1. A solution of propanoic acid, CH_3CH_2COOH, has a pH of 2.89 at 25 °C.

What is $[H^+]$ in this solution?

A. 1.7×10^{-6} mol dm^{-3}
B. 4.6×10^{-4} mol dm^{-3}
C. 1.3×10^{-3} mol dm^{-3}
D. 0.46 mol dm^{-3}

Your answer ☐

[1]

2. A buffer solution is based on methanoic acid, HCOOH ($K_a = 1.70 \times 10^{-4}$ mol dm^{-3}) and methanoate ions, $HCOO^-$.

In the buffer solution, the HCOOH concentration is half the $HCOO^-$ concentration.

What is the pH of the buffer solution?

A. 2.47
B. 3.07
C. 3.47
D. 4.07

Your answer ☐

[1]

3. Which statement is correct for a neutral solution at any temperature?

A. $K_w = 1.00 \times 10^{-14}$ mol^2 dm^{-6}
B. The solution contains only H_2O
C. $[H^+] = [OH^-]$
D. pH = 7

Your answer ☐

[1]

4. Two elements, **A** and **B**, react to form an ionic compound with the formula $\mathbf{A_2B_3}$. In this compound, **A** and **B** both have the electron configuration $1s^22s^22p^63s^23p^6$.

Deduce possible identities of the ions in $\mathbf{A_2B_3}$.

A:

B:

---

[2]

5(a). This question is about acids and bases.

Nitric acid, HNO_3, and nitrous acid, HNO_2, are two Brønsted–Lowry acids containing nitrogen.

A student measures the pH of 0.0450 mol dm^{-3} solutions of HNO_3 and HNO_2 (pK_a = 3.35) and found that the acids had different pH values.

i. Explain why the pH values are different.

[1]

ii. Calculate the pH value of 0.0450 mol dm^{-3} HNO_3 to **two** decimal places.

Show your working.

pH = ... **[1]**

iii. Calculate the pH value of 0.0450 mol dm^{-3} HNO_2 to **two** decimal places.

Show your working.

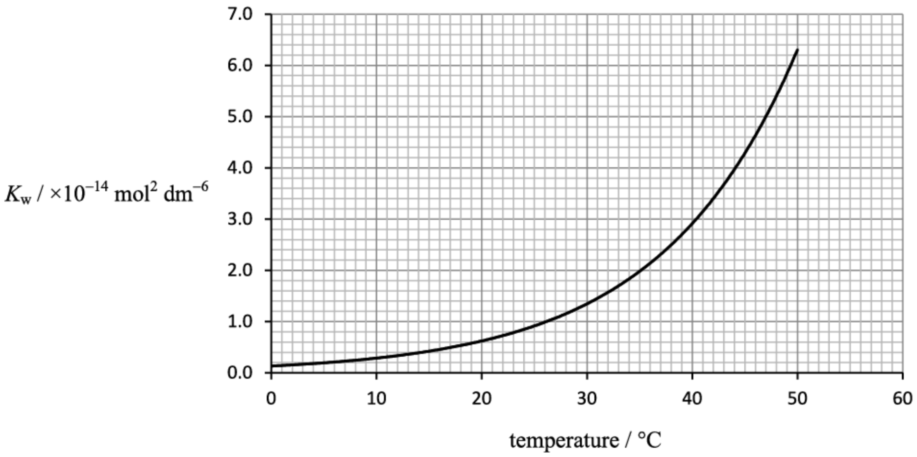
pH = ... **[3]**

(b). Rubidium hydroxide, RbOH, is a strong alkali. A technician is asked to prepare a 250.0 cm^3 solution of RbOH with a pH of 12.500.

Calculate the mass of RbOH that the technician needs to use.

mass = ...g **[4]**

6. The dissociation of water is measured by the ionic product of water, K_w. The value of K_w varies with temperature as shown in the graph below.



Calculate the pH of water at body temperature, 37 °C.

pH = ... **[3]**

7. The complex ion, $[Fe(H_2O)_6]^{3+}$, behaves as a weak Brønsted−Lowry acid in aqueous solution. The equation below represents the dissociation of aqueous $[Fe(H_2O)_6]^{3+}$ ions, together with the K_a value.

$$[Fe(H_2O)_6]^{3+}(aq) \rightleftharpoons [Fe(H_2O)_5OH]^{2+}(aq) + H^+(aq) \qquad K_a = 6.00 \times 10^{-3} \text{ mol dm}^{-3}$$

i. Write the expression for the acid dissociation constant, K_a, for $[Fe(H_2O)_6]^{3+}$.

[1]

ii. Calculate the pH of a 0.100 mol dm^{-3} solution of $[Fe(H_2O)_6]^{3+}$ to **two** decimal places.

pH = ... **[2]**

8. Methanoic acid is added to water. An acid−base equilibrium is set up containing two acid−base pairs.

Suggest a mechanism for the forward reaction in this equilibrium.

Your mechanism should use displayed formulae and curly arrows, and show all species present at equilibrium.

[2]

9(a). Ethers are a homologous series of organic compounds containing the R−O−R functional group.

The structures and names of two ethers are shown in **Fig. 4.1.**

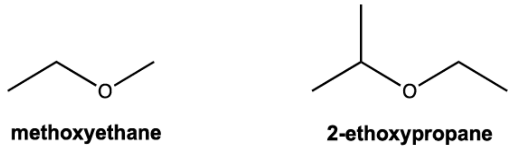


Fig. 4.1

Draw the **skeletal** formula of the ether, 2-ethoxy-3-methylbutane.

[1]

(b). Ethers can be prepared by nucleophilic substitution of haloalkanes with alkoxide ions, RO^-.

i. Alkoxide ions can be prepared by reacting sodium with an alcohol. A gas is also formed.

Write an equation for the formation of methoxide ions from sodium and an alcohol.

[1]

ii. Methoxyethane, shown in **Fig. 4.1**, can be prepared by reacting bromoethane, CH_3CH_2Br, with methoxide ions, CH_3O^-.

Suggest the mechanism for the nucleophilic substitution of CH_3CH_2Br with CH_3O^-.

Show curly arrows, charges, relevant dipoles, and products.

[3]

iii. In this mechanism, explain how CH_3O^- ions have acted as a nucleophile.

State the type of bond fission that takes place.

[1]

(c). 2-Ethoxypropane, shown in **Fig. 4.1**, is analysed by ^1H NMR spectroscopy.

Complete the table to predict the ^1H NMR spectrum of 2-ethoxypropane.

You may **not** need to use all the rows.

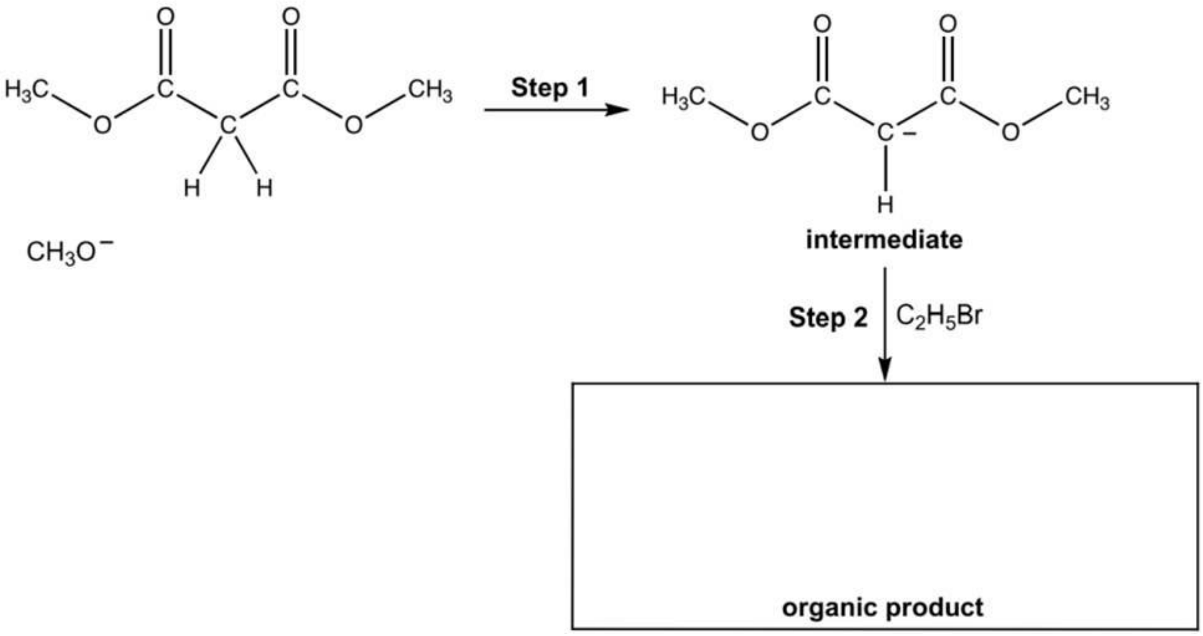
Chemical shift, δ/ppm	Relative peak area	Splitting pattern

[4]

(d). In organic reactions, alkoxide ions can also act as a base.

The diagram below shows an incomplete mechanism for the reaction of a diester with methoxide ions, CH_3O^- (**Step 1**), followed by reaction of the intermediate with bromoethane (**Step 2**).

i. For **Step 1**, add curly arrows to show how CH_3O^- reacts with the diester to form the intermediate. In the box, draw the structure of the organic product formed in **Step 2**.



[3]

ii. Explain how CH_3O^- ions have acted as a base in this mechanism.

---

[1]

10(a). A student investigates the reactions of two weak monobasic acids: 2-hydroxypropanoic acid, $CH_3CH(OH)COOH$, and butanoic acid, $CH_3CH_2CH_2COOH$.

The student wants to prepare a standard solution of 2-hydroxypropanoic acid that has a pH of 2.19.

Plan how the student could prepare 250 cm^3 of this standard solution from solid 2-hydroxypropanoic acid.

In your answer you should provide detail of the practical procedure that would be carried out, including appropriate quantities and necessary calculations.

K_a for 2-hydroxypropanoic acid is 1.38×10^{-4} mol dm^{-3} at 25 °C.

[8]

(b). 2-Hydroxypropanoic acid is a slightly stronger acid than butanoic acid. The two acids are mixed together and an acid–base equilibrium is set up.

Suggest the equilibrium equation and identify the conjugate acid–base pairs.

$CH_3CH(OH)COOH + CH_3CH_2CH_2COOH \rightleftharpoons$ ....

[2]

(c). To prepare a buffer solution, 75.0 cm^3 of 0.220 mol dm^{-3} butanoic acid is reacted with 50.0 cm^3 of 0.185 mol dm^{-3} sodium hydroxide.

K_a for butanoic acid is 1.5×10^{-5} mol dm^{-3} at 25 °C.

i. Calculate the pH of 0.185 mol dm^{-3} sodium hydroxide at 25 °C.

Give your answer to **two** decimal places.

pH = ... **[2]**

ii. Calculate the pH of the buffer solution at 25 °C.

Give your answer to **two** decimal places.

Show **all** your working.

pH = ... **[4]**

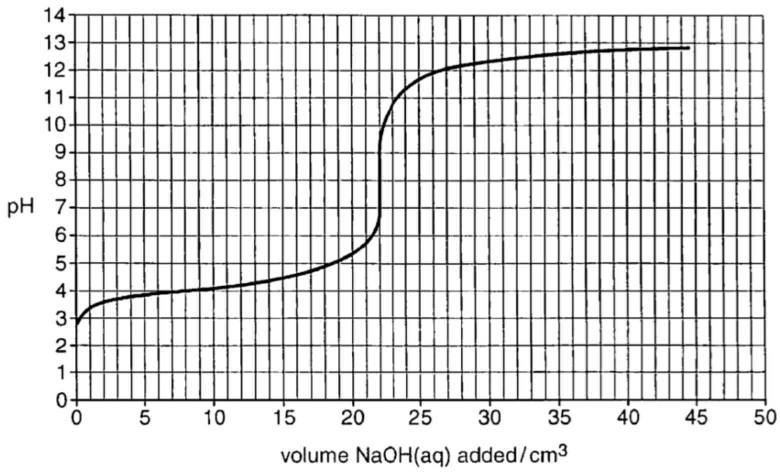
11(a). This question is about different weak acids.

A student carries out a titration to determine the concentration of a solution of ethanoic acid.

The method is outlined below.

- A 25.0 cm^3 sample of $CH_3COOH(aq)$ is pipetted into a conical flask.
- The $CH_3COOH(aq)$ is titrated by adding 0.125 mol dm^{-3} NaOH from a burette.
- The pH of the solution is measured continuously, with stirring, as the NaOH(aq) is added.

The pH titration curve is shown below.



i. How could the student measure the pH continuously as the NaOH(aq) is added?

[1]

ii. Determine the unknown concentration, in mol dm^{-3}, of the $CH_3COOH(aq)$.
Show your working.

concentration of $CH_3COOH(aq)$ = ...mol dm^{-3} **[2]**

(b). The table shows the pH ranges of four indicators.

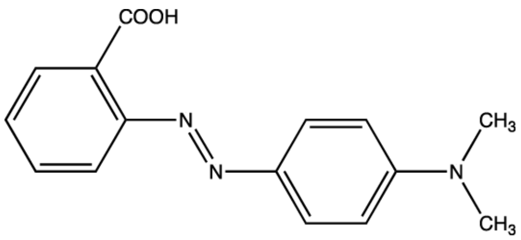
Indicator	congo red	methyl red	brilliant yellow	alizarin yellow R
pH range	3.0−5.0	4.4−6.2	6.6−7.8	10.1−12.0

i. Choose, with a reason, the indicator from the table that is most suitable for the student's titration in **(a)**.

[1]

ii. An indicator is a weak acid, HA, which has a different colour from its conjugate base, A^-.

For methyl red, the HA form is red and the A^- form is yellow.
The structure of methyl red is shown below.



methyl red

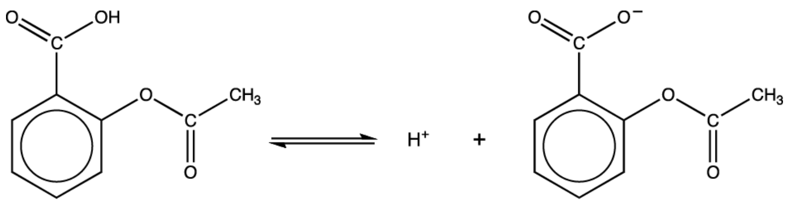
Draw the structure of the conjugate base of methyl red and explain, in terms of equilibrium, the colours of methyl red at low pH, at high pH, and at the end point of a titration. You can use HA and A^- in your explanation.

explanation:

[4]

(c). Aspirin is a weak acid with a pK_a value of 3.40 and a solubility in water of 1.00×10^{-2} g cm^{-3} at body temperature (37 °C).

The equation for the dissociation of aspirin in aqueous solution is shown below.



aspirin

i. Calculate the pH of a saturated solution of aspirin in water at body temperature.

pH = ... **[4]**

ii. 'Soluble aspirin' is usually sold as the sodium or calcium salt of aspirin.

Suggest why salts of aspirin are more soluble than aspirin in water.

[1]

iii. The stomach contains hydrochloric acid at a pH of about 1–3.

Explain why swallowing soluble aspirin may lead to irritation of the stomach lining.

[2]

12. A student carries out an initial rates investigation on the reaction below.

$$5I^-(aq) + IO_3^-(aq) + 6H^+(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$$

From the results, the student determines the rate equation for this reaction:

$$rate = k\,[I^-(aq)]^2\,[IO_3^-(aq)]\,[H^+(aq)]^2$$

The table below shows some of the student's results.

i. Complete the table by adding the missing initial rates in the boxes.

	$[I^-(aq)]$ / mol dm^{-3}	**$[IO_3^-(aq)]$ / mol dm^{-3}**	**$[H^+(aq)]$ / mol dm^{-3}**	**Initial rate / mol dm^{-3} s^{-1}**
Experiment 1	0.015	0.010	0.020	0.60
Experiment 2	0.045	0.010	0.020	
Experiment 3	0.060	0.040	0.080	

[2]

ii. Calculate the rate constant, *k*, for this reaction. Include units.

Give your answer to **two** significant figures.

k = ... units ....**[3]**

iii. The student repeats Experiment 1 using 0.020 mol dm^{-3} methanoic acid, HCOOH(aq) (pK_a = 3.75), instead of 0.020 mol dm^{-3} HC*l*(aq) as a source of H^+(aq).

Determine the initial rate in this experiment. Show your working.

initial rate = ... mol dm^{-3} s^{-1} **[3]**

13(a). Ethanoic acid, CH_3COOH, is a weak Brønsted—Lowry acid.

An acid—base equilibrium is set up when ethanoic acid is added to water.

Write the equation for the equilibrium that would be set up and label the two conjugate acid—base pairs.

.... + ... $\rightleftharpoons$ .... + ...

....

[2]

(b). An aqueous solution of CH_3COOH has a pH of 3.060.
This solution contains both hydrogen ions and hydroxide ions.

i. How can an aqueous solution of an acid contain hydroxide ions?

[1]

ii. Calculate the concentration of hydroxide ions in this solution of ethanoic acid.

concentration of hydroxide ions = ... mol dm^{-3} **[2]**

(c). A student adds an excess of aqueous ethanoic acid to solid calcium carbonate.
The resulting solution is able to act as a buffer solution.

i. Write a full equation for the reaction between ethanoic acid and solid calcium carbonate.

[1]

ii. Explain why this buffer solution has formed.

[1]

iii. Explain how this buffer solution controls pH when either an acid or an alkali is added.

In your answer you should explain how the equilibrium system allows the buffer solution to control the pH.

[5]

(d). A biochemist plans to make up a buffer solution with a pH of 5.000.

The biochemist adds solid sodium ethanoate, CH_3COONa, to 400 cm^3 of 0.200 mol dm^{-3} ethanoic acid.

K_a for ethanoic acid = 1.75×10^{-5} mol dm^{-3}

Calculate the mass of sodium ethanoate that the biochemist needs to dissolve in the ethanoic acid to prepare this buffer solution.

Assume that the volume of the solution remains constant at 400 cm^3 on dissolving the sodium ethanoate.

[5]

14(a). A student is supplied with 0.500 mol dm^{-3} potassium hydroxide, KOH, and 0.480 mol dm^{-3} propanoic acid, C_2H_5COOH.

The acid dissociation constant, K_a, for C_2H_5COOH is 1.35×10^{-5} mol dm^{-3}.

C_2H_5COOH is a weak Brønsted–Lowry acid.

What is meant by a *weak acid* and *Brønsted–Lowry acid*?

[1]

(b). Calculate the pH of 0.500 mol dm^{-3} potassium hydroxide.

pH = ... **[2]**

(c). The student dilutes 25.0 cm^3 0.480 mol dm^{-3} C_2H_5COOH by adding water until the total volume is 100.0 cm^3.

i. Write the expression for K_a for C_2H_5COOH.

[1]

ii. Calculate the pH of the diluted solution.

pH = ... **[3]**

(d). A student prepares a buffer solution containing propanoic acid C_2H_5COOH and propanoate ions, $C_2H_5COO^-$. The concentrations of C_2H_5COOH and $C_2H_5COO^-$ are both 1.00 mol dm^{-3}.

The following equilibrium is set up.

$$C_2H_5COOH(aq) \rightleftharpoons C_2H_5COO^-(aq) + H^+(aq)$$

The acid dissociation constant, K_a, for C_2H_5COOH is 1.35×10^{-5} mol dm^{-3}.

i. Calculate the pH of this buffer solution.

Give your answer to **two** decimal places.

pH = ... **[1]**

ii. A small amount of aqueous ammonia, NH_3(aq), is added to the buffer solution.

Explain, in terms of equilibrium, how the buffer solution would respond to the added NH_3(aq).

[2]

iii. The student adds 6.075 g Mg to 1.00 dm^3 of this buffer solution.

Calculate the pH of the new buffer solution.

Give your answer to **two** decimal places

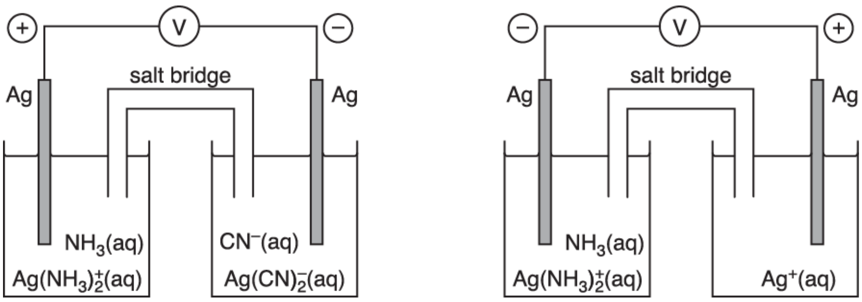
pH = ... **[4]**

15. Three redox systems, **C**, **D** and **E** are shown in Table 6.1.

C	$Ag(NH_3)_2{}^+(aq) + e^- \rightleftharpoons Ag(s) + 2NH_3(aq)$
D	$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$
E	$Ag(CN)_2{}^-(aq) + e^- \rightleftharpoons Ag(s) + 2CN^-(aq)$

Table 6.1

The two cells below were set up in an experiment to compare the standard electrode potentials of redox systems **C**, **D** and **E**. The signs on each electrode are shown.



The CN^- ion is the conjugate base of a very toxic weak acid.

In aqueous solutions of CN^- ions, an acid−base equilibrium is set up.

i. Complete the equation for this equilibrium and label the conjugate acid−base pairs.

CN^- + H_2O ⇌ .... + ...

....

[1]

ii. Explain, in terms of equilibrium, why acidic conditions should **not** be used with cells containing $CN^-(aq)$ ions.

[1]

16(a). A chemist carries out some experiments using nitrous acid, HNO_2(aq).

HNO_2 is a weak acid with a K_a value of 4.69×10^{-4} mol dm^{-3} at the temperature of the chemist's experiments.

Write the expression for K_a for HNO_2(aq).

[1]

(b). Calculate the pH of 0.120 mol dm^{-3} HNO_2(aq).

Give your answer to **two** decimal places.

pH = ... **[2]**

(c). The chemist prepares 1dm^3 of a buffer solution by mixing 200 cm^3 of 0.200 mol dm^{-3} HNO_2 with 800 cm^3 of 0.0625 mol dm^{-3} sodium nitrite, $NaNO_2$.

i. Calculate the pH of the buffer solution.

Give your answer to **two** decimal places.

pH = ... **[4]**

ii. Explain how this buffer solution controls pH when:
- a small amount of HC*l*(aq) is added
- a small amount of NaOH(aq) is added.

In your answer, include the equation for the equilibrium in the buffer solution and explain how ***this*** *equilibrium system controls the pH.*

[4]

(d). The dissociation of water is shown below.

$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$

At 60 °C, the ionic product of water, K_w, is 9.311×10^{-14} mol^2 dm^{-6}.

At 25 °C, the ionic product of water, K_w, is 1.000×10^{-14} mol^2 dm^{-6}.

i. Explain whether the dissociation of water is an exothermic or endothermic process.

[1]

ii. Predict, using a calculation, whether a pH of 7 at 60 °C is neutral, acidic or alkaline.

[2]

iii. pK_w, pKa and pH are logarithmic scales.

Calculate pK_w at 60 °C.

Give your answer to **two** decimal places.

pK_w = ...**[1]**

iv. 20.0 cm^3 of 0.0270 mol dm^{-3} NaOH is diluted with water and the solution made up to 100 cm^3 at 60 °C.

Calculate the pH of the diluted solution of NaOH at 60 °C.

Give your answer to **two** decimal places.

pH = ... **[3]**

17. A 0.040 mol dm^{-3} solution of a weak monobasic acid is 1.0% dissociated.

What is the value of K_a for the acid?

A 2.0×10^{-7} mol dm^{-3}

B 4.0×10^{-6} mol dm^{-3}

C 4.0×10^{-4} mol dm^{-3}

D 4.0×10^{-2} mol dm^{-3}

Your answer ☐

[1]

18(a). This question is about vitamin C, $C_6H_8O_6$.

Vitamin C is a weak monobasic acid with a K_a value of 6.76×10^{-5} mol dm^{-3}.

i. Write the expression for K_a for vitamin C.

[1]

ii. Calculate pK_a for vitamin C, to **two** decimal places.

[1]

iii. A bottle of vitamin C supplements contains tablets, each containing 500 mg of vitamin C.

A student dissolves three vitamin C tablets in water and makes up the solution to a volume of 250.0 cm^3.

Calculate the pH of the solution.

Give your answer to **two** decimal places.

pH = ... **[4]**

(b). Low acidity vitamin C tablets are less acidic than tablets containing just vitamin C.

A student dissolves a low acidity vitamin C tablet in water.

- The tablet contains a mixture of 300 mg of vitamin C, $C_6H_8O_6$, and the sodium salt of vitamin C, $C_6H_7O_6Na$.
- The pH of the solution is 4.02.

i. Calculate the ratio $C_6H_7O_6^-$: $C_6H_8O_6$ in the solution.

Show your working.

$$\frac{[C_6H_7O_6^-]}{[C_6H_8O_6]} = \frac{\dots\dots\dots\dots}{1}$$ **[3]**

ii. Calculate the mass of $C_6H_7O_6Na$, in mg, in the low acidity vitamin C tablet.

mass = ... mg **[1]**

(c). The sodium salt of vitamin C can be made by reacting vitamin C with aqueous sodium hydroxide.

An aqueous solution of sodium hydroxide had a pH of 12.72 at 298 K.

Calculate the concentration, in mol dm^{-3}, of the NaOH solution.

concentration = ... mol dm^{-3} **[2]**

19. When concentrated sulfuric acid is added to water, dissociation takes place in two stages.

Stage 1: $H_2SO_4 \rightarrow H^+ + HSO_4^-$

Stage 2: $HSO_4^- \rightleftharpoons H^+ + SO_4^{2-}$

i. 0.100 mol dm^{-3} sulfuric acid has a pH of 0.96.

Explain this observation. Your answer should include a calculation.

[3]

ii. A student adds an excess of aqueous sodium carbonate to dilute sulfuric acid.

- Predict what the student would observe.
- Explain what happens to the equilibrium in **Stage 2** as the aqueous sodium carbonate is added.

Observation ....

Explanation ....

[2]

20. HA and **HB** are two strong monobasic acids.

25.0 cm^3 of 6.0 mol dm^{-3} **HA** is mixed with 45.0 cm^3 of 3.0 mol dm^{-3} **HB**.

What is the $H^+(aq)$ concentration, in mol dm^{-3}, in the resulting solution?

A 1.9

B 2.1

C 4.1

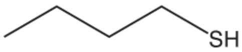
D 4.5

Your answer [ ] **[1]**

21. This question is about organic molecules that have a strong smell.

Thiols are foul-smelling, organic sulfur compounds with the functional group –SH.

Butane-1-thiol, shown below, contributes to the strong smell of skunks.



butane-1-thiol

i. Thiols are weak acids.

Write the expression for the acid dissociation constant, K_a, for butane-1- thiol.

[1]

ii. Thiols react with carboxylic acids to form thioesters.

Write an equation for the reaction of butane-1-thiol with ethanoic acid.

Use structures for all organic compounds with the functional groups clearly displayed.

[2]

iii. When beer is exposed to light, 3-methylbut-2-ene-1-thiol is formed, which gives an unpleasant smell and flavour to the beer.

Draw the **skeletal** formula for 3-methylbut-2-ene-1-thiol.

[1]

iv. Propane-1,3- dithiol reacts with carbonyl compounds in a condensation reaction to form a cyclic organic sulfur product.

Write an equation for the reaction of propane-1,3-dithiol with propanone.

Use structures for organic compounds.

[2]

22(a). This question is about the properties and reactions of ethanoic acid, CH_3COOH.
Ethanoic acid is a weak acid with an acid dissociation constant, K_a, of 1.75×10^{-5} mol dm^{-3} at 25 °C.

A student uses a pH meter to measure the pH of a solution of CH_3COOH at 25 °C.
The measured pH is 2.440.

Calculate the concentration of ethanoic acid in the solution.

Give your answer to **three** significant figures.

concentration = ______________________ mol dm^{-3} **[3]**

(b). Ethanoic acid is a weak acid with an acid dissociation constant, K_a, of 1.75×10^{-5} mol dm^{-3} at 25 °C.

Ethanoic acid is added to another weak acid, fluoroethanoic acid, FCH_2COOH ($K_a = 2.19 \times 10^{-3}$ mol dm^{-3}).
An equilibrium is set up containing two acid-base pairs.

Complete the equilibrium and label the conjugate acid-base pairs as **A1**, **B1** and **A2**, **B2**.

$CH_3COOH + FCH_2COOH \rightleftharpoons$ ______________ + ______________

[2]

(c). The student plans to prepare a buffer solution that has a pH of 4.50. The buffer solution will contain ethanoic acid, CH_3COOH, and sodium ethanoate, CH_3COONa.

The student plans to add 9.08 g CH_3COONa to 250 cm^3 of 0.800 mol dm^{-3} CH_3COOH. The student assumes that the volume of the solution does not change.

i. Show by calculation whether, or not, the student's experimental method would produce the required pH.

Show **all** your working.

[5]

ii. When the student prepares the buffer solution, the volume of solution increases slightly.

Suggest whether the pH of the buffer solution would be the same, greater than, or less than your calculated value in **(c)(i)**.

Explain your reasoning.

[2]

23. A buffer solution is prepared by mixing 200 cm^3 of 2.00 mol dm^{-3} propanoic acid, CH_3CH_2COOH, with 600 cm^3 of 1.00 mol dm^{-3} sodium propanoate, CH_3CH_2COONa.

K_a for $CH_3CH_2COOH = 1.32 \times 10^{-5}$ mol dm^{-3}

What is the pH of the buffer solution?

A 4.58

B 4.70

C 5.06

D 5.18

Your answer ☐ **[1]**

24(a). This question is about acids and bases found in the home.

Ethanoic acid, CH_3COOH, is the acid present in vinegar.

A student carries out an experiment to determine the pK_a value of CH_3COOH.

- The concentration of CH_3COOH in the vinegar is 0.870 mol dm^{-3}.
- The pH of the vinegar is 2.41.

i. Write the expression for the acid dissociation constant, K_a, of CH_3COOH.

[1]

ii. Calculate the pK_a value of CH_3COOH.

Give your answer to **two** decimal places.

pK_a = ... **[3]**

iii. Determine the percentage dissociation of ethanoic acid in the vinegar.

Give your answer to **three** significant figures.

percentage dissociation = ... % **[1]**

(b). Many solid drain cleaners are based on sodium hydroxide, NaOH.

- A student dissolves 1.26 g of a drain cleaner in water and makes up the solution to 100.0 cm^3.
- The student measures the pH of this solution as 13.48.

Determine the percentage, by mass, of NaOH in the drain cleaner.

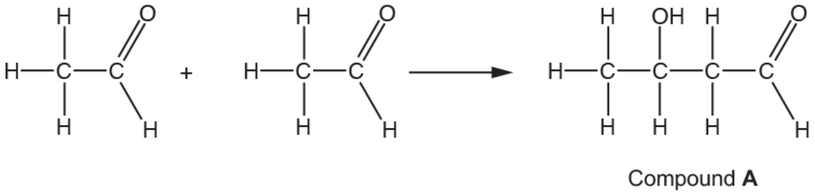
Give your answer to **three** significant figures.

percentage = ... % **[4]**

25. This question is about organic reactions.

Compound **A** is formed when ethanal is mixed with OH^-(aq) ions, which act as a catalyst.

The balanced equation is shown in **reaction 6.1** below.



Reaction 6.1

i. Give the systematic name for compound **A**.

[1]

ii. What type of reaction has taken place?

[1]

iii. **Reaction 6.1** takes place in two steps. OH^- ions act as a catalyst.

In **step 1**, ethanal reacts with OH^- ions to set up an acid–base equilibrium.

In **step 2**, compound **A** is formed.

- Complete the equilibrium for **step 1** and label the conjugate acid–base pairs as: **A1**, **B1** and **A2**, **B2**.

CH^3CHO + OH^- ⇌ +

- Suggest the equation for **step 2**.

[3]

iv. A similar reaction takes place when propanone, $(CH_3)_2CO$, is mixed with $OH^-(aq)$ ions.

Draw the structure of the organic product of this reaction.

[1]

26. A reaction is first order with respect to H^+. At a pH of 1, the initial rate is 2.4×10^{-3} mol dm^{-3} s^{-1}.

What is the initial rate at a pH of 3?

initial rate =.. mol dm^{-3} s^{-1} **[1]**

27(a). Benzoic acid, C_6H_5COOH, is added to some foods as a preservative.

A student prepares benzoic acid as outlined below.

Step 1	The student mixes 4.00 cm^3 of phenylmethanol, $C_6H_5CH_2OH$, (density = 1.04 g cm^{-3}) with sodium carbonate and aqueous potassium manganate(VII), as an oxidising agent. The mixture is heated under reflux.
Step 2	The resulting mixture is cooled and then acidified with concentrated HC*l* . Impure crystals of benzoic acid appear.
Step 3	The student recrystallises the impure crystals to obtain 1.59 g of pure benzoic acid.

In **Step 1**, sodium carbonate, Na_2CO_3, makes the reaction mixture alkaline.

Write an ionic equation to show how carbonate ions form an alkaline solution in water.

[1]

(b). In **Step 2**, explain why the mixture must be acidified so that crystals of benzoic acid appear.

[1]

(c). Write the overall equation for the preparation of benzoic acid from phenylmethanol.

Use [O] for the oxidising agent.

[1]

(d). Calculate the percentage yield of benzoic acid.

Give your answer to **3** significant figures.

percentage yield = ... % **[3]**

(e). In **Step 3**, describe how the student can recrystallise the impure crystals to obtain pure benzoic acid.

[2]

28. The equation shows the dissociation of the acid H_3AsO_4 in water.

$H_3AsO_4 + H_2O \rightleftharpoons H_2AsO_4^- + H_3O^+$

Which pair is a conjugate acid–base pair?

A H_3AsO_4 and H_2O

B $H_2AsO_4^-$ and H_3O^+

C H_3AsO_4 and H_3O^+

D H_3O^+ and H_2O

Your answer ☐ **[1]**

29. Healthy human blood needs to be maintained at a pH of 7.40 for the body to function normally.

*Carbonic acid, H_2CO_3, is a weak acid which, together with hydrogencarbonate ions, HCO_3^-, acts as a buffer to maintain the pH of blood.

The pK_a value for the dissociation of carbonic acid is 6.38.

Explain, in terms of equilibrium, how the carbonic acid–hydrogencarbonate mixture acts as a buffer in the control of blood pH, and calculate the $[HCO_3^-] : [H_2CO_3]$ ratio in healthy blood.

[6]

30(a). This question is about weak acids.

The K_a values of three weak acids are shown in **Table 20.1**.

Weak acid	**K_a / mol dm^{-3}**
iodic(V) acid, $HIO_3(aq)$	1.78×10^{-1}
propanoic acid, $C_2H_5COOH(aq)$	1.35×10^{-5}
hydrocyanic acid, $HCN(aq)$	6.17×10^{-10}

Table 20.1

Calculate the pH of 0.0800 mol dm^{-3} $C_2H_5COOH(aq)$.

Give your answer to **2** decimal places.

pH = ... **[2]**

(b). A student adds a total of 45.0 cm^3 of 0.100 mol dm^{-3} NaOH(aq) to 25.0 cm^3 of 0.0800 mol dm^{-3} $C_2H_5COOH(aq)$ and monitors the pH throughout.

i. Show by calculation that 20.0 cm^3 of NaOH(aq) is required to reach the end point.

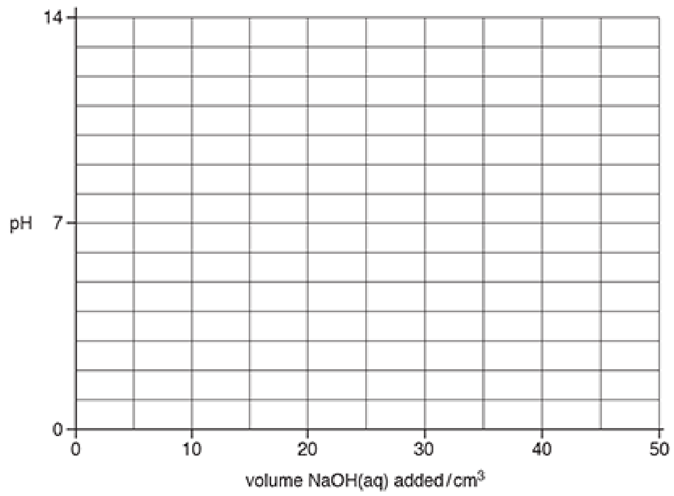
[1]

ii. Calculate the pH of the final solution.

Give your answer to **2** decimal places.

pH = ... **[4]**

iii. On the axes below, sketch a pH curve for the pH changes during the addition of 45.0 cm^3 of 0.100 mol dm^{-3} NaOH(aq) to 25.0 cm^3 of 0.0800 mol dm^{-3} $C_2H_5COOH(aq)$.



[3]

iv. The student considers using the four indicators in **Table 20.2** for the titration.

Indicator	pH range
Cresol red	0.2 – 1.8
Bromophenol blue	3.0 – 4.6
Cresol purple	7.6 – 9.2
Indigo carmine	11.6 – 14.0

Table 20.2

Explain which indicator would be most suitable for the titration.

[1]

v. The student repeats the experiment starting with 25.0 cm^3 of 0.0800 mol dm^{-3} **HCN**(aq) and adding a total of 45.0 cm^3 of 0.100 mol dm^{-3} NaOH(aq).

Predict **one** similarity and **one** difference between the pH curve with C_2H_5COOH(aq) and the pH curve with HCN(aq). Use the information in **Table 20.1**, and your answer to **(b)(iii)**.

Similarity

Difference

[2]

(c). The student calculates the pH of 0.0800 mol dm^{-3} HIO_3(aq). The student assumes that the equilibrium concentration of HIO_3(aq) is the same as the initial concentration of HIO_3(aq).

The student measures the pH, and finds that the measured pH value is different from the calculated pH value.

Explain why the measured pH is different from the calculated pH.

[1]

31. This question is about two different types of acid found in organic compounds, carboxylic acids and sulfonic acids, as shown in **Fig. 6.1**.

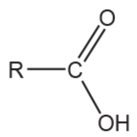
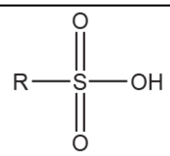
	
Carboxylic acid	Sulfonic acid

Fig. 6.1

Ethanoic acid, CH_3COOH, and methanesulfonic acid, CH_3SO_2OH, are both monobasic acids.
The pK_a values are shown in the table.

Acid		**pK_a**
Ethanoic acid	CH_3COOH	4.76
Methanesulfonic acid	CH_3SO_2OH	–1.90

A student suggests that 1.0 mol dm^{-3} CH_3SO_2OH should have a lower pH value than 1.0 mol dm^{-3} CH_3COOH.

Write an equation, showing conjugate acid–base pairs, for the equilibrium of CH_3SO_2OH with water and explain, with reasons, whether the student is correct.

Label the conjugate acid–base pairs: **A1**, **B1** and **A2**, **B2**.

[4]

32. Phosphoric acid is a tribasic acid.

What is the mass of $Ca(OH)_2$ that completely neutralises 100 cm^3 of 0.100 mol dm^{-3} phosphoric acid?

A 0.49 g

B 0.74 g

C 1.11 g

D 2.22 g

Your answer **[1]**

33. 20 cm^3 of 0.10 mol dm^{-3} hydrochloric acid is added to 10 cm^3 of 0.10 mol dm^{-3} sodium hydroxide.

What is the pH of the resulting mixture?

A 1.00

B 1.18

C 1.30

D 1.48

Your answer **[1]**

34(a). This question is about reactions and uses of the weak acids methanoic acid, HCOOH, and ethanoic acid, CH_3COOH.

The K_a values of HCOOH and CH_3COOH are shown in **Table 18.1**.

Weak acid	**K_a / mol dm^{-3}**
HCOOH	1.82×10^{-4}
CH_3COOH	1.78×10^{-5}

Table 18.1

A student adds methanoic acid to ethanoic acid.

An equilibrium is set up containing two acid-base pairs.

Complete the equilibrium and label the conjugate acid-base pairs as **A1**, **B1** and **A2**, **B2**.

$HCOOH + CH_3COOH \rightleftharpoons$ .... + ...

....

[2]

(b). Use **Table 18.1** to answer the following questions.

i. The student measures the pH of $CH_3COOH(aq)$ as 2.72.

Show that the concentration of the $CH_3COOH(aq)$ is 0.204 mol dm^{-3}.

[2]

ii. The student plans to make a buffer solution of pH 4.00 from a mixture of $CH_3COOH(aq)$ and sodium ethanoate, $CH_3COONa(aq)$.

The student mixes 400 cm^3 of 0.204 mol dm^{-3} $CH_3COOH(aq)$ with 600 cm^3 of $CH_3COONa(aq)$.

Calculate the concentration of $CH_3COONa(aq)$ needed to prepare this buffer solution of pH 4.00.

concentration = ... mol dm^{-3} **[4]**

35. An aqueous solution of ethanoic acid, CH_3COOH, has a concentration of 0.50 mol dm^{-3}. pK_a for CH_3COOH = 4.76 at 25 °C.

What is the pH of the ethanoic acid solution at 25 °C?

A 2.53

B 2.68

C 4.91

D 5.06

Your answer ☐ **[1]**

36(a). This question is about acids, bases and buffers.

Sodium hydroxide, NaOH, is a strong base.

Calculate the pH of 0.140 mol dm^{-3} NaOH(aq) at 298 K.

Give your answer to **2** decimal places.

pH = ... **[2]**

(b). Nitrous acid, HNO_2, is a weak Brønsted–Lowry acid with a pK_a value of 3.34 at room temperature.

HNO_2 can be prepared by reacting N_2O_3 with water.
HNO_2 is the only product.

A chemist makes up a buffer solution by the following method.

Step 1	The chemist weighs a sample of N_2O_3. Water is then added to form 100 cm^3 of 0.500 mol dm^{-3} HNO_2(aq).
Step 2	The chemist adds 100 cm^3 of 0.150 mol dm^{-3} NaOH(aq) to the 100 cm^3 solution of 0.500 mol dm^{-3} solution of HNO_2(aq). The resulting solution is made up to 1.00 dm^3.

Explain why a buffer solution forms in **Step 2**. Determine the pH of this buffer solution and the mass of N_2O_5 that was used in **Step 1**.

[6]

37. This question is about nitrogen and its compounds.

Hydrazoic acid, HN_3, is a weak acid ($K_a = 2.51 \times 10^{-5}$ mol dm^{-3}).

i. Calculate the pH of 0.125 mol dm^{-3} hydrazoic acid.
Give your answer to **2** decimal places.

pH = ...**[2]**

ii. When added to water, hydrazoic acid forms an equilibrium mixture containing conjugate acid–base pairs.
Complete the equation for this equilibrium and label the conjugate acid–base pairs as: **A1**, **B1** and **A2**, **B2**.

Equation	HN_3	+	....	⇌	....	+	....
Acid-base pairs	....		....		....		....

[2]

iii. In the Schmidt reaction, hydrazoic acid, HN_3, reacts with carboxylic acids to form primary amines.

For example, HN_3 reacts with RCOOH to form RNH_2 and two gases that are found in the atmosphere.

Write the equation for the reaction of HN_3 with 2-methylbutanoic acid.

Show structures for organic compounds.

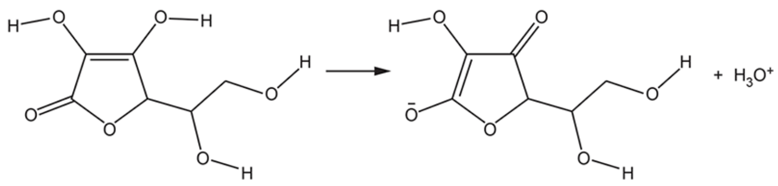
[3]

38. Vitamin C, $C_6H_8O_6$, is a weak acid (K_a = 7.94 × 10 $^{-5}$ (mol dm^{-3})), which is often referred to as ascorbic acid.

i. In aqueous solution, vitamin C donates a proton to water:

$C_6H_8O_6 + H_2O \rightleftharpoons C_6H_7O_6^{\ -} + H_3O^+$

Add curly arrows to the diagram to suggest the mechanism for this process.



[2]

ii. The student dissolves 0.150 mol of vitamin C in water and makes the solution up to 250 cm^3 in a volumetric flask.

Calculate the pH of this solution of vitamin C.

Give your answer to **2** decimal places.

pH = ... **[3]**

39. The equilibrium equation for an indicator, HA, is shown below.

Equation:	HA(aq)	$\rightleftharpoons$	A^-(aq)	+	H^+(aq)
Colour:	Blue		Yellow		

The indicator is added to a solution. The indicator turns a yellow colour.

An excess of aqueous sodium hydroxide is then added.

Which statement describes how the colour of this solution would be expected to change?

A Colour changes from yellow to blue.

B Colour changes from yellow to green.

C Colour changes from yellow to green and then to blue.

D Colour stays yellow.

Your answer ☐ **[1]**

40. Ammonia and water react to set up an acid-base equilibrium.

What are the Brønsted-Lowry acids in the equilibrium mixture?

A H_2O and OH^-

B OH^- and NH_3

C NH_4^+ and H_2O

D NH_4^+ and NH_3

Your answer ☐ **[1]**

41. This question is about acids and buffer solutions.

Glycolic acid, $HOCH_2COOH$, (pK_a = 3.83) is a weak monobasic acid used in some skincare products.

A buffer solution is prepared by adding 60.0 cm^3 of 0.750 mol dm^{-3} glycolic acid to 40.0 cm^3 of 0.625 mol dm^{-3} potassium hydroxide, KOH.

i. Explain why a buffer solution is formed.

[1]

ii. Calculate the pH of the buffer solution that has been prepared.

Give your answer to **2** decimal places.

pH = ... **[4]**

iii. A small amount of aqueous ammonia, NH_3(aq), is added to the buffer solution.

Explain, in terms of equilibrium, how the buffer solution would respond to the added NH_3(aq).

[2]

42. This question is about the reactions of Group 2 metals and their compounds.

A sample of barium oxide is added to distilled water at 25 °C.

A colourless solution forms containing barium hydroxide, $Ba(OH)_2$.

The solution is made up to 250.0 cm^3 with distilled water.

The pH of this solution is 13.12.

i. Determine the mass of barium oxide that was used.

Give your answer to **3** significant figures.

mass of barium oxide = ... g **[5]**

ii. 10 cm^3 of dilute sulfuric acid is added to 10 cm^3 of the colourless solution of $Ba(OH)_2$. Write an ionic equation, including state symbols, for the reaction.

[1]

43. What is the percentage dissociation of a 0.015 mol dm^{-3} solution of methanoic acid, HCOOH (K_a = 1.60 × 10^{-4} mol dm^{-3})?

A 0.016%

B 1.1%

C 1.82%

D 10.3%

Your answer ☐ **[1]**

44(a). This question is about acids and bases.

Table 20.1 shows the ionic product, K_w, of water at 25 °C and 40 °C.

Table 20.1

Temperature / °C	**K_w / mol^2 dm^{-6}**
25	1.00×10^{-14}
40	2.92×10^{-14}

i. Calculate the pH of water at 40 °C.

Give your answer to **2** decimal places.

pH = ... **[2]**

ii. **Table 20.1** shows different K_w values at 25 °C and at 40 °C. A student suggests that water is neutral at these temperatures.

Explain why this student is correct.

[1]

(b). A student reacts strontium metal with water to make a 250.0 cm^3 solution of aqueous strontium hydroxide, $Sr(OH)_2$. The solution contains 0.145 g of strontium hydroxide.

- Write an equation for the reaction of strontium with water.
- Calculate the pH of this 250.0 cm^3 solution of strontium hydroxide at 40 °C.
  You should refer back to **Table 20.1** at the start of **(a)**.

  Give your answer to **2** decimal places.

Equation

Calculation

pH = ... **[5]**

(c). A student reacts an excess of magnesium with 25.0 cm^3 of 0.500 mol dm^{-3} hydrochloric acid, HC*l*.

The student also reacts an excess of magnesium with 25.0 cm^3 of 0.500 mol dm^{-3} ethanoic acid, CH_3COOH.

i. Construct an ionic equation for the reaction of magnesium with an acid.

[1]

ii. Explain why these two reactions of magnesium produce the same volume of gas but at different rates.

[3]

(d). Butanoic acid, $CH_3CH_2CH_2COOH$, is a weak monobasic acid.

i. Explain what is meant by the term **monobasic acid**.

[1]

ii. A buffer solution is prepared by dissolving 3.39g of potassium hydroxide in 250 cm^3 of 0.376 mol dm^{-3} butanoic acid.

This buffer solution has a pH of 5.07 at 25 °C.

Calculate the acid dissociation constant, K_a, of butanoic acid at 25°C.

Assume that the volume of the solution remains constant at 250 cm^3 when the potassium hydroxide is dissolved.

K_a = ... mol dm^{-3} **[4]**

(e). A buffer solution has a pH of 4.50.

When a small volume of water is added to this buffer solution, the pH does **not** change.

Explain why the pH does **not** change.

[1]

45. A student investigates the rate of a reaction that is 1st order with respect to hydrochloric acid, HC*l*(aq).

- The student carries out a reaction using 0.680 mol dm^{-3} HC*l*(aq). The initial rate is 9.52×10^{-4} mol dm^{-3} s^{-1}.
- The student dilutes a different sample of 0.680 mol dm^{-3} HC*l* (aq) with water. The pH of this diluted acid is 1.50.
- The student repeats the reaction using the same volume of this diluted acid.

Determine the initial rate using this diluted acid.

initial rate = ... mol dm^{-3} s^{-1} **[3]**

46. Which solution can be added to CH_3COOH(aq) to make a buffer solution?

A CH_3COONa(aq)

B HCOOH(aq)

C HC*l* (aq)

D NaC*l* (aq)

Your answer ☐ **[1]**

47(a). Chloroethanoic acid, $ClCH_2COOH$, is a weak monobasic acid.

i. Write the expression for the acid dissociation constant, K_a, of $ClCH_2COOH$.

[1]

ii. The expression for the acid dissociation constant, K_a, of $ClCH_2COOH$ can be simplified to:

$$K_a = \frac{[H^+]^2}{[ClCH_2COOH]}$$ **Expression 19.1**

State one approximation that allows the expression from **(a)(i)** to be simplified to **Expression 19.1**.

[1]

iii. A student carries out an experiment to determine the pK_a value of a solution of $ClCH_2COOH$.

- The concentration of $ClCH_2COOH$ is 0.090 mol dm^{-3}.
- The pH of $ClCH_2COOH$ is 1.95.

Use **Expression 19.1** to calculate the pK_a value of $ClCH_2COOH$.

Give your answer to **2** decimal places.

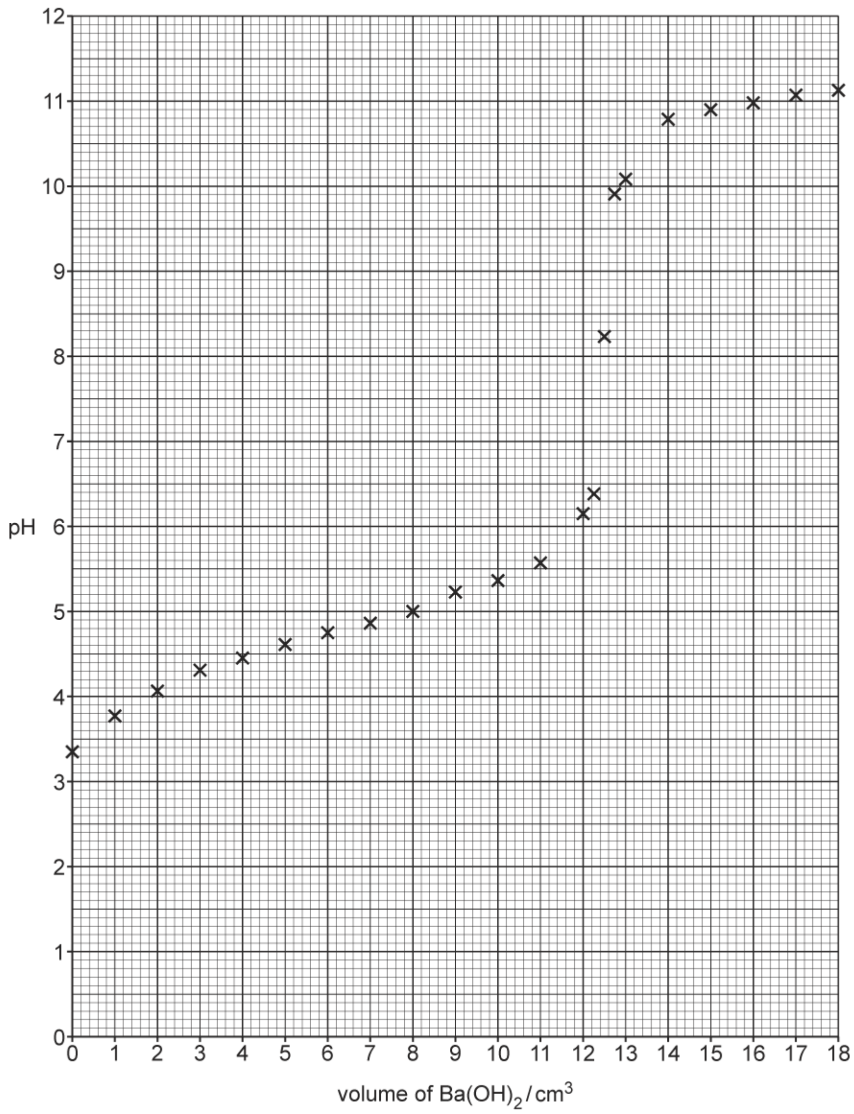
pK_a = ... **[3]**

(b). A student titrates a 10.0 cm^3 sample of ethanoic acid, CH_3COOH, against an aqueous solution of 0.0560 mol dm^{-3} $Ba(OH)_2$.

$2CH_3COOH + Ba(OH)_2 \rightarrow Ba(CH_3COO)_2 + 2H_2O$

The student used a pH meter to measure the pH of the mixture after every addition of $Ba(OH)_2$ throughout the titration.

The student's results are shown below.



i. Draw a best-fit curve on the graph and calculate the concentration of the CH_3COOH solution.

CH_3COOH concentration = ... mol dm^{-3} **[5]**

ii. The end point of the titration can also be found by observing the colour change of an indicator.

The pH ranges of some indicators are shown in the table.

Indicator	pH range
Malachite green	0.2 − 1.8
Bromophenol blue	2.8 − 4.6
Phenol red	6.8 − 8.4
Phenolphthalein	8.2 − 10.0

Identify the indicator in the table that would be suitable to observe the end point of the titration between CH_3COOH and $Ba(OH)_2$.

[1]

48. Red blood cells contain haemoglobin which transports oxygen around the body.

For efficient transportation of oxygen, healthy human blood must be maintained at a pH value between 7.35 and 7.45.

Human blood acts as a buffer due to the presence of carbonic acid, H_2CO_3, and hydrogencarbonate, HCO_3^-, ions as shown below.

$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ $K_a = 4.27 \times 10^{-7}$ mol dm^{-3}

- Explain, using ligand substitution, how haemoglobin transports oxygen around the body.
- Determine whether a sample of blood with a $[HCO_3^-] : [H_2CO_3]$ ratio of 8.5:1 is healthy.

[5]

49(a). What is the pH of 1.00 dm^3 of 0.400 mol dm^{-3} of NaOH(aq) at 298 K?

pH = ... **[2]**

(b). Water is added to 10.0 cm^3 of 0.750 mol dm^{-3} HC*l* (aq) to produce 100 cm3 of diluted HC*l* (aq).

What is the pH of the diluted HC*l* (aq)?

Give your answer to **2** decimal places.

pH = ... **[1]**

(c). A solution has concentrations of 0.300 mol dm^{-3} CH_3COOH(aq) and 0.100 mol dm^{-3} CH_3COONa(aq).

K_a for CH_3COOH = 1.75 × 10^{-5} mol dm^{-3} at 298 K.

What is the pH of the solution at 298 K?

Give your answer to **2** decimal places.

pH = ... **[2]**

50. This question is about the chemistry of compounds containing phosphorus.

Phosphorus forms several acids including H_3PO_4 and H_3PO_3.

H_3PO_4 is a tribasic acid. The equilibria for the dissociations are shown below.

1 $H_3PO_4 \rightleftharpoons H^+ + H_2PO_4^-$

2 $H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$

3 $HPO_4^{2-} \rightleftharpoons H^+ + PO_4^{3-}$

i. During the equilibria, $H_2PO_4^-$ behaves both as an acid and as a base.

Explain this statement, using the equilibria **1**, **2** and **3**, as required.

[2]

ii. In a H_3PO_3 molecule, the O atoms are covalently bonded to the P atom. The H atoms are bonded to the O atoms.

Draw the structure of a H_3PO_3 molecule, showing all the bonds.

On your diagram, add the values for the O−P−O and P−O−H bond angles.

[3]

iii. The systematic name of H_3PO_4 is phosphoric(V) acid.

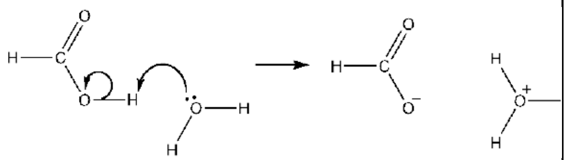
What is the systematic name of H_3PO_3?

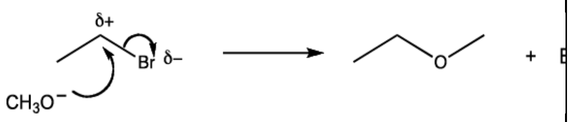
[1]

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			C	1	
			Total	**1**	
2			D	1	
			Total	**1**	
3			C	1	
			Total	**1**	
4			**A**: Sc^{3+} **B**: S^{2-}	2	
			Total	**2**	
5	a	i	HNO_3 is a strong acid **AND** HNO_2 is a weak acid	1	**ALLOW** HNO_3 completely dissociates **AND** HNO_2 partially dissociates **ALLOW** $HNO_3 \rightarrow H^+ + NO_3^-$ **AND** $HNO_2 \rightleftharpoons H^+ + NO_2^-$ **IGNORE** HNO_3 is a stronger acid **ORA** **IGNORE** HNO_3 produces more H^+
		ii	pH = −log 0.0450 = 1.35 (**2 DP** required)	1	
		iii	**FIRST CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 2.35, award all **three** calculation marks $K_a = 10^{-3.35}$ **OR** 4.47×10^{-4} (mol dm^{-3}) $[H^+] = \sqrt{(K_a \times [HNO_2])}$ **OR** $\sqrt{(K_a \times [HA])}$ **OR** $\sqrt{(K_a \times 0.0450)}$ **OR** 4.48×10^{-3} (mol dm^{-3}) pH = 2.35 (**2 DP** required)	3	**ALLOW** 2 SF to calculator value: $4.466835922 \times 10^{-4}$, correctly rounded **IGNORE** HNO_3 in working Always **ALLOW** calculator value irrespective of working as number may have been kept in calculator. ***Note:*** *pH = 2.35 is obtained from all three values above* *From no square root, pH = 4.70. Worth K_a mark only.*
	b		**FIRST CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.810 (g) award 4 marks $[H^+] = 10^{-12.500} = 3.16 \times 10^{-13}$ (mol dm^{-3}) $[OH^-] = \frac{K_w}{[H^+]} = \frac{1.00 \times 10^{-14}}{3.16 \times 10^{-13}} = 0.0316$ (mol dm^{-3}) $n(RbOH) = 0.0316 \times \frac{250}{1000} = 7.91 \times 10^{-3}$ (mol)	4	Always **ALLOW** calculator value irrespective of working as number may have been kept in calculator. **ALLOW** alternative approach using pOH: pOH = 14.000 − 12.500 = 1.500 $[OH^-] = 10^{-1.500} = 0.0316$ **ALLOW ECF** from $[H^+]$ derived using K_w

			mass RbOH = $7.91 \times 10^{-3} \times 102.5 = 0.810$ (g)		and $[OH^-]$ BUT **DO NOT ALLOW** an acid pH. **ALLOW** 0.81 g, up to calculator value but take care as rounding could be from any stage. *Last 3 SF figure is zero and is treated as a 'trailing zero' as specific number of SF has not been asked for.*
			Total	**9**	
6			K_w value from graph from 2.2 to 2.4 × 10^{-14} ($mol^2\ dm^{-6}$) Using 2.4×10^{-14}, $[H^+] = \sqrt{2.4 \times 10^{-14}}$ **OR** 1.55×10^{-7} pH = −log (1.55×10^{-7}) = 6.81 (using $K_w = 2.4 \times 10^{-14}$)	3	Actual $K_w = 2.38 \times 10^{-14}\ mol^2\ dm^{-6}$ **ALLOW ECF** only if candidate uses a value between 2.0 and 2.6×10^{-14} ($mol^2\ dm^{-6}$), i.e. from the approximately correct region of the graph **ALLOW** 6.8 (1DP) up to calculator value **ALLOW ECF** only if candidate has generated a value of $[H^+]$ by attempting to take a square root of a value between 2.0 and 3.0×10^{-14}
			Total	**3**	
7		i	$K_a = \frac{[[Fe(H_2O)_5OH]^{2+}(aq)][H^+(aq)]}{[[Fe(H_2O)_6]^{3+}(aq)]}$	1	state symbols **not** required
		ii	$[H^+] = \sqrt{6.00 \times 10^{-3} \times 0.100}$ **OR** 0.0245 ($mol\ dm^{-3}$) pH = −log 0.0245 = 1.61	2	**ALLOW ECF** from calculated $[H^+]$ provided that **BOTH** 6.0×10^{-3} **AND** 0.100 only have been used **ALLOW** calculation via quadratic equation → pH 1.66
			Total	**3**	
8			 1 mark for correct reactants **AND** products **AND** correct positioning of + and − charges on products 1 mark for two correct curly arrows **AND** H_2O curly arrow starting from O lone pair	2	
			Total	**2**	

<table>
<tr><td>9</td><td>a</td><td></td><td>✓</td><td>1</td><td></td></tr>
<tr><td></td><td>b</td><td>i</td><td>$2Na + 2CH_3OH \rightarrow 2Na^+ + 2CH_3O^- + H_2$ ✓</td><td>1</td><td>ALLOW $2Na + 2CH_3OH \rightarrow 2CH_3ONa + H_2$</td></tr>
<tr><td></td><td></td><td>ii</td><td>

Curly arrow from CH_3O^- to carbon atom of C-Br bond ✓

Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$ AND curly arrow from C–Br bond to the Br atom ✓

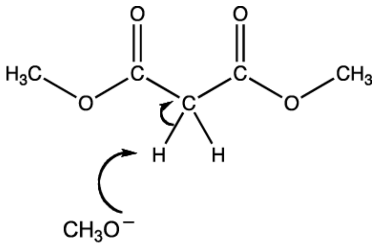
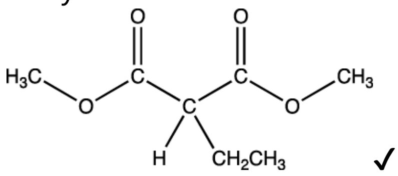
Products of reaction (must not be ambiguous) ✓</td><td>3</td><td>ALLOW correct structural OR skeletal OR displayed formula OR mixture of the above as long as non-ambiguous.

The curly arrow must start from O atom of CH_3O^-
AND must start either from a lone pair or from the negative charge.

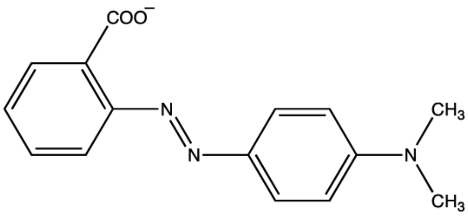
No need to show lone pair if curly arrow comes from negative charge.

ALLOW S_N1
Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, and curly arrow from C–Br bond to the Br atom.
Correct carbocation drawn.
AND curly arrow from CH_3O^- to carbocation.
The curly arrow must start from the oxygen atom of the CH_3O^-, and must start either from a lone pair or from the negative charge.</td></tr>
<tr><td></td><td></td><td>iii</td><td>CH_3O^- donates an electron pair
AND heterolytic fission ✓</td><td>1</td><td>ASSUME ‘it’ refers to CH_3O^-</td></tr>
<tr><td></td><td>c</td><td></td><td><table><tr><th>Chemical shift, δ/ppm</th><th>Relative peak area</th><th>Splitting pattern</th><th></th></tr><tr><td>0.5−1.9</td><td>3</td><td>Triplet</td><td>✓</td></tr><tr><td>3.0−4.3</td><td>2</td><td>Quartet</td><td>✓</td></tr><tr><td>0.5−1.9</td><td>6</td><td>Doublet</td><td>✓</td></tr><tr><td>3.0−4.3</td><td>1</td><td>Heptet</td><td>✓</td></tr></table></td><td>4</td><td>ALLOW δ values ± 0.2 ppm, as a range or a value within the range

ALLOW multiplet for heptet</td></tr>
</table>

	d	i	 Curly arrow from CH_3O^- to H of CH_2 ✓ Curly arrow from C–H bond to C of CH_2 ✓  ✓	3	The curly arrow must start from **O atom** of CH_3O^- **AND** must start either from a lone pair or from the negative charge. No need to show lone pair if curly arrow comes from negative charge. **ALLOW** any unambiguous structure, skeletal, displayed, structural or combination.
		ii	CH_3O^- accepted a proton ✓	1	**ASSUME** 'it' refers to CH_3O^-
			Total	**14**	
10	a		$[H^+] = 10^{-pH} = 10^{-2.19} = 6.46 \times 10^{-3}$ (mol dm^{-3}) $[CH_3CH(OH)COOH] = \frac{[H^+]^2}{K_a} = \frac{(6.46 \times 10^{-3})^2}{1.38 \times 10^{-4}}$ $= 0.0302$(mol dm^{-3}) $n(CH_3CH(OH)COOH) = \frac{0.302 \times 250}{1000} = 0.0755$ mol Mass of $CH_3CH(OH)COOH = 0.0755 \times 90 = 6.80$ g Dissolve 6.80 g of the solid in distilled water (less than 250 cm^3) in a beaker (then) transfer the solution to a 250 cm^3 volumetric flask **AND** ensure that all solution is washed out of beaker (washings transferred to volumetric flask) (then) make solution up to 250 cm^3 with distilled water **AND** ensure thorough mixing by inverting the flask several times	8	**ALLOW** 5 marks for 6.80 g through any calculation. **ALLOW ECF** for incorrect calculation of mass. Mass used must be linked to calculation.
	b		$CH_3CH(OH)COO^- + CH_3CH_2CH_2COOH_2^+$ $CH_3CH(OH)COOH$ **AND** $CH_3CH(OH)COO^-$	2	State symbols **NOT** required **ALLOW** labels 'acid 1', 'base 1' etc. **ALLOW ECF** for second mark

			$CH_3CH_2CH_2COOH$ **AND** $CH_3CH_2CH_2COOH_2^+$ **Both** pairs identified		
	c	i	$[H^+] = \frac{1 \times 10^{-14}}{0.185} = 5.405 \times 10^{-14}$ (Use of K_w) pH = $-\log(5.405 \times 10^{-14})$ = 13.27	2	**ALLOW** $5.405405405 \times 10^{-14}$ and correct rounding to 5.4×10^{-14} **ALLOW** alternative approach using pOH: pOH = –log(0.185) = 0.73 pH = 14 – 0.73 = 13.27 Correct answer scores **BOTH** marks **ALLOW** 13.267
		ii	$n(A^-) = 9.25 \times 10^{-3}$ (mol) $n(HA) = 0.0165 - 9.25 \times 10^{-3} = 7.25 \times 10^{-3}$ (mol) $[H^+] = K_a \times \frac{[HA]}{[A^-]}$ pH = $-\log(1.5 \times 10^{-5} \times \frac{0.058}{0.074})$ = 4.93 **OR** pH = $-\log(1.5 \times 10^{-5} \times \frac{1000 \times \frac{7.25 \times 10^{-3}}{125}}{1000 \times \frac{9.25 \times 10^{-3}}{125}})$ = 4.93 **Final mark** also via Henderson-Hasselbalch equation: pH = $pK_a - \log\frac{[HA]}{[A^-]}$ = 4.82 – (–0.11) = 4.93 **OR** pH = $pK_a + \log\frac{[A^-]}{[HA]}$ = 4.82 + 0.11 = 4.93	4	**ALLOW** HA / acid and A^-/salt throughout for butanoate and butanoic acid **ALLOW** $pK_a = -\log K_a$ **OR** $-\log 1.5 \times 10^{-3}$ **OR** 4.82 **ALLOW ECF** from incorrect values of $n(A^-)$ or $n(HA)$ **ALLOW** pH = $-\log(1.5 \times 10^{-5} \times \frac{7.25 \times 10^{-3}}{9.25 \times 10^{-3}})$ = 4.93
			Total	**16**	
11	a	i	Using a pH probe on a data logger **OR** pH meter	1	
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = **0.11(0)** (mol dm^{-3}), award **2 marks** …………………………………………………… $n(NaOH) = \frac{0.125 \times 22.0}{1000} = 2.75 \times 10^{-3}$ (mol) concentration of $CH_3COOH = \frac{2.75 \times 10^{-3} \times 1000}{25.0}$ = 0.11(0) (mol dm^{-3})	2	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below. …………………………………………………… **ANNOTATE WITH TICKS AND CROSSES, etc** **ALLOW ECF:** $n(NaOH) \times 1000/25.00$

	b	i	Brilliant yellow **AND** Vertical section / rapid pH change matches the pH range / end point / colour change (of the indicator)	1	**ALLOW** pH range (of the indicator) matches equivalence point **ALLOW** end point / colour change matches equivalence point **IGNORE** colour change matches end point (*colour change is the same as end point*)
		ii	 Explanation: Acid / H^+ reacts with A^- **AND** equilibrium (position) shifts towards HA (to give a red colour) Alkali / OH^- reacts with HA/H^+ **AND** equilibrium (position) shifts towards A^- (to give a yellow colour) At end point, equal amounts of HA and A^- **AND** orange colour	4	**ALLOW** direction of equilibrium shift if equilibrium shown: HA ⇌ H^+ + A^- i.e. 'towards HA' is equivalent to 'to left' i.e. 'towards A^-' is equivalent to 'to right' **ALLOW** yellow−red colour
	c	i	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **If** answer = 2.33 **award 4 marks** $K_a = 10^{-3.40} = 3.98 \times 10^{-4}$ (mol dm^{-3}) Concentration of aspirin $= \frac{1.00 \times 10^{-2}}{180} \times 1000$ = 0.0556 (mol dm^{-3}) $[H^+] = \sqrt{(K_a \times [HA])}$ $= \sqrt{(3.98 \times 10^{-4} \times 0.0556)}$ $= 4.70 \times 10^{-3}$ (mol dm^{-3}) pH = −log 4.70×10^{-3} = 2.33	4	**ALLOW ECF** **ALLOW ECF only** from $[H^+]$ calculation using $[H^+] = \sqrt{(K_a \times [HA])}$
		ii	Salts are ionic **AND** attracted to polar H_2O	1	
		iii	COO^- reacts with H^+ forming COOH Aspirin precipitates out	2	**ALLOW** equilibrium shifts to left
			Total	**15**	

1 2		i	5.4(0) ✓ 614.4(0) ✓	2	**IGNORE** sign **ALLOW** 614 **OR** 610 **Examiner's Comments** Able candidate usually obtained both marks but average and weaker candidates often experienced problems, particularly with the rate for Experiment 3. The commonest mistakes stemmed from not using the squared terms in the rate equation, resulting in rates of 1.80 for Experiment 2 and 9.60 for Experiment 3. Other incorrect answers for Experiment 3, such as 21.6 were the result of multiplying the rate in Experiment 1 by various multiples of 4. Answers: Experiment 2, 5.40 mol dm^{-3} s^{-1}; Experiment 3, 614.40 mol dm^{-3} s^{-1}
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 6.7×10^8 **OR** 670000000 dm^{12} mol^{-4} s^{-1}, award **3 marks** **IF** answer = 6.7×10^8 **OR** 670000000 with incorrect units, award **2 marks** *k* to <2 SF: 666666666.7 ✓ **OR** *k* to 2 SF: 6.7×10^8 **OR** 670000000 ✓✓ units: dm^{12} mol^{-4} s^{-1} ✓	3	**ALLOW ECF** from incorrect initial rates if 1st experimental results have **not** been used. **(Look to 4(c)(i) to check)** *i.e.* **IF** other rows have been used, then calculate the rate constant from data chosen. For *k*, **ALLOW** 1 mark for the following: 6.6×10^8 recurring 6.6×10^8 2 SF answer for *k* **BUT** one power of 10 out i.e. 6.7×10^9 **OR** 6.7×10^7 **ALLOW** units in any order, e.g. mol^{-4} dm^{12} s^{-1} **Examiner's Comments** Almost all candidates used the information from Experiment 1 to calculate a value for the rate constant. Most were able to obtain 6.6 recurring with most middle and able candidates correctly rounding their answer to the required two significant figures. Weaker responses showed incorrect powers of 10, rounding to two decimal places (in this case three significant figures) and incorrect rounding to 6.6. Rounding and

					significant figures are a basic GCSE mathematical skill. Candidates are well advised to check any significant figure or decimal place requirements in calculations before moving on the next question. Candidates coped well with the unfamiliar units for the rate constant of a fifth order reaction. The examiners accepted units in any order but the more correct positive before negative order of indices was usually seen. Answer: 6.7 10^{8} dm^{12} mol^{-4} s^{-1}
		iii	(K_a =) $10^{-3.75}$ **OR** 1.78×10^{-4} (mol dm^{-3}) ✓ $[H^+]$ **=** $\sqrt{1.78 \times 10^{-4} \times 0.0200}$ = 1.89×10^{-3} (mol dm^{-3}) ✓ initial rate = 6.7×10^{8} x 0.01 x 0.015^{2} x $(1.89 \times 10^{-3})^{2}$ = 5.33×10^{-3} to 5.38×10^{-3} (mol dm^{-3} s^{-1}) **OR** 5.3×10^{-3} to 5.4×10^{-3} (mol dm^{-3} s^{-1}) ✓ Actual value will depend on amount of acceptable rounding in steps and whether figures kept in calculator even if rounding is written down. **ALLOW** any value in range given above.	3	***FULL ANNOTATIONS MUST BE USED*** .... **For ALL marks, ALLOW 2 SF** up to calculator value correctly rounded $1.77827941 \times 10^{-4}$ **ALLOW** $\sqrt{10^{-3.75} \times 0.0200}$ for first marking point **ALLOW** 1.88×10^{-3} (mol dm^{-3}) **ALLOW ECF** from calculated $[H^+(aq)]$ and calculated answer for *k* from **4(c)(ii)** e.g. If no square root taken, $[H^+]$ = 3.56×10^{-6} mol dm^{-3} and *rate* = 1.91×10^{-8} **OR** 1.9×10^{-8} by **ECF** **Examiner's Comments** This question linked two areas of the specification, pH calculations of weak acids with reaction rates. Overall candidates coped admirably with the challenge and most calculated the $[H^+]$ successfully. Weaker candidates often made no further progress but many candidates then moved forwards to correctly calculate the initial rate. The examiners used the candidate answer from 4(c)(ii) for ECF purposes. Because of the range of possible intermediate roundings in this calculation, a generous range of values was allowed for the initial rate. Answer: 5.33 10^{-3} to 5.38 10^{-3} dm^{12} mol^{-4} s^{-1}

			Total	8	
13	a		$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$ ✓ Acid 1 Base 2 Acid 2 Base 1 ✓	2	**IGNORE** state symbols (even if incorrect) **ALLOW** 1 **AND** 2 labels the other way around. **ALLOW** 'just acid' and 'base' labels if linked by lines so that it is clear what the acid—base pairs are **ALLOW** A and B for 'acid' and 'base' **IF** proton transfer is wrong way around **ALLOW** 2nd mark for idea of acid—base pairs, *i.e.* $CH_3COOH + H_2O \rightleftharpoons CH_3COOH_2^+ + OH^-$ ✗ Base 2 Acid 1 Acid 2 Base 1 ✓ **NOTE** For the 2nd marking point (acid—base pairs), this is the **ONLY** acceptable **ECF** *i.e., **NO ECF** from impossible chemistry* **Examiner's Comments** Most candidates showed an acid-base equilibrium involving proton transfer and then identified the acid-base pairs. The acid-base pairs were usually correctly identified but the proton transfer was sometimes shown the wrong way round. Common errors included omission of a positive charge on H_3O^+ and an equilibrium involving OH^- ions rather than water. Neither approach could be credited.
	b	i	Water dissociates / ionises **OR** $H_2O \rightleftharpoons H^+ + OH^-$ **OR** $2H_2O \rightleftharpoons H_3O^+ + OH^-$ ✓	1	**ALLOW** $K_w = [H^+] [OH^-]$ **OR** $[H^+] [OH^-] = 10^{-14}$ ($mol^2 dm^{-6}$) **IGNORE** breaking for dissociation **IGNORE** water contains H^+ and OH^- **IGNORE** $H_2O \rightarrow H^+ + OH^-$ *i.e. no equilibrium sign* **IGNORE** $2H_2O \rightarrow H_3O^+ + OH^-$ *i.e. no equilibrium sign* **Examiner's Comments** The key required feature was the

					dissociation of water but many instead discussed dissociation of the acid.
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = 1.15×10^{-11}, award 2 marks** .... $[H^+] = 10^{-3.06} = 8.71 \times 10^{-4}$ (mol dm^{-3}) ✓ $[OH^-] = \frac{1.00 \times 10^{-14}}{8.71 \times 10^{-4}} = 1.15 \times 10^{-11}$ (mol dm^{-3}) ✓ **ALLOW** answer to two or more significant figures 2SF: 1.1×10^{-11}; 4SF: 1.148×10^{-11}; calculator $1.148153621 \times 10^{-11}$	2	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below. .... **ALLOW 2 SF:** 8.7×10^{-4} up to calculator value of 8.7096359×10^{-4} correctly rounded **ALLOW** alternative approach using pOH: pOH = 14 − 3.06 = 10.94 ✓ $[OH^-] = 10^{-10.94} = 1.15 \times 10^{-11}$ (mol dm^{-3}) ✓ **Examiner's Comments** The majority of candidates correctly calculated the hydroxide ion concentration via K_w. Another less popular but successful approach was via pOH. Either approach could result in both marks. Weaker candidates were successful in calculating the hydrogen ion concentration but this was then often shown also as the hydroxide ion concentration in the final answer. Answer: 1.15×10^{-11} mol dm^{-3}
	c	i	$2CH_3COOH + CaCO_3 \rightarrow (CH_3COO)_2Ca + CO_2 + H_2O$ ✓	1	**IGNORE** state symbols **ALLOW** ⇌ provided that reactants on LHS For $CO_2 + H_2O$, **ALLOW** H_2CO_3 **ALLOW** $Ca(CH_3COO)_2$ **ALLOW** $(CH_3COO^-)_2Ca^{2+}$ **BUT DO NOT ALLOW** if either charge is missing or incorrect **Examiner's Comments** The equations seen were certainly better than in previous sessions, perhaps as candidates will have practised similar questions from past papers. Ionic signs within the formula of calcium ethanoate were allowed but both were then needed.

					Common errors included an incorrect formula of calcium ethanoate with one ethanoate group only and an unbalanced ethanoic acid on the left-hand side of the equation.
		ii	solution contains CH_3COOH **AND** CH_3COO^- ✓	1	**ALLOW** names: ethanoic acid for CH_3COOH ethanoate for CH_3COO^- **ALLOW** calcium ethanoate **OR** $(CH_3COO)_2Ca$ for CH_3COO^- **IGNORE** 'acid, salt, conjugate base; responses must identify the acid and conjugate base as ethanoic acid and ethanoate **IGNORE** ethanoic acid is in excess *(in question)* **BUT DO ALLOW** some ethanoic acid is left over / present / some ethanoic acid has reacted **IGNORE** equilibrium: $CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$ *Dissociation of ethanoic acid only* **Examiner's Comments** The mark scheme was specific in wanting the names or formulae of the components of the buffer solution and also the idea that some ethanoic acid remains. More general responses in terms of an acid and its conjugate base were not credited.
		iii	**Quality of written communication, QWC** 2 marks are available for explaining how the equilibrium system allows the buffer solution to control the pH on addition of H^+ and OH^- (see below) .... $CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$ ✓ .... CH_3COOH reacts with added alkali	5	***FULL ANNOTATIONS MUST BE USED*** .... **Note: If there is no equilibrium equation then the two subsequent equilibrium marks are not available: max 2** **DO NOT ALLOW** $HA \rightleftharpoons H^+ + A^-$ **DO NOT ALLOW** more than one equilibrium equation. .... **ALLOW** response in terms of H^+, A^- and HA

			OR $CH_3COOH + OH^- \rightarrow$ **OR** added alkali reacts with H^+ **OR** $H^+ + OH^- \rightarrow$ ✓ Equilibrium → right **OR** Equilibrium → CH_3COO^- ✓ (**QWC**) CH_3COO^- reacts with added acid ✓ Equilibrium → left **OR** Equilibrium → CH_3COOH ✓ (**QWC**)		**IF** more than one equilibrium shown, it **must** be clear which one is being referred to by labeling the equilibria. **ALLOW** weak acid reacts with added alkali **DO NOT ALLOW** acid reacts with added alkali **ALLOW** conjugate base reacts with added acid **DO NOT ALLOW** salt / base reacts with added acid **Examiner's Comments** The role of buffers in controlling pH is a common recall question and most candidates had prepared their rehearsed answers. Well-prepared candidates were thus able to collect full or nearly full marks for this part. There was a significant minority of candidates who had obviously not learnt this part of the specification and, despite their best efforts to invent answers, there was rarely anything that the examiners could credit. This was a great pity because marks were effectively being thrown away. Candidates are recommended to construct their responses using the weak acid equilibrium equation only. Some candidates shown both the correct relevant equilibrium but also others, including for calcium ethanoate. Subsequent explanations in terms of equilibrium were then ambiguous as the examiner could not tell which equilibrium was being discussed. Some candidates thankfully did label and reference multiple equilibria so that some credit could be awarded.
	d		**FIRST, CHECK THE ANSWER ON ANSWER LINE**	5	***FULL ANNOTATIONS MUST BE USED*** .... **IF** there is an alternative answer, check to see if there is any **ECF** credit possible.

			IF answer = 11.48 OR 11.5 (g), award 5 marks .... $[H^+] = 10^{-5}$ (mol dm^{-3}) ✓ .... **$[CH_3COO^-]$** = $\frac{1.75\times10^{-5}}{10^{-5}}$ ✓ × 0.200 = 0.350 mol dm^{-3} ✓ *n*(**CH_3COONa / CH_3COO^-**) in 400 cm^3 = 0.350 × $\frac{400}{1000}$ = 0.14(0) (mol) ✓ .... mass **CH_3COONa** = 0.140 × 82.0 = 11.48 **OR** 11.5 (g) ✓ For **ECF**, ***n*(CH_3COONa/CH_3COO^-) must** have been calculated in step before		**Incorrect use of $[H^+] = \sqrt{([CH_3COOH] \times K_a)}$ scores zero** **BUT IGNORE** if an alternative successful method is present **Incorrect use of K_w, 1 max for $[H^+] = 10^{-5}$ (mol dm^{-3})** **BUT IGNORE** if an alternative successful method is present .... **ALLOW** *n*(**CH_3COONa / CH_3COO^-**) = $\frac{1.75\times10^{-5}}{10^{-5}}$ ✓ × 0.08 = 0.14(0) (mol) ✓✓ **Note: There is no mark just for** *n*(**CH_3COOH**) in 400 cm^3 = 0.200 × $\frac{400}{1000}$= 0.08 (mol) .... As alternative for the 4th and 5th marks, **ALLOW**: mass of CH_3COONa in 1 dm^3 = 0.350 × 82.0 = 28.7 g ✓ mass of CH_3COONa in 400 cm^3 = 28.7 × $\frac{400}{1000}$= 11.48 g ✓ .... **COMMON ECF** 4.592 **OR** 4.6 g **AWARD** 4 marks *use of 400 / 1000 twice* **ALLOW** variants of Henderson—Hasselbalch equation. $pK_a = -\log(1.75 \times 10^{-5}) = 4.757$ ✓ *Calc: 4.75696. … .* $\log\frac{[CH_3COO^-]}{[CH_3COOH]} = pH - pK_a = 5 - 4.757$ = 0.243 $\frac{[CH_3COO^-]}{[CH_3COOH]} = 10^{0.243} = 1.75$ ✓ $[CH_3COO^-]$ = 1.75 × 0.200 = 0.350 mol dm^{-3} ✓

					n(CH_3COONa/CH_3COO^-) in 400 cm^3 $= 0.350 \times \frac{400}{1000} = 0.14(0)$ (mol) ✓ .... mass CH_3COONa = 0.140 × 82.0 = 11.48 **OR** 11.5 (g) ✓ **Examiner's Comments** Able candidates answered this question with comparative ease, collecting all five marks for a carefully constructed answer. This was in contrast to weaker candidate who struggled, often resorting to the 'square root' method for calculating the pH of a weak acid. The calculation started off with an easy mark for calculating the hydrogen ion concentration from the pH. Unfortunately, this 'square root' method then resulted in another hydrogen ion concentration which contradicted the original. Other weak candidates resorted to use of K_w. The result was that weaker candidates would often score no marks at all for this part. Many candidates were aware of the importance of the acid/base ratio in buffer calculations and were able to gain at least some marks for this part. The commonest error in partially successful responses was with the scaling factor of 400/1000, being either omitted to give an answer of 28.7 g, or used twice to give an answer of 4.952 g Answer: 11.48 g
			Total	**17**	
14	a		Proton / H^+ donor **AND** Partially dissociates / ionises ✓	1	**Examiner's Comments** For most candidates, this was an easy mark, although some only responded for a weak acid (partial dissociation) or for a Brønsted–Lowry acid (proton donor).
	b		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 13.7(0), award **2 marks**		

			$[H^+] = \frac{1.00 \times 10^{-14}}{0.5(00)}$ **OR** $2(.00) \times 10^{-14}$ (mol dm^{-3}) ✓ pH = −log 2(.00) × 10^{-14} = **13.7(0)** ✓	2	For pOH method:, **ALLOW** pOH = $-\log[OH^-]$ = 0.3(0) ✓ (calculator 0.301029995) **ALLOW** pH = 14 − 0.3 = 13.7 ✓ **ALLOW** 13.7 up to calculator value of 13.69897 correctly rounded. **ALLOW ECF** from incorrect $[H^+(aq)]$ provided that pH > 7 **Examiner's Comments** The majority of candidates correctly calculated the pH via K_w. Another less popular but successful approach was via pOH. Either approach could result in both marks. Weaker candidates sometimes calculated the pH as 0.30 (from −log 0.500). This gained no credit. Answer: pH = 13.70
	c	i	$(K_a =) \frac{[H^+]\,[C_2H_5COO^-]}{[C_2H_5COOH]}$ ✓	1	**IGNORE** $\frac{[H^+]^2}{[C_2H_5COOH]}$ **OR** $\frac{[H^+]\,[A^-]}{[HA]}$ **ALLOW** $[H_3O^+]$ for $[H^+]$ **IGNORE** state symbols **Examiner's Comments** Almost all candidates successfully wrote the expression for K_a. Responses using $[H^+(aq)]^2$ were not credited. Rarely, the expression was shown inverted or square brackets were omitted from one or more of the terms. Candidates are recommended to carefully check the formulae as this easy mark was sometimes not awarded for a missing C atom within a formula (even in the scripts of able candidates).
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = **2.9(0)**, award **3 marks** .... $[C_2H_5COOH]$ = 0.12(0) mol dm^{-3} ✓ $[H^+] = \sqrt{K_a \times [C_2H_5COOH]} = \sqrt{1.35 \times 10^{-5} \times 0.12(0)}$		**ALLOW** HA for C_2H_5COOH and A^- for $C_2H_5COO^-$

			OR 1.27×10^{-3} (mol dm^{-3}) ✓		**ALLOW ECF** from incorrectly calculated $[C_2H_5COOH]$ **ALLOW** 1.27×10^{-3} to calculator value of $1.272792206 \times 10^{-3}$ correctly rounded
		ii	pH = −log 1.27×10^{-3} = **2.9(0)** ✓ **NOTE**: The final two marks are **ONLY** available from attempted use of K_a **AND** $[C_2H_5COOH]$	3	**ALLOW** $2.9(0) \times 10^{-3}$ to calculator value of 2.895242493 correctly rounded **ALLOW** use of quadratic equation which gives same answer of 2.90 from 0.120 mol dm^{-3} .... **COMMON ERRORS (MUST be to AT LEAST 2 DP unless 2nd decimal place is 0)** **pH = 2.59 2 marks** $-\log\sqrt{(1.35 \times 10^{-5} \times 0.480)}$ *Original conc* **pH = 5.79 2 marks** $-\log(1.35 \times 10^{-5} \times 0.120)$ *No* √ **pH = 5.19 1 mark** $-\log(1.35 \times 10^{-5} \times 0.480)$ *Original conc, no* √ **pH = 4.87 0 marks** $-\log(1.35 \times 10^{-5})$ = 4.87 $-\log K_a$ **Examiner's Comments** This part discriminated extremely well. The added stage of an initial dilution to a stock weak acid pH calculation created problems for many candidates. Although most were able to use the correct square root expression to obtain a value for $[H^+(aq)]$, the concentration used was often incorrect. Although just a four times dilution from 0.480 mol dm^{-3} to 0.120 mol dm^{-3}, many candidates obtained 0.120 using learnt equations rather than the simple ratio. Others used the original concentration of 0.480 mol dm^{-3} or incorrectly calculated concentrations, commonly seen as 0.0480, 0.0120 or even 0.192 (from × 4). Some candidates calculated $[H^+(aq)]$ using 0.480 mol dm^{-3} but then divided by 4 before calculating

					the pH. Able candidates invariably obtained the correct pH but many obtained pH values from the values above such as a pH of 2.59 (from 0.480 mol dm^{-3}), for which partial credit could be awarded. Answer: pH = 2.90
	d	i	pH = −log 1.35 × 10^{-5} = **4.87** ✓	1	**ONLY** correct answer **DO NOT ALLOW** 4.9 *(Question asks for 2 DP)* **Examiner's Comments** Some candidates correctly calculated the pH here as −log Ka but most used the standard buffer pH method, using a 1:1 acid–base ratio. Weak candidates often first took the square root of the Ka value, obtaining a pH of 2.43. Unfortunately, some candidates rounded a correct pH to 4.9, despite a two decimal place requirement being emphasised in the question. Answer: pH = 4.87
		ii	**Added ammonia** C_2H_5COOH removes added NH_3 / alkali / base **OR** $C_2H_5COOH + NH_3$ / OH^- → **OR** NH_3 / alkali reacts with / accepts H^+ **OR** $H^+ + NH_3$ → **OR** $H^+ + OH^-$ → ✓		**ALLOW** use of HA / weak acid / acid for C_2H_5COOH; **ALLOW** use of NH_4OH for NH_3
		ii	Equlibrium → $C_2H_5COO^-$ **OR** Equilibrium → right ✓	2	**ALLOW** A^- for $C_2H_5COO^-$ **ASSUME** that equilibrium applies to that supplied in the question, i.e. **IGNORE** any other equilibria **Examiner's Comments** The role of buffers in controlling pH is a common recall question and most candidates had prepared their rehearsed answers. Although this question asked for the addition of ammonia as a specific base, all but the weakest candidates identified that this was a question about addition of a base. The commonest and best answers stated that NH_3 accepts a

					proton to form NH_4^+ (with many ionic equations seen). The correct equilibrium shift was usually included.
		iii	***CHECK WORKING CAREFULLY AS CORRECT NUMERICAL ANSWER IS POSSIBLE FROM WRONG VALUES*** ………………………………………………………… **ALLOW** HA and A^- throughout **Amount of Mg (1 mark)** $n(Mg) = \frac{6.075}{24.3} = 0.25(0)$ mol ✓ ………………………………………………………… **Moles / concentrations (2 marks)** $n(C_2H_5COOH) = 1.00 - (2 \times 0.25) = 0.50$ (mol) ✓ $n(C_2H_5COO^-) = 1.00 + (2 \times 0.25) = 1.50$ (mol) ✓ ………………………………………………………… **[H^+] and pH (1 mark)** $[H^+] = 1.35 \times 10^{-5} \times \frac{0.50}{1.50}$ **OR** 4.5×10^{-6} (mol dm^{-3}) pH = $-\log 4.5 \times 10^{-6}$ = **5.35 2 dp required** ✓ **NOTE: IF there is no prior working,** **ALLOW 4 MARKS for** $[H^+] = 1.35 \times 10^{-5} \times \frac{0.50}{1.50}$ **AND** pH **IF the ONLY response is pH = 5.35, award 1 mark ONLY** ………………………………………………………… **Award a maximum of 1 mark (for *n*(Mg) = 0.25 mol) for:** pH value from K_a square root approach (weak acid pH) pH value from K_w / 10^{-14} approach (strong base pH) ………………………………………………………… **ALLOW** alternative approach based on Henderson−Hasselbalch equation for final 1 mark $pH = pK_a + \log\frac{1.5}{0.5}$ **OR** $pK_a - \log\frac{0.5}{1.5}$ pH = 4.87 + 0.48 = 5.35 ✓**ALLOW** $-\log K_a$ for pK_a	4	***FULL ANNOTATIONS MUST BE USED*** ………………………………………………………… **For *n*(Mg), 1 mark** **ALLOW ECF for ALL** marks below from incorrect *n*(Mg) **ECF ONLY** available from concentrations that have • subtracted 0.50 **OR** 0.25 from 1 for [C_2H_5COOH] • added 0.50 **OR** 0.25 to 1 for [$C_2H_5COO^-$] ***i.e.*** **For moles / concentration 1 mark (1 mark lost)** 1. $n(C_2H_5COOH) = 0.75$ **AND** $n(C_2H_5COO^-) = 1.25$ 2. $n(C_2H_5COOH) = 0.50$ **AND** $n(C_2H_5COO^-) = 1.25$ 3. $n(C_2H_5COOH) = 0.75$ **AND** $n(C_2H_5COO^-) = 1.50$ ………………………………………………………… **ALLOW ECF ONLY** for the following giving 1 additional mark and a total of **3 marks** 1. $[H^+] = 1.35 \times 10^{-5} \times \frac{0.75}{1.25}$ pH = $-\log 8.1 \times 10^{-6}$ 2. $[H^+] = 1.35 \times 10^{-5} \times \frac{0.50}{1.25}$ pH = $-\log 5.4 \times 10^{-6}$ 3. $[H^+] = 1.35 \times 10^{-5} \times \frac{0.75}{1.50}$ pH = $-\log 6.75 \times 10^{-}$ **Examiner's Comments** This buffer calculation was aimed as stretch and challenge and the majority of candidates struggled to derive the concentrations of CH_3CH_2COOH and $CH_3CH_2COO^-$. An easy mark for the amount of magnesium added was available for almost all candidates. The problem was then to derive the amount and concentration of CH_3CH_2COOH that

					would be obtained 0.500 mol^{-3}. Many did not identify that Mg and CH_3CH_2COOH react in a 1:2 molar ratio, subtracting 0.25, instead of 0.50, from the original concentration. Rarely did candidates realise that the $CH_3CH_2COO^-$ concentration would increase from the initial concentration of 1 mol dm^{-3}. Others assumed that no $CH_3CH_2COO^-$ was present at the start. Consequently, candidates often used a variety of acid–base ratios in their buffer calculation. Instead of the correct ratio of 0.5/1.5, it was very common to see 0.75/1.25, 0.75/0.25, and especially 0.5/1, 0.75/1 and 0.25/1.0. The very best candidates tackled the problem with apparent ease but this was seen comparatively rarely in scripts of other candidates. Answer: pH = 5.35
			Total	**14**	
1 5		i	CN^- + H_2O ⇌ **HCN** + **OH^-** **AND** Base 2 Acid 1 Acid 2 Base 1 ✓	1	State symbols **NOT** required **ALLOW** CNH and HO^- (i.e. any order) **ALLOW** 1 **and** 2 labels the other way around. **ALLOW** 'just acid' and 'base' labels throughout if linked by lines so that it is clear what the acid-base pairs are. **Examiner's Comments** The majority of candidates were able to complete the equation for acid–base equilibrium and to identify the acid–base pairs. Candidates are advised to use numbers to label the acid–base pairs, such as 'acid 1' and 'base 1'. Attempts at using 'acid' and 'conjugate base' are ambiguous when more than one acid–base pair is involved. Although credited, it was strange to see hydrogen cyanide often written as CNH.
		ii	H^+ reacts with CN^- **OR** HCN forms **OR** equation: $H^+ + CN^- \rightarrow HCN$ (**ALLOW** ⇌)	1	**ALLOW** Acid reacts with / removes OH^- ions (to form HCN) **ALLOW** CNH (i.e. any order)

			OR CN^- accepts a proton / H^+ **OR** equilibrium shifts right **AND** CN^- is removed ✓		**IGNORE** other equilibrium comments **Examiner's Comments** The majority of candidates recognised that acid conditions would lead to protonation of CN^-forming toxic HCN.
			Total	**2**	
16	a		$(K_a =) \frac{[H^+]\,[NO_2^-]}{[HNO_2]}$ ✓ **IGNORE** state symbols	1	**IGNORE** $\frac{[H^+]^2}{[HNO_2]}$ **OR** $\frac{[H^+]\,[A^-]}{[A]}$ **ALLOW** H_3O^+ for H^+ Square brackets **required** **Examiner's Comments** Almost all candidates successfully wrote the expression for K_a. Responses using $[H^+(aq)]^2$ were not credited. Rarely, the expression was shown inverted or square brackets were omitted from one or more of the terms. For most candidates, this was an easy mark.
	b		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 2.12 award **2 marks** .... $[H^+] = \sqrt{K_a \square [HNO_2]} = 7.502 \times 10^{-3}$ (mol dm^{-3}) ✓ pH = −log 7.502×10^{-3} = 2.12 ✓ **pH to 2 DP**	2	.... **ALLOW** intermediate value from 3 SF (7.50 up to calculator value of $7.501999733 \times 10^{-3}$ **ALLOW** 1 mark for 2.1 **OR** answer > 2 DP (i.e. not 2 DP) **ONLY ALLOW** pH mark by **ECF** if K_a **AND** 0.120 used and **AND** pH < 7 .... **COMMON ERRORS (MUST be to 2 DP)** **pH = 4.25 No square root:1 mark** $[H^+] = (4.69 \times 10^{-4} \times 0.120) = 5.628 \times 10^{-5}$ (mol dm^{-3}) pH = −log 5.628×10^{-5} = 4.25 ✓ **pH = 0.92 no K_a used:** **zero marks** pH = −log 0.120 = 0.92

					pH = 13.08 K_w / pOH used: **zero marks** pH = $-\log \frac{1.00 \times 10^{-4}}{0.120}$ **OR** 14 – log 0.120 = 13.08 **Examiner's Comments** Most candidates calculated $[H^+]$ as the square root of $K_a \times [HNO_2]$, and then the correct pH value. The commonest errors were incorrect rounding of the pH value (e.g. 2.13) and missing out the square root (giving 4.25). Answer: pH = 2.12
	c	i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = **3.43**, **AWARD 4 marks** …………………………………………… *Expression: K_a × acid / base ratio* Use of $K_a \times \frac{[HNO_2]}{[NO_2^-]}$ **OR** $4.69 \times 10^{-4} \times \frac{[HNO_2]}{[NO_2^-]}$ ✓ *Using correct concs / mol in expression* $[H^+] = 4.69 \times 10^{-4} \times \frac{0.0400}{0.0500}$ ✓ *Subsumes previous mark* *Calculation of* $[H^+]$ $[H^+] = 3.752 \times 10^{-4}$ (mol dm^{-3}) ✓ *pH to 2 DP (From 3.42573717)* pH = $-\log 3.752 \times 10^{-4}$ = 3.43 ✓ **NO marks** are available using K_a square root approach (weak acid pH) $K_w/10^{-14}$ approach (strong base pH) …………………………………………… **ALLOW** alternative approach based on Henderson–Hasselbalch equation (**ALLOW** $-\log K_a$ for pK_a) pH = pK_a + log $\frac{[NO_2^-]}{[HNO_2]}$ **OR** pK_a – log $\frac{[HNO_2]}{[NO_2^-]}$ ✓ pH = pK_a + log $\frac{0.0500}{0.0400}$ **OR** pK_a – log $\frac{0.0400}{0.0500}$ ✓ pH = pK_a + 0.097 ✓ pH = 3.329 + 0.097 = 3.43 ✓	4	***FULL ANNOTATIONS MUST BE USED*** …………………………………………… **ALLOW** just $K_a \times \frac{acid}{salt}$ *expression* **Mark** by **ECF** from $4.69 \times 10^{-4} \times \frac{[NO_2^-]}{[HNO_2]}$ *inverted expression* **Mark** by **ECF** from incorrect $[HNO_2]$ and $[NO_2^-]$ **ONLY** award **marks** for a pH calculation via K_a **AND** using concentrations / mol derived from the question **DO NOT ALLOW** final pH mark by **ECF** if pH > 7 …………………………………………… **COMMON ERRORS BUT CHECK WORKING** **pH = 2.82 3 marks** initial concs: 0.200 and 0.0625 **pH = 3.23 3 marks** 0.0400 and 0.0500 acid / base ratio inverted **pH = 3.83 2 marks** initial concs: 0.200 and 0.0625 and ratio inverted **pH = 2.73 3 marks**

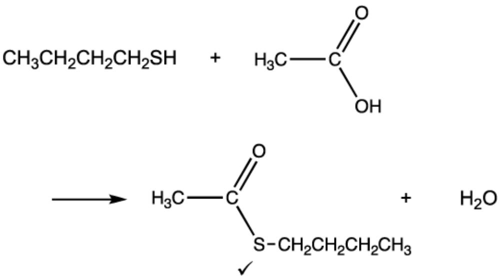
					Incorrect $[NO_2^-]$ = 0.01 and correct $[HNO_2]$ = 0.04 **pH = 4.03 3 marks** correct $[NO_2^-]$ = 0.05 and incorrect $[HNO_2]$ = 0.01 **Examiner's Comments** This buffer calculation was easier than some on recent papers as the equilibrium moles had been provided. Some candidates tried to mimic the approach for a more complex calculation, introducing errors where there were none. The simpler problem allowed more candidates to obtain the correct value for the pH of the buffer solution than in recent examinations. Answer: pH = 3.43
		ii	**Equilibrium: 1 mark** $HNO_2 \rightleftharpoons H^+ + NO_2^-$ ✓ (ignore state symbols) **Control of pH: 2 marks (QWC)** ***Added HCl*** NO_2^- reacts with added acid / HCl / H^+ **OR** $NO_2^- + H^+ \rightarrow$ **OR** more HNO_2 forms ✓ ***Added NaOH*** HNO_2 reacts with added alkali / NaOH / OH^- **OR** $HNO_2 + OH^- \rightarrow$ **OR** more NO_2^- forms **OR** H^+ reacts with added alkali / NaOH **OR** $H^+ + OH^- \rightarrow$ ✓ **Equilibrium shift:** **1 mark for shifts in $HNO_2 \rightleftharpoons H^+ + NO_2^-$ (See 1st mark)** Equilibrium for added **acid** → **left** **AND** Equilibrium for added **alkali** → **right** ✓ (QWC)	4	***FULL ANNOTATIONS MUST BE USED*** .... **IGNORE** $HA \rightleftharpoons H^+ + A^-$ Equilibrium sign **essential** **BUT ALLOW** small slips in its appearance if it is obviously an attempt to show an equilibrium sign rather than an arrow **QWC: Quality of written communication** **DO NOT ALLOW** HA and A^- for HNO_2 and NO_2^- **IGNORE just** acid reacts with added alkali **IGNORE just** conjugate base / salt / base reacts with added acid **DO NOT ALLOW** salt / base reacts with added acid **AWARD** 'shift mark' **ONLY** if correct equilibrium equation has been given **IGNORE** any other equilibria in response

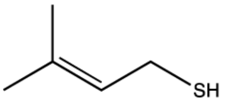
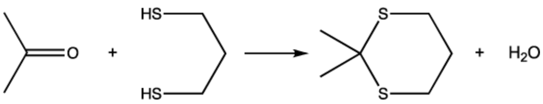
					Examiner's Comments The role of buffers in controlling pH is a common question and most candidates had prepared their rehearsed answers. Consequently these candidates could obtain the four marks easily. As always, candidates who had not learnt the work produced muddled responses that made little sense and could not be credited.
	d	i	Endothermic **AND** K_w increases with temperature **OR** Endothermic **AND** dissociation increases **with temperature** **OR** Endothermic **AND** (dissociation) involves breaking bonds ✓	1	Endothermic **and** reason required for the mark **ALLOW** Endothermic **AND** increasing temperature shifts equilibrium / reaction to the right / favours forward reaction **DO NOT ALLOW** breaking hydrogen bonds **OR** intermolecular bonds / forces **Examiner's Comments** Candidates were expected to predict the type of energy change using the provided information. Credit was given for responses linking an endothermic change with the increase of K_w with temperature or breaking bonds during dissociation.
		ii	***OH^- concentration*** $[OH^-] = \frac{9.311 \times 10^{-14}}{1.00 \times 10^{-7}} = 9.311 \times 10^{-7}$ (mol dm^{-3}) ✓ ***Explanation (dependent on 1st mark)*** $9.311 \times 10^{-7} > 1.(00) \times 10^{-7}$ **OR** $[OH^-] > [H^+]$ **OR** OH^- in excess **AND** Alkaline ✓	2	***H^+ OR OH^- concentration (neutral pH)*** $[H^+] = [OH^-] = \sqrt{(9.311 \times 10^{-14})} = 3.05 \times 10^{-7}$ (mol dm^{-3}) ✓ ***Explanation (dependent on 1st mark)*** pH = −log (3.05×10^{-7}) = 6.5 → 6.515501837 (calc) **AND** Alkaline ✓ **Examiner's Comments** Most candidates calculated a value for $[H^+]$ using the K_w value at 60°C. Many recognised that $[OH^-] > [H^+]$ giving an alkaline solution. An alternative and equally valid method seen was to calculate the pH of a neutral solution at

					60°C as 6.52 and then to relate water at a pH of 7 as being alkaline. Many using this approach thought that water would be acidic rather than alkaline, presumable because 6.52 < 7.00.
		iii	pK_w = 13.03 ✓	1	**ONLY** correct answer **Examiner's Comments** Despite the novel context, almost all candidates obtained the correct pK_w value of 13.03.
		iv	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = **10.76**, award **3 marks** .... ***Dilution 1 mark*** $[OH^-(aq)] = [NaOH(aq)] = \frac{0.0270}{5} = 0.00540$ (mol dm^{-3}) ✓ ***[H⁺] 1 mark*** $[H^+(aq)] = \frac{9.311 \times 10^{-14}}{0.00540} = 1.72 \times 10^{-11}$ (mol dm^{-3}) ✓ Calculator: $1.724259259 \times 10^{-11}$ ***pH 1 mark*** pH = −log 1.72×10^{-11} = **10.76** ✓ .... **ALLOW** pOH method for 2nd and 3rd mark: pOH = −log 0.00540 = 2.27 ✓ (calculator 2.26760624) pH = 13.03 − 2.27 = 10.76 ✓	3	***FULL ANNOTATIONS MUST BE USED*** .... **ALLOW** dilution **AFTER** calculation of $[H^+(aq)]$ i.e. original $[H^+] = \frac{9.311 \times 10^{-14}}{0.0270} = 3.45 \times 10^{-12}$ (mol dm^{-3}) After dilution, $[H^+] = 3.45 \times 10^{-12} \times 5 = 1.72 \times 10^{-11}$ (mol dm^{-3}) ✓ pH = −log 1.72×10^{-11} = **10.76** ✓ **ALLOW ECF** from incorrect $[H^+(aq)]$ provided that pH > 7 .... **COMMON ERRORS (MUST be to 2 DP)** **pH = 11.73** At 25°C (1.00×10^{-14}): **2 marks** pH = −log 1.85×10^{-12} = **11.73** **pH = 11.46** No dilution at 60°C (9.311×10^{-14}) **2 marks** pH = −log(3.45×10^{-12}) = **11.46** **pH = 12.43** No dilution **AND** 25°C (1.00×10^{-14}) **1 mark** pH = −log(3.70×10^{-13}) = **12.43** **pH = 12.16** × 5 instead of ÷ 5 at 60°C (9.311×10^{-14}) **2 marks** pH = −log(6.879×10^{-13}) = **12.16** **pH = 13.13 ×** 5 instead of ÷ 5 at 25°C (1.00×10^{-14}) **1 mark** pH = −log(7.407×10^{-14}) = **13.13** **NOTE:** Attempts at dilution → 0.0270 with error in powers of 10 → 12.46 from 0.00270, etc may give 2 marks by **ECF**

					Examiner's Comments The majority of candidates correctly calculated the pH via K_w but many had problems in initially deriving the concentration of the diluted solution of NaOH. Some candidates did not consider the dilution at all; others produced long calculations of this simple dilution, obtaining an array of concentrations. Provided that this concentration was then converted to a pH by a correct method, credit could still be given for the second part of the problem. Answer: pH = 10.76
			Total	**18**	
17			**B**	1	
			Total	**1**	
18	a	i	(K_a =) $\frac{[H^+][C_6H_7O_6^-]}{[C_6H_8O_6]}$ ✓ **ALL** species **MUST** have square brackets State symbols **not** required **TAKE CARE** that 'H' is different on top and bottom of expression	1	**ALLOW** $[H_3O^+]$ for $[H^+]$ **IGNORE** state symbols, even if wrong **IGNORE** $\frac{[H^+]^2}{[C_6H_8O_6]}$ **OR** $\frac{[H^+]^2[A^-]}{[HA]}$
		ii	$pK_a = -\log K_a = -\log (6.76 \times 10^{-5}) = 4.17$ ✓	1	Answer required to **two DP**
		iii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer** = 2.82 award 4 marks .... ***n*(vitamin C)** = $\frac{3 \times 0.500}{176}$ = $8.52(2) \times 10^{-3}$ (mol) ✓ **[vitamin C]** = $8.52 \times 10^{-3} \times \frac{1000}{250}$ = 0.0341 (mol dm^{-3}) ✓ **$[H^+]$** = $\sqrt{(K_a \times [C_6H_8O_6])}$ **OR** $\sqrt{(6.76 \times 10^{-5} \times 0.0341)}$ **OR** 1.52×10^{-3} mol dm^{-3} ✓ **pH** = $-\log(1.52 \times 10^{-3}) = 2.82$ ✓ Answer required to **two DP**	4	**ALLOW ECF** from incorrect *n*(vitamin C) **ALLOW ECF** from incorrect [vitamin C] **must** be derived from $\sqrt{(K_a \times [C_6H_8O_6])}$ **ALLOW ECF** from incorrect $[H^+]$ but **ONLY** if derived from $\sqrt{(K_a \times [C_6H_8O_6])}$

	b	i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF ratio** = 0.708 award 3 marks .... $[H^+] = 10^{-pH} = 10^{-4.02} = 9.55 \times 10^{-5}$ (mol dm^{-3}) ✓ $\frac{[C_6H_7O_6^-]}{[C_6H_8O_6]} = \frac{K_a}{[H^+]} = \frac{6.76 \times 10^{-5}}{9.55 \times 10^{-5}}$ ✓ $= \frac{0.708}{1}$ ✓	3	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below .... ***ANNOTATIONS MUST BE USED*** **ALLOW ALTERNATIVE** using Henderson−Hasselbalch equation .... **ALLOW** 9.55×10^{-5} up to calculator value of $9.54992586 \times 10^{-5}$ correctly rounded **ALLOW** ECF from incorrect $[H^+]$ **ALLOW** 0.71 (2 SF) up to calculator value correctly rounded
		ii	mass of $C6H_7O_6Na = 0.708 \times \frac{300}{176} \times 198.0$ = 239 **OR** 240 (mg) ✓	1	**ALLOW ECF** from answer to **(i)**
	c		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer** = 0.0524 (mol dm^{-3}) award 2 marks .... $[H^+(aq)] = 10^{-pH} = 10^{-12.72}$ $= 1.91/1.9 \times 10^{-13}$ (mol dm^{-3}) ✓ $[NaOH] / [OH^-(aq)] = \frac{K_w}{[H^+(aq)]} = \frac{1.0 \times 10^{-14}}{1.91 \times 10^{-13}}$ = 0.0524 (mol dm^{-3}) ✓	2	**ALLOW** alternative approach via pOH pOH = 14 − 12.72 = 1.28 ✓ $[NaOH] / [OH^-(aq)] = 10^{-pOH}$ = 0.0524 (mol dm^{-3}) ✓ **ALLOW** any value between 0.052 and 0.053 *answer depends on degree of rounding for H^+ but 2 SF minimum* calculator: 0.052480746
			Total	**12**	
19		i	Complete dissociation would give $[H^+]$ = 0.2 (mol dm^{-3}) ✓ pH from complete dissociation = −log 0.2 = 0.7 **OR** actual $[H^+] = 10^{-0.96}$ = 0.11 (mol dm^{-3})✓	3	

			Stage 1 is complete dissociation **AND** **Stage 2** is partial dissociation ✓		**IGNORE Stage** 1 is a strong acid **AND Stage 2** is a weak acid.
		ii	Observation: fizzing ✓ H^+ reacts with carbonate **AND** (Stage 2) equilibrium shifts to the right ✓	2	**ALLOW** effervescence/'bubbling'
			Total	**5**	
20			**C**	1	**ALLOW** 4.1 in the box
			Total	**1**	
21		i	$K_a = \frac{[H^+][C_4H_9S^-]}{[C_4H_9SH]}$ ✓ *Square brackets required*	**1**	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non- ambiguous **Examiner's Comment:** This part was very well answered. Candidates responded with either near molecular formulae, such as C_4H_9SH, structural formulae or with skeletal formulae. Some candidates made careless errors such as omitting the negative charge or showing $[H^+]^2$ as numerator rather than $[C_4H_9S^-][H^+]$.
		ii	 Structure of thioester ✓ Complete equation ✓	**2**	**ALLOW** correct skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous **ALLOW** C_4H_9SH **ALLOW** CH_3COOH Thioester functional group **must** be fully displayed, **OR** as a skeletal formula but allow SC_4H_9 in thioester **Examiner's Comment:** In this part, candidates were expected to apply their knowledge and understanding of esterification to thiols and thioesters. Over half the candidates obtained a correct structure of the thioester. Most of these candidates constructed a balanced

					equation although some omitted the water product. Common errors included formation of a conventional ester and H_2S, and retaining the O atom from the OH in the carboxyl group to form –COOS–. As with 4(b)(i), structural and skeletal formulae were used. Candidates are less likely to omit H atoms if the skeletal formula is used.
		iii	 ✓	**1**	**IF** correct **skeletal** formula is shown, **IGNORE** displayed formula in a second structure **Examiner's Comment:** Just over half the candidates drew the correct structure, displaying a good understanding of interpreting organic nomenclature when drawing a structure. Common errors included omission of the CH_2 adjacent to the terminal –SH group and placing the branch or double bond in wrong positions. Some candidates spoilt an otherwise good response by showing a structural formula or a mixture of skeletal and structural formulae.
		iv	 Reactants ✓ Products **AND** balanced equation ✓	**2**	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non- ambiguous **Examiner's Comment:** In this part, candidates were expected to apply their knowledge and understanding of condensation to an entirely new context. One mark was allocated for the reactants and this was usually scored. The second mark for the novel cyclic compound and water was much more difficult, aimed at stretch and challenge. A significant number of candidates interpreted the information to obtain a correct cyclic structure but this mark was the domain of the most able candidates.
			Total	**6**	

2 2	a		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = **0.753,** award **3 marks** …………………………………………………… [H+] m= $10^{-pH} = 10^{-2.440} = 3.63 \times 10^{-3}$ (mol dm^{-3}) ✓ $[CH_3COOH] = \frac{[H^+]^2}{K_a}$ **OR** $\frac{(3.63 \times 10^{-3})^2}{1.75 \times 10^{-5}}$ ✓ = 0.753 (mol dm^{-3}) ✓	3	**ALLOW** use of **HA** and **A^-** **ALLOW 3 SF** up to calculator value of $3.630780548 \times 10^{-3}$ correctly rounded **NOTE:** Answer is same from unrounded $[H^+]$ calculator value and 3 SF $[H^+]$ value **ALLOW** 0.749 if $[H^+]$ has been subtracted from $[CH_3COOH]$ for greater accuracy at end **Examiner's Comments** Most candidates coped with this commonly seen type of calculation and were able to correctly calculate the concentration of the weak acid
	b		$CH_3COOH + FCH_2COOH \rightleftharpoons CH_3COOH_2^+ + FCH_2COO^-$ ✓ **B2 A1 A2 B1** **OR** **B1 A2 A1 B2** ✓ *i.e. labels other way round*	2	Watch for opposite order on RHS, i.e.: $FCH_2COO^- + CH_3COOH_2^+$ Take **great care** matching labels **ALLOW ECF** for incorrect proton transfer as below. This is the **ONLY ECF** $CH_3COOH + FCH_2COOH \rightleftharpoons CH_3COO^- + FCH_2COOH_2^+$ × **A1 B2 B1 A2** **OR** **A2 B1 B2 A1** ✓**ECF** *i.e. labels other way round* **Examiner's Comments** For the able candidate, this question was quite straightforward but for the weaker candidate, there were many pitfalls. Candidates struggled with the idea that

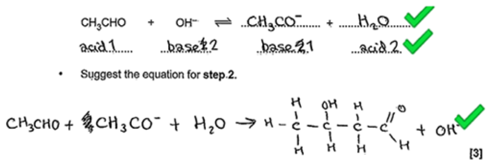
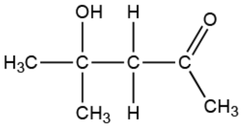
					the equilibrium needed a positive ion and a negative ion on the product side. Others were unable to use K_a values in order to decide which of the two starting acids should become protonated. Finally, the assigning of the conjugate acid-base pairs was also challenging.
	c	i	**$[CH_3COO^-]$** $n(CH_3COONa) = \frac{9.08}{82.0}$ **OR** 0.111 ✓ (Calc: 0.110731 $[CH_3COO^-] = \frac{9.08}{82.0} \times \frac{1000}{250} = 0.443$ (mol dm^{-3}) **OR** $n(CH_3COOH) = 0.800 \times \frac{250}{1000} = 0.200$ (mol) ✓ **$[H^+]$** $[H^+] = K_a \times \frac{[CH_3COOH]}{[CH_3COO^-]}$ **OR** $K_a \times \frac{n(CH_3COOH)}{n(CH_3COO^-)}$ $= 1.75 \times 10^{-5} \times \frac{0.800}{0.443}$ **OR** $1.75 \times 10^{-5} \times \frac{0.20}{0.11}$ $= 3.16 \times 10^{-5}$ (mol dm^{-3}) ✓ **pH** **(must come from *calculated* [H+])** pH = −log (3.16×10^{-5}) = 4.50 ✓ .... **LAST 3 marks** are **NOT** available using • K_a square root approach (weak acid pH) • $K_w/10^{-14}$ approach (strong base pH) .... **Henderson-Hasselbalch (HH) alternative** pKa = −log 1.75×10^{-5} = 4.757 (or 4.756961951..) $pH = pK_a + \log \frac{[CH_3COO^-]}{[CH_3COOH]}$ **OR** $= pK_a - \log \frac{[CH_3COOH]}{[CH_3COO^-]}$ **OR** $pK_a + \log \frac{0.443}{0.800}$ **OR** $= pK_a - \log \frac{0.800}{0.443}$ ✓ $= pK_a - 0.257$ ✓ $= 4.757 - 0.257 = 4.50$ ✓	5	**ALLOW** 2 sig fig **ALLOW** use of **HA** and **A$^-$** Mark by **ECF** .... **Alternative method** (If both methods are attempted, mark the method which produces the higher mark) **[H+]** $[H^+] = 10^{-pH} = 10^{-4.50}$ $= 3.16 \times 10^{-5}$ (mol dm^{-3}) ✓ **$[CH_3COO^-]$** $[CH_3COO^-] = K_a \times \frac{[CH_3COOH]}{[H^+]}$ **OR** $1.75 \times 10^{-5} \times \frac{0.800}{3.16 \times 10^{-5}}$ ✓ $= 0.443$ (mol dm^{-3}) ✓ **mass of CH_3COONa** mass $CH_3COONa = 0.443 \times \frac{250}{1000}$ **OR** 0.111 ✓ $0.111 \times 82.0 =$ **9.08** (g) ✓ .... **Common errors** **4.64** Use of $M(CH_3COONa) = 60$ 4 marks **2.40** Use of K_a of FCH_2COOH 4 marks **Examiner's Comments** This question caused difficulty for all but the more able. For many weaker candidates getting beyond a concentration of CH_3COONa was a problem. Once again, candidates should

					be advised to show every step in their calculation. This would allow method marks to be applied in the absence of a correct final answer.
		ii	pH is the same/constant ✓ ratio/proportion [HA]/[A^-] is the same ✓	2	M2 is dependent upon M1 **ALLOW** Change in [HA] and [A^-] is proportional **Examiner's Comments** Only the very able were able to explain that the ratio of concentrations of acid and salt would remain constant and as K_a is constant, [H^+] and therefore pH would remain constant.
			Total	**12**	
23			**C**	**1 (AO 2.6)**	**Examiner's Comments** This relatively difficult pH calculation was readily done successfully by higher ability candidates, but lower ability candidates found it difficult, with answer B proving a popular choice.
			Total	**1**	
24	a	i	$K_a = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]}$ ✓	**1**	**IGNORE** state symbols Must be square brackets **IGNORE** expressions with HA or with [H^+]^2 **Examiner's Comments** Almost universally known. Common errors were the use of [HA], [A^-] or [H^+]^2.
		ii	**FIRST, CHECK ANSWER ON ANSWER LINE** **IF answer = 4.76 award 3 marks** -- **[H^+] = 10^{-pH}** = $10^{-2.41}$ = 3.89×10^{-3} (mol dm^{-3}) ✓ ***K_a***	**3**	**ALLOW** use of **HA** and **A^-** **ALLOW 3 SF** up to calculator value of: $3.89045145 \times 10^{-3}$ correctly rounded K_a $1.739725573 \times 10^{-3}$ **NOTE:** 1.74×10^{-5} is same from

			$= \frac{[H^+]^2}{[CH_3COOH]} = \frac{(3.89 \times 10^{-3})^2}{0.870}$ $= 1.74 \times 10^{-5}$ (mol dm^{-3}) ✓ **pK_a** $= -\log K_a = -\log 1.74 \times 10^{-5} = 4.76$ ✓		unrounded [H^+] calculator value and 3 SF [H^+] value **2 DP required** **<u>Examiner's Comments</u>** This three-step calculation was successfully completed by almost all candidates. The common errors were to omit giving the final answer to 2 decimal places or to use [H^+] rather than [H^+]^2 in the calculation, leading to a pK_a of 2.35.
		iii	% dissociation $= \frac{[H^+]}{[CH_3COOH]} \times 100$ $= \frac{3.89 \times 10^{-3}}{0.870} \times 100 = 0.447$(%) ✓	**1**	**3 SF required** **<u>Examiner's Comments</u>** This proved a more difficult calculation than expected, but higher ability candidates realised that [H^+] (determined from the pH) divided by the given concentration of CH_3COOH was required. Answers had to be expressed to three significant figures in order to receive credit.
	b		**FIRST, CHECK ANSWER ON ANSWER LINE** **IF answer = 95.9(%) award 4 marks** **---** **[H^+] = 10^{-pH}** $= 10^{-13.48} = 3.31 \times 10^{-14}$ (mol dm^{-3}) ✓ **[OH^-] from K_w** $= \frac{1.00 \times 10^{-14}}{3.31 \times 10^{-14}} = 0.302$ (mol dm^{-3}) ✓ ***Mass of* (NaOH)** $= 0.302 \times \frac{100}{1000} \times 40.0 = 1.21$ (g) ✓	**2**	**ALLOW ECF** throughout **IGNORE** rounding errors beyond 3rd SF throughout **ALLOW** 3.3×10^{-14} (mol dm^{-3}) **ALLOW** 0.30 **ALLOW** 0.303 if 3.3×10^{-14} used in the first marking point **ALLOW** pOH method:, pOH = 14 − 13.48 = 0.52 [OH^-] = $10^{-0.52}$ = 0.302 (mol dm^{-3})

			% of NaOH to 3 SF $= \frac{1.21}{1.26} \times 100 = 95.9$ (%) ✓		**ALLOW** $[OH^-] \times 0.1 \times 40$ Rounding $[OH^-]$ to 0.3(0) gives 1.2/1.26 = 95.2% Award 4 marks Rounding $[OH^-]$ to 0.303 gives 1.212/1.26 = 96.2% Award 4 marks **Examiner's Comments** To help candidates, on this occasion early rounding was ignored and consequently most candidates scored full marks in this multi-step calculation. However, candidates should be advised not to round in the early stages of calculations such as this, as this introduces rounding errors into the final answer. Candidates should be encouraged to indicate what they are attempting to calculate in unstructured calculations such as this. The first step was frequently seen as $10^{-13.48} = 3.31\ldots \times 10^{-14}$ which most examiners could take to be $[H^+]$. However, it is clearer to write $[H^+] = 10^{-13.48} = 3.31\ldots \times 10^{-14}$ mol dm^{-3}. Even inclusion of units would help some candidates achieve partial credit as this might allow examiners to determine what a candidate is attempting to do.
			Total	**9**	
25		i	3-hydroxybutanal ✓	1	**ALLOW** 3-hydroxybutan-1-al **IGNORE** lack of hyphens or addition of commas **ALLOW** 4-oxobutan-2-ol **OR** 1-oxobutan-3-ol **DO NOT ALLOW** • 3-hydroxybutal • 3-hydroxylbutanal

					Examiner's Comments Most candidates made good attempts at the name, the difficulty being that hydroxyl group needed to be shown as a hydroxy- prefix, rather than the suffix -ol. Common errors included 2-hydroxybutanal (counting the carbon chain from the wrong end) and 2- or 3-hydroxybutanoic acid (reading the aldehyde group as a carboxylic acid).
		ii	Addition ✓	1	**IGNORE** nucleophilic **OR** electrophilic **OR** radical **DO NOT ALLOW** addition–elimination, condensation, polymerisation **Examiner's Comments** This part was answered well with most choosing nucleophilic addition. Credit was given just for 'addition'.
		iii	**ALLOW** any formula provided that number and type of atoms and charge are correct, e.g. For CH_3CHO, **ALLOW** CH_3COH, C_2H_4O, etc. **Step 1**: • Correct equation ✓ • One correct acid–base pair ✓ i.e. A1 and B1 **OR** A2 and B2 $CH_3CHO + OH^- \rightleftharpoons {}^-CH_2CHO + H_2O$ **OR** $CH_3CHO + OH^- \rightleftharpoons CH_3CO^- + H_2O$ ✓ **A1** **B2** **B1** **A2** **OR** **A2** **B1** **B2** **A1**	3	Throughout, **IGNORE** 'connectivity in any formula or structures shown. Examples in Answer column and in 6a(iv) guidance below **Step 1: ALLOW** H^+ transfer from OH^-, i.e. $CH_3CHO + OH^- \rightleftharpoons CH_3CH_2O^+ + O^{2-}$ ✓ **B2** **A1** **A2** **B1** **OR** **B1** **A2** **A1** **B2** **Step 2:** $CH_3CHO + CH_3CH_2O^+ + O^{2-} \rightarrow$ $CH_3CHOHCH_2CHO + OH^-$ ✓

			Step 2: $CH_3CHO + {}^-CH_2CHO + H_2O \rightarrow$ $CH_3CHOHCH_2CHO + OH^-$ ✓ For $^-CH_2CHO$: **ALLOW** CH_2CHO^-; CH_3CO^-; $C_2H_3O^-$ For $CH_3CHOHCH_2CHO$, **ALLOW** $C_4H_8O_2$		For $CH_3CH_2O^+$: **ALLOW** CH_3CHOH^+, $C_2H_5O^+$ **<u>Examiner's Comments</u>** This novel question linked together acid–base equilibria with a multi-step process. Many candidates completed an equation to generate acid–base pairs, which were then usually assigned correctly. The final equation was challenging but the highest ability candidates were able to combine together all the information with their earlier responses to arrive at the correct equation. See Exemplar 15. **Exemplar 15** 
		iv	 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous For connectivity, **ALLOW** | OH | CH_3 CH_3– C_3H– OH— *(Connectivity not being assessed)* **<u>Examiner's Comments</u>** This part was one of the most challenging on the paper. Candidates needed to link the earlier information for combining two ethanal molecules to derive the product for combining two propanone molecules. Despite the challenge, the highest ability candidates were able to come up with the correct structure.
			Total	**6**	

2 6			Initial rate = $10^{-2} \times 2.4 \times 10^{-3}$ s^{-1} **= 2.4×10^{-5} (mol dm^{-3} s^{-1})** ✓	1 AO 2.2	**Examiner's Comments** This part tested an understanding of pH as a logarithmic scale and the relationship between rates and order. This part discriminated extremely well. A pH of 3 meant that the H^+ concentration would be 100 times less than at a pH of 1. Being a first order reaction with respect to H^+, the initial rate is simply 100 times less than at a pH of 1: 2.4×10^{-5} mol dm^{-3} s^{-1}. The higher-ability candidates identified the relationships and often wrote the correct answer on the answer line with no visible working (presumably doing the calculation in their head). Others used their well-learnt equations to calculate the same correct answer. Many candidates found the calculation difficult and 7.2×10^{-3} ($3 \times (2.4 \times 10^{-3})$) was a very common incorrect answer. If candidates had fully scrutinised this answer, they may have realised that a more dilute solution cannot produce a faster rate.
			Total	**1**	
2 7	a		$CO_3^{2-} + H_2O \rightarrow OH^- + HCO_3^-$ **OR** $CO_3^{2-} + H_2O \rightarrow 2OH^- + CO_2$ ✓	1 AO 1.2	**ALLOW** $CO_3^{2-} + 2H_2O \rightarrow 2OH^- + H_2CO_3$ **IGNORE** state symbols **ALLOW** inclusion of Na^+ as spectator ion, e.g. $2Na^+ + CO_3^{2-} + H_2O \rightarrow 2OH^- + 2Na^+ + CO_2$ **IGNORE** $Na_2CO_3 + H_2O \rightarrow 2NaOH + CO_2$ *Ionic equation required* **IGNORE** equation with H^+ or H_3O^+ e.g. $CO_3^{2-} + H^+ \rightarrow OH^- + CO_2$ *Question asks for reaction with H_2O* **Examiner's Comments** This equation presented problems for

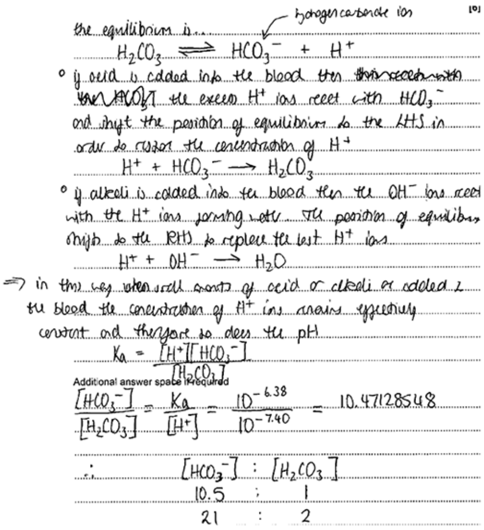
					many candidates, despite the question asking for an equation between carbonate ions and water. An acceptable equation had to be ionic and needed to produce OH^- (for the alkaline solution) and either HCO_3^- or CO_2. Many candidates wrote an equation with H^+ instead of H_2O, with lower ability candidates showing the carbonate ion with the wrong charge as CO_3^-. Many candidates wrote full equations despite the question asking for an ionic equation. Candidates do need to read the instructions in the question.
	b		Acid/H^+/HCl reacts with **OR** protonates • benzoate / $C_6H_5COO^-$ • carboxylate / salt (to form benzoic acid) ✓	1 AO 2.3	**ALLOW** suitable equation, e.g. $C_6H_5COO^- + H^+ \rightarrow C_6H_5COOH$ **IGNORE** responses purely in terms of neutralisation of alkali, e.g. Acid/H^+/HCl **neutralises** / reacts with/removes alkali / OH^- / CO_3^{2-} / Na_2CO_3 **Examiner's Comments** Candidates found this part extremely difficult. The question was aimed to stretch and challenge. Many candidates followed on directly from part (a), stating in simple terms that the alkaline solution needed to be neutralised to remove hydroxide ions. However, candidates were expected to recognise that the alkaline conditions would lead to benzoate ions rather than benzoic acid being present in the mixture. The mixture is acidified to protonate the benzoate. The hint in the question was about making the benzoic acid appearing when acid is added.
	c		$C_6H_5CH_2OH + 2[O] \rightarrow C_6H_5COOH + H_2O$ ✓	1 AO 2.6	**ALLOW** molecular, structural, displayed formulae, etc e.g. molecular: $C_7H_8O + 2[O] \rightarrow C_7H_6O_2 + H_2O$ **Examiner's Comments** This part discriminated well with many candidates being able to write a correct

					equation using their knowledge of the oxidation of alcohols. Mistakes usually resulted in the balancing with either [O] instead of 2[O] or $2H_2O$ instead of H_2O. Written equations always need to be checked for the atoms balancing.
	d		**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 33.8 OR 33.9 (%) award 3 marks** --- **Theoretical moles** $n(C_6H_5COOH)$ **OR** $n(C_6H_5CH_2OH)$ $= \frac{4.00 \times 1.04}{108.0}$ **OR** 0.0385….. (mol) ✓ **Actual moles** $n(C_6H_5COOH) = \frac{1.59}{122.0}$ **OR** 0.013(0)…. (mol) ✓ % yield = $\frac{0.0130...}{0.0385....} \times 100$ = 33.8% **OR** 33.9 (3 sig fig) ✓ *Answer depends on some intermediate roundings to 3SF*	3 AO2.8×1 AO2.8×1 AO1.2	**ALLOW ECF** for each step Calculator = 0.03851851852 Calculator = 0.01303278689 --- **Alternative method using mass** 1. Theoretical moles = 0.0385 mol 2. Mass = 0.0385 × 122.0 = 4.70 g 3. % yield = $\frac{1.59}{4.70} \times 100$ = 33.8% --- **Common errors** 35.2% → 2 marks • From $\frac{4.00}{108}$ = 0.0370 *(no use of density)* 36.5 **OR** 36.6% → 2 marks • $\frac{4.00/1.04}{108} = \frac{3.846}{108}$ = 0.0356 *(÷ density instead of × density)* **<u>Examiner's Comments</u>** Candidates are well practised with percentage yield calculations with about half obtaining the correct percentage

					yield of 33.8 or 33.9% to secure all 3 marks. Many were able to secure partial credit for incorrect answers, provided that the working was laid out clearly. Some responses showed a simple percentage of the two masses with no consideration of moles or molar masses. Such a response received no credit.
	e		Dissolve in the **minimum** quantity of **hot** water/solvent ✓ Cool **AND** Filter **AND** (leave to) dry ✓ *All three needed*	2 AO 3.3 x2	**ALLOW** any solvent **DO NOT ALLOW** use of drying agent (e.g. $MgSO_4$) **IGNORE** • Initial filtering • hot filtration to remove insoluble impurities **<u>Examiner's Comments</u>** Many candidates produced thorough responses, showing that they had encountered recrystallisation as a technique in their practical work. Most candidates were aware that the impure product is dissolved in a minimum volume of hot solvent, although 'minimum' was sometimes omitted. The subsequent stages were sometimes incomplete or in the wrong order. Many were aware that the hot solution can be passed through fluted filter paper to remove solid impurities. (This is beyond the specification requirements for A Level but good practice). Most candidates were aware of the need to filter (usually under reduced pressure)

					but the necessary cooling stage to form the crystals was sometimes omitted. Finally, many responses omitted the need to dry the crystals. Candidates did sometimes dry the crystals by adding an anhydrous salt (e.g. $CaCl_2$ or $MgSO_4$), a clear confusion with drying an organic liquid. Others described the purification of an organic liquid for their response, including use of a separating funnel, drying and distillation.
			Total	**8**	
28			D	1 (AO 1.2)	
			Total	**1**	
29			***Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.*** **Level 3 (5–6 mark)** Detailed explanation of equilibrium, the action of the buffer and correct calculation of $[HCO_3^-]$: $[H_2CO_3]$ ratio. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Detailed explanation of equilibrium **and** the action of the buffer. **OR** Detailed explanation of equilibrium **and** correct calculation of $[HCO_3^-]$: $[H_2CO_3]$ ratio. **OR** Detailed explanation of the action of the buffer **and** correct calculation of $[HCO_3^-]$: $[H_2CO_3]$ ratio. **OR** Partial explanations of equilibrium, **and** the action of the buffer **and** attempt calculation of $[HCO_3^-]$: $[H_2CO_3]$ ratio. *There is a line of reasoning presented*	6 (AO1.1 ×2) (AO1.2 ×2) (AO3.1 ×1) (AO3.2 ×1)	**Indicative scientific points may include:** *(State symbols not required in equations)* **Equilibrium and equilibrium shifts** • $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ • Addition of H^+ causes $\rightleftharpoons$ to shift to left • Addition of OH^- causes $\rightleftharpoons$ to shift to right **Action of buffer** • Increase in H^+ / addition of acid leads to: $H^+(aq) + HCO_3^-(aq) \rightarrow H_2CO_3(aq)$ **OR** HCO_3^- reacts with added acid • Increase in OH^- / addition of alkali leads to: $H^+(aq) + OH^-(aq) \rightarrow H2O(l)$ **OR** $H_2CO_3(aq) + OH^-(aq) \rightarrow HCO_3^-(aq) + H_2O(l)$ **OR** H_2CO_3 reacts with added alkali **Calculation of $[HCO_3^-]$: $[H_2CO_3]$ ratio** • $K_a = 10^{-6.38}$ **OR** 4.17×10^{-7} (mol dm^{-3}) • $[H^+] = 10^{-7.40}$ **OR** 3.98×10^{-8} (mol dm^{-3})

			with some structure. The information presented is relevant and supported by some evidence. **Level 1 (1–2 marks)** Detailed explanation of equilibrium. **OR** Correct calculation of $[HCO_3^-] : [H_2CO_3]$ ratio. **OR** Detailed explanation of the action of the buffer. **OR** Partial explanations of equilibrium **and** the action of the buffer.' **OR** Partial explanation of equilibrium **and** attempt at calculation of $[HCO_3^-] : [H_2CO_3]$ ratio.' **OR** Partial explanation of the action of the buffer **and** attempt at calculation of $[HCO_3^-] : [H_2CO_3]$ ratio. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• $\frac{[HCO_3^-]}{[H_2CO_3]}$ **OR** $\frac{4.17 \times 10^{-7}}{3.98 \times 10^{-8}}$ • ratio = 10.47(:1) OR 10.48(:1) **ALLOW** 10.5 OR 10(:1) (after working shown) **ALLOW** $\frac{4.2 \times 10^{-7}}{4.0 \times 10^{-8}}$ **And** ratio = 10.5 **OR** 11 (after working shown) **ALLOW** $\frac{[H_2CO_3]}{[HCO_3^-]}$ **OR** $\frac{3.98 \times 10^{-}}{4.17 \times 10^{-7}}$ **And** ratio = 1 : 0.095 .. **<u>Examiner's Comments</u>** This Level of Response question was generally well answered with many candidates achieving maximum marks by simply considering what was required in the question. The calculation of the $[HCO_3^-] : [H_2CO_3]$ ratio was well described although sometimes the final expression of the ratio left ambiguity as it was hard to tell whether the ratio given referred to the $[HCO_3^-] : [H_2CO_3]$ ratio or the $[H_2CO_3] : [HCO_3^-]$ ratio The buffer reactions on separate addition of acid (H^+ ions) and alkali (OH^- ions) were explained and, better still, shown in equation form. The direction of shift on the $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ equilibrium was invariably correct, but many candidates did not achieve credit for responses such as 'Addition of H^+ ions shifts the equilibrium to the left' because they did not give the equilibrium which was undergoing shift. An example of a complete answer gaining L3 (6 marks) is given.

					Exemplar 5  the equilibrium is... (hydrogencarbonate ion) [6] $H_2CO_3 \rightleftharpoons HCO_3^- + H^+$ • if acid is added into the blood then the excess H^+ ions react with HCO_3^- and shift the position of equilibrium to the LHS in order to restore the concentration of H^+ $H^+ + HCO_3^- \rightarrow H_2CO_3$ • if alkali is added into the blood then the OH^- ions react with the H^+ ions forming water. The position of equilibrium shifts to the RHS to replace the lost H^+ ions $H^+ + OH^- \rightarrow H_2O$ ⇒ in this way when small amounts of acid or alkali are added to the blood the concentration of H^+ ions remains effectively constant and therefore so does the pH $K_a = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$ Additional answer space if required $\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{K_a}{[H^+]} = \frac{10^{-6.38}}{10^{-7.40}} = 10.47128548$ ∴ $[HCO_3^-] : [H_2CO_3]$ 10.5 : 1 21 : 2 The candidate clearly writes the equilibrium at the top. The first bullet point gives a chemical equation for the reaction occurring when H^+ ions are added as well as the shift in equilibrium. The second bullet point gives a chemical equation for the reaction occurring when OH^- ions are added as well as the shift in equilibrium. The steps in the calculation are clearly shown and the ratio is clear.
			Total	**6**	
30	a		**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 2.98 award 2 marks** ------------------------------------- $[H^+] = \sqrt{(K_a \times [C_2H_5COOH])} = 1.039 \times 10^{-3}$ (mol dm^{-3}) ✓ pH = –log 1.039×10^{-3} = 2.98 (**Must be to 2 DP**) ✓	2 (AO 2.2 ×2)	**ALLOW ECF** throughout **ONLY ALLOW** pH mark by **ECF** if K_a **AND** 0.080 used and **AND** pH <7 **Common errors (Must be to 2 DP)** One mark for pH = 5.97 (*No square root*): One mark for pH = 0.92 **OR** pH = 5.15 (*Using incorrect K_a values*) **<u>Examiner's Comments</u>** Most candidates could calculate the pH of a weak acid although a significant number gave the answer as 3.0, presumably confusing the demand for

					two decimal points with two significant figures.
	b	i	$n(C_2H_5COOH)$ = (0.0800 × $\frac{25.0}{1000}$) =) 0.002 (mol) **AND** V(NaOH) = $\frac{0.002}{0.100}$ × 1000 = (= 20(.0) cm^3) ✓	1 (AO 2.5)	**ALLOW** 0.02 dm^3 if unit given Mark is for **WORKING** which could all be shown as 1 step **ALLOW** method showing 20cm^3 NaOH contains the same moles as acid $n(C_2H_5COOH)$ = 0.08(00) x 0.025(0) = 0.002 (mol) and n(NaOH) = 0.02(00) x 0.1 = 0.002(00) (mol) **<u>Examiner's Comments</u>** Showing by calculation something already known is a skill that some candidates find challenging. Many responses included rows of figures with '20 cm^3' appearing at the end. Clarity of working is essential and in questions such as this, candidates are advised to include word descriptions of what they are calculating, even if it is abbreviations such as 'n' for number of moles.
		ii	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 12.55 award 4 marks** -- ***Excess mol of NaOH:*** $n(OH^-)_{excess}$ = $n(OH^-)$ – $n(C_2H_5COOH)$ = (0.100 × $\frac{45.0}{1000}$) – (0.0800 × $\frac{25.0}{1000}$) = 0.0045 – 0.002 = 0.0025 (mol) ✓ ***Concentration of OH^-:*** $[OH^-]$ = ($\frac{0.0025}{70.0 \times 10^{-3}}$) = 0.0357 (mol dm^{-3}) ✓	4 (AO 1.2 ×1) (AO 2.6 ×3)	**ALLOW ECF** throughout For first mark **ALLOW** (Excess volume of NaOH = 25(.0) cm^3) $n(OH^-)_{excess}$ = 0.100 × $\frac{25.0}{1000}$ = 0.0025 (mol) Common errors If initial V(NaOH) = 45 cm^3 $[OH^-]$ = 0.0643 (mol) $[H^+]$ = 1.56 × 10^{-13} (mol dm^{-3}) pH = 12.81 award three marks (no 1st mark) If $n(OH^-)_{excess}$ is used in $[H^+]$ calculation $n(OH^-)_{excess}$ = 0.0025 (mol) $[H^+]$ = $\frac{1.00 \times 10^{-14}}{0.0025}$ =4.(00) × 10^{-12} (mol dm^{-3})

			Concentration of H^+: $[H^+] = (\frac{1.00 \times 10^{-14}}{0.0357})$ = 2.8×10^{-13} (mol dm^{-3}) ✓ ***Conversion to pH:*** pH = (–log 2.8×10^{-13}) = 12.55 ✓		pH = 11.40 award three marks (no 2nd mark) **ALLOW** pOH method for last two marks pOH = – log[OH^-] =1.447 pH = 14 – 1.447 = 12.55 **ALLOW** ECF for conversion from [H^+] to pH provided value calculated is above 7 and from derived [H^+] **<u>Examiner's Comments</u>** This calculation proved difficult with once again, many figures and sums appearing with little indication as to their relevance. Responses to 20bi/ii often featured rows of figures and random sums without a single word about what the figures were or sums were set to calculate. Candidates should remember to provide written indications of what it is they're working out – presenting the calculations without any annotations can make it harder for error carried forward marks to be given if there is an error in their calculation.
		iii	**Shape** Slight rise/flat, **AND** (near) vertical, **AND** then slight rise/flat ✓ **pH** Vertical section within the extremes of pH 5 to 12 and a minimum range of three pH units **AND** middle of vertical section (equivalence point) needs to be above pH 7 ✓ **End point** Vertical section at ~ 20 cm^3 NaOH ✓	3 (AO 2.3 ×1) (AO 2.4 ×2)	If pH curves wrong way round (i.e. adding acid to alkali), **ONLY award mark for End point** (~ 20 cm^3) **<u>Examiner's Comments</u>** This weak acid / strong alkali titration curve required candidates to apply their knowledge. Some candidates found it difficult to draw an adequate titration curve. The key points to titration curves are: • A 'vertical' section at the end point • The vertical section with pH range correct to relative to the strength of acid/alkali

					• A correct equivalence point relative to pH 7 with respect to the strength of acid/alkali • A 'shallow curve' leading from 0 cm3 to vertical section • A 'shallow curve' leading from the vertical section to the total volume added For this reaction: • The vertical section was at 20 cm^3 (given in 20bi) • As it was a weak acid and strong alkali reacting, the vertical section should start above pH 5 and finish around pH 11 • The equivalence point (half-way up the vertical section) for a weak acid / strong alkali titration should be above pH 7 • The starting pH should be that of the weak acid, C_2H_5COOH (answer to 20(a)) • The final pH should be that of the final solution (answer to 20(b)(ii))
		iv	cresol purple **AND** pH range matches vertical section/rapid pH change **OR** end point/colour change matches vertical section/rapid pH change ✓	1 (AO 3.3)	**ALLOW** pH range (of the indicator) matches equivalence point **ALLOW** end point/colour change matches equivalence point **IGNORE** colour change matches end point *Colour change is the same as end point* **<u>Examiner's Comments</u>** Some candidates realised that the most suitable indicator for a weak acid / strong alkali titration would be cresol purple. For incorrect responses, other indicators appeared to be selected at random, suggesting that candidates were unclear on the criteria for selected a suitable indicator.
		v	**similarity**: end point / volume (20 cm^3) of NaOH needed to neutralise **OR** **final** pH / shape of curve after end point ✓ **difference**: HCN higher **starting** pH	2 (AO 3.2 ×2)	End point must not refer to same pH **ALLOW** different equivalence point **IGNORE** different starting pH

			OR HCN shorter vertical section ✓		**Examiner's Comments** When identifying a similarity, many candidates confused the term 'equivalence point' with the term 'end point'. For differences, many candidates realised that HCN had a different K_a to C_2H_5COOH but often did not appreciate that this would lead to a starting point with a higher pH.
	c		HIO_3 dissociation is not negligible / dissociates to a significant extent **OR** Large K_a **and** HIO_3 is 'stronger' (weak) acid **OR** $[HIO_3\ ]_{eqm}$ is significantly lower than $[HIO_3\ ]_{initial/undissociated}$ ✓	1 (AO 3.3)	**ALLOW** use of HA **Ignore** $[HIO_3]_{equilibrium}$ < $[HIO_3\ ]_{initial/undissociated}$ **ALLOW** $[HIO_3]_{equilibrium}$ ~ $[HIO_3]_{undissociated}$ is no longer a valid assumption **ALLOW** $[HIO_3]$ has a larger K_a so the assumption that $[HIO_3]$ at equilibrium = $[HIO_3]$ initially so assumption is not valid **Examiner's Comments** Very few candidates scored the mark for this question. The most common error was to write 'HIO_3 dissociates'. While correct, this is true of all weak acids. The subtlety in this question was to realise that because K_a was relatively high, the resultant acid strength would mean that the degree of dissociating was significant enough so initial $[HIO_3]$ was significantly less than $[HIO_3]$ at equilibrium. In other words, the assumption $[HIO_3]$initial = $[HIO_3]$equilibrium is not valid in this case.
			Total	**14**	
3 1			$CH_3SO_2OH + H_2O \rightleftharpoons CH_3SO_2O^- + H_3O^+$ ✓ **A1** **B2** **B1** **A2** ✓ For an equilibrium shown using CH_3COOH instead of H_2O, mark acid–base pairs by **ECF**, i.e.	4 (AO 2.1×2)	**ALLOW** → for ⇌ **ALLOW** acid–base pairs labelled other way round. i.e. $CH_3SO_2OH + H_2O \rightleftharpoons CH_3SO_2O^- + H_3O^+$ **A2** **B1** **B2** **A1**

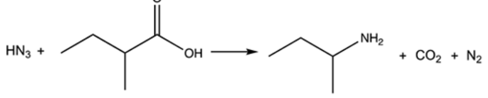
			$CH_3SO_2OH + CH_3COOH \rightleftharpoons CH_3SO_2O^- + CH_3COOH_2^+$ ☒ **A1** **B2** **B1** **A2** **ECF** ✓ CH_3SO_2OH dissociates more (than CH_3COOH) **OR** CH_3SO_2OH is a stronger acid ✓ ***ORA*** *in terms of CH_3COOH being a weaker acid* Student is correct **AND** (sulfonic acid has) lower pK_a/higher K_a **OR** greater $[H^+]$ **ORA** ✓	(AO 3.1) (AO 3.2)	**ALLOW** small slip If **ONE** charge is missing from equilibrium. **ALLOW ECF** for acid–base pairs mark **IGNORE** 'more acidic' *Response needs strength/dissociation* **ALLOW** maths explanation for final 2 marks, e.g. $Ka(CH_3COOH) = 10^{-(4.76)} = 1.74 \times 10^{-5}$ $[H^+] = \sqrt{(1.74 \times 10^{-5}) \times 1)} = 4.17 \times 10^{-3}$ $pH = -\log 4.17 \times 10^{-3} = 2.38$ ✓ $K_a(CH_3SO_2OH) = 10^{-(-1.90)} = 79.4$ $[H^+] = \sqrt{(79.4) \times 1)} = 8.91$ $pH = -\log 8.91 = -0.95$ ✓ **BOTH** pH calcs subsumes 'Student is correct' **<u>Examiner's Comments</u>** Most candidates completed a correct equilibrium equation and assigned the correct acid-base pairs. A significant number of candidates used ethanoic acid instead of water in the equation. The examiners allowed error carried forward in this case for the acid-base pairs. Candidates found it much more difficult to explain whether the sulfonic acid had a lower pH value. The higher-attaining candidates answered concisely. They usually identifying that the sulfonic acid would have a lower pH as the pK_a value was lower (or the K_a value greater), leading to more dissociation than

					ethanoic acid. Lower-attaining candidates often produced unfocussed and lengthy responses, sometimes relating increased dissociation in an acid to a higher, rather than a lower, pH. Some candidates approached their explanation mathematically, calculating pH values for ethanoic acid and sulfonic acid from their concentrations and pKa values. If correct, this approach was fully credited.
			Total	**4**	
32			**C**	1 (AO 2.2)	
			Total	**1**	
33			**D**	1 (AO 2.2)	
			Total	**1**	
34	a		$HCOOH + CH_3COOH \rightleftharpoons HCOO^- + CH_3COOH_2^+$ ✓ **A1 B2 B1 A2** **OR** **A2 B1 B2 A1** ✓ **CARE:** Both + and – charges required for products in equilibrium **DO NOT AWARD** the 2nd mark from an equilibrium expression that omits either charge	2 (AO 1.2×2)	**IGNORE** state symbols (even if wrong) **IF** proton transfer is wrong way around **ALLOW** 2nd mark for idea of acid–base pairs, ***i.e***. $HCOOH + CH_3COOH \rightleftharpoons HCOOH_2^+ + CH_3COO^-$ **B2 A1 A2 B1** **NOTE** For the 2nd marking point (acid–base pairs), this is the **ONLY** acceptable **ECF** ***i.e. NO ECF** from impossible chemistry*
	b	i	$[H^+] = 10^{-2.72}$ **OR** 1.905×10^{-3} (mol dm^{-3}) ✓ $[CH_3COOH] = \frac{(1.905 \times 10^{-3})^2}{1.78 \times 10^{-5}}$ ✓ (= 0.204 mol dm^{-3})	2 (AO 2.4×2)	**ALLOW** 2SF up to calculator value of $1.905460718 \times 10^{-3}$ **ALLOW** use of [HA] Mark is for working.
		ii	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer =** 2.4×10^{-2} (mol dm^{-3}) **award 4 marks** ---	4 (AO 3.3×3)	**ALLOW ECF** **ALLOW** [HA] and [A⁻] in working

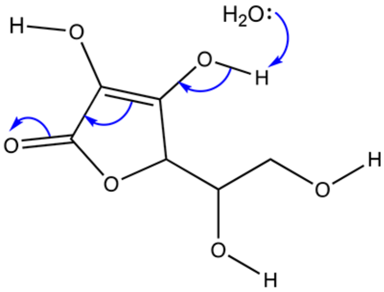
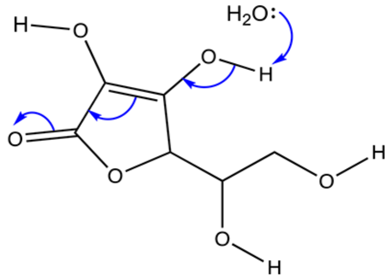
			Calculation of H^+ in buffer $[H^+]$ buffer = $10^{-4.00}$ **OR** 1×10^{-4} (mol dm^{-3}) ✓ **Calculation of CH_3COOH in buffer** $n(CH_3COOH)$ **OR** $[CH_3COOH]_{buffer}$ $= \frac{0.204}{1000} \times 400$ **OR** 8.16×10^{-2} ✓ **Calculation of $[CH_3COO^-]$ in buffer (in 1 dm^3)** $[CH_3COO^-]_{buffer} = 1.78 \times 10^{-5} \times \frac{8.16 \times 10^{-2}}{1 \times 10^{-4}}$ **OR** 1.5×10^{-2} (mol dm^{-3}) ✓ **Calculation of original $[CH_3COO^-]$ (in 600 cm^3)** $[CH_3COO^-]_{initial} = (\frac{1.45248 \times 10^{-2} \times 1000}{600})$ $= 2.4 \times 10^{-2}$ (mol dm^{-3}) ✓ --- **ALLOW** alternative approach based on Henderson–Hasselbalch equation (**ALLOW** $-\log K_a$ for pK_a) e.g. $pH = pK_a + \log\frac{[CH_3COOH]}{[CH_3COO^-]}$ **OR** $pK_a - \log\frac{[CH_3COO^-]}{[CH_3COOH]}$ **OR** $4 = 4.75 + \log\frac{8.16 \times 10^{-2}}{[CH_3COO^-]}$ **OR** $4.75 - \log\frac{[CH_3COO^-]}{8.16 \times 10^{-2}}$ ✓ $\log[CH_3COO^-] = 4 - 4.75 - 1.09 = -1.84$ ✓ $[CH_3COO^-]_{buffer} = 1.5 \times 10^{-2}$ ✓ $[CH_3COO^-]_{initial} = 2.4 \times 10^{-2}$ ✓	(AO 3.4×1)	**ALLOW** 1.5×10^{-2} up to calculator value 1.45248×10^{-2} (mol dm^{-3}) **ALLOW** 2.4×10^{-2} up to calculator value 2.4208×10^{-2} (mol dm^{-3}) **COMMON ERRORS BUT CHECK WORKING** $[CH_3COO^-]_{initial} = 8.7 \times 10^{-3}$ — 3 marks *600 and 1000 inverted* $[CH_3COO^-]_{initial} = 3.6 \times 10^{-6}$ — 3 marks *$[CH_3COOH] : [H^+]$ inverted* $[CH_3COO^-]_{initial} = 1.3 \times 10^{-6}$ *$[CH_3COOH] : [H^+]$ inverted AND 600 and 1000 inverted* — 2 marks No volumes used = 3.6×10^{-2} — 2 marks **ALLOW** $-\log K_a$ for pK_a --- **<u>Examiner's Comments</u>** This question required the candidate to calculate the original concentration of ethanoate ions in the buffer. Higher-attaining students gained full credit. Most students calculated the concentration in the buffer solution but did not factor for the original solution. Lower-attaining candidates often scored the first two marking points but did not use the buffer equation.
			Total	**8**	

35			A	1 (AO2.6)	
			Total	**1**	
36	a		**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 13.15 award 2 marks** --- $[H+] = \frac{1.00 \times 10^{-14}}{0.140} = 7.14..... \times 10^{-14}$ (mol) ✓ pH = –log (7.14….. × 10^{-14}) = 13.15 **2 DP** required	2 (AO2.2×2)	**ALLOW ECF** providing pH>7 Calculator: 7.142857143 × 10^{-14} **ALLOW** pOH method pOH = –log(0.14) = 0.85……… ✓ pH = 14.00 – (0.85……) = 13.15 ✓
	b		*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Reaches a comprehensive conclusion with most detail and few errors for the formation of the buffer **AND** Calculation of the correct buffer pH **AND** Correct mass of N_2O_3. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Reaches a sound conclusion with some detail and some errors for Formation of buffer **AND** Calculation of the buffer pH **OR** Formation of buffer **AND** Mass of N_2O_3. **OR** Calculation of the buffer pH **AND** Mass of N_2O_3. **OR** Partial explanations of formation of the buffer **AND** buffer pH **AND** Mass of N_2O_3. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1–2 marks)** Attempts, with some success, to: Describe formation of buffer **OR** Calculate buffer pH	6 (AO1.2×2) (AO2.6×2) (AO3.1×2)	**Indicative scientific points may include:** **1. Formation of buffer** • Acid / HNO_2 is in excess • $HNO_2 + NaOH \rightarrow NaNO_2 + H_2O$ • Partial neutralisation of HNO_2 → formation of NO_2^-/ $NaNO_2$ • Buffer contains HNO_2 **AND** NO_2^- /$NaNO_2$ **2. Calculation of buffer pH** • $n(HNO_2)$ added = 0.0500 (mol) • n(NaOH) added = 0.0150 (mol) • $n(NO_2^-)$ formed = 0.0150 (mol) • $n(HNO_2)$ remaining = 0.0500 – 0.0150 = 0.0350 (mol) • Ka = $10^{-3.34}$ = 4.57… × 10^{-4} (mol dm^{-3}) • Concentrations = mol (volume 1 dm^3) • $[H^+] = \frac{4.57... \times 10^{-4} \times 0.0350}{0.0150}$ = 1.0665…. × 10^{-3} (mol dm^{-3}) • pH = 2.97 • pH to 2 dec places **3. Calculation of mass of N_2O_3** • 1 mol N_2O_3 → 2 mol HNO_2 **OR** $N_2O_3 + H_2O \rightarrow 2HNO_2$ • $n(HNO_2)$ = 0.0500 (mol) • $n(N_2O_3)$ = 0.0500/2 = 0.0250 (mol) • $m(N_2O_3)$ = 0.0250 × 76 = 1.9(0) g

			OR Obtain mass of N_2O_3 . *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		**Examiner's Comments** This part the higher-attaining candidates had a good understanding of how a buffer was made by making the conjugate base and by having some of the weak acid remaining. Lower-attaining candidates often did not mention this and used the OH^- ion as the conjugate base. Descriptions often moved on to an attempt to explain how the buffer solution worked, which was not asked for in the question. Higher-attaining candidates were able to calculate the pH but many candidates did not take into account the final amount of nitrous acid after partial neutralisation. Lower-attaining candidates often used the weak acid calculation route. The mass of N_2O_3 was generally well calculated with a few omissions of the ratio or an incorrect relative formula mass. Candidates should be encouraged to display their working and link the numbers to the appropriate chemical, citing moles or concentration. **OCR support** Further support can be found in the pH and Buffers delivery guide: Delivery Guide for OCR AS/A Level Chemistry A
			Total	**8**	
37		i	FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 2.75 award 2 marks --- - $[H^+]^2 = K_a \times [HN_3]) = 2.51 \times 10^{-5} \times 0.125$ $[H^+] = \surd(K_a \times [HN_3])$ $[H^+]^2 = 2.51 \times 10^{-5} \times 0.125$ **OR** $[H^+] = \surd (2.51 \times 10^{-5} \times 0.125)$ **OR** $[H^+]$ =1.77…. × 10^{-3} (mol dm^{-3}) ✓ pH = –log 1.77…. × 10^{-3} = 2.75 (Must be to **2DP**) ✓	2 (AO2.2× 2)	**ALLOW ECF** throughout **IGNORE** error with HN_3 shown as NH3 **ALLOW** pH mark by **ECF** **ONLY** if 2.51 × 10^{-5} × 0.125 used **AND** pH < 7 --- -- **Common errors (Must be to 2 DP)** pH = 5.50 → 1 mark (*No square root*) $[H^+]$ = 6.26 × 10^{-4} from √ (2.51 × 10^{-5}) × 0.125 pH = 3.20 → 1 mark $[H^+]$ = 8.87 × 10^{-6} from √ (0.125) × 2.51 × 10^{-5}

					pH = 5.05 → 1 mark **Examiner's Comments** Most candidates found this pH calculation easy and most obtained a pH of 2.75 for both marks.
		ii	• Correct equation ✓ • Correct acid–base pair labels for correct equation ✓ HN_3 + H_2O ⇌ N_3^- + H_3O^+ ✓ **A1** **B2** **B1** **A2** ✓ **OR** **A2** **B1** **B2** **A1**	2 (AO1.2×2)	**ALLOW** 1 mark for one correct acid–base pair **WITH** correct labels e.g. H_2O H_3O^+ **WITH** B1 A1 **OR** B2 A2 **Examiner's Comments** This unfamiliar acid–base pair question was answered comparatively well. Most candidates identified one correctly labelled acid–base pair, usually H_3O^+ and H_2O. The higher-attaining candidates were able to write the correct equation and to identify both acid–base pairs.
		iii	Structure of 2-methylbutanoic acid ✓ Structure of organic product (primary amine) ✓ CO_2 **AND** N_2 as products ✓ 	3 (AO3.2×2) (AO2.6)	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous **Common error** With NH_3, → CO_2 + H_2 **ALLOW ECF** for equation using a different amine isomer of the organic product *e.g.* $(CH_3)_2CHCH_2NH_2$ **DO NOT ALLOW ECF** from unbranched species, e.g. $CH_3CH_2CH_2NH_2$ **IGNORE** HN_3 in equation, even if missing **IGNORE** poor connectivity to all groups **Examiner's Comments** Candidates were expected to interpret information for an unfamiliar organic

					reaction and to write a balanced question. The information included important clues which were sometimes ignored, showing the importance of using any information provided. The structure of 2-methylbutanoic acid was usually correct although many candidates did show 3-methylbutanoic acid instead, numbering from the wrong end of the chain. The amine structure proved to be more difficult with many showing an amide instead. Even when an amine was shown, it often included four C atoms instead of three. Finally, candidates were told that the two gases (N_2 and CO_2) are present in the atmosphere. Many candidates clearly did not use this clue, included substances that are not atmospheric gases such as H_2, H_2O and NH_3. As always, the advice is to use the information provided – it often includes hints to help candidates. **Misconception** Branched and substituted carboxylic acids are named counting from the start of the main stem, e.g. In Q5(b)(iii), 2-methylbutanoic acid is $CH_3CH(CH_3)CH_2COOH$. The correct name is obtained by starting from the carbon atom with the functional group. i.e. The COOH carbon in number 1: 2-methylbutanoic acid is $CH_3CH_2CH(CH_3)COOH$. The same rule is used for all organic compounds, e.g. 2-methylbutanal is $CH_3CH_2CH(CH_3)CHO$ and **not** $CH_3CH(CH_3)CH_2CHO$
			Total	**7**	
38		i		2 (2 ×AO3.2)	**IGNORE incorrect curly arrows** **IGNORE** 'double' curly arrows such as:

			 3 **OR** 4 curly arrows correct → 2 marks ✓ ✓ 1 curly arrow correct → 1 mark ✓		 **H_2O Curly arrow** must • start from, **OR** be traced back to **any point across width** of lone pair on H_2O**:** **<u>Examiner's Comments</u>** This novel mechanism assessed a candidate's understanding of curly arrows, and four curly arrows were needed. One mark was available for one correct curly arrow, usually from the H_2O: or from the C=O. 2 marks were given for three or four correct curly arrows. The two curly arrows within the ring structure proved to be the most difficult. The question discriminated extremely well: many candidates were able to secure one mark with the most able being given both marks. A candidate showing all four curly arrows correctly demonstrated an excellent understanding of curly arrows.
		ii	**FIRST CHECK ANSWER ON THE ANSWER LINE** **If answer = 2.16 award 3 marks** --- - [Vitamin C] = 0.150 × 4 = 0.600 (mol dm^{-3}) ✓ *0.6 seen anywhere* $[H^+]$ = √ (K_a × [Vitamin C]) = √ (7.94 × 10^{-5} × 0.600) = 6.90 × 10^{-3} (mol dm^{-3}) ✓ pH = -log $[H^+]$ = -log 6.90 × 10^{-3} = 2.16 ✓ **2 DP required**	3 (2 ×AO2.4) (1 ×AO1.2)	**For $[H^+]$** **ALLOW ECF** from incorrect [vitamin C] for pH **ALLOW ECF ONLY** if $[H^+]$ has been derived from K_a **AND** [vitamin C] --- -- **COMMON ERRORS** pH = 4.32 2/3 calculation marks *No square root of* (7.94 × 10^{-5} × 0.600) pH = 2.46 2/3 calculation marks *No ×2 4* (7.94 × 10^{-5} × 0.150) pH = 2.76 2/3 calculation marks *÷ 4* (7.94 × 10^{-5} × 0.0375) pH = 4.92 1/3 calculation mark *No square root AND 0.150* pH = 5.53 1/3 calculation mark *No square root AND 0.0375*

Examiner's Comments

Most candidates had learnt a standard method for calculating the pH of a weak acid. with the correct answer of 2.16 being seen on very many scripts. Success required conversion of 0.150 moles of vitamin C in 250 cm^3 to its concentration as 0.600 mol^{-3}, calculation of $[H^+]$ using $[H^+] = \sqrt{(K_a \times [HA])}$ and determination of pH using $-\log[H^+]$.

Common errors usually resulted from one mistake and could still be rewarded with 2 of the available 3 marks. Examples are shown below.

- pH = 4.32 *No square root of* $(7.94 \times 10^{-5} \times 0.600)$
- pH = 2.46 *No conversion of 0.150 mol to 0.600 mol* dm^{-3} → $(7.94 \times 10^{-5} \times 0.150)$
- pH = 2.76 ÷ 4 instead of × 4 for concentration → $(7.94 \times 10^{-5} \times 0.0375)$

AfL

pH calculations are common in A Level Chemistry

There are four different types, and it is essential that the standard methods for determination of $[H^+]$ in the calculations are **learnt**:

- pH of strong acids
- pH of weak acids, using K_a and [HA]
- pH of strong bases, using K_w and $[OH^-]$
- pH of buffers, using K_a and $[HA]/[A^-]$

It is extremely likely that at least one of these types of pH calculation will feature in at least one of the A Level units.

			Total	**5**	
39			**D**	1(AO2.3)	**Examiner's Comments** This was well answered, with many candidates understanding that the addition of an alkali will react with the H^+ ions and will keep the position of equilibrium on the right hand side.
			Total	**1**	
40			**C**	1(AO1.2)	**Examiner's Comments** This was generally well answered. The key to candidates arriving at the correct answer ,C, was to write out the equation for ammonia reacting with water. The correct identification of the acids can then be made. Option B was chosen as the candidate identified the B-L bases and option D was chosen by candidates who linked up a B-L acid – base pair.
			Total	**1**	
41		i	(Glycolic) acid is in **excess/partially neutralised** **AND** glycolate/potassium glycolate (ions) are present/produced ✓	1 (AO1.1)	**ALLOW** some acid remains **ALLOW** conjugate base for glycolate ions/salt of weak acid **ALLOW** $HOCH_2COO^-$ **Examiner's Comments** Many candidates did not answer the question and instead described what a buffer was. Very few candidates correctly explained that a weak acid was being added to a base, sometimes mentioning the formation of the salt or conjugate base. The majority also did not include the importance of there being excess acid, or some acid remaining, after the partial neutralisation.
		ii	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 3.93 award 4 marks** --- **Initial amounts** $n(HOCH_2COOH) = 0.750 \times \frac{60.0}{1000}$ **OR** 0.045(0) (mol)	4 (AO1.2×1) (AO2.8×3)	**ALLOW ECF** throughout

			AND n(KOH) = $0.625 \times \frac{40.0}{1000}$ **OR** 0.025(0) ✓ **Amounts in the buffer solution** $n(HOCH_2COOH)$ = 0.0450 − 0.0250 **OR** 0.02(00) (mol) **AND** $n(HOCH_2COO^-)$ 0.025(0) (mol) ✓ **pH** $K_a = 10^{-3.83}$ **OR** 1.479 & $\times 10^{-4}$ ✓ $[H^+] = \frac{1.479 ... \times 10^{-4} \times 0.200}{0.250}$ **OR** 1.183×10^{-4} (mol dm^{-3}) pH = 3.93 (**2 DP**) ✓		**ALLOW use of moles for concentration** $[H^+] = \frac{1.479 ... \times 10^{-4} \times 0.0200}{0.0250}$ **Common errors** **3 marks** pH = 3.57 not using n(HA) remaining **2 marks** pH = 3.75 using HA and KOH concentrations within question **<u>Examiner's Comments</u>** Most candidates were able to derive a value for K_a from pK_a and calculate the number of moles of glyolic acid and potassium hydroxide reacting. Less were successful in determining the moles or concentrations present in the buffer solution causing many to get the common error of 3.57. Many candidates tried to calculate pH for the weak acid, without considering changes to concentrations or the buffering effect. Clarity of working is essential and in questions such as this, candidates are advised to include word descriptions of what they are calculating, even if it is abbreviations such as 'n' for number of moles.
		iii	NH_3 / OH^- reacts with H^+ / $HOCH_2COOH$ / (Glycolic) acid ✓ $HOCH_2COOH \rightleftharpoons H^+ + HOCH_2COO^-$ **AND** Equilibrium shifts to the right ✓	2 (AO1.2×2)	**ALLOW** NH_3 will act as a base (and form NH_4^+) **ALLOW** NH_3 decreases $[H^+]$ **ALLOW** $HA \rightleftharpoons H^+ + A^-$ Equilibrium equation needs to be shown. **<u>Examiner's Comments</u>** Most candidates correctly described the ammonia reacting with the glycolic acid or with hydrogen ions, although some

					thought that ammonia was acidic. Many of them then went on to say that "the equilibrium will move to the right" without realising that the equilibrium had not itself appeared within the question, and so they needed to write it out to gain marks. A few candidates thought that ammonia was an acid, due to the 3 × Hs in the molecule.
			Total	**7**	
4 2		i	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 2.53(g) award 5 marks** **--** **[H⁺]** = $10^{-13.12}$ **OR** 7.58..... × 10^{-14} (mol dm^{-3}) ✓ **[OH⁻]** = $\frac{1 \times 10^{-14}}{7.58........ \times 10^{-14}}$ **OR** 0.1318 .... (mol dm^{-3}) ✓ $n(OH^-)$ in 250 cm^3 = $\frac{0.1318.....}{4}$ **OR** 0.0329...... (mol) ✓ $n(Ba(OH)_2)$ or $n(BaO)$ = $\frac{0.0329.......}{2}$ **OR** 0.0164..... (mol) ✓ **Mass of BaO** = 0.0164..... × 153.3 = 2.53 (g) **3SF** ✓	5 (AO2.4×5)	**ALLOW ECF and 3SF throughout.** **ALLOW** calculation process in any order. **IGNORE** rounding errors past **3SF** **---** Calculator: 7.58577575 × 10^{-14} Calculator: 0.1318256739 **ALLOW** alternative approach using pOH for first 2 marks. $p[OH^-]$ = 14 − 13.12 = 0.88 $[OH^-]$ = $10^{-0.88}$ = 0.1318..... Calculator: 0.03295641846 0.033(0) comes from $[OH^-]$ = 0.132 Calculator: 0.01647820923 Calculator: 2.526109475 **Common errors 4 marks** 5.05g Not dividing by 2 2.82g Use of M_r for $Ba(OH)_2$ 5.06g rounds to 0.132 in M2 then not dividing by 2 **3 marks** 5.65g not dividing by 2 and using Mr for $Ba(OH)_2$

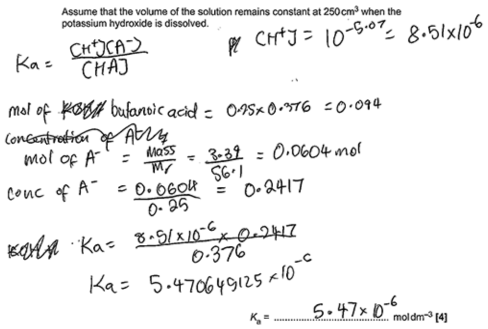
					Examiner's Comments Although few candidates got the correct final answer, however almost all achieved some marks from this calculation through error carried forward, with marks spread across the available range. Almost all candidates were able to find the concentrations of hydrogen and hence hydroxide ions. A few candidates successfully used p[OH$^-$] method. Most were able to calculate the moles of hydroxide ions in 250cm^3. Many then did not realise the need to half this number to find the moles of barium, and/or used the Mr for barium hydroxide instead of barium oxide.
		ii	$Ba^{2+}(aq) + 2H^+(aq) + SO_4^{2-}(aq) + 2OH^-(aq) \rightarrow BaSO_4(s) + 2H_2O(l)$ ✓	1 (AO3.2)	**ALLOW** multiples **ALLOW** $H^+(aq) + OH^-(aq) \rightarrow H2O(l)$ **OR** $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ **Examiner's Comments** This question was answered well, with many candidates giving one of the equations in the 'ALLOW' part of the mark scheme. Those candidates who did not gain this mark gave full equations or missed out state symbols.
			Total	**6**	
43			**D**	1 (AO 2.6)	**Examiner's Comments** The most successful candidates showed their workings for the correct answer of D.
			Total	**1**	
44	a	i	**FIRST CHECK THE ANSWER ON ANSWER LINE** **if answer = 6.77 award 2 marks** --- $K_w = [H^+][OH^-]$ **OR** $K_w = [H^+]^2$ **OR** $[H^+] = \sqrt{K_w}$ ✓ $([H^+] = \sqrt{(2.92 \times 10^{-14})})$ pH = $-\log(1.71 \times 10^{-7}) = 6.77$ ✓	2 (AO 1.1 × 1) (AO 2.2 × 1)	**DO NOT ALLOW** use of A^- or X^- **Examiner's Comments** Most candidates were given the first mark from a correct or rearranged equation. Many candidates then answered this question correctly and were given both marks. Those who didn't, either used 1.00×10^{-7} as [OH$^-$] when calculating

					$[H^+]=Kw/[OH^-]$ or calculated pH as -log(2.92×10^{-14}).
		ii	(In pure water), $[H^+]$ (always) equals $[OH^-]$	1 (AO 3.2 × 1)	**ALLOW** moles/number of H^+ is (always) equal to moles/number of OH^-. **DO NOT ALLOW** ratio $[H^+] : [OH^-]$ doesn't change **<u>Examiner's Comments</u>** This question proved difficult with only a few candidates able to state that in neutral water, $[H^+] = [OH^-]$. Many candidates said that as the pH is close to 7, water is therefore neutral.
	b		• **Equation** $Sr + 2H_2O \rightarrow Sr(OH)_2 + H_2$ ✓ **CHECK THE ANSWER ON ANSWER LINE** **if answer = 11.51 award 4 calculation marks** -- • **$n(Sr(OH)_2)$** $= \frac{0.145}{121.6} = 1.1924... \times 10^{-3}$ ✓ • **$[OH^-]$** $= 2 \times (1.1924 \times 10^{-3} \div 0.25)$ $= 9.539... \times 10^{-3}$ ✓ • **[H+]** $= K_w \div [OH^-]$ $= \frac{0.145}{121.6} = 3.061... \times 10^{-12}$ ✓ • **pH** $= -\log(3.061... \times 10^{-12}) = 11.51$ ✓ **2 DP** required	5 (AO 2.6) (AO 2.4 × 3) (AO 1.2 × 1)	**IGNORE** state symbols (even if wrong) **ALLOW** multiples **ALLOW** $Sr^{2+} + 2OH^-$ for $Sr(OH)_2$ **ALLOW** 3 SF up to the calculated value. Ignore RE after 3SF. **ALLOW** ECF throughout but final answer must be pH>7 **Final answer must be from calculated values.** **Common errors for 3 calculation marks** 11.98 *(Use of $K_w = 1 \times 10^{-14}$)* 11.21 *(no × 2)* 10.91 *(÷ by 2)* **Common error for 2 calculation marks** pH = 11.67 *(no × 2 and wrong K_w)* -- **Alternative method for:-** **pH = pKw – pOH**

					○ ***n*($Sr(OH)_2$)** $= \frac{0.145}{121.6} = 1.1924... \times 10^{-3}$ ○ **[OH^-]** $= 2 \times (1.1924 \times 10^{-3} \div 0.25) = 9.539... \times 10^{-3}$ ○ ***pH*** = *pKw - pOH* *= (-log 2.92 x 10^{-14}) - (-log 9.539..x 10^{-3})* • ***pH*** *= 13.53(46) - 2.02(05)* **= 11.51** **Examiner's Comments** Most candidates wrote the correct equation. Common errors were using Sr^{2+} as reactant, not balancing the H_2O and not having the H_2 as second product. Most candidates calculated the moles of $Sr(OH)_2$ correctly but fewer recognised that [OH^-] = twice the [$Sr(OH)_2$]. As a result, most candidates scored 3 calculation marks. A few candidates chose the incorrect K_w value.
	c	i	$Mg + 2H^+ \rightarrow Mg^{2+} + H_2$ ✓	1 (AO 2.6)	**ALLOW** multiples **ALLOW** Mg^{+2} **IGNORE** state symbols **Examiner's Comments** Ionic equations still present candidates with a challenge. A few candidates scored the mark but many candidates gave a full equation or one that contained a mismatch of spectator ions as well as the correct ions.

		ii	HC*l* is a strong acid/completely dissociates **AND** CH_3COOH is a weak acid/partially dissociates ✓ Greater H^+ concentration in HC*l* **AND** More frequent collisions / faster rate of reaction ✓ More CH_3COOH dissociates until same number of moles of H^+ released **OR** same total moles H^+ produced (by the end) **OR** (Both acids are monobasic) and have the same number of moles of acid ✓	3 (AO 1.1 × 1) (AO 3.1 × 2)	**IGNORE** HCl is a strong**<u>er</u>** acid than ethanoic acid. **ALLOW** ORA **DO NOT ALLOW** dibasic/tribasic **<u>Examiner's Comments</u>** This question proved challenging for the candidates to identify the three ideas: Those of comparing acids, comparing moles and comparing rates. Very few candidates were able to score the 3 marks. Most candidates recognised the different strength of the two acids, but some only used comparative language. Some linked the moles of acid used to the volume of gas produced but many simply restated the same volume and concentration which is given within the question. Only a few candidates linked the higher initial $[H^+]$ in HCl to the increased rate through more frequent collisions. A common issue was describing the rate of dissociation rather than the $[H^+]$ present in determining the rate of the reactions or mentioning that it dissociates more but not linking this to the H+ concentration.
	d	i	One **mole** of (butanoic) acid donates/dissociates to form one **mole** of protons/H^+ ✓	1 (AO 1.1)	**ALLOW** One **molecule** of (butanoic) acid donates/dissociates to form one proton/H^+ **ALLOW** only one hydrogen ion in the acid can be replaced per molecule (in an acid-base reaction) **<u>Examiner's Comments</u>** Very few candidates wrote the complete definition of a monobasic acid. Most wrote "donates one proton" only, omitting

					mole or molecule. Some candidates described donating electrons or OH^-.
		ii	**FIRST CHECK THE ANSWER ON ANSWER LINE** **IF ANSWER = 1.5(3) x 10^{-5} award 4 marks** -- • $[H^+] = 10^{-pH}$ **OR** $10^{-5.07}$ **OR** 8.51×10^{-6} ✓ • $(\frac{3.39}{56.1})$ **OR** 0.0604 (0.06042781) (*n*A^- in buffer) = (n(KOH)) **OR** 0.0604 x 4 **OR** 0.242 ✓ ([A^-] in buffer) • *n*HA in buffer = (0.376 x 0.25) – 0.0604 = (0.094) – 0.0604 **OR** 0.0336 (0.03357219...) **OR** [HA] in buffer = (0.376 – 0.242) **OR** 0.0336 x 4 **OR** 0.134 (0.13428877) ✓ • $K_a = [H^+][A^-] \div [HA]$ $= \frac{8.51 \times 10^{-6} \times 0.242}{0.134}$ $= 1.5..... \times 10^{-5}$ (1.5319942×10^{-5})✓	4 (AO 1.2 × 1) (AO 2.6 × 3)	**FULL ANNOTATIONS MUST BE USED** -- **ALLOW ECF** throughout **ALLOW 2 SF** for [H^+] (use of pH) **ALLOW** 3 SF up to the calculated value. Ignore RE after 3SF for moles and concentration values Mark use of 2SF in working as incorrect **once** and then allow ECF **ALLOW** full marks for use of moles (volumes cancel) $K_a = \frac{8.51 \times 10^{-6} \times 0.0604}{0.0336}$ $=1.53 \times 10^{-5}$ **ALLOW** final answer to 2SF **Common errors for 3 marks** 5.47(1731026) x 10^{-6} (not subtracting moles of KOH from HA) **<u>Examiner's Comments</u>** This calculation proved difficult with many figures and sums appearing with little indication as to their relevance. Candidates should remember to provide written indications of what it is they're working out – presenting the calculations without any annotations can make it harder for error carried forward marks to be given if there is an error in their calculation. Few candidates scored all 4

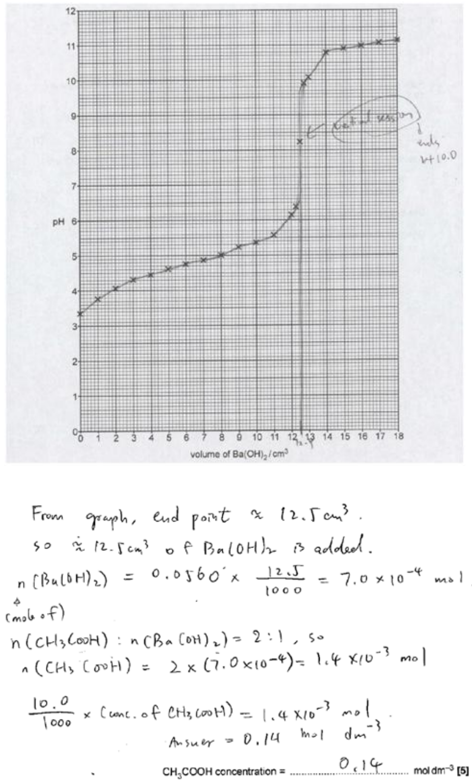
					marks. Most found the concentration of H^+ from the pH and the moles of KOH correctly but did not recognise they had to take away the moles of KOH from those of HA to find the remaining concentration of HA. Some candidates then used the [H+] as the [HA]. A few candidates tried a [H^+] squared expression of a weak acid. Exemplar 2  Assume that the volume of the solution remains constant at 250 cm^3 when the potassium hydroxide is dissolved. Ka = [H+][A-] / [HA] [H+] = 10$^{-5.07}$ = 8.51x10^{-6} mol of butanoic acid = 0.25x0.376 = 0.094 mol of A$^-$ = Mass/Mr = 3.39/56.1 = 0.0604 mol conc of A$^-$ = 0.0604/0.25 = 0.2417 Ka = 8.51x10^{-6} x 0.2417 / 0.376 Ka = 5.470649125x10^{-6} K_a = 5.47x10^{-6} mol dm^{-3} [4] The candidate has clearly set out the calculation so each numerical value can be linked and the steps understood. The only error is not calculating the excess acid (i.e. not subtracting moles OH- from initial moles acid) so 3 marks were given.
	e		ratio/proportion [HA]/[A-] is the same	1 (AO 3.1)	**ALLOW** Change in [HA] and [A-] is proportional **ALLOW** the concentrations of the weak acid and conjugate base change by same amount **<u>Examiner's Comments</u>** **Misconception** Only the most successful candidates linked the pH not changing to the ratio of [HA] and [A-] not changing on addition of water. The majority of candidates described the buffer being able to

					minimise pH change on addition of small amounts of acid or base or that water being neutral would not affect the pH.
			Total	**18**	
4 5			**FIRST CHECK THE ANSWER ON ANSWER LINE** **If range = 4.4 × 10^{-5} – 4.5 × 10^{-5} (kJ mol^{-1}) award 3 marks** -- [H+] = $10^{-1.50}$ **OR** 0.0316 … **OR** 0.032 mol dm^{-3} ✓ **1 mark** ***THEN 2 APPROACHES:*** ***EITHER:*** **Factor that concentration changes by** **1 mark** Factor = $\frac{0.0316.....}{0.680}$ = 0.0465… times **OR** $\frac{0.680}{0.0316.....}$ = 21.5..... times ✓ **Initial rate with diluted acid** **1 mark** = 0.0465… × 9.52 × 10^{-4} **OR** $\frac{9.52 \times 10^{-4}}{21.5.....}$ = 4.43 × 10–5 (mol dm^{-3} s^{-1}) ✓ ***OR:*** **Rate α concentration (1st order)** **1 mark**	3 (AO 3.1 ×3)	Calculator: 0.0316227766 **ALLOW** $10^{-1.5}$ **ECF** possible from incorrect [H^+] From unrounded [H+], Calculator: 0.04650408324 **From [H^+] = 0.032**, Factor = 21.25 From unrounded [H^+], Calculator = 4.427188724 × 10^{-5} **From [H^+] = 0.032**, rate = 4.48 × 10^{-5} -- **ECF** possible from incorrect [H^+] **DO NOT ALLOW ECF** unless derived from concentration and rate **SUMMARY** **M1 [H^+] 0.0316…. OR 0.032 1 mark** **M2 Working 0.0465 OR 21.5 OR 1.4 × 10^{-3} OR 714 1 mark** **M3 Initial rate Range: 4.4 × 10^{-5} – 4.5 × 10^{-5} 2 SF or more** *depends on intermediate rounding* ***CHECK*** **1 mark** **Examiner's Comments** The marks for this calculation were much more polarised than the calculation in Question 2 (a). Many candidates worked through the problem methodically to get an answer for the initial rate between 4.4 × 10^{-5} and 4.5 × 10^{-5} mol dm^{-3} s^{-1}. A substantial number of candidates worked out [H^+]

			$k = \frac{\text{rate}}{[\text{HCl}]} = \frac{9.52 \times 10^{-4}}{0.680} = 1.4(0) \times 10^{-3}$ **OR** Constant = $\frac{0.680}{9.52 \times 10^{-4}}$ = 714.2857… ✓ **Initial rate with diluted acid** = $1.4(0) \times 10^{-3} \times 0.0316$ … **OR** $\frac{0.0316\ldots}{714.2857\ldots}$ = 4.43×10^{-5} (mol dm^{-3} s^{-1}) ✓		using 10^{-pH} for 1 mark but were then unable to progress any further. This was a novel calculation, requiring candidates to develop their own strategy for its solution. Candidates who found this question difficult often attempted a solution based on stock weak acid calculation, using $[H^+]^2/[HA]$.
			Total	**3**	
46			**A**	1	**Examiner's Comments** The correct answer was A. Formation of a buffer solution can either be from either: • a weak acid and a salt of the weak acid, e.g. CH3COOH/CH3COONa • an excess of a weak acid and a strong alkali, e.g. excess CH3COOH/NaOH A few candidates suggested the other alternatives in equal measure.
			Total	**1**	
47	a	i	$(K_a) = \frac{[H^+]\,[ClCH_2COO^-]}{[ClCH_2COOH]}$	1	**DO NOT ALLOW** without square brackets **DO NOT ALLOW** $\frac{[H^+]^2}{[ClCH_2COOH]}$ **DO NOT ALLOW** $\frac{[H^+][A^-]}{[HA]}$ **Examiner's Comments** Most candidates scored the marking point. They realised that the full formulae were needed although some candidates

					left off the square brackets or used HA or $[H]^2$. Care should be taken in checking the correct amount and location of H in the formula. As an acid dissociates to form a H^+, it is important to acknowledge only one H^+ is dissociated from the correct part of the molecule.
		ii	$[H^+] = [A^-]$ **OR** $[H^+]$ from water is negligible **OR** dissociation of water is negligible ✓	1	Answer must be in terms of concentration **ALLOW** $[H^+] \approx [A^-]$ **IGNORE** HA ⇌ $H^+ + A^-$ is a 1:1 mole ratio. **<u>Examiner's Comments</u>** This question required the candidate to understand that the dissociation of water to produce H^+ ions had no effect on the overall $[H^+]$ of the solution, leading to $[H^+] = [A^-]$. This was mostly answered well but some candidates used the idea of $[H^+] = [OH^-]$.
		iii	**FIRST CHECK ANSWER ON ANSWER LINE** **If answer = 2.85 OR 2.86 OR 2.87 award 3 marks** -- $([H^+] =)\ 10^{-1.95}$ **OR** = 1.1(22…) × 10^{-2} ✓ $(K_a) = \left(\frac{[H^+]^2}{[ClCH_2COOH]}\right)$ $= \frac{(1.122\ldots \times 10^{-2})^2}{(0.090)}$ **OR** $\frac{(1.12 \times 10^{-2})^2}{(0.090)}$ **OR** $\frac{(1.1 \times 10^{-2})^2}{(0.090)}$ = 1.4(0) × 10^{-3} **OR** = 1.39 × 10^{-3} **OR** = 1.34 × 10^{-3} ✓ $(pK_a = -\log_{10}(K_a) =)$ 2.85, 2.86 OR 2.87 (**2DP**) ✓	3	**ALLOW ECF** throughout **ALLOW** $[H^+] = 1.1 \times 10^{-2}$ up to calculator value **ALLOW** 2 sig figs up to calculator value. **ALLOW** calculations based on finding the $[HA]_{equ}$ $\frac{(1.122\ldots \times 10^{-2})^2}{(0.079)}$ **OR** $\frac{(1.12 \times 10^{-2})^2}{(0.079)}$ **OR** $\frac{(1.1 \times 10^{-2})^2}{(0.079)}$ = 1.59 × 10^{-3} **OR** = 1.59 × 10^{-3} **OR** = 1.53 × 10^{-3} ✓ $(pK_a = -\log_{10}(K_a) =)$ 2.80 **OR** 2.80 **OR** 2.81 (**2DP**) ✓ **Must be 2DP** **Common error:** **2 marks** 0.90 (not using $[H^+]^2$) **<u>Examiner's Comments</u>** Candidates made good progress with this calculation, many gaining 2 or 3 marks,

					including error carried forward. Common errors included, in various combinations: using -log[-1.95]; using an incorrect value for the concentration of C/CH_2COOH; and using 10^{-Ka}.
	b	i	Smooth s-shaped curve using a best fit line that goes through the majority of points. ✓ Reading off x-axis at 12.5 cm^3 ✓ $n(Ba(OH)_2)$ =) $0.0560 \times \frac{12.5}{1000}$ $= 7.00 \times 10^{-4}$ ✓ $n(CH_3COOH$ =) 2 × (moles $Ba(OH)_2$) $= 1.40 \times 10^{-3}$ ✓ (concentration =) $\frac{1.4 \times 10^{-3}}{(10/1000)}$ = 0.14(0) (mol dm^{-3}) ✓ Alternative method based on calculating pK_a from the half neutralisation point. pH and [H^+] reading will come from the candidates graph and the data points provided. e.g. pH at half neutralisation 6.25 cm^3 = pH 4.7 = pK_a ✓ $K_a = 10^{-4.7}$ $= 1.995 \times 10^{-5}$ ✓ [H^+] at pH 3.3 (obtained from data on the graph provided) $10^{-3.3} = 5.012 \times 10^{-4}$ (mol dm^{-3}) ✓ $[HA] = \frac{[H^+]^2}{[K_a]}$ $= \frac{(5.012 \times 10^{-4})^2}{(1.995 \times 10^{-5})}$ = 0.0126 (mol dm^{-3}) ✓	5	**DO NOT ALLOW** point to point **DO NOT ALLOW** tram/feather lines. **ALLOW** Reading off x-axis from 12.4 – 12.6 cm^3 **ALLOW** ECF throughout **ALLOW** 3SF or more unless there is a trailing zero Alternative answers: 0.139 (mol dm^{-3}) (from reading off x-axis at 12.4 cm^3) 0.141 (mol dm^{-3}) (from reading off x-axis at 12.6 cm^3) **Common errors:** 3 Marks 0.134 (Use of 12 cm^3) 0.202 (use of 18 cm^3) **ALLOW** MP2 for $K_a = 1.7 \times 10^{-5}$ to 1.8×10^{-5} (knowledge of actual K_a value) **ALLOW** ECF from any quoted K_a **Examiner's Comments** Nearly all candidates were able to draw the line of best fit and linked the sharp vertical section of the graph with the volume of $Ba(OH)_2$ needed to neutralise the ethanoic acid. Candidates should aim to produce a smooth line of best fit and avoid 'tram' lines when the pencil is taken off the paper and the curve started again. The line should go through most points. Some candidates misinterpreted the graph and used values of 8, 12, 12.2,

					12.25 and 18. However, the remainder of the calculation was accessible, and most candidates scored well with ECF marks from this point. There was occasional division of 2 for the moles of ethanoic acid and dividing by the original volume of $Ba(OH)_2$ rather than the $10cm^3$ of ethanoic acid. Exemplar 3  This candidate scored all available marks. This is a very good example of a candidate displaying their working. The response was well communicated indicating the end point, links were made to what was being calculated and how the next number was obtained.
		ii	Phenol red **OR** Phenolphthalein ✓	1	Both indicators can change colour on the sharp vertical section of the candidates curve. **<u>Examiner's Comments</u>** Nearly all candidates scored this marking point. Phenol red and Phenolphthalein were good choices of indicator as their colour changed on the sharp vertical

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>section of the graph, depending on how the top end of the line of best fit was drawn. Occasionally malachite green and bromophenol blue were seen.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>11</td><td></td></tr>
<tr><td>48</td><td></td><td></td><td>
Oxygen (O lone pair) forms a <u>coordinate/dative</u> bond to <u>Fe(II)/Fe/Iron/Fe^{2+}</u> ✓

replaced by H_2O or CO_2
OR
O_2 bonds <u>reversibly</u> (with metal ion) ✓

FIRST CHECK ANSWER ON ANSWER LINE
If 7.3(0) AND not healthy / below 7.35 award three calculation marks
----

$[H^+] = K_a \times \frac{[H_2CO_3]}{[HCO_3^-]}$
OR
$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{K_a}{[H^+]}$ ✓

$[H^+] = 5.02 \times 10^{-8}$ ✓

pH = −log(5.02×10^{-8}) = 7.3(0)
AND not healthy / below 7.35 ✓

<u>Alternative method 1:</u>

pH of healthy blood is between 7.35 and 7.45

<table>
<tr><td>pH 7.35</td><td></td><td>pH 7.45</td><td></td></tr>
<tr><td>$[H^+] = 4.47 \times 10^{-8}$</td><td>OR</td><td>$[H^+] = 3.55 \times 10^{-8}$</td><td>✓</td></tr>
<tr><td>$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{K_a}{[H^+]}$</td><td></td><td>$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{K_a}{[H^+]}$</td><td>✓</td></tr>
<tr><td>$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{4.27 \times 10^{-7}}{4.47 \times 10^{-8}}$</td><td></td><td>$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{4.27 \times 10^{-7}}{3.55 \times 10^{-8}}$</td><td></td></tr>
<tr><td>$\frac{[HCO_3^-]}{[H_2CO_3]}$ = 9.55:1</td><td></td><td>$\frac{[HCO_3^-]}{[H_2CO_3]}$ = 12:03:1</td><td></td></tr>
</table>
</td><td>5</td><td>
ALLOW word equations using → and ⇌

IGNORE number of coordinate bonds

ALLOW ORA

<u>Check for alternative methods on mark scheme.</u>
ALLOW ECF throughout

ALLOW $[A^-]$ for $[HCO_3^-]$ AND/OR [HA] for $[H_2CO_3]$ (asked for in 19 a) ii))

ALLOW $[H^+] = K_a \div \frac{[HCO_3^-]}{[H_2CO_3]}$

ALLOW $\frac{[H_2CO_3]}{[HCO_3^-]} = \frac{[H^+]}{K_a}$

$[H^+]$ value subsumes MP3

ALLOW $[H^+] = 5.02 \times 10^{-8}$ up to the calculator value ($5.023529412 \times 10^{-8}$)

DO NOT ALLOW a weak acid approach for marking points 3 and 5. i.e. $[H^+]$ can be awarded.

ALLOW 7.3 up to calculator value (pH =7.298991951)

ALLOW $[H^+] = 3.98 \times 10^{-8}$ from average pH 7.40 used.
3

<u>Examiner's Comments</u>

The key chemistry that candidates needed to discuss in their response was as follows:

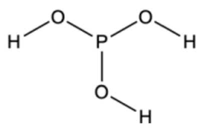
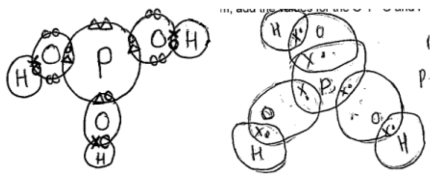
• O_2 molecules forming coordinate bonds with and Fe^{2+} ions in haemoglobin. Often candidates omitted the Fe^{2+} and just stated it was to haemoglobin
</td></tr>
</table>

			8.5:1 does not lie in the range of 9.55:1 to 12.03:1 **AND** unhealthy ✓ **<u>Alternative method 2:</u>** $pH = pK_a + \log \frac{[HCO_3^-]}{[H_2CO_3]}$ ✓ pKa = 6.37 ✓ $6.37 + \log \frac{(8.5)}{(1)}$ 7.3(0) **AND** not healthy / below 7.35 ✓		• O_2 **molecules** being replaced by another **ligand** (e.g. H_2O or CO_2) The calculation using the $[HCO_3^-]$: $[H_2CO_3]$ ratio of 8.5 : 1 was well described, although sometimes the final expression of the ratio left ambiguity as it was hard to tell whether the ratio given referred to the $[HCO_3^-]$: $[H_2CO_3]$ ratio or the $[H_2CO_3]$: $[HCO_3^-]$ ratio. ECF was given for the $[H^+]$ and then the pH linked to whether the blood was healthy. A smaller number of candidates approached the question by calculating the ratio of $[HCO_3^-]$: $[H_2CO^3]$ for both pH 7.35 <u>and</u> pH 7.45 and then compared <u>both</u> ratios to the ratio of 8.5 : 1 for healthy blood. A few candidates attempted the calculation by the weak acid approach using $[H^+]^2$. In this case only the $[H^+]$ was given.
			Total	**5**	
49	a		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF pH = 13.6(0), award 2 marks** -- $K_w = [H^+] \times 0.400$ **OR** $1.00 \times 10^{-14} = [H^+] \times 0.400$ **OR** $[H^+] = \frac{K_w}{0.400}$ **OR** $[H^+] = \frac{1.00 \times 10^{-14}}{0.400}$ **OR** $[H^+] = 2.5 \times 10^{-14}$ ✓ $pH = -\log 2.5 \times 10^{-14} = 13.6(0)$ ✓ **ALLOW** 13.6..... up to calculator value of 13.60205999 correctly rounded	2	**ALLOW ECF** from incorrect $[H^+]$ calculated from [OH−] **AND** K_w ....for pH > 7 **ONLY** **ALLOW** method based on pOH: **pOH** = −log 0.400 = 0.40 ✓ *Calculator: 0.39794...* pH = 14 − 0.40 = 13.6(0) ✓ **<u>Examiner's Comments</u>** Questions 1 (a), 1 (b) and 1 (c) required candidates to calculate the pH of a base, a diluted strong acid and a buffer solution. These different types of pH calculation form the basis of acid-base chemistry, all requiring the relationship

					pH = −log[H^+] at some stage. Most candidates showed competency in their pH calculations. A number of candidates often did not appreciate the type of pH calculation required. Question 1(a) was a standard pH calculation of a strong base and this was an easy start to the paper. Most candidates used K_w and the concentration of NaOH to determine the H^+ concentration of 2.5 ✓ 10^{-14} mol dm^{-3}, from which the pH of 13.60 can be calculated using pH = −log[H^+]. Some candidates first determined pOH as 0.40, and the pH using 14.00 − 0.40. This approach is based on sound chemistry and is acceptable. Several candidates often calculated the pH as −log 0.4 = 0.4 and gave this as their answer. NaOH is a common alkali and cannot have a pH <7 and this should have triggered that the candidate had made an error.
	b		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF pH = 1.12, award 1 mark** -- pH = −log 0.075 = **1.12** ✓ ***2 DP required***	1	**Examiner's Comments** This question was answered well although nearly a half of candidates made errors. The initial solution had been diluted by 10 times and its concentration had been reduced from 0.750 to 0.0750 mol dm^{-3}. From here pH = −log[H^+] gives the correct answer of 1.12 to 2 decimal places, required by the question. Candidates found Question 1 (b) more difficult than 1 (a) or 1 (c). There seemed to be little pattern in candidate errors, the dilution being the difficult part of the question. Some did not dilute the initial concentration of 0.750 mol dm^{-3}, giving 2.12. Others divided 0.750 by 2 instead of 10 or introduced 90 into the calculation as 90 cm3 of water would have been added. The most disappointing error was for a correct calculation to be displayed using the wrong number of decimal places. Two decimal places should be the norm for

					pH, reflecting the accuracy of most pH meters.
	c		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF pH = 4.28, award 2 marks** -- $1.75 \times 10^{-5} = \frac{[H^+] \times 0.100}{0.300}$ **OR** $[H^+] = \frac{1.75 \times 10^{-5} \times 0.300}{0.100}$ **OR** $[H^+] = 5.25 \times 10^{-5}$ (mol dm^{-3}) ✓ pH = -log 5.25 × 10^{-5} = 4.28 ✓ ***2 DP required***	2	COMMON ERRORS **1 mark for 5.23** inverted [HA] and [A$^-$] $[H^+] = \frac{1.75 \times 10^{-5} \times 0.100}{0.300}$ **OR** $5.83.... \times 10^{-6}$ × pH = -log 5.83.... × 10^{-6} = **5.23 ✓ ECF** **1 mark for 4.46** [HA] = 0.2 instead of 0.3 $[H^+] = \frac{1.75 \times 10^{-5} \times 0.200}{0.100}$ **OR** 3.5×10^{-5} × pH = -log 3.5 × 10^{-5} = **4.46 ✓ ECF** Other **ECF** available from **ONE** transcription error **ONLY, e.g.** 1.57 × 10^{-5} for K_a = 1.75 × 10^{-5} **Zero marks for square root approach e.g. via** $K_a = \frac{[H^+]^2}{0.300}$ **Zero marks for [A$^-$] : [HA] = 0.1 : 0.1** $[H^+] = \frac{1.75 \times 10^{-5} \times 0.100}{0.100} = 1.75 \times 10^{-5}$ × **i.e. pH = 4.76** × **ALLOW Henderson-Hasselbalch for both marks:** e.g. $pH = 4.76 + \log \frac{0.100}{0.300}$ **OR** $pH = -\log(1.75 \times 10^{-5}) + \log \frac{0.100}{0.300}$ ✓ **OR** $pH = -\log(1.75 \times 10^{-5}) - \log \frac{0.300}{0.100}$ pH = **4.28** ✓ **<u>Examiner's Comments</u>** This question was a standard calculation for the pH of a buffer solution and most candidates correctly identified the mixture

					as being a buffer. Most candidates used the expression for K_a and the concentrations of the weak acid and its salt to determine the H^+ concentration of 5.25×10^{-5} mol dm^{-3}. From here, the pH of 4.28 can easily be calculated. A common error was for the concentrations of the weak acid and its salt to be substituted into the K_a expression the wrong way round, producing an answer of 5.23. As there was only one error, this answer was given 1 mark with error carried forward (ECF). A few candidates first subtracted 0.1 from 0.3, using concentration values of 0.2 and 0.1 instead of 0.3 and 0.1. This gave an answer of 4.46 which was also given 1 mark. The substantial number of less successful responses fell into the trap of using the pH method for calculating the pH of a weak acid rather than a buffer, squaring the H^+ concentration. This was the wrong method to apply for a pH buffer calculation and was not given any marks.
			Total	**5**	
50		i	In (Equilibrium) **1**, $H_2PO_4^-$/It acts as a base **AND** accepts/gains H^+/a proton **OR** $H_2PO_4^-$ forms H_3PO_4 ✓ In (Equilibrium) **2**, $H_2PO_4^-$/It acts as an acid, **AND** donates/loses H^+/a proton **OR** $H_2PO_4^-$ forms HPO_4^{2-} ✓	2	**ALLOW** description for 1 or 2 as long as unambiguous, e.g. Equation 1, etc **IGNORE** missing charge on $H_2PO_4^-$ throughout **IGNORE** reference to $H_2PO_4^{2-}$ acting as an acid/base **OR** Equilibrium **3** *Question is about $H_2PO_4^-$* **ALLOW** 'dissociates into H^+ and $H_2PO_4^{2-}$' **IGNORE** 'partially' <u>**Examiner's Comments**</u> Candidates were expected to link proton-transfer behaviour in acids and bases to the provided equilibria. The question

					differentiated between candidates well. Some candidates just stated that an acid is a proton donor and a base a proton acceptor without referring to the provided equilibria. This was the answer to a much simpler question and could not be given marks. The best responses demonstrated excellent understanding within the context of the equilibria. Such candidates clearly explained how $H_2PO_4^-$ behaves as an acid in the forward reaction of Equilibrium 2 and as a base in the reverse reaction of Equilibrium 1.
		ii	Diagram showing **all** bonds correctly ✓  • 3 bonds only around each P • 2 bonds only around each O • Each O bonded to an H **Bond angles** O-P-O = 107° ✓ P-O-H = 104.5° ✓	3	**IGNORE** geometry **ALLOW** dot and cross diagram showing 2 shared electrons for each bond .... and **IGNORE** any lone pairs e.g.  Unambiguous bond angles may be shown on dot and cross diagram **ALLOW** 106-108° **ALLOW** 104-105° <u>**Examiner's Comments**</u> Most candidates used the information in the question to draw a correct displayed formula of H_3PO_3. Another acceptable approach was to show a 'dot-and-cross' diagram. Candidates usually chose 104.5° for the P-O-H bond angles although a significant number suggested 180°. The O-P-O bond angle proved to be more difficult. Many suggested 120° by ignoring the lone pair of electrons on the P atom. The

					shape was analogous with NH_3 giving a bond angle of 107°. Overall, candidates answered this question well. Candidates are advised to assess the number of bonded pairs and lone pairs around each atom when suggesting bond angles. This would have reduced the number of incorrect bond angles such as 180° for P-O-H and 120° for O-P-O.
		iii	phosphoric(III) **acid** ✓ *Oxidation number **MUST** be in correct place*	1	**DO NOT ALLOW** phosphoric acid (III) **DO NOT ALLOW** phosphorous acid **<u>Examiner's Comments</u>** Most candidates wrote the correct systematic name of phosphorus(III) acid and the clue given in the question for the name of H_3PO_4 should have helped. Common errors included phosphorus(IV) acid, the same as for H_3PO_4, and the (III) oxidation number being placed after 'acid' in the name. The commonest error though, was hydrogen phosphate. Candidates are advised to use any information provided in the question, which often contains clues. This certainly would have prevented hydrogen phosphate as a response.
			Total	**6**	