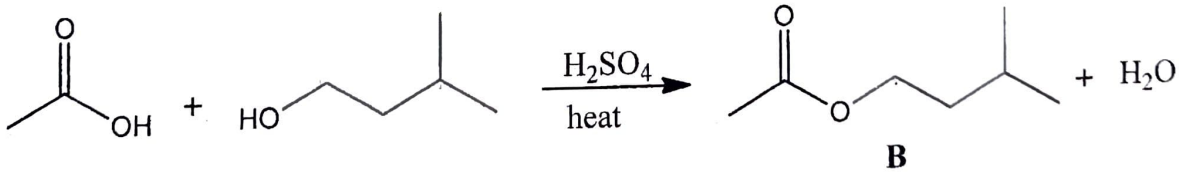
(i) Calculate the IHD and state all possible interpretations. **(2 marks)**

(ii) Draw line-bond formula and give IUPAC name for an isomer that is a straight chain acyl chloride (acid chloride). **(3 marks)**

(iii) Draw line-bond formulae for two (2) isomers with cyclobutane as parent chain and state their isomeric relationship as chain, positional or functional isomers. **(3 marks)**

(iv) One of the isomers decolorizes bromine water. Interpret this result and state two (2) other functional groups that could be present in this isomer. **(2 marks)**

(b) Esters are pleasant sweet-fruity smelling substances frequently used in perfumery and food industry. One common banana flavor **B** used for candy products is prepared by the reaction shown below:

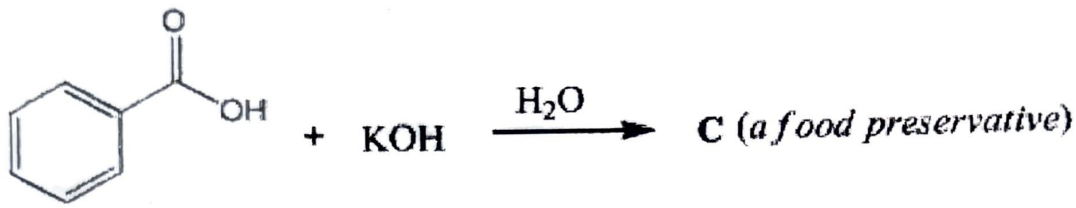


B

(i) Name the type of reaction. **(1 mark)**

(ii) Give the **IUPAC** name for **B.** **(2 marks)**

(c) A frequently used food preservative, **C**, is prepared as shown below:



Identify **C** (line-bond structure) and circle the most electrophilic center on its structure.

(2 marks)

[TOTAL: 15 Marks]

END OF EXAMINATION

USEFUL DATA

Physical contants

Avogadro constant, N_A	6.022×10^{23} mol^{-1}
Acceleration due to gravity	9.8 m s^{-2}
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Mass of electron, m_e	9.11×10^{-31} kg
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Universal gas constant, R	8.3145 J mol^{-1} K^{-1}
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	62.364 L torr mol^{-1} K^{-1}
	62.364 L mmHg mol^{-1} K^{-1}

Pressure conversions

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1 bar $= 1.00000 \times 10^5$ Pa
$= 1.00000 \times 10^5$ N m^{-2}

Other conversion factors

V= J C^{-1} 1 eV $= 1.602 \times 10^{-19}$ J
1 J = 1 kg m^{2}s^{-2}

	E°(V)
$Cl_2 + 2\,e^- \leftrightharpoons 2\,Cl^-(aq)$	+1.36
$ClO^-(aq) + H_2O(l) + 2\,e^- \leftrightharpoons Cl^-(aq) + 2OH^-$	+ 0.89