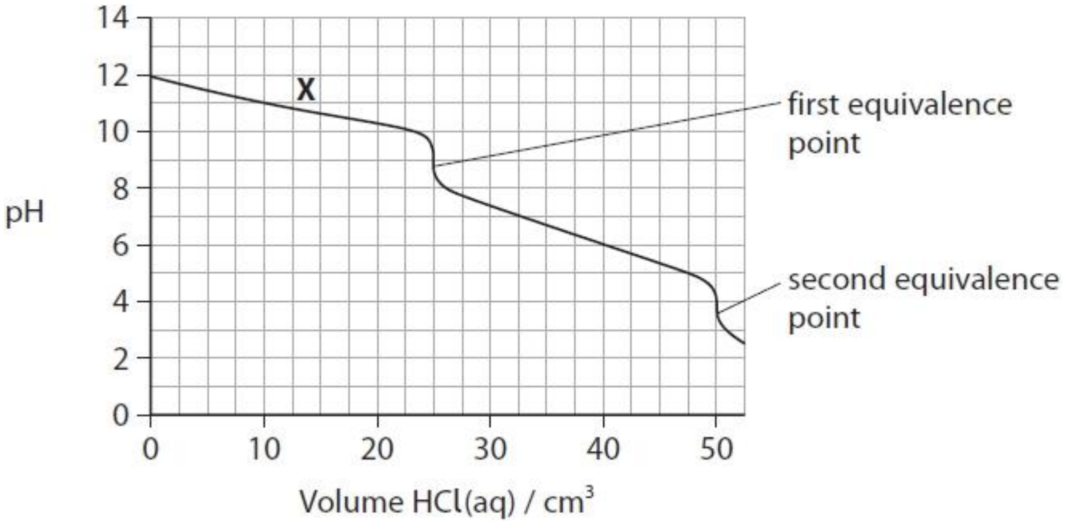
## Questions

**Q1.**

This question is about acids and bases.

Hydrochloric acid, with a concentration of 0.100 mol $dm^{-3}$, is added to 25.0 $cm^3$ of 0.100 mol $dm^{-3}$ aqueous sodium carbonate and the pH is measured.

The titration curve is shown.




The reaction takes place in two steps.
The equation for the reaction taking place in the first step is

$$Na_2CO_3(aq) + HCl(aq) \rightarrow NaHCO_3(aq) + NaCl(aq)$$

(i) Deduce a suitable indicator to identify the first equivalence point.

Justify your answer using values from the Data Booklet.

**(2)**

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(ii) Write the equation for the reaction taking place at the second equivalence point.
State symbols are not required.

**(1)**

(iii) Explain how the solution at point **X** on the graph can act as a buffer solution.

**(3)**

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**(Total for question = 6 marks)**

**Q2.**

This question is about an experiment to determine the equilibrium constant, $K_c$ , for an esterification reaction producing propyl ethanoate. The equation for the reaction is

$$\underset{\text{ethanoic acid}}{CH_3COOH(l)} + \underset{\text{propan-1-ol}}{CH_3CH_2CH_2OH(l)} \rightleftharpoons \underset{\text{propyl ethanoate}}{CH_3COOCH_2CH_2CH_3(l)} + H_2O(l)$$

In an experiment to determine the equilibrium constant, $K_c$ , the following steps were carried out.

- 6.0 cm$^3$ of ethanoic acid (0.105 mol), 6.0 cm$^3$ of propan-1-ol (0.080 mol) and 2.0 cm$^3$ of dilute hydrochloric acid were mixed together in a sealed boiling tube.
In this pre-equilibrium mixture, there is 0.111 mol of water
- The mixture was left for one week, at room temperature and pressure, to reach equilibrium
- The equilibrium mixture and washings were transferred to a volumetric flask and the solution made up to exactly 250.0 cm$^3$ using distilled water
- 25.0 cm$^3$ samples of the **diluted** equilibrium mixture were titrated with a solution of sodium hydroxide, concentration 0.200 mol dm$^{-3}$, using phenolphthalein as the indicator
- The mean titre was 23.60 cm$^3$ of 0.200 mol dm$^{-3}$ sodium hydroxide solution.

(a) State the role of the hydrochloric acid in the esterification reaction.

**(1)**

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(b) (i) Calculate the total amount, in moles, of acid present in the **volumetric flask** in the equilibrium mixture.

**(2)**

(ii) The 2.0 cm$^3$ of dilute hydrochloric acid contained 0.00400 mol of $H^+$(aq) ions.
Use this and your answer to part (b)(i) to calculate the amount, in moles, of ethanoic acid present in the equilibrium mixture.

**(1)**

(c) (i) The initial mixture in the boiling tube contained 0.105 mol of ethanoic acid.

Use your answer to (b)(ii) to calculate the amount, in moles, of ethanoic acid that reacted to form the ester in the equilibrium mixture.

**(1)**

(ii) Use information given in the method, and your answer to (c)(i), to calculate the amounts, in moles, of propan-1-ol, propyl ethanoate and water that are present in the equilibrium mixture.

**(3)**

Moles of propan-1-ol at equilibrium

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Moles of propyl ethanoate at equilibrium

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Moles of water at equilibrium

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(d) (i) Write the expression for the equilibrium constant, $K_c$ , for this reaction.

$$CH_3COOH(l) + CH_3CH_2CH_2OH(l) \rightleftharpoons CH_3COOCH_2CH_2CH_3(l) + H_2O(l)$$

**(1)**

(ii) Explain why it is possible, in this case, to calculate $K_c$ using equilibrium amounts in moles, rather than equilibrium concentrations.

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(iii) Calculate the value of $K_c$.
Give your answer to an appropriate number of significant figures.

**(2)**

(e) The pink colour of the phenolphthalein fades after the end-point of the titration has been reached.

Give a possible explanation for this observation.

**(2)**

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(f) Explain what you could do to confirm that one week is sufficient time for the mixture to reach equilibrium.

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(g) A student repeated the experiment, but left the mixture in a water bath at 40 °C until equilibrium was reached.

$$CH_3COOH(l) + CH_3CH_2CH_2OH(l) \rightleftharpoons CH_3COOCH_2CH_2CH_3(l) + H_2O(l) \qquad \Delta_r H^{\ominus} = +21.4\ kJ\ mol^{-1}$$

Deduce the effect, if any, on this student's value for $K_c$ compared with that obtained in part (d)(iii).

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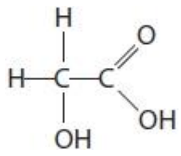
**(Total for question = 19 marks)**

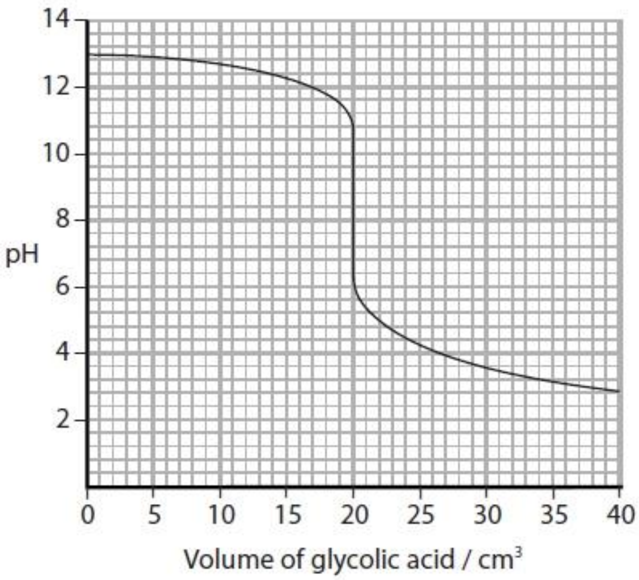
**Q3.**

2-Hydroxyethanoic acid, also known as glycolic acid, $CH_2OHCOOH$, is an alpha hydroxy acid used in some skincare products.
It has a $K_a$ value of $1.5 \times 10^{-4}$ mol dm$^{-3}$.

The structure of glycolic acid is




The titration curve for adding glycolic acid to 25.0 cm$^3$ of 0.100 mol dm$^{-3}$ sodium hydroxide is shown.




(i) Use the information given in your Data Booklet to select a suitable indicator for this titration, including the colour change you would expect to see.

Justify your selection.

**(3)**

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(ii) What is the concentration of this glycolic acid in mol $dm^{-3}$?

**(1)**

☐ **A** 0.080

☐ **B** 0.100

☐ **C** 0.125

☐ **D** 0.250

(iii) The pH of the solution containing just sodium glycolate and water is

**(1)**

☐ **A** 2.8

☐ **B** 6.0

☐ **C** 8.3

☐ **D** 11.0

**(Total for question = 5 marks)**

**Q4.**

This is a question about buffer solutions.

One of the systems controlling the pH of blood is the carbonic acid-hydrogencarbonate buffer system.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Explain how this buffer system helps to control the pH of blood when extra carbon dioxide is present due to strenuous exercise.

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**(Total for question = 3 marks)**

**Q5.**

This question is about buffer solutions.

A buffer solution was formed by mixing 20.0 $cm^3$ of sodium hydroxide solution of concentration 0.100 mol $dm^{-3}$ with 25.0 $cm^3$ of ethanoic acid of concentration 0.150 mol $dm^{-3}$.

$$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$$

Calculate the pH of this buffer solution.

[$K_a$ for ethanoic acid = $1.74 \times 10^{-5}$ mol $dm^{-3}$]

**(5)**

**(Total for question = 5 marks)**

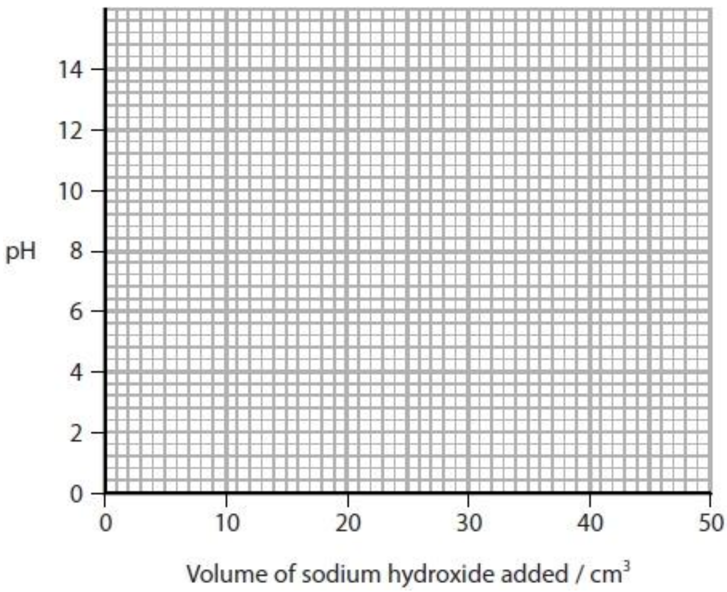
**Q6.**

This question is about weak acids.

(i) Propanoic acid, $CH_3CH_2COOH$, is a weak acid.

On the grid below, sketch the change in pH during the addition of 50.0 $cm^3$ of 0.100 mol $dm^{-3}$ sodium hydroxide solution to 25.0 $cm^3$ of 0.100 mol $dm^{-3}$ propanoic acid solution.

**(4)**




(ii) Explain how you would use the graph in (i) to obtain the value of the acid dissociation constant, $K_a$ , for propanoic acid.

You are **not** expected to calculate this value.

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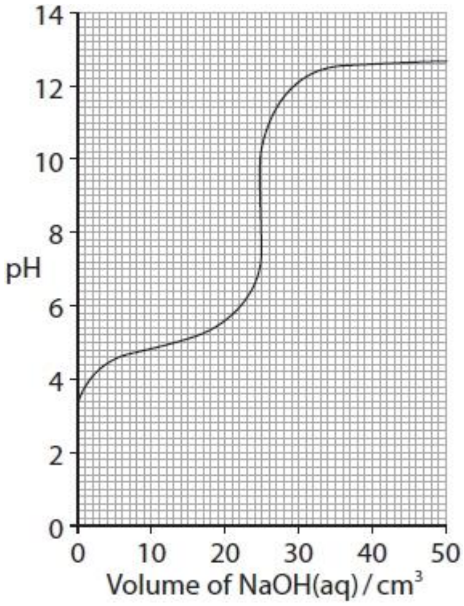
**(Total for question = 6 marks)**

**Q7.**

This question is about a titration experiment carried out by a group of students to determine the concentration of a solution of ethanoic acid using sodium hydroxide.

The sketch shows the pH changes during a titration of 25.0 $cm^3$ of ethanoic acid with sodium hydroxide of the same concentration.




The ideal indicator for this titration will change colour on the addition of a very small volume of sodium hydroxide solution at a titre value very close to the equivalence point of the reaction.

(i) Assess the suitability of methyl red as an indicator for this titration. Make use of the Data Booklet in answering this question.

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(ii) Complete the table, with a tick (✓) or a cross (X), to show whether or not the indicator would be suitable for use in this titration.

**(1)**

| Indicator | pH range | Tick or Cross |
|---|---|---|
| Bromocresol purple | 5.2 – 6.8 | |
| Thymol blue | 8.0 – 9.6 | |
| Thymolphthalein | 8.3 – 10.6 | |
| Alizarin yellow R | 10.1 – 13.0 | |

**(Total for question = 5 marks)**

**Q8.**

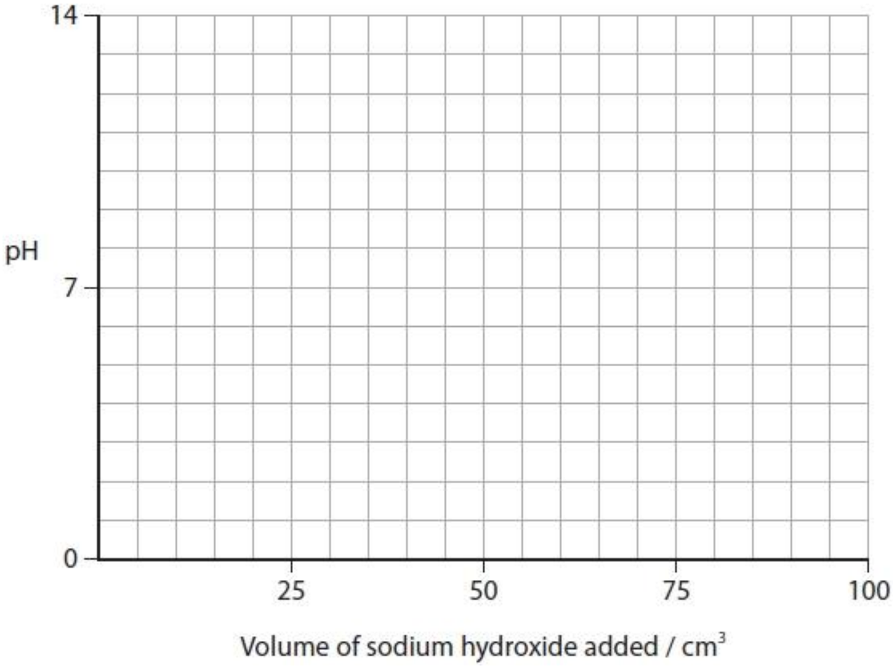
This is a question about buffer solutions.

A weak acid-strong base titration curve can be used to demonstrate buffer action.

(i) Draw a titration curve for the addition of

100 $cm^3$ of sodium hydroxide solution of concentration 0.100 mol $dm^{-3}$ to 40.0 $cm^3$ of propanoic acid solution of concentration 0.100 mol $dm^{-3}$ which has a pH of 3.0.
Show the part of the curve that demonstrates buffer action.

**(4)**




(ii) Describe, without calculation, how you would use your curve to determine the value of $K_a$ for propanoic acid.

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**(Total for question = 6 marks)**

**Q9.**

Pineapple juice contains the weak acids citric acid ($C_6H_8O_7$) and ascorbic acid ($C_6H_8O_6$). The amount of each compound in a sample of 150 $cm^3$ of pineapple juice can be determined by titration.

Experiment **1** is designed to determine the total amount of acid. 10.0 $cm^3$ samples of pineapple juice are transferred to separate conical flasks and titrated with a solution of sodium hydroxide of known concentration.

The total amount of acid in the 150 $cm^3$ sample of pineapple juice is $8.00 \times 10^{-3}$ mol.

(i) Give a reason why methyl orange would **not** be a suitable indicator to use in this titration.

**(1)**

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(ii) A student did not notice an air bubble in the tip of the burette **before** carrying out one of their accurate titrations. During this titration, the air bubble escaped.

Explain the effect this mistake would have on the value of this titre.

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**(Total for question = 3 marks)**

**Q10.**

Pineapple juice contains the weak acids citric acid ($C_6H_8O_7$) and ascorbic acid (C6H8O6). The amount of each compound in a sample of 150 $cm^3$ of pineapple juice can be determined by titration.

Experiment **1** is designed to determine the total amount of acid. 10.0 $cm^3$ samples of pineapple juice are transferred to separate conical flasks and titrated with a solution of sodium hydroxide of known concentration.

The total amount of acid in the 150 $cm^3$ sample of pineapple juice is $8.00 \times 10^{-3}$ mol.

(b) Experiment **2** is carried out to determine the amount of ascorbic acid ($C^6H^8O^6$) in the pineapple juice.

An outline procedure for this experiment is given.

Step **1** 5.00 $cm^3$ of the pineapple juice is added to a conical flask.

Step **2** Deionised water, a small amount of HCl(aq), a few crystals of potassium iodide, KI, and 3 drops of starch solution are also added to the flask.

Step **3** The contents of the flask are swirled to ensure the KI dissolves fully.

Step **4** The resultant mixture is titrated with a solution of potassium iodate(V), $KIO_3$(aq), of concentration 0.00100 mol $dm^{-3}$.

The reactions that take place are

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

$$C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2H^+(aq) + 2I^-(aq)$$

Only the ascorbic acid reacts with the iodine.

(i) The end-point of the titration is when the starch changes colour.

Explain how this occurs, including the colour change.

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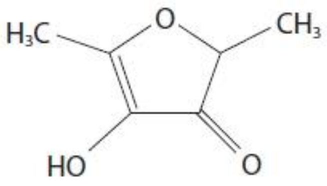
(ii) The **total** amount of acid in the 150 $cm^3$ sample is $8.00 \times 10^{-3}$ mol.

The mean titre in Experiment **2** using 5.00 $cm^3$ of pineapple juice is 9.50 $cm^3$.

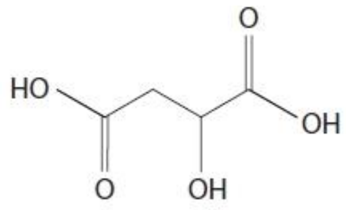
Calculate the mass of **citric acid** in the 150 $cm^3$ sample.

**(5)**

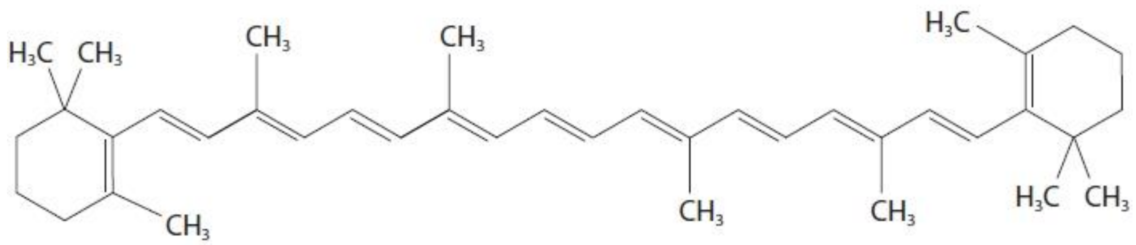
(c) While doing background research for the experiment, a student found that three other compounds, **D**, **E** and **F**, are often present in pineapple juice.




Compound **D**




Compound **E**




Compound **F**

Predict which one of these compounds is most likely to affect the result of Experiment **1** and hence predict the effect on the mass of citric acid calculated in (ii).

Justify your answer.

**(3)**

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**(Total for question = 11 marks)**

**Q11.**

This question is about the titration of a weak acid with a strong base.

A standard solution of ethanedioic acid, which is a weak, diprotic acid, can be used to determine the concentration of a sodium hydroxide solution. 25.0 $cm^3$ of the ethanedioic acid solution, with concentration 3.80 g $dm^{-3}$, was pipetted into a conical flask. A few drops of indicator solution were added. The ethanedioic acid was titrated with the sodium hydroxide solution which was in the burette. The titration was repeated and the following results were obtained.

[Molar mass of ethanedioic acid = 90.0 g mol−1]

| | Titration 1 | Titration 2 | Titration 3 | Titration 4 |
|---|---|---|---|---|
| Final reading / $cm^3$ | 18.00 | 17.60 | 35.30 | 27.70 |
| Initial reading / $cm^3$ | 0.00 | 0.00 | 17.60 | 10.05 |
| Titre / $cm^3$ | 18.00 | 17.60 | 17.70 | 17.65 |
| Titre used to find the mean titre (✓) | | | | |
| | | | Mean titre / $cm^3$ | |

(i) In the appropriate row, tick (✓) those titre values that should be used to find the mean, and use these titres to calculate it.

Write the value of the mean titre in the box provided in the table of results.

**(2)**

(ii) Ethanedioic acid is a weak acid. Name a suitable indicator for this titration and state the colour change at the end-point.

**(2)**

Name of indicator

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Colour change at the end-point from

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(iii) The equation for the reaction of ethanedioic acid with sodium hydroxide is

$$C_2H_2O_4 + 2NaOH \rightarrow C_2O_4Na_2 + 2H_2O$$

Calculate the concentration of the sodium hydroxide solution, in mol $dm^{-3}$.
Give your answer to **three** significant figures.

**(4)**

**(Total for question = 8 marks)**

**Q12.**

500 $cm^3$ of a buffer solution of pH = 4.70 is required.

Calculate the volume of 0.800 mol $dm^{-3}$ sodium ethanoate solution and of 0.800 mol $dm^{-3}$ ethanoic acid needed to make this buffer.

[$K_a$ for ethanoic acid = $1.74 \times 10^{-5}$ mol $dm^{-3}$]

**(3)**

**(Total for question = 3 marks)**

**Q13.**

This question is about acids and buffer solutions.

A buffer solution was made using 20.0 $cm^3$ of a butanoic acid solution, of concentration 0.100 mol $dm^{-3}$ and 30.0 $cm^3$ of sodium butanoate solution, of concentration 0.305 mol $dm^{-3}$.

[$K_a = 1.52 \times 10^{-5}$ mol $dm^{-3}$ at 298K]

(i) Calculate the pH of this buffer solution at 298 K.

**(4)**

(ii) Explain why the pH of the buffer solution hardly changes when a few drops of sodium hydroxide solution are added to it.

Include an equation or equations in your answer.

Use $C_3H_7COOH$ as the formula for butanoic acid.

**(2)**

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**(Total for question = 6 marks)**

**Q14.**

This question is about weak acids.

A weak acid, HX, has a $K_a$ value of $5.25 \times 10^{-5}$ mol dm$^{-3}$. A solution was formed by mixing 10.5 cm$^3$ of 0.800 mol dm$^{-3}$ dilute sodium hydroxide with 25.0 cm$^3$ of 0.920 mol dm$^{-3}$ HX(aq).

Calculate the pH of the solution formed, showing all your working.

**(5)**

**(Total for question = 5 marks)**

**Q15.**

This is a question about buffer solutions.

A buffer solution with a pH of 3.90 is required.

Calculate the **mass**, in grams, of sodium ethanoate that should be added to 50.0 $cm^3$ of an ethanoic acid solution of concentration 0.800 mol $dm^{-3}$ to form this buffer solution.

Give your answer to an appropriate number of significant figures.

[$K_a$ for ethanoic acid = $1.74 \times 10^{-5}$ mol $dm^{-3}$]

**(5)**

**(Total for question = 5 marks)**

**Q16.**

**Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.**

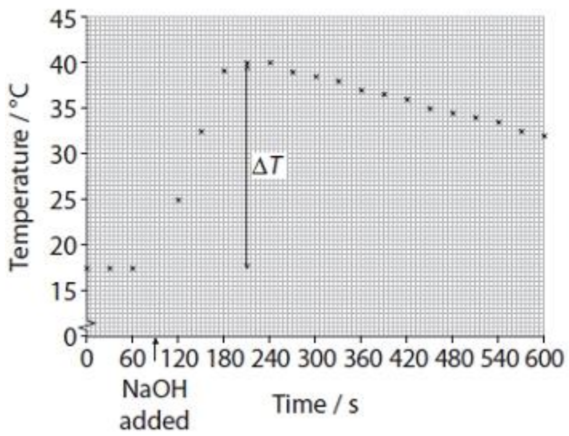
The standard molar enthalpy change of neutralisation is the enthalpy change when an acid and an alkali react under standard conditions to form one mole of water.

An experiment was carried out with a solution of ethanoic acid and sodium hydroxide solution of the same concentration.

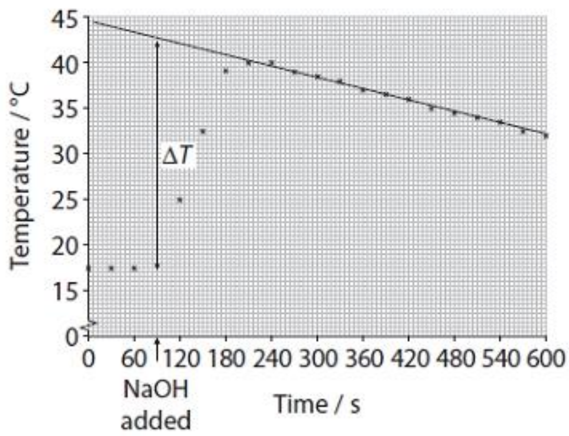
(i) Which graph shows the correct way that the maximum temperature rise should be determined?

**(1)**

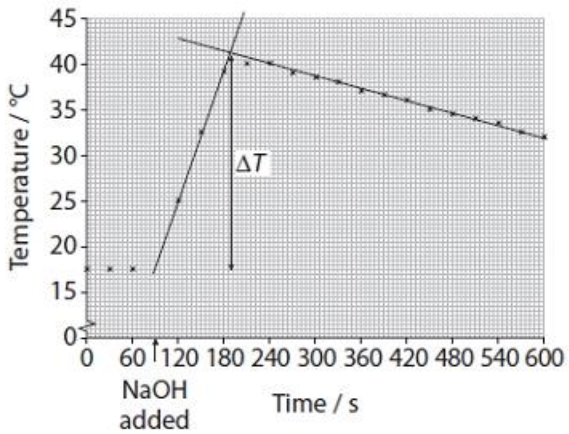
☐ **A**



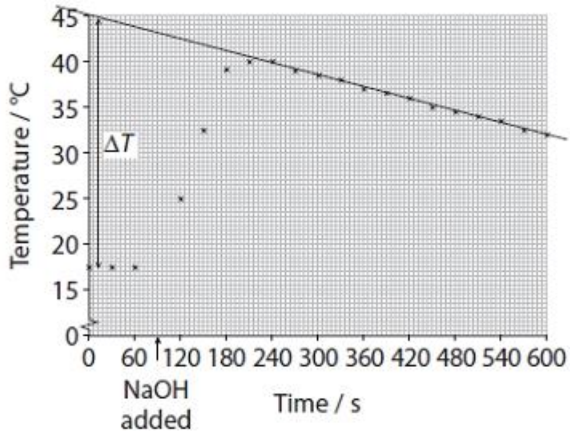

☐ **B**




☐ **C**




☐ **D**



(ii) Explain why the data book value for the standard enthalpy change of neutralisation of ethanoic acid with sodium hydroxide is –55.2 kJ $mol^{-1}$ but the value for hydrochloric acid is –57.1 kJ $mol^{-1}$.

(2)

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**(Total for question = 3 marks)**

**Q17.**

This question is about buffer solutions.

A buffer solution is formed from disodium hydrogenphosphate, containing $HPO_4^{2-}$ ions, and sodium dihydrogenphosphate, containing $H_2PO_4^-$ ions.

Write the **ionic** equations involving $HPO_4^{2-}$ and $H_2PO_4^-$ ions to show how this solution acts as a buffer solution.

(2)

**(Total for question = 2 marks)**

## Mark Scheme

Q1.

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (i) | • phenolphthalein **(1)**<br>• pH at equivalence point / 9 is very close / ±1 to p$K_{in}$ / 9.3<br>**or**<br>pH range is (completely) within the (first) vertical jump in the titration curve / between the range of (pH) 8.5 - pH9.5 **(1)** | Allow recognisable spellings<br>Allow indicator will change colour in the vertical section of the curve / at the end / equivalence point<br>Accept correct reference to the pH range for phenolphthalein from the data book (8.2-10.0) if there is a connection to the graph<br>Do not allow colourless to pink/red if the colour change of phenolphthalein is mentioned | **(2)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (ii) | • equation | Example of equation<br>$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$<br>or<br>$HCO_3^- + H^+ \rightarrow H_2O + CO_2$<br>Allow<br>$NaHCO_3 + HCl \rightarrow NaCl + H_2CO_3$<br>Allow multiples<br>Ignore state symbols even if incorrect | **(1)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (iii) | • (solution at **X**) contains a large amount of / reservoir of carbonate ions / $CO_3^{2-}$ **and** hydrogencarbonate ions/ $HCO_3^-$ **(1)**<br><br>• carbonate ions / $CO_3^{2-}$ react with added hydrogen ions / $H^+$ / acid **or** $CO_3^{2-} + H^+ \rightarrow HCO_3^-$ **(1)**<br><br>• hydrogencarbonate ions / $HCO_3^-$ react with added hydroxide ions / $OH^-$ / alkali **or** $HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$ **(1)** | Allow there is a large amount of $Na_2CO_3$ and $NaHCO_3$<br>Allow solution at X contains a reservoir of an acid and its conjugate base<br><br>Allow $Na_2CO_3$ reacts with added hydrogen ions / $H^+$ / acid to form $NaHCO_3$<br>**or**<br>$CO_3^{2-} + HCl \rightarrow HCO_3^- + Cl^-$<br>**or**<br>$A^- + H^+ \rightarrow HA$<br><br>Allow $NaHCO_3$ reacts with added hydroxide ions (to form $Na_2CO_3 + H_2O$)<br>Allow hydroxide ions react with hydrogen ions to form water **and** hydrogencarbonate ions dissociate to replace / form hydrogen ions<br>**or**<br>$OH^- + H^+ \rightarrow H_2O$ **and** $HCO_3^- \rightarrow CO_3^{2-} + H^+$<br>**or**<br>$HA + OH^- \rightarrow A^- + H_2O$<br>Allow ⇌ in equations<br>Ignore state symbols | **(3)** |

**Q2.**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (a) | Any one from:<br><br>Catalyst / speeds up reaction / increases rate / increases rate of attainment of equilibrium / lowers activation energy | Ignore any mention of protonation or mechanism for catalysis<br>Do not award additional incorrect types of reaction | (1) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (b)(i) | • calculation of moles of $H^+$ in 25.0 $cm^3$ **(1)**<br><br>• calculation of moles of $H^+$ in 250 $cm^3$ flask **(1)** | Ignore SF throughout 8(b)(i) to 8(c)(ii) except 1 SF, which should be penalised once only<br><br>Example of calculation:<br><br>(moles NaOH = 0.200 x $\frac{23.60}{1000}$)<br>= 0.00472 (mol) (= mol $H^+$ in 25.0 $cm^3$)<br><br>(= 10 x 0.00472) = 0.0472 (mol) (in 250 $cm^3$)<br><br>Allow TE for M2 on moles of NaOH<br><br>Correct answer with or without working scores 2 marks | **(2)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (b)(ii) | • subtracts moles of $H^+$ in HCl from answer to (b)(i) | Example of calculation:<br><br>0.0472 – 0.00400 = 0.0432 (mol)<br><br>Allow TE on answer to part (b)(i) | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (c)(i) | • calculation of moles of $CH_3COOH$ that have reacted | Example of calculation:<br><br>(0.105 — 0.0432) = 0.0618<br><br>Allow TE on part (b)(ii) unless negative value | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (c)(ii) | • calculation of equilibrium moles of $CH_3CH_2CH_2OH$ **(1)**<br><br>• calculation of equilibrium moles of $CH_3COOCH_2CH_2CH_3$ **(1)**<br><br>• calculation of equilibrium moles of $H_2O$ **(1)** | Example of calculation:<br><br>0.0800 — 0.0618 = 0.0182<br><br>0.0618<br><br>0.111 + 0.0618 = 0.1728<br><br>Allow TE on answer to part (c)(i) unless negative value | **(3)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (d)(i) | $(K_c =) \frac{[CH_3COOCH_2CH_2CH_3][H_2O]}{[CH_3COOH][CH_3CH_2CH_2OH]}$ | IGNORE state symbols even if incorrect<br>Do not award round brackets | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (d)(ii) | An explanation that makes reference to the following points:<br>• Same number of moles/molecules on both sides of the equation (1)<br>• (so) volume / V cancels in $K_c$ expression (1) | 2 marks could be scored by a correct mathematical expression showing V or $dm^3$ cancel<br>Allow same number of terms on top and bottom of $K_c$ expression<br>Allow units cancel out<br>Allow "**all** divided by the same volume" | (2) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (d)(iii) | • calculates value of $K_c$ (1)<br>• final value of $K_c$ quoted to 2 or 3 SF (1) | Example of calculation<br>$K_c = \frac{(0.0618) \times (0.1728)}{(0.0432) \times (0.0182)} =$ 13.58241758<br>= 14 / 13.6 (no units)<br>Correct answer with no working gains full marks<br>Ignore units<br>No TE on wrong $K_c$ expression | 2 |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (e) | An explanation that makes reference to the following points:<br>• the equilibrium shifts to the left **or** the mixture absorbs carbon dioxide from the atmosphere (1)<br>• so the mixture is (becoming more) acidic / the acid reforms (1) | Mark independently<br>Allow no longer alkaline<br>Do not award just "pH decreases" | (2) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (f) | An explanation that makes reference to the following points:<br>• carry out / repeat experiment **and** leave for longer than a week (1)<br>• the titre value / $K_c$ value will remain unchanged (if equilibrium has been established) (1) | Ignore pH probes / checking pH<br>Allow repeat experiment **and** check titres within first week<br>Allow moles / concentration are unchanged<br>Ignore just "results unchanged" | (2) |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (g) | An answer that makes reference to the following points:<br><br>• $K_c$ value will be greater than that calculated in (d)(iii) **(1)**<br><br>• because the (forward) reaction is endothermic<br>**or**<br>backward / reverse reaction is exothermic **(1)** | M2 depends on M1<br><br>Ignore<br>References to the equilibrium position shifting to the right (with increasing temperature) | **(2)** |

**Q3.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (i) | • named indicator **(1)**<br><br>• matching colour **change** **(1)** | <u>Examples of indicators and colour changes</u><br>phenol red – red to orange / yellow<br>phenolphthalein ((in ethanol)) – red / pink to colourless (do not allow purple or clear)<br>bromothymol blue – blue to yellow<br><br>M2 is conditional on a correct indicator in M1<br>Do not allow unsuitable indicators e.g. litmus | **(3)** |
| | • pH range (of indicator) / quoted range lies (completely) in the vertical region (on the titration curve)<br>**or**<br>indicator will change colour in the vertical / straight / steep region of the graph<br>**or**<br>pH range of indicator and pH range of vertical region of the graph stated, as long as they overlap<br>**(1)** | Stand alone mark<br>Allow<br>p$K_{in}$ (± 1) is in the vertical jump<br>**or**<br>p$K_{in}$ is nearest to the pH at the end / equivalence point<br>**or**<br>indicator will change colour at the end / equivalence point<br>**or**<br>(because it is a) titration of a weak acid with a strong base | |

| Question Number | Answer | Mark |
|---|---|---|
| (ii) | **The only correct answer is C**<br><br>***A*** *is not correct because used the volumes the wrong way round*<br><br>***B*** *is not correct because not used the volume of glycolic acid from the graph*<br><br>***D*** *is not correct because used a 1:2 mole ratio* | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| (iii) | **The only correct answer is C**<br><br>***A*** *is not correct because this is the pH of glycolic acid*<br><br>***B*** *is not correct because this is the pH at the end of the vertical jump in the curve*<br><br>***D*** *is not correct because this is the pH at the start of the vertical jump* | (1) |

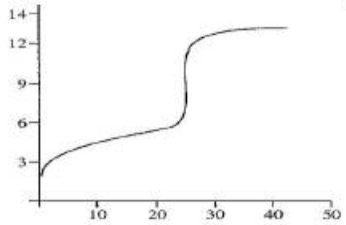
**Q4.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| | An answer that makes reference to the following points: | | (3) |
| | • carbon dioxide dissolved in the blood forms carbonic acid (and so this concentration increases) **(1)** | Can be shown in an equation Do not award '$CO_2$ reacts with $H^+$ to form carbonic acid' | |
| | • the equilibrium will shift to the right and produces more $H^+$/acid ions **(1)** | Allow<br>Carbonic acid (partially) dissociates to produce $H^+$<br>Do not award '$CO_2$ reacts with $H^+$ so equilibrium shifts to the right to produce more $H^+$' | |
| | • the (high) concentration of hydrogencarbonate ions suppress the ionisation of carbonic acid (to help to control pH) **or**<br>the (large) reservoir/excess of hydrogencarbonate ions combine with the $H^+$ ions (to help to control blood pH) **(1)** | | |
| | | Ignore general comments about the effects of adding acid and/or alkali to a buffer which do not relate to carbon dioxide | |

**Q5.**

| Question Number | Answer | Additional Guidance | Mark |
| --- | --- | --- | --- |
| | • calculation of the amount of NaOH / salt **(1)** | Example of calculation<br>amount of NaOH = amount of salt formed<br>=0.100 x 20.0/1000 = 0.00200 | **(5)** |
| | • calculation of initial amount of acid **(1)** | initial amount of acid = 0.150 x 25.0/1000<br>= 0.00375 | |
| | • calculation of the amount of acid left **(1)** | amount of acid left = 0.00375 − 0.00200<br>= 0.00175 | |
| | • calculation of [H⁺] **(1)** | total volume = 20.0 + 25.0 = 45.0 ($cm^3$)<br>[salt] = 0.00200 x 1000/45.0 = 0.0444 ($mol\ dm^{-3}$)<br>[acid] = 0.00175 x 1000/45.0 = 0.0389($mol\ dm^{-3}$)<br>$K_a = \frac{[H^+][salt]}{[acid]}$ so $[H^+] = K_a\frac{[acid]}{[salt]}$<br>$[H^+] = 1.74 \times 10^{-5} \times 0.0389/0.0444$<br>$= 1.52446 \times 10^{-5}$ ($mol\ dm^{-3}$)<br>Allow use of moles instead of concentrations | |
| | • calculation of pH **(1)** | $pH = -\log[H^+] = -\log(1.52446 \times 10^{-5})$<br>= 4.817 / 4.82 / 4.8<br>Allow TE for each step<br>Ignore SF except 1 SF<br>Correct answer without working score (5)<br>Allow alternative methods, for example<br>$pH = pK_a - \log\frac{[acid]}{[salt]}$<br>$pH = -\log 1.74 \times 10^{-5} - \log\frac{0.0389}{0.0444}$<br>pH = 4.817 / 4.82 / 4.8 scores M4 and M5<br>**or**<br>$pH = pK_a + \log\frac{[salt]}{[acid]}$<br>$pH = -\log 1.74 \times 10^{-5} + \log\frac{0.0444}{0.0389}$<br>pH = 4.817 / 4.82 / 4.8 scores M4 and M5 | |

**Q6.**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (i) | A sketch graph which shows the following:<br>• a starting pH between 2 and 4 (inclusive) **(1)**<br>• correct general shape and ends at pH = 12-13 **(1)**<br>• (any) vertical at 25 $cm^3$ **(1)**<br>• vertical between pH = 6 - 7 and pH = 10 – 12 **(1)** | <br>Vertical must be no more than 5 pH units within these ranges | **(4)** |

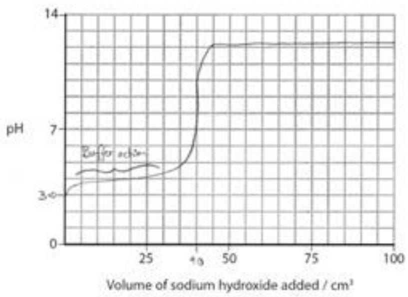
| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| (ii) | An explanation that makes reference to the following points:<br>• (Read off) **pH** at half-neutralisation (point) / pH at 12.5 ($cm^3$)<br>OR<br>**pH** at half-equivalence (point) **(1)**<br>• As pH = p$K_a$ / [$H^+$] = $K_a$ / $K_a$ = $10^{-pH}$ **(1)** | May be shown on the sketch graph<br>ALLOW read equivalence vol, add same volume of (propanoic) acid and measure pH<br><br>M2 dependent on mentioning half equivalent / 12.5 $cm^3$ | **(2)** |

**Q7.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (i) | An assessment that includes<br>• **(M1)** the vertical part of the graph is at ~7 - 10/ the mid-point is at 8.5-8.8 **(1)**<br>• **(M2)** the mid-point of the colour change of methyl red is 5.1 **(1)**<br>• **(M3)** pH range of methyl red does not lie (completely) within the vertical range of the pH curve (so it is not suitable) **(1)**<br>• **(M4)** the colour change will be complete before the equivalence point is reached **(1)** | Allow 'equivalence point/end-point' for 'the vertical part of the graph/ the mid-point'<br><br>Allow methyl red changes colour in the range/ has a pH range 4.2 - 6.3/ p$K_{in}$ 5.1<br><br>Allow, after stating M1 and M2, 'this means that methyl red is unsuitable'<br><br>Allow end-point/neutralisation point for equivalence point<br>Do not award colour change to red<br><br>Ignore references to choice of other indicators | **(4)** |

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>(ii)</td><td>An answer that includes<br>• two ticks and two crosses as shown</td><td>
<table>
<tr><th>Indicator</th><th>pH range</th><th>Tick or Cross</th></tr>
<tr><td>Bromocresol purple</td><td>5.2 - 6.8</td><td>x</td></tr>
<tr><td>Thymol blue</td><td>8.0 - 9.6</td><td>✓</td></tr>
<tr><td>Thymolphthalein</td><td>8.3 - 10.6</td><td>✓</td></tr>
<tr><td>Alizarin yellow R</td><td>10.1 - 13.0</td><td>x</td></tr>
</table>
Do not award blank boxes for (x)</td><td>(1)</td></tr>
</table>

## Q8.

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>(i)</td><td>• general shape of weak acid-strong base curve (1)<br><br>• curve starts at pH of 3.0 and ends at pH of 12-13 (1)<br><br>• vertical part of the curve at 40 cm$^3$ (1)<br><br>• labelling of area indicating buffer action (1)</td><td>Exemplar graph<br>
<br>Ignore missing initial rise in pH Vertical part must cover 3-5 pH units between 6 – 11<br>The curve should reach pH~12-13 by 10cm$^3$ after vertical section<br><br>The curve must start at zero and continue to 100 cm$^3$<br><br>Allow buffering area to be labelled anywhere between ~5 and 35 cm$^3$ inclusive</td><td>(4)</td></tr>
</table>

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (ii) | An answer that makes reference to<br>• determine the pH at the point when half of the acid is neutralised (1)<br>• $K_a = 10^{-pH}$ / $K_a = 10^{-pK_a}$ (1) | Standalone marks<br>Allow 'pH at half-equivalence point'<br>Allow 'pH at half neutralisation point'<br>Accept description in words such as inverse log of minus pH or value is p$K_a$ and so inverse log of minus value gives $K_a$ Allow p$K_a$ = -log $K_a$<br>Ignore any calculation | (2) |

**Q9.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (i) | An answer that makes reference to one of the following points:<br>• the colour of the pineapple juice masks the colour change **or**<br>methyl orange only works with a strong acid **or**<br>methyl orange does not change colour in the vertical section of the titration curve | Allow methyl orange is a similar colour to pineapple juice<br>Accept methyl orange cannot be used with a weak acid (and strong alkali)<br>Allow the pH range / 3.2-4.4 / p$K_{in}$ of methyl orange is below the equivalence point / too low Allow the colour change would occur before the equivalence point / is not over the equivalence point<br>Allow the pH at the equivalence point is not in the pH range of methyl orange<br>Allow end point for equivalence point<br>Ignore just 'no colour change observed'<br>Ignore just 'end point is not accurate' | (1) |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (ii) | An explanation that makes reference to the following points:<br>• the titre value would be greater (than expected) **(1)**<br>• as the titre value includes the volume of the air bubble (as well as sodium hydroxide solution) **(1)** | M2 conditional on M1 scored<br>Allow some alkali / solution is used to fill the air bubble / jet<br>Allow there is less sodium hydroxide in the burette than expected | **(2)** |

**Q10.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (i) | An explanation that makes reference to the following points:<br>• (at the end point) all ascorbic acid is used up so the iodine is no longer reduced (to iodide ions) **or** ascorbic acid reacts with the iodine until all the (ascorbic) acid is used up **(1)**<br>• the (slight excess) iodine reacts / forms complex with the starch **(1)**<br>• (changing from yellow) to a blue/black colour **(1)** | Stand alone<br>Allow starch in the presence of iodine<br>Do not award starch and iodide ions<br>Stand alone<br>Allow just black or just (dark) blue<br>Ignore initial colour of solution<br>Do not award blue/black to colourless | **(3)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (ii) | • calculation of amount of $IO_3^-$ (aq) **(1)**<br>• calculation of amount of iodine / ascorbic acid in 5.00 $cm^3$ sample **(1)**<br>• calculation of amount of ascorbic acid in 150.0 $cm^3$ sample **(1)**<br>• calculation of amount of citric acid in 150.0 $cm^3$ sample **(1)**<br>• calculation of mass of citric acid in 150.0 $cm^3$ sample **(1)** | <u>Example of calculation</u><br>= (9.50/1000) x 0.00100 = 9.50 x $10^{-6}$ (mol)<br>= 9.50 x $10^{-6}$ x 3 = 2.85 x $10^{-5}$ (mol)<br>TE on M1<br>= 2.85 x $10^{-5}$ x 30 = 8.55 x $10^{-4}$ (mol)<br>TE on M2<br>= 8.00 x $10^{-3}$ – 8.55 x $10^{-4}$ = 7.145 x $10^{-3}$ (mol)<br>TE on M3<br>= 7.145 x $10^{-3}$ x 192 = 1.37184 g = 1.37 (g)<br>TE on M4<br>Ignore SF except 1 SF<br>Correct answer with some or no working scores (5) | **(5)** |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| | An explanation that makes reference to the following points:<br>• compound **E** **and** as it has (two) COOH / (carboxylic) acid group(s) **(1)**<br>• these / this will (also) react with the NaOH / in the titration (in Experiment **1**) **(1)**<br>• (the titre will be greater in Experiment **1** so suggests a greater total amount of acid) so the final mass of citric acid calculated will be greater (than the true amount) **or** the total amount of acid (calculated from the titration) includes citric acid and **E** so the actual mass of citric acid is less (than calculated in (b)(ii) **(1)** | Allow Compound **E** is a (di)carboxylic acid<br>Ignore reference to OH group<br>Do not award carbonyl group(s)<br>Do not award if OH group reacts with NaOH<br>Conditional on compound **E** selected | **(3)** |

**Q11.**

| Question Number | Acceptable Answer | Additional Guidance | Mark |
| --- | --- | --- | --- |
| **(i)** | • ticks under titration numbers 2, 3, 4 **(1)**<br><br>• 17.65 ($cm^3$) **(1)** | ignore **X** under Titration 1<br><br><u>example of calculation</u><br>$\frac{17.60 + 17.70 + 17.65}{3}$<br>= 17.65<br>scroll down as mean titre value may be written below (i) rather than in the table<br>units not required<br>must be 2 dp<br>TE from M1<br>if Titration 1 has been ticked (17.74) | **(2)** |

| Question Number | Acceptable Answer | Additional Guidance | Mark |
| --- | --- | --- | --- |
| **(ii)** | • Phenolphthalein/ methyl orange **(1)**<br><br>• colourless to pink / red to orange **(1)** | M2 depends on M1<br>allow any indicator other than litmus or universal indicator<br>allow minor errors in spelling of phenolphthalein but not phenyl....<br><br>do not award red/pink-red for phenolphthalein nor yellow for methyl orange<br>allow correct colour change for other indicators | **(2)** |

| Question Number | Acceptable Answer | Additional Guidance | Mark |
|---|---|---|---|
| (iii) | • converts [acid] from g $dm^{-3}$ to mol $dm^{-3}$ **(1)**<br><br>• calculates moles of acid in 25 $cm^3$ **(1)**<br><br>• calculates moles of sodium hydroxide in titre $cm^3$ **(1)**<br><br>• converts moles of sodium hydroxide in titre to mol $dm^{-3}$ and gives the answer 3 SF **(1)** | Example of calculation<br><br>3.80/90.0 = *4.22 x $10^{-2}$ (mol $dm^{-3}$)<br><br>ans to M1 x 25 x $10^{-3}$<br>25 x $10^{-3}$ x *4.22 x $10^{-2}$ = **1.0556 x $10^{-3}$ (mol)<br>allow M1 and M2 in any order<br>one mark only if not divided by 90.0<br><br>ans to M2** x 2<br>= 1.0556 x $10^{-3}$ x 2 = ***2.111 x $10^{-3}$ (mol)<br><br>= ans to M3*** x 1000/17.65 = 0.1196<br>= 0.120 (mol $dm^{-3}$)<br><br>correct answer with no working scores 4 marks | **(4)** |

**Q12.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| | EITHER<br><br>• calculation of $[H^+(aq)]$ **(1)**<br>• calculation of ratio of [acid]/[salt] or [salt]/[acid] **or** correct values substituted into expression for ratio **(1)**<br><br>• calculation of volume of acid required and salt required **(1)**<br><br>OR<br><br>• calculation of log [acid]/[salt] using Henderson-Hasselbalch **(1)**<br>• calculation of ratio of [acid]/[salt] **(1)**<br><br>• calculation volume of acid required and salt required **(1)** | <u>Example of calculation</u><br><br>$[H^+(aq)] = 10^{-4.70} = 1.9953 \times 10^{-5}$ (mol $dm^{-3}$)<br><br>[acid]/[salt] = $1.9953 \times 10^{-5} / 1.74 \times 10^{-5}$<br>= 1.1467 : 1 / 1 : 0.872<br>**or**<br>[salt]/[acid] = $1.74 \times 10^{-5} / 1.9953 \times 10^{-5}$<br>= 0.872 : 1 / 1 : 1.1467<br><br>(1.1467 /2.1467) x 500 = 267 $cm^3$ acid<br>500 – 267 = 233 $cm^3$ salt<br><br>4.7595 – 4.70 = 0.05945<br><br>$10^{0.05945}$ = 1.1467 : 1<br><br>(1.1467 / 2.1467) x 500 = 267 $cm^3$ acid<br>500 – 267 = 233 $cm^3$ salt<br>Allow 270 $cm^3$ acid and 230 $cm^3$ salt<br><br>Ignore SF except 1 SF but allow 2 / 2.0 / 2.00 x $10^{-5}$ for M1 in 'EITHER'<br><br>Allow TE from M1 throughout<br><br>Correct answer with no working scores (3) | **(3)** |

**Q13.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (i) | • calculation of acid concentration (1)<br><br>• calculation of salt concentration (1)<br><br>• calculation of hydrogen ion concentration (1)<br><br>• calculation of pH (1) | Example of calculation<br><br>[Acid] = ((0.100 x (20 ÷ 50))<br>= 0.04 (mol $dm^{-3}$)<br><br>$[A^-]$ = ((0.305 x (30 ÷ 50))<br>= 0.183 (mol $dm^{-3}$)<br><br>$[H^+]$ = 1. 52 x $10^{-5}$ mol x (0.04 ÷ 0.183)<br>= 3.322 x $10^{-6}$ (mol $dm^{-3}$)<br><br>pH= -log(3.322 x $10^{-6}$)<br>= 5.48/5.5<br><br>Correct answer without working scores (4)<br>Ignore SF except 1SF<br><br>Allow M3 and M4 if just moles and no volumes are used<br><br>Accept use of the Henderson-Hasselbalch equation | (4) |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (ii) | An answer which includes<br><br>• suitable equation(s) (1)<br><br>• The pH stays approximately constant because there is a large reservoir of undissociated acid and so the ratio of acid:salt does not change (1) | Example equation<br><br>$C_3H_7COOH + NaOH \rightarrow C_3H_7COONa + H_2O$<br>OR<br>$C_3H_7COOH + OH^- \rightarrow C_3H_7COO^- + H_2O$<br><br>Allow<br>$OH^- + H^+ \rightarrow H_2O$ followed by<br>$C_3H_7COOH \rightarrow C_3H_7COO^- + H^+$<br><br>Allow use ⇌ of in all of above equations<br><br>Allow (The pH stays approximately constant) as the hydroxide ions react to form water and butanoic acid dissociates to replace the hydrogen ions used up | (2) |

**Q14.**

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| | • calculates moles of $X^-$ / NaOH present in the mixture **(1)**<br><br>• calculates moles of HX which remain unreacted **(1)**<br><br>• calculates / shows ratio of [HX] to [$X^-$] OR ratio of moles of HX : $X^-$ (as total V cancels) **(1)**<br><br>• re-arranges $K_a$ or p$K_a$ expression correctly and substitutes appropriate values **(1)**<br><br>• final pH to 2 or 3SF **(1)** | Example of calculation:<br><br>(moles of $X^-$ = mol NaOH = $\frac{0.8(00) \times 10.5}{1000}$)<br>= 0.0084(0) / 8.4(0) x $10^{-3}$ (mol)<br><br>(moles of HX − mol NaOH = $\frac{0.92(0) \times 25.0}{1000}$ − 0.0084(0)<br>= 0.023(0) − 0.0084(0))<br><br>= 0.0146 / 1.46 x $10^{-2}$ (mol)<br><br>[HX] = $\frac{0.0146}{0.0355}$ **and** [$X^-$] = $\frac{0.0084(0)}{0.0355}$<br><br>= 0.411 **and** 0.237 (mol $dm^{-3}$)<br><br>Allow use of the ratio of the moles as above (as total V cancels)<br><br>$[H^+] = K_a \times \frac{[HX]}{[X^-]} = 5.25 \times 10^{-5} \times \frac{0.411}{0.237}$<br>$[H^+] = 9.10443038 \times 10^{-5}$ (mol $dm^{-3}$)<br><br>pH = 4.04<br>Allow use of pH expression to get answer:<br>pH = p$K_a$ − log $\frac{[HX]}{[X^-]}$ or p$K_a$ + log$\frac{[X^-]}{[HX]}$ | **(5)** |
| | | ALLOW TE M5 for calculation of pH from any [$H^+$]<br>Correct answer with no working scores (5) | |

**Q15.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| | • **(M1)** calculation of $[H^+]$ **(1)**<br><br>• **(M2)** rearrangement of $K_a$ and calculation of ethanoate concentration **(1)**<br><br>• **(M3)** calculation of the number of moles of ethanoate in the buffer volume **(1)**<br><br>• **(M4)** calculation of the mass of sodium ethanoate in the buffer volume **(1)**<br><br>• **(M5)** answer to 2/3 SF **(1)** | Example of calculation<br>$[H^+] = 10^{-3.9} = 1.2589..\times 10^{-4}$ (mol dm$^{-3}$)<br><br>$[CH_3COO^-] = \frac{(1.74 \times 10^{-5} \times 0.800)}{1.2589.. \times 10^{-4}} =$<br><br>=0.11057.. (mol dm$^{-3}$)<br><br>n=(0.11057.. x 0.05 =) 5.5285..x $10^{-3}$ (mol)<br><br>m=(5.5285..x $10^{-3}$ x 82=) 0.453339..<br><br>m=0.45/ 0.453 (g)<br>Award this mark only if there has been some attempt at calculation using an $M_r$<br><br>TE at each stage<br><br>If Henderson-Hasselbalch equation used<br>**(M1)** for calculation of p$K_a$ = 4.759<br>**(M2)** for rearrangement and calculation of ethanoate concentration<br>Remaining marking points as above | (5) |

**Q16.**

| Question Number | Answer | Mark |
|---|---|---|
| (i) | **The only correct answer is B**<br><br>***A*** *is not correct because there is no extrapolation to the largest temperature increase carried out*<br><br>***C*** *is not correct because the extrapolation is at the wrong time*<br><br>***D*** *is not correct because the extrapolation extends beyond the time of addition of alkali* | (1) |

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| (ii) | An explanation that makes reference to<br>• ethanoic acid is a weak(er) acid / only partially ionised/dissociated **(1)**<br>• (some) **energy** is used to fully/completely ionise the ethanoic acid **(1)** | Allow hydrochloric acid is a strong(er) acid/fully ionised<br><br>Do not award 'more NaOH will react so more energy given off' | (2) |

**Q17.**

| Question Number | Answer | Additional Guidance | Mark |
|---|---|---|---|
| | • $HPO_4^{2-} + H^+ \rightarrow H_2PO_4^-$<br>**or**<br>$HPO_4^{2-} + H_3O^+ \rightarrow H_2PO_4^- + H_2O$<br>**(1)**<br>• $H_2PO_4^- + OH^- \rightarrow HPO_4^{2-} + H_2O$<br>**(1)** | Penalise non-ionic equations, e.g. using NaOH or HCl once only<br><br>Equations must show reaction of ions with $H^+$ / $H_3O^+$ and $OH^-$<br>Allow $\rightleftharpoons$<br>Ignore state symbols<br><br>Allow $H_2PO_4^- \rightarrow HPO_4^{2-} + H^+$<br>**and**<br>$H^+ + OH^- \rightarrow H_2O$ | **(2)** |