

Section A

Answer **all** questions in this section.

- 1 Ethanol can be oxidised by acidified potassium dichromate(VI) to ethanoic acid in a two-step process.



- 0 1 . 1 In order to ensure that the oxidation to ethanoic acid is complete, the reaction is carried out under reflux.

Describe what happens when a reaction mixture is refluxed and why it is necessary, in this case, for complete oxidation to ethanoic acid.

[3 marks]

The mixture is heated to its boiling point for a prolonged time, with a vertical (water-cooled) condenser fitted on top of the flask.

Vapour that is formed escapes from the liquid mixture, is condensed (changed back into liquid) in the condenser and returns to the liquid mixture in the flask.

This is necessary because ethanal is very volatile: under reflux any ethanal and ethanol that initially evaporate are returned to the flask and can then be oxidised, so oxidation to ethanoic acid is complete.

- 0 1 . 2 Write a half-equation for the overall oxidation of ethanol into ethanoic acid.

[1 mark]



- 0 1 . 3** The boiling points of the organic compounds in a reaction mixture are shown in **Table 1**.

Table 1

Compound	ethanol	ethanal	ethanoic acid
Boiling point / °C	78	21	118

Use these data to describe how you would obtain a sample of ethanal from a mixture of these three compounds. Include in your answer a description of the apparatus you would use and how you would minimise the loss of ethanal. Your description of the apparatus can be either a description in words or a labelled sketch.

[5 marks]

Heat the mixture gently in a round-bottomed flask (warm water bath).

Fit a still head containing a thermometer.

Connect a water-cooled condenser to the still head, leading to a collecting vessel cooled in an ice bath.

Collect the sample that distils at the boiling point of ethanal, 21 °C.

The cooled collection vessel is needed to reduce evaporation of the volatile ethanal, minimising its loss.

Question 1 continues on the next page

- 0 1 . 4** Use your knowledge of structure and bonding to explain why it is possible to separate ethanal in this way.

[2 marks]

There is hydrogen bonding in ethanol and ethanoic acid but no hydrogen bonding in ethanal.

The intermolecular forces in ethanal (dipole-dipole) are weaker than hydrogen bonding, so ethanal has a much lower boiling point.

- 0 1 . 5** A student obtained a sample of a liquid using the apparatus in Question 1.3.

Describe how the student could use chemical tests to confirm that the liquid contained ethanal and did **not** contain ethanoic acid.

[5 marks]

Test for ethanal: add Tollens' reagent to a sample of the liquid (made by adding 1 drop of aqueous sodium hydroxide to aqueous silver nitrate, then enough aqueous ammonia to dissolve the precipitate formed).

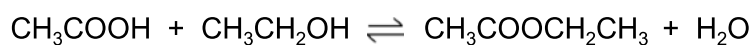
Warm the mixture in a water bath.

Result: a silver mirror forms, so ethanal (an aldehyde) is present.

Test for ethanoic acid: add sodium hydrogencarbonate (or sodium carbonate) solution to a fresh sample.

Result: no effervescence is observed (no CO_2), hence no acid is present.

- 2 Ethanol and ethanoic acid react reversibly to form ethyl ethanoate and water according to the equation:



A mixture of 8.00×10^{-2} mol of ethanoic acid and 1.20×10^{-1} mol of ethanol is allowed to reach equilibrium at 20°C .

- The equilibrium mixture is placed in a graduated flask and the volume made up to 250 cm^3 with distilled water.
- A 10.0 cm^3 sample of this equilibrium mixture is titrated with sodium hydroxide added from a burette.
- The ethanoic acid in this sample reacts with 3.20 cm^3 of $2.00 \times 10^{-1}\text{ mol dm}^{-3}$ sodium hydroxide solution.

- 0 2 . 1 Calculate the value for K_c for the reaction of ethanoic acid and ethanol at 20°C . Give your answer to the appropriate number of significant figures.

[6 marks]

$$n(\text{NaOH}) = 3.20 \times 2.00 \times 10^{-1} / 1000 = 6.40 \times 10^{-4}\text{ mol}$$

$$= n(\text{acid}) \text{ in the } 10.0\text{ cm}^3 \text{ sample}$$

$$n(\text{acid}) \text{ in } 250\text{ cm}^3 \text{ at equilibrium} = 25 \times 6.40 \times 10^{-4} = 1.60 \times 10^{-2}\text{ mol}$$

$$\text{acid reacted} = 8.00 \times 10^{-2} - 1.60 \times 10^{-2} = 6.40 \times 10^{-2}\text{ mol}$$

$$= \text{moles of ester and of water formed} = 6.40 \times 10^{-2}\text{ mol}$$

$$\text{ethanol at equilibrium} = 1.20 \times 10^{-1} - 6.40 \times 10^{-2} = 5.60 \times 10^{-2}\text{ mol}$$

$$K_c = [\text{CH}_3\text{COOCH}_2\text{CH}_3][\text{H}_2\text{O}] / [\text{CH}_3\text{COOH}][\text{CH}_3\text{CH}_2\text{OH}]$$

$$\text{volumes cancel: } K_c = (6.40 \times 10^{-2})^2 / (1.60 \times 10^{-2} \times 5.60 \times 10^{-2})$$

$$K_c = 4.5714 = 4.57 \text{ (3 s.f.)}$$

$$K_c = \underline{4.57}$$

Question 2 continues on the next page

A student obtained the titration results given in **Table 2**.

Table 2

	Rough	1	2	3
Final burette reading / cm³	4.60	8.65	12.85	16.80
Initial burette reading / cm³	0.10	4.65	8.65	12.85
Titre / cm³	<i>4.50</i>	<i>4.00</i>	<i>4.20</i>	<i>3.95</i>

0 2 . **2** Complete **Table 2**.

[1 mark]

0 2 . **3** Calculate the mean titre and justify your choice of titres.

[2 marks]

Calculation

$$\text{mean of titres 1 and 3} = (4.00 + 3.95) / 2 = 3.975 = 3.98$$

$$\text{Mean titre} = \underline{\quad 3.98 \quad} \text{cm}^3$$

Justification Titres 1 and 3 are concordant (within 0.10 cm³);

titre 2 is not concordant and the rough titre is ignored.

0 2 . **4** The pH ranges of three indicators are shown in **Table 3**.

Table 3

Indicator	pH range
Bromocresol green	3.8–5.4
Bromothymol blue	6.0–7.6
Thymol blue	8.0–9.6

Select from **Table 3** a suitable indicator for the titration of ethanoic acid with sodium hydroxide.

[1 mark]

Thymol blue

- 0 2 . 5** The uncertainty in the mean titre for this experiment is $\pm 0.15 \text{ cm}^3$.

Calculate the percentage uncertainty in this mean titre.

[1 mark]

$$\% \text{ uncertainty} = 0.15 / 3.98 \times 100 = 3.77$$

Percentage uncertainty = 3.77 %

- 0 2 . 6** Suggest how, using the same mass of ethanoic acid, the experiment could be improved to reduce the percentage uncertainty.

[2 marks]

*Use a lower concentration of NaOH (e.g. dilute the NaOH ten times),
so that a larger titre is required, which reduces the percentage
uncertainty in the titre.*

Turn over for the next question

3

A peptide is hydrolysed to form a solution containing a mixture of amino acids. This mixture is then analysed by silica gel thin-layer chromatography (TLC) using a toxic solvent. The individual amino acids are identified from their R_f values.

Part of the practical procedure is given below.

1. **Wearing plastic gloves to hold a TLC plate**, draw a pencil line 1.5 cm from the bottom of the plate.
2. Use a capillary tube to apply a very small drop of the solution of amino acids to the mid-point of the pencil line.
3. Allow the spot to dry completely.
4. In the developing tank, add the developing solvent to **a depth of not more than 1 cm**.
5. Place your TLC plate in the developing tank.
6. Allow the developing solvent to rise up the plate **to the top**.
7. Remove the plate and quickly mark the position of the solvent front with a pencil.
8. Allow the plate to dry **in a fume cupboard**.

0 3 . **1** Parts of the procedure are in bold text.

For each of these parts, consider whether it is essential and justify your answer.

[4 marks]

Wearing plastic gloves: essential, to prevent contamination from the hands onto the plate.

Solvent depth not more than 1 cm: essential, because if the solvent is too deep (above the pencil line) it will dissolve the mixture from the plate.

Solvent rising to the top: not essential, because the R_f value can be calculated if the solvent front does not reach the top of the plate.

Drying in a fume cupboard: essential, because the solvent is toxic (hazardous) and its vapour must not be breathed in.

- 0 3 . 2** Outline the steps needed to locate the positions of the amino acids on the TLC plate and to determine their R_f values.

[4 marks]

Spray the dried plate with a developing agent (e.g. ninhydrin) or view it under UV light to locate the spots; mark each spot with pencil.

Measure the distance from the initial pencil line to the centre of each spot (x).

Measure the distance from the initial pencil line to the solvent front line (y).

Calculate R_f value = x / y for each amino acid.

- 0 3 . 3** Explain why different amino acids have different R_f values.

[2 marks]

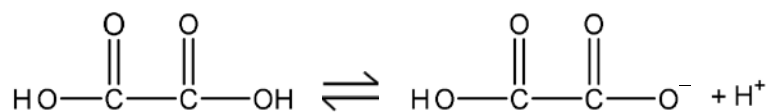
Different amino acids have different polarities (different R groups).

Therefore they have different retention on the stationary phase (silica) and different solubility in the developing solvent, so they travel different distances.

4

Ethanedioic acid is a weak acid.

Ethanedioic acid acts, initially, as a monoprotic acid.



0 4

1

Use the concept of electronegativity to justify why the acid strengths of ethanedioic acid and ethanoic acid are different.

[6 marks]

Both acids are of the form RCOOH: in ethanoic acid R = CH₃, whilst in ethanedioic acid R = COOH.

The un-ionised COOH group in ethanedioic acid contains two very electronegative oxygen atoms, so it has a negative inductive (electron-withdrawing) effect, pulling electron density away from the other COOH group.

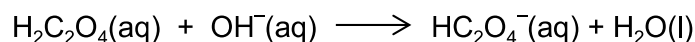
The CH₃ group in ethanoic acid has a positive inductive (electron-pushing) effect, pushing electron density towards its COOH group.

So the O-H bond in ethanedioic acid is more polarised (the H becomes more δ+) than in ethanoic acid, and the H is lost more easily.

Therefore ethanedioic acid dissociates more into H⁺ ions and is a stronger acid than ethanoic acid.

0 4 . 2

A buffer solution is made by adding 6.00×10^{-2} mol of sodium hydroxide to a solution containing 1.00×10^{-1} mol of ethanedioic acid ($\text{H}_2\text{C}_2\text{O}_4$). Assume that the sodium hydroxide reacts as shown in the following equation and that in this buffer solution, the ethanedioic acid behaves as a monoprotic acid.



The dissociation constant K_a for ethanedioic acid is $5.89 \times 10^{-2} \text{ mol dm}^{-3}$.

Calculate a value for the pH of the buffer solution.

Give your answer to the appropriate number of significant figures.

[5 marks]

$$n(\text{OH}^-) = n(\text{HOOCCOO}^-) \text{ formed} = 6.00 \times 10^{-2} \text{ mol}$$

$$n(\text{HOOCCOOH}) \text{ remaining} = 1.00 \times 10^{-1} - 6.00 \times 10^{-2} = 4.00 \times 10^{-2} \text{ mol}$$

$$K_a = [\text{H}^+][\text{A}^-] / [\text{HA}] \quad \text{so} \quad [\text{H}^+] = K_a \times [\text{HA}] / [\text{A}^-]$$

$$[\text{H}^+] = 5.89 \times 10^{-2} \times (4.00 \times 10^{-2} \text{ N}) / (6.00 \times 10^{-2} \text{ N})$$

$$[\text{H}^+] = 3.927 \times 10^{-2} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log_{10}(3.927 \times 10^{-2}) = 1.406 = 1.41$$

$$\text{pH} = \underline{\quad 1.41 \quad}$$

Question 4 continues on the next page

- 0 4 . 3** In a titration, the end point was reached when 25.0 cm^3 of an acidified solution containing ethanedioic acid reacted with 20.20 cm^3 of $2.00 \times 10^{-2} \text{ mol dm}^{-3}$ potassium manganate(VII) solution.

Deduce an equation for the reaction that occurs and use it to calculate the original concentration of the ethanedioic acid solution.

[4 marks]

Equation $5\text{H}_2\text{C}_2\text{O}_4 + 6\text{H}^+ + 2\text{MnO}_4^- \rightarrow 2\text{Mn}^{2+} + 10\text{CO}_2 + 8\text{H}_2\text{O}$

Calculation

$$n(\text{MnO}_4^-) = 20.20 \times 2.00 \times 10^{-2} / 1000 = 4.04 \times 10^{-4} \text{ mol}$$

$$n(\text{H}_2\text{C}_2\text{O}_4) = 5/2 \times 4.04 \times 10^{-4} = 1.01 \times 10^{-3} \text{ mol}$$

$$\text{concentration} = \text{moles} / \text{volume (in dm}^3\text{)}$$

$$= 1.01 \times 10^{-3} \times 1000 / 25.0 = 4.04 \times 10^{-2} \text{ mol dm}^{-3}$$

Original concentration = 4.04×10^{-2} mol dm^{-3}

- 5 A sample of ethanedioic acid was treated with an excess of an unknown alcohol in the presence of a strong acid catalyst. The products of the reaction were separated and analysed in a time of flight (TOF) mass spectrometer. Two peaks were observed at $m/z = 104$ and 118 .

0 5 . 1 Identify the species responsible for the two peaks.

[2 marks]

$m/z = 104$: $[CH_3OCOCOOH]^+$ (methyl hydrogen ethanedioate ion)

$m/z = 118$: $[CH_3OCOCOOCH_3]^+$ (dimethyl ethanedioate ion)

0 5 . 2 Outline how the TOF mass spectrometer is able to separate these two species to give two peaks.

[4 marks]

The positive ions are accelerated by an electric field to a constant

kinetic energy (all ions have the same kinetic energy, $KE = \frac{1}{2}mv^2$).

The positive ions with m/z of 104 have the same kinetic energy as those with m/z of 118 but are lighter, so they move faster.

Therefore the ions with m/z of 104 arrive at the detector first, so the two species reach the detector at different times and give two peaks.

Section B

Answer **all** questions in this section.

Only **one** answer per question is allowed.

For each answer completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



0 6

Which change requires the largest amount of energy?

[1 mark]



0 7

A sample of 2.18 g of oxygen gas has a volume of 1870 cm³ at a pressure of 101 kPa.

What is the temperature of the gas?

The gas constant is $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$.

[1 mark]

A 167 K ☐

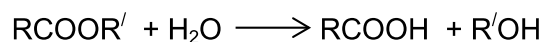
B 334 K ☒

C 668 K ☐

D 334 000 K ☐

0 8

An ester is hydrolysed as shown by the following equation.



What is the percentage yield of RCOOH when 0.50 g of RCOOH ($M_r = 100$) is obtained from 1.0 g of RCOOR' ($M_r = 150$)?

[1 mark]

- | | | |
|----------|-----|----------------------------------|
| A | 33% | ☐ |
| B | 50% | ☐ |
| C | 67% | ☐ |
| D | 75% | ☒ |

0 9

A saturated aqueous solution of magnesium hydroxide contains 1.17×10^{-3} g of $\text{Mg}(\text{OH})_2$ in 100 cm^3 of solution. In this solution, the magnesium hydroxide is fully dissociated into ions.

What is the concentration of $\text{Mg}^{2+}(\text{aq})$ ions in this solution?

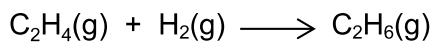
[1 mark]

- | | | |
|----------|---|----------------------------------|
| A | $2.82 \times 10^{-2} \text{ mol dm}^{-3}$ | ☐ |
| B | $2.01 \times 10^{-3} \text{ mol dm}^{-3}$ | ☐ |
| C | $2.82 \times 10^{-3} \text{ mol dm}^{-3}$ | ☐ |
| D | $2.01 \times 10^{-4} \text{ mol dm}^{-3}$ | ☒ |

Turn over for the next question

1 0

The rate equation for the hydrogenation of ethene



is $\text{Rate} = k[\text{C}_2\text{H}_4][\text{H}_2]$

At a fixed temperature, the reaction mixture is compressed to triple the original pressure.

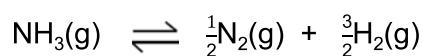
What is the factor by which the rate of reaction changes?

[1 mark]

- A** 6 ☐
- B** 9 ☒
- C** 12 ☐
- D** 27 ☐

1 1

When one mole of ammonia is heated to a given temperature, 50% of the compound dissociates and the following equilibrium is established.



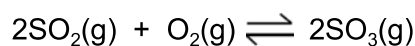
What is the total number of moles of gas present in this equilibrium mixture?

[1 mark]

- A** 1.5 ☒
- B** 2.0 ☐
- C** 2.5 ☐
- D** 3.0 ☐

1 2

Which change would alter the value of the equilibrium constant (K_p) for this reaction?



[1 mark]

- A** Increasing the total pressure of the system. ☐
- B** Increasing the concentration of sulfur trioxide. ☐
- C** Increasing the concentration of sulfur dioxide. ☐
- D** Increasing the temperature. ☒

1 3

What is the pH of a $0.020 \text{ mol dm}^{-3}$ solution of a diprotic acid which is completely dissociated?

[1 mark]

A 1.00 ☐

B 1.40 ☒

C 1.70 ☐

D 4.00 ☐

1 4

The acid dissociation constant, K_a , of a weak acid HA has the value $2.56 \times 10^{-4} \text{ mol dm}^{-3}$

What is the pH of a $4.25 \times 10^{-3} \text{ mol dm}^{-3}$ solution of HA?

[1 mark]

A 5.96 ☐

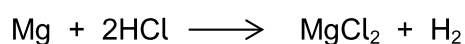
B 3.59 ☐

C 2.98 ☒

D 2.37 ☐

1 5

Magnesium reacts with hydrochloric acid according to the following equation.



A student calculated the minimum volume of 2.56 mol dm^{-3} hydrochloric acid required to react with an excess of magnesium to form 5.46 g of magnesium chloride ($M_r = 95.3$).

Which of the following uses the correct standard form and the appropriate number of significant figures to give the correct result of the calculation?

[1 mark]

A $4.476 \times 10^{-2} \text{ dm}^3$ ☐

B $4.48 \times 10^{-2} \text{ dm}^3$ ☒

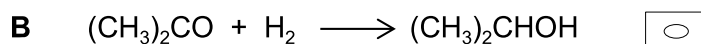
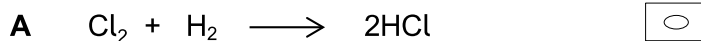
C $4.50 \times 10^{-2} \text{ dm}^3$ ☐

D $44.8 \times 10^{-3} \text{ dm}^3$ ☐

1 6

In which reaction is hydrogen acting as an oxidising agent?

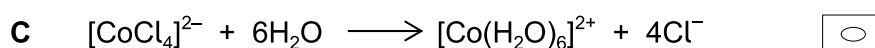
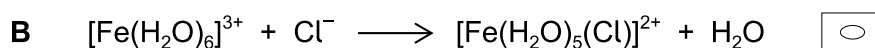
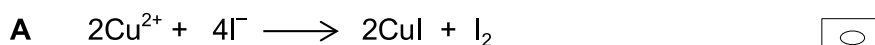
[1 mark]



1 7

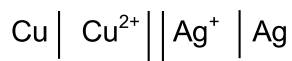
In which reaction is the metal oxidised?

[1 mark]



1 8

The following cell has an EMF of +0.46 V.



Which statement is correct about the operation of the cell?

[1 mark]

A Metallic copper is oxidised by Ag^+ ions. ☒

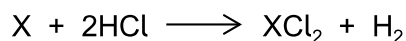
B The silver electrode has a negative polarity. ☐

C The silver electrode gradually dissolves to form Ag^+ ions. ☐

D Electrons flow from the silver electrode to the copper electrode via an external circuit. ☐

1 9

In an experiment to identify a Group 2 metal (X), 0.102 g of X reacts with an excess of aqueous hydrochloric acid according to the following equation.



The volume of hydrogen gas given off is 65 cm³ at 99 kPa pressure and 303 K. The gas constant is $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$.

Which is X?

[1 mark]

- A** Barium ☐
- B** Calcium ☒
- C** Magnesium ☐
- D** Strontium ☐

2 0

What forms when a solution of sodium carbonate is added to a solution of gallium(III) nitrate?

[1 mark]

- A** A white precipitate of gallium(III) carbonate. ☐
- B** A white precipitate of gallium(III) hydroxide. ☐
- C** A white precipitate of gallium(III) carbonate and bubbles of carbon dioxide. ☐
- D** A white precipitate of gallium(III) hydroxide and bubbles of carbon dioxide. ☒

2 1

Which compound gives a colourless solution when an excess of dilute aqueous ammonia is added?

[1 mark]

- A** MgCl_2 ☐
- B** AgCl ☒
- C** CuCl_2 ☐
- D** AlCl_3 ☐

2 2

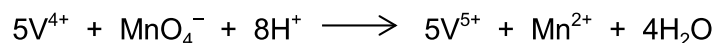
What is the final species produced when an excess of aqueous ammonia is added to aqueous aluminium chloride?

[1 mark]

- A $[\text{Al}(\text{NH}_3)_6]^{3+}$ ☐
- B $[\text{Al}(\text{OH})_3(\text{H}_2\text{O})_3]$ ☒
- C $[\text{Al}(\text{OH})_4(\text{H}_2\text{O})_2]^-$ ☐
- D $[\text{Al}(\text{OH})(\text{H}_2\text{O})_5]^{2+}$ ☐

2 3

The following equation represents the oxidation of vanadium(IV) ions by manganate(VII) ions in acid solution.



What volume of $0.020 \text{ mol dm}^{-3}$ KMnO_4 solution is required to oxidise completely a solution containing 0.010 mol of vanadium(IV) ions?

[1 mark]

- A 10 cm^3 ☐
- B 25 cm^3 ☐
- C 50 cm^3 ☐
- D 100 cm^3 ☒

2 4

How many isomers have the molecular formula C_5H_{12} ?

[1 mark]

- A 2 ☐
- B 3 ☒
- C 4 ☐
- D 5 ☐

2 5

Which molecule is **not** produced when ethane reacts with bromine in the presence of ultraviolet light?

[1 mark]

A $\text{C}_2\text{H}_4\text{Br}_2$ ☐

B HBr ☐

C H_2 ☒

D C_4H_{10} ☐

2 6

How many structural isomers have the molecular formula $\text{C}_4\text{H}_9\text{Br}$?

[1 mark]

A 2 ☐

B 3 ☐

C 4 ☒

D 5 ☐

2 7

What is the major product of the reaction between but-1-ene and DBr ? (D is deuterium and represents ^2H)

[1 mark]

A $\text{CH}_2\text{DCH}_2\text{CH}_2\text{CH}_2\text{Br}$ ☐

B $\text{CH}_2\text{DCH}_2\text{CHBrCH}_3$ ☐

C $\text{CH}_3\text{CH}_2\text{CHBrCH}_2\text{D}$ ☒

D $\text{CH}_3\text{CH}_2\text{CHDCH}_2\text{Br}$ ☐

2 8

Why are fluoroalkanes unreactive?

[1 mark]

A Fluorine is highly electronegative. ☐

B The F^- ion is very stable. ☐

C They are polar molecules. ☐

D The C-F bond is very strong. ☒

2 9

Which alcohol could **not** be produced by the reduction of an aldehyde or a ketone? [1 mark]

- A 2-methylbutan-1-ol ☐
- B 2-methylbutan-2-ol ☒
- C 3-methylbutan-1-ol ☐
- D 3-methylbutan-2-ol ☐

3 0

Which compound forms optically active compounds on reduction? [1 mark]

- A $\text{CH}_3\text{CH}_2\text{C}(\text{CH}_3)=\text{CHCH}_3$ ☐
- B $\text{CH}_3\text{CH}_2\text{C}(\text{CH}_3)=\text{CH}_2$ ☐
- C CH_3COCH_3 ☐
- D $\text{CH}_3\text{CH}_2\text{COCH}_3$ ☒

3 1

How many secondary amines have the molecular formula $\text{C}_4\text{H}_{11}\text{N}$? [1 mark]

- A 2 ☐
- B 3 ☒
- C 4 ☐
- D 5 ☐

3 2

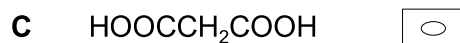
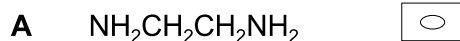
Which compound has the highest boiling point? [1 mark]

- A C_2H_4 ☐
- B C_2H_6 ☐
- C CH_3NH_2 ☒
- D CH_3F ☐

3 3

Which compound can polymerise by reaction with itself?

[1 mark]

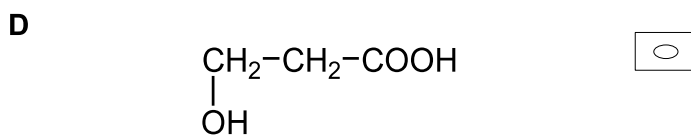
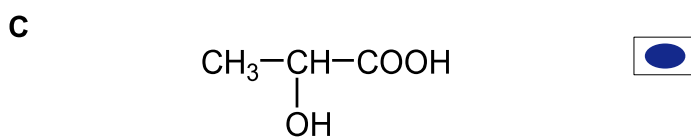
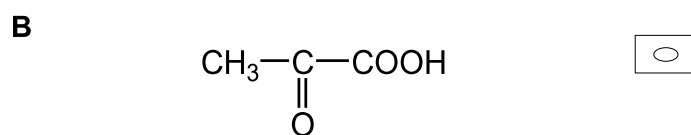
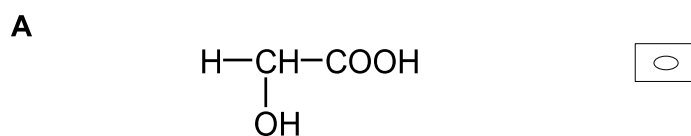


3 4

A drug is designed to simulate one of the following molecules that adsorbs onto the active site of an enzyme.

Which molecule requires the design of an optically active drug?

[1 mark]



Turn over for the next question

3	5
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Which amine has only **three** peaks in its proton NMR spectrum?

[1 mark]

- A** Methylamine ☐
- B** Trimethylamine ☐
- C** Diethylamine ☒
- D** Propylamine ☐

END OF QUESTIONS