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2024

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Candidate Number

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# Chemistry

Assessment Unit A2 1

*assessing*

Further Physical and  
Organic Chemistry

**MV18**

**[ACH14]**

**TUESDAY 28 MAY, MORNING**

## Time

2 hours, plus your additional time allowance.

## Instructions to Candidates

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.

Answer **all sixteen** questions in **Sections A and B**.

**You must answer the questions in the spaces provided.**

**Do not write on blank pages.**

Complete in black ink only. **Do not write with a pencil.**

## Information for Candidates

The total mark for this paper is 110.

Quality of written communication will be assessed in Questions **14(a)** and **16(c)(iii)**.

The figures in brackets printed at the end of each question indicate the marks awarded to each question or part question. A Periodic Table of Elements, containing some data, is included with this question paper.

## Section A

For each of the following questions, only **one** of the lettered responses (A–D) is correct.

**Select the correct response for each question and write the appropriate letter in the space provided.**

1 Which one of the following compounds does **not** react with nucleophiles? [1 mark]

- A  $\text{CH}_3\text{CH}_2\text{CHO}$
- B  $\text{CH}_3\text{CHCH}_2$
- C  $\text{CH}_3\text{CH}_2\text{COCH}_3$
- D  $\text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}$

Answer \_\_\_\_\_

2 In which one of the following reaction mixtures does a redox reaction occur? [1 mark]

- A ethanal and hydrogen cyanide
- B ethanal and Tollens' reagent
- C ethanoic acid and sodium hydroxide
- D ethanoyl chloride and ethanol

Answer \_\_\_\_\_

3 The boiling point of ethyl ethanoate is 77 °C. The boiling point of pentyl hexanoate is 226 °C. Which one of the following is responsible for the higher boiling point of pentyl hexanoate? [1 mark]

- A covalent bonds
- B hydrogen bonds
- C permanent dipole-dipole attractions
- D van der Waals' forces

Answer \_\_\_\_\_

4 Propanone reacts with 2,4-dinitrophenylhydrazine to form a 2,4-dinitrophenylhydrazone. Which one of the following is the molecular formula of the 2,4-dinitrophenylhydrazone? [1 mark]

- A  $C_9H_8N_4O_4$
- B  $C_9H_{10}N_3O_4$
- C  $C_9H_{10}N_4O_4$
- D  $C_9H_{11}N_4O_4$

Answer \_\_\_\_\_

- 5 Which one of the following is correct for the entropy change and enthalpy change for a reaction which is feasible at all temperatures? [1 mark]

|   | $\Delta S$ | $\Delta H$ |
|---|------------|------------|
| A | negative   | negative   |
| B | negative   | positive   |
| C | positive   | negative   |
| D | positive   | positive   |

Answer \_\_\_\_\_

- 6 Which one of the following statements is **not** correct? [1 mark]

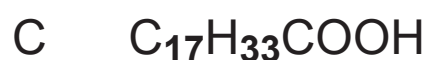
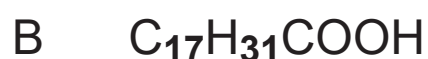
- A a benzene molecule contains 24 electrons
- B all carbon-carbon bonds in benzene are the same length
- C benzene undergoes substitution reactions
- D chlorine reacts more slowly with benzene than it does with ethene

Answer \_\_\_\_\_

7 A pure sample of a fat is known to be the triester of glycerol and a fatty acid.

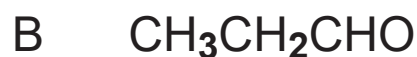
0.30 mol of the fat requires 21.6 dm<sup>3</sup> of hydrogen at room temperature for complete hydrogenation. Which one of the following is the formula of the fatty acid in the fat?

[1 mark]



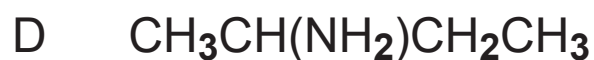
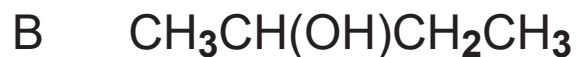
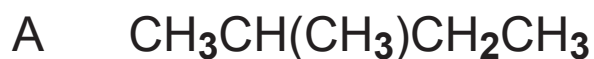
Answer \_\_\_\_\_

8 Propanone can be reduced to form an alcohol. Which one of the following is an isomer of the alcohol formed, which belongs to a different homologous series? [1 mark]



Answer \_\_\_\_\_

9 Which one of the following does **not** contain an asymmetric centre? [1 mark]



Answer \_\_\_\_\_

10 The rate of decomposition of ethanal at  $500^\circ\text{C}$  is given by the equation:

$$\text{rate} = k [\text{ethanal}]^2$$

Which one of the following shows the units for  $k$ ? [1 mark]

A  $\text{s}^{-1}$

B  $\text{mol dm}^{-3} \text{s}^{-1}$

C  $\text{mol}^{-1} \text{dm}^3 \text{s}^{-1}$

D  $\text{mol}^{-2} \text{dm}^6 \text{s}^{-1}$

Answer \_\_\_\_\_

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**(Questions continue overleaf)**

## Section B

Answer **all six** questions in this section

**11** A cleaning solution is a solution of sodium hydroxide.

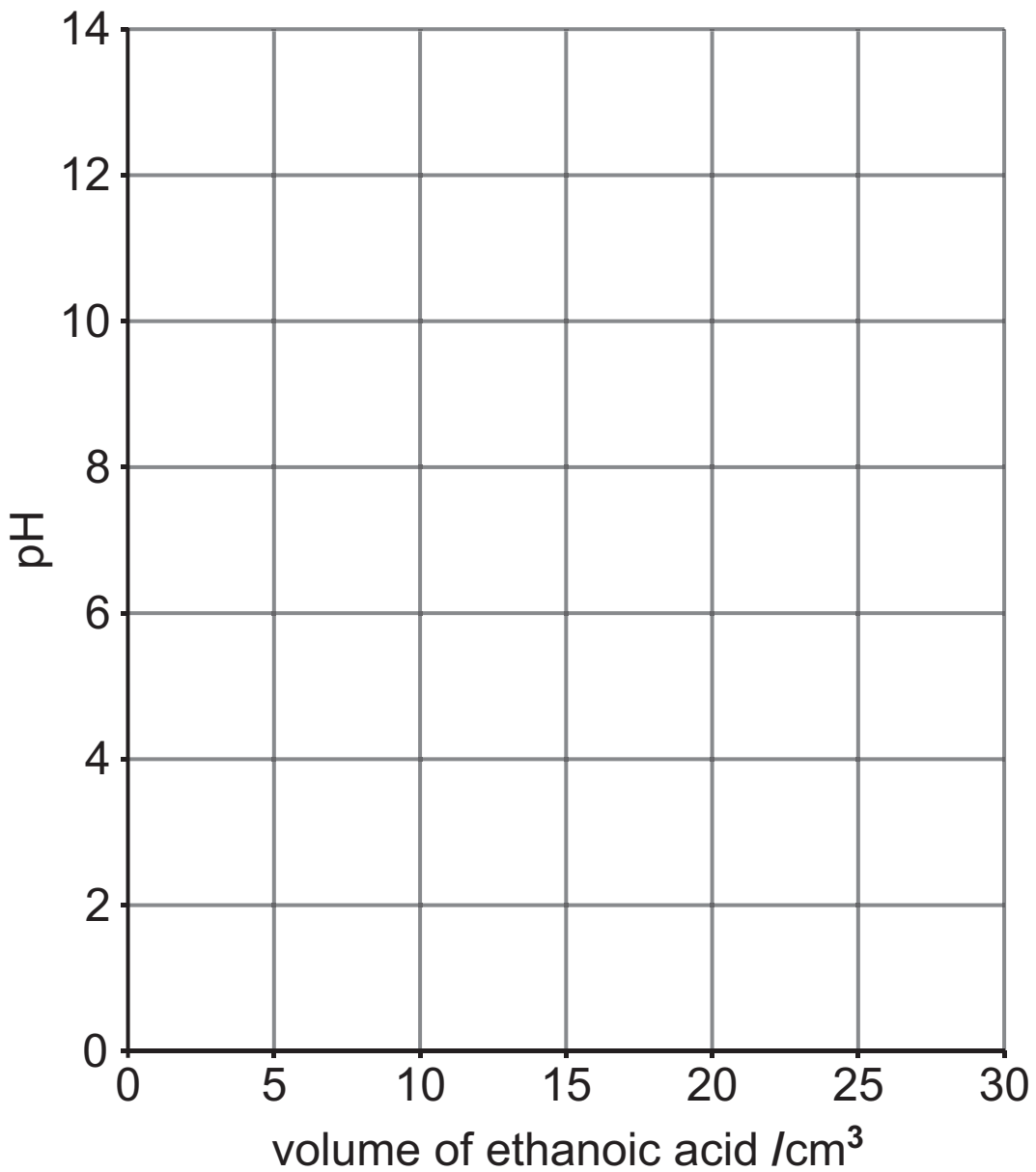
- (a) A sample of  $25.0\text{ cm}^3$  of the cleaning solution was titrated using  $0.525\text{ mol dm}^{-3}$  ethanoic acid. The mean titre was found to be  $17.2\text{ cm}^3$ .
- (i) Calculate the concentration, in  $\text{mol dm}^{-3}$ , of sodium hydroxide in the cleaning solution. Give your answer to 3 significant figures. [2 marks]

Answer \_\_\_\_\_  $\text{mol dm}^{-3}$

- (ii) Calculate the pH of the cleaning solution at  $25^\circ\text{C}$ . Give your answer to 2 decimal places. [2 marks]  
 $K_w = 1.00 \times 10^{-14}\text{ mol}^2\text{ dm}^{-6}$  at  $25^\circ\text{C}$ .

Answer \_\_\_\_\_

**(iii)** Using your answer to **(a)(ii)** and the information given in the question, sketch the titration curve for this titration on the axes below. [3 marks]



**(iv)** Name an indicator for this titration and explain why it is a suitable choice. [2 marks]

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(b) 25.0 cm<sup>3</sup> of the cleaning solution may also be titrated using 0.525 mol dm<sup>-3</sup> sulfuric acid.

(i) Describe two ways in which the titration curve would be different to the one in (a)(iii). [2 marks]

1. \_\_\_\_\_

\_\_\_\_\_

2. \_\_\_\_\_

\_\_\_\_\_

(ii) 20.0 cm<sup>3</sup> of the 0.525 mol dm<sup>-3</sup> sulfuric acid were placed in a volumetric flask and the volume made up to 250.0 cm<sup>3</sup> using deionised water. Calculate the pH of the resulting solution. Give your answer to 2 decimal places. [3 marks]

Answer \_\_\_\_\_

(c) Sodium hydroxide reacts with phosphoric acid,  $\text{H}_3\text{PO}_4$ , to form salts including sodium hydrogenphosphate,  $\text{Na}_2\text{HPO}_4$ . The hydrogenphosphate ion can act as a Brønsted–Lowry acid and as a Brønsted–Lowry base.

(i) Write an equation for the reaction between sodium hydroxide and phosphoric acid to form sodium hydrogenphosphate. [1 mark]

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(ii) Show, using equations, how the hydrogenphosphate ion can act as a Brønsted–Lowry acid and as a Brønsted–Lowry base in aqueous solution. [2 marks]

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(iii) Another salt of phosphoric acid is sodium phosphate,  $\text{Na}_3\text{PO}_4$ . Explain why a solution of sodium phosphate is alkaline. [1 mark]

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**12** Butanoic acid and 2-hydroxypropanoic acid are weak monobasic acids. The table below summarises some properties of both acids.

| <b>Acid</b>             | <b>Formula</b>                                       | <b>Boiling point /°C</b> | <b>Acid dissociation constant (<math>K_a</math>) at 25°C /mol dm<sup>-3</sup></b> |
|-------------------------|--|--------------------------|---|
| butanoic acid           | CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> COOH | 163.5                    | $1.51 \times 10^{-5}$   |
| 2-hydroxypropanoic acid | CH <sub>3</sub> CH(OH)COOH                           | 122.0                    | $1.38 \times 10^{-4}$   |

(a) (i) Define the term **monobasic acid**. [1 mark]

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(ii) Suggest why the boiling point of butanoic acid is higher than the boiling point of 2-hydroxypropanoic acid. [2 marks]

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(iii) On mixing 2-hydroxypropanoic acid with butanoic acid, an acid-base equilibrium is set up. Give the formula for the base and its conjugate acid for the forward reaction in this equilibrium. [2 marks]

base: \_\_\_\_\_

conjugate acid: \_\_\_\_\_

(iv) Calculate the mass of 2-hydroxypropanoic acid required to produce a 250.0 cm<sup>3</sup> solution with a pH of 2.40. Give your answer to 3 significant figures.  
[4 marks]

Answer \_\_\_\_\_ g

**(b)** 2-hydroxypropanoic acid,  $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$ , is also known as lactic acid. Industrially, lactic acid is produced by the addition of hydrogen cyanide to ethanal to form a hydroxynitrile followed by hydrolysis of the hydroxynitrile.

**(i)** Write the equation for the reaction of ethanal with hydrogen cyanide to form the hydroxynitrile.  
[1 mark]

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**(ii)** Suggest the IUPAC name for the hydroxynitrile formed in the reaction of ethanal and hydrogen cyanide. [1 mark]

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**(iii)** Name the mechanism for the reaction of ethanal with hydrogen cyanide. [1 mark]

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**(iv)** Draw the three-dimensional structures for the two optical isomers of the hydroxynitrile formed in **(b)(i)**.  
[2 marks]

(v) Define the term **optical isomers**. [1 mark]

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(vi) Write the equation for the acid hydrolysis of the hydroxynitrile formed in (b)(i) to produce lactic acid. [2 marks]

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(vii) State why the lactic acid produced is not optically active. [1 mark]

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**13** Ethanoic acid and ethane-1,2-diol react together to form the diester  $C_6H_{10}O_4$ .



**(a)** Draw the structure for the diester  $C_6H_{10}O_4$ . [1 mark]

**(b)** A mixture of 0.550 moles of ethanoic acid and 0.205 moles of ethane-1,2-diol was allowed to reach equilibrium.

| Substance                          | $CH_3COOH$ | $HOCH_2CH_2OH$ | $C_6H_{10}O_4$ | $H_2O$ |
|------------------------------------|------------|----------------|----------------|--------|
| Initial amount in mixture /mol     | 0.550      | 0.205          | 0              | 0      |
| Equilibrium amount in mixture /mol | 0.260      |                |                |        |

**(i)** Complete the table above. [3 marks]

**(ii)** Write an expression for the equilibrium constant,  $K_c$ , for this reaction. [1 mark]

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**(iii)** Explain why the total volume of the mixture is not needed to calculate the value of  $K_c$ . [1 mark]

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**(iv)** Calculate the value of  $K_c$  for this equilibrium reaction. [2 marks]

Answer \_\_\_\_\_

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(b) Some data for the hydrolysis of propyl methanoate are given below.

| Experiment | [HCOOCH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub> ]<br>/mol dm <sup>-3</sup> | [OH <sup>-</sup> ]<br>/mol dm <sup>-3</sup> | Initial rate of the<br>reaction ( $\times 10^{-4}$ )<br>/mol dm <sup>-3</sup> s <sup>-1</sup> |
|------------|---|---|---|
| 1          | 0.040   | 0.030                                       | 4.00  |
| 2          | 0.040   | 0.045                                       | 6.00  |
| 3          | 0.060   | 0.045                                       | 9.00  |
| 4          | 0.120   | 0.060                                       | to be calculated  |

- (i) State the order of the reaction with respect to propyl methanoate. [1 mark]

Answer \_\_\_\_\_

- (ii) State the order of the reaction with respect to hydroxide ions. [1 mark]

Answer \_\_\_\_\_

- (iii) Calculate the initial rate of reaction for **Experiment 4**. [1 mark]

Answer \_\_\_\_\_ mol dm<sup>-3</sup> s<sup>-1</sup>

- (iv) State the effect, if any, of increasing the temperature on the value of the rate constant. [1 mark]
-

(c) Fats are formed from glycerol and fatty acids. The table below shows some fatty acids.

| Fatty acid | IUPAC name                 | Formula  |
|------------|----------------------------|--|
| <b>A</b>   | octadecanoic acid          | $\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$   |
| <b>B</b>   | octadec-9-enoic acid       |  |
| <b>C</b>   | octadeca-9,12-dienoic acid | $\text{CH}_3(\text{CH}_2)_4\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$ |

(i) State the IUPAC name of glycerol. [1 mark]

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(ii) Write the formula for the fatty acid **B** in **the table**.  
[1 mark]

(iii) Write the equation for the formation of a fat from one molecule of glycerol and three molecules of fatty acid **A**. [2 marks]

**15** Group I elements are highly reactive and form a variety of compounds many of which are very soluble in water.

(a) Rubidium ignites spontaneously when exposed to air to form rubidium oxide.

The following enthalpy changes can be used to calculate the standard enthalpy of formation of rubidium oxide.

| Enthalpy change | Equation  | $\Delta H$<br>/kJ mol <sup>-1</sup> |
|-----------------|---|-------------------------------------|
| A               | $\text{Rb(s)} \rightarrow \text{Rb(g)}$   | +86                                 |
| B               | $\text{Rb(g)} \rightarrow \text{Rb}^+(\text{g}) + \text{e}^-$                         | +402                                |
| C               | $\frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{O}(\text{g})$                      | +249                                |
| D               | $\text{Rb}_2\text{O(s)} \rightarrow 2\text{Rb}^+(\text{g}) + \text{O}^{2-}(\text{g})$ | +2161                               |
| E               | $\text{O}(\text{g}) + \text{e}^- \rightarrow \text{O}^-(\text{g})$                    | -142                                |
| F               | $\text{O}^-(\text{g}) + \text{e}^- \rightarrow \text{O}^{2-}(\text{g})$               | +844                                |

(i) Write an equation for the standard enthalpy of formation of rubidium oxide. [1 mark]

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(ii) Name the enthalpy changes C, D and E in the table above. [3 mark]

C \_\_\_\_\_

D \_\_\_\_\_

E \_\_\_\_\_

**(iii)** Calculate the standard enthalpy of formation of rubidium oxide. [2 marks]

Answer \_\_\_\_\_ kJ mol<sup>-1</sup>

**(b)** Rubidium reacts vigorously with gaseous iodine to form the white solid, rubidium iodide.

**(i)** Write an equation, including state symbols, for the formation of rubidium iodide. [1 mark]

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**(ii)** Using the following data, calculate the enthalpy of solution of rubidium iodide. [2 marks]



Answer \_\_\_\_\_ kJ mol<sup>-1</sup>

(c) Sodium nitrate decomposes on heating, to form sodium nitrite and oxygen, as shown by the equation below.



The minimum temperature required for this decomposition is 968 K.

The table below shows some standard enthalpy of formation data and some entropy values.

| Substance             | $\Delta_f H^\ominus$ /kJ mol <sup>-1</sup> | Entropy /J K <sup>-1</sup> mol <sup>-1</sup> |
|-----------------------|--|--|
| NaNO <sub>3</sub> (s) | -467                                       | to be calculated                             |
| NaNO <sub>2</sub> (s) | -359                                       | 120  |
| O <sub>2</sub> (g)    | 0  | 205  |

(i) What is the systematic name for sodium nitrite?  
[1 mark]

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(ii) Suggest why the decomposition temperature of potassium nitrate would be higher than the decomposition temperature of sodium nitrate.  
[2 marks]

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- (iii)** Calculate the enthalpy change for the decomposition of sodium nitrate as shown by the equation below:  
[2 marks]



Answer \_\_\_\_\_

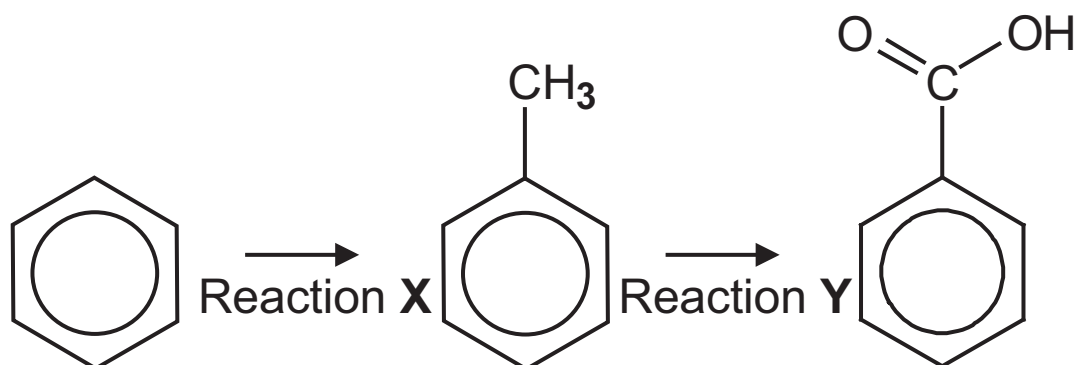
- (iv)** Using the minimum temperature required for the decomposition (968 K) and your answer to **(c)(iii)**, calculate the entropy change in  $\text{J K}^{-1} \text{mol}^{-1}$  for the decomposition. [3 marks]

Answer \_\_\_\_\_  $\text{J K}^{-1} \text{mol}^{-1}$

- (v)** Using your answer to **(c)(iv)**, calculate the entropy value for sodium nitrate. [2 marks]

Answer \_\_\_\_\_  $\text{J K}^{-1} \text{mol}^{-1}$

**16 (a)** Benzoic acid is formed from benzene in a process which involves two reactions **X** and **Y**.



During Reaction **X**, benzene reacts with chloromethane in the presence of aluminium chloride. In Reaction **Y**, methylbenzene is heated with acidified potassium dichromate(VI) solution.

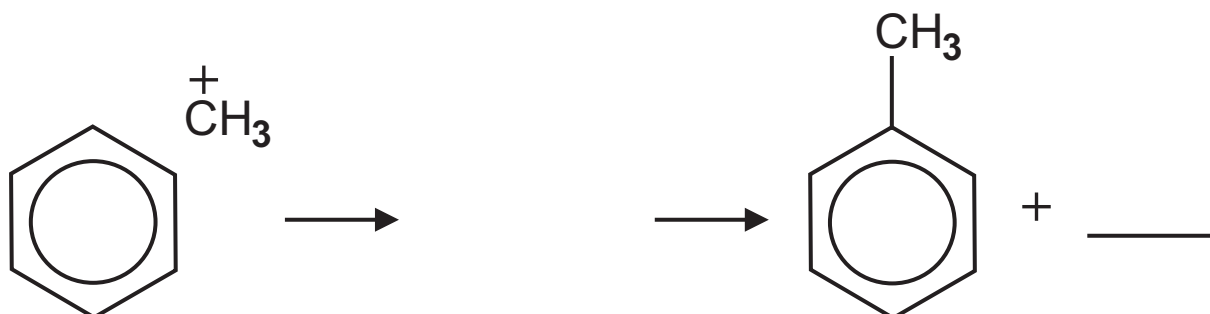
**(i)** State the function of aluminium chloride during Reaction **X**. [1 mark]

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**(ii)** Name the mechanism for Reaction **X**. [1 mark]

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(iii) The mechanism for Reaction X is shown below.  
Complete the mechanism. [5 marks]



(iv) Suggest the type of reaction that is taking place during Reaction Y. [1 mark]

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(v) Benzoic acid reacts with phosphorus pentachloride.  
Write an equation for this reaction. [1 mark]

---

**(b)** Methyl benzoate, a colourless liquid ester, is formed by the reaction of benzoic acid with methanol in the presence of a catalyst. The crude methyl benzoate distillate is collected over the temperature range 197 °C to 201 °C.

**(i)** Name a suitable catalyst for this reaction.  
[1 mark]

---

**(ii)** The crude ester is purified and a pure sample of methyl benzoate is collected at 199 °C.

Outline, in general, the three main steps carried out in the purification of the crude ester to obtain a pure sample of methyl benzoate at 199 °C. [3 marks]

Step 1. \_\_\_\_\_

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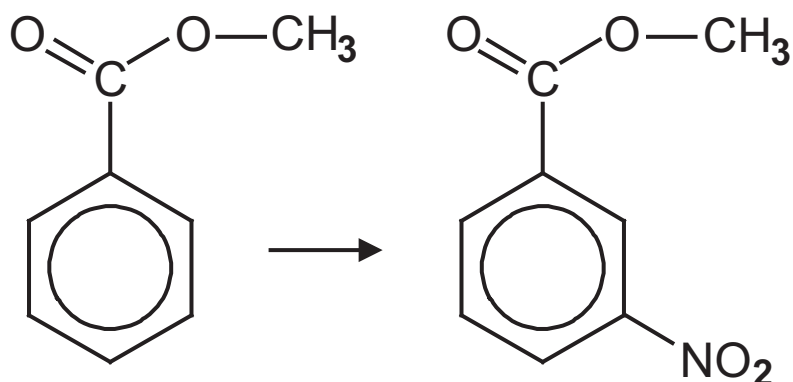
Step 2. \_\_\_\_\_

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Step 3. \_\_\_\_\_

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(c) Nitration of methyl benzoate produces methyl 3-nitrobenzoate. A nitrating mixture is used in this reaction.



(i) Name the two reagents which are mixed together to form the nitrating mixture. [2 marks]

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(ii) The nitronium ion forms in the nitrating mixture. Write an equation for the formation of the nitronium ion. [2 marks]

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**This is the end of the question paper**

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