Mini Mock Questions A2 CHEMISTRY UNIT 4 ACIDS, BASES AND BUFFERS

Q1. This question is about Brønsted-Lowry acids of different strengths.
(a) State the meaning of the term Brønsted–Lowry acid. (1)
(b) (i) Write an expression for the acid dissociation constant $K_a$ for ethanoic acid. (1)
(ii) The value of $K_a$ for ethanoic acid is $1.75 \times 10^{-5}$ mol dm$^{-3}$ at 25 °C. Calculate the concentration of ethanoic acid in a solution of the acid that has a pH of 2.69 (4)
(c) The value of $K_a$ for chloroethanoic acid (ClCH$_2$COOH) is $1.38 \times 10^{-3}$ mol dm$^{-3}$ at 25 °C.
(i) Write an equation for the dissociation of chloroethanoic acid in aqueous solution. (1)
(ii) Suggest why chloroethanoic acid is a stronger acid than ethanoic acid. (2)
(d) P and Q are acids. X and Y are bases. The table shows the strength of each acid and base.

<table>
<thead>
<tr>
<th>Acids</th>
<th>Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>strong</td>
<td>weak</td>
</tr>
<tr>
<td>P</td>
<td>Q</td>
</tr>
</tbody>
</table>

The two acids were titrated separately with the two bases using methyl orange as indicator. The titrations were then repeated using phenolphthalein as indicator. The pH range for methyl orange is 3.1 – 4.4. The pH range for phenolphthalein is 8.3 – 10.0. For each of the following titrations, select the letter, A, B, C, or D, for the correct statement about the indicator(s) that would give a precise end-point.

A Both indicators give a precise end-point.
B Only methyl orange gives a precise end-point.
C Only phenolphthalein gives a precise end-point.
D Neither indicator gives a precise end-point.

(i) Acid P with base X
(ii) Acid Q with base X
(iii) Acid Q with base Y
(e) Using a burette, 26.40 cm$^3$ of 0.550 mol dm$^{-3}$ sulfuric acid were added to a conical flask containing 19.60 cm$^3$ of 0.720 mol dm$^{-3}$ aqueous sodium hydroxide. Assume that the sulfuric acid is fully dissociated. Calculate the pH of the solution formed. Give your answer to 2 decimal places. (6)(Total 18 marks)

Q2. Lactic acid, CH$_3$CH(OH)COOH, is formed in the human body during metabolism and exercise. This acid is also formed by the fermentation of carbohydrates such as sucrose, C$_{12}$H$_{22}$O$_{11}$.
(a) (i) Give the IUPAC name for lactic acid. (1)
(ii) Write an equation for the formation of lactic acid from sucrose and water. (1)
(b) A molecule of lactic acid contains an asymmetric carbon atom. The lactic acid in the body occurs as a single enantiomer. A racemic mixture (racemate) of lactic acid can be formed in the following two-stage synthesis.

\[
\text{CH}_3\text{C}==\text{O} \xrightarrow{\text{Stage 1}} \text{H—C—CN} \xrightarrow{\text{Stage 2}} \text{H—C—COOH}
\]

(i) Name and outline a mechanism for Stage 1. (5)
(ii) Give the meaning of the term racemic mixture (racemate). (1)
(iii) Explain how you could distinguish between a racemic mixture (racemate) of lactic acid and one of the enantiomers of lactic acid. (2)
(c) A mixture of lactic acid and its salt sodium lactate is used as an acidity regulator in some foods. An acidity regulator makes sure that there is little variation in the pH of food.
(i) Write an equation for the reaction of lactic acid with sodium hydroxide. (1)
(ii) The acid dissociation constant $K_a$ for lactic acid has the value $1.38 \times 10^{-4}$ mol dm$^{-3}$ at 298 K. Calculate the pH of an equimolar solution of lactic acid and sodium lactate. (2)
(iii) Suggest an alternative name for the term acidity regulator. Explain how a mixture of lactic acid and sodium lactate can act as a regulator when natural processes increase the acidity in some foods. (3)
(d) A disposable “see-through” plastic cup is made from PLA, poly(lactic acid). PLA is the condensation polymer formed from lactic acid. The polymer is described as 100% biodegradable and 100% compostable. Compostable material breaks down slowly in contact with the moist air in a garden bin. This produces compost that can be used to improve soil. The manufacturers stress that PLA cups differ from traditional plastic cups that are neither biodegradable nor compostable.
(d) (i) Draw a section of PLA that shows two repeating units. (2)
(ii) Name the type of condensation polymer in PLA. (1)
(iii) An intermediate in the production of PLA is a cyclic compound \( \text{(C}_8\text{H}_8\text{O}_4) \) that is formed from two PLA molecules. Draw the structure of this cyclic compound. (1)
(iv) Traditional non-biodegradable plastic cups can be made from poly(phenylethene), commonly known as polystyrene. Draw the repeating unit of poly(phenylethene). (1)
(v) The manufacturers of PLA claim that the material will break down to compost in just 12 weeks. Suggest one reason why PLA in landfill may take longer than 12 weeks to break down. (1) (Total 22 marks)

Q3. In this question, give all values of pH to 2 decimal places.
(a) The ionic product of water has the symbol \( K_w \).
(i) Write an expression for the ionic product of water. (1)
(ii) At 42 °C, the value of \( K_w \) is \( 3.46 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6} \). Calculate the pH of pure water at this temperature. (2)
(iii) At 75 °C, a 0.0470 mol dm\(^{-3} \) solution of sodium hydroxide has a pH of 11.36. Calculate a value for \( K_w \) at this temperature. (2)
(b) Methanoic acid (HCOOH) dissociates slightly in aqueous solution.
(i) Write an equation for this dissociation. (1)
(ii) Write an expression for the acid dissociation constant \( K_a \) for methanoic acid. (1)
(iii) The value of \( K_a \) for methanoic acid is \( 1.78 \times 10^{-4} \text{ mol dm}^{-3} \) at 25 °C. Calculate the pH of a 0.0560 mol dm\(^{-3} \) solution of methanoic acid. (3)
(iv) The dissociation of methanoic acid in aqueous solution is endothermic. Deduce whether the pH of a solution of methanoic acid will increase, decrease or stay the same if the solution is heated. Explain your answer. (3)
(c) The value of \( K_a \) for methanoic acid is \( 1.78 \times 10^{-4} \text{ mol dm}^{-3} \) at 25 °C. A buffer solution is prepared containing 2.35 \( \times \) \( 10^{-2} \) mol of methanoic acid and 1.84 \( \times \) \( 10^{-2} \) mol of sodium methanoate in 1.00 dm\(^3 \) of solution.
(i) Calculate the pH of this buffer solution at 25 °C. (3)
(ii) A 5.00 cm\(^3 \) sample of 0.100 mol dm\(^{-3} \) hydrochloric acid is added to the buffer solution in part (c)(i). Calculate the pH of the buffer solution after this addition. (4) (Total 20 marks)

Q4. This question is about several Brønsted–Lowry acids and bases.
(a) Define the term Brønsted–Lowry acid. (1)
(b) Three equilibria are shown below. For each reaction, indicate whether the substance immediately above the box is acting as a Brønsted–Lowry acid (A) or a Brønsted–Lowry base (B) by writing A or B in each of the six boxes.

(i) \( \text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+ \)
(ii) \( \text{CH}_3\text{NH}_2 + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{NH}_3^+ + \text{OH}^- \)
(iii) \( \text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{H}_3\text{NO}_3^+ + \text{HSO}_4^- \)

(c) A 25.0 cm\(^3 \) sample of 0.0850 mol dm\(^{-3} \) hydrochloric acid was placed in a beaker. Distilled water was added until the pH of the solution was 1.25. Calculate the total volume of the solution formed. State the units. (3)
(d) At 298 K, the value of the acid dissociation constant \( (K_a) \) for the weak acid HX in aqueous solution is \( 3.01 \times 10^{-5} \) mol dm\(^{-3} \).
(i) Calculate the value of \( pK_a \) for HX at this temperature. Give your answer to 2 decimal places. (1)
(ii) Write an expression for the acid dissociation constant \( (K_a) \) for the weak acid HX. (1)
(iii) Calculate the pH of a 0.174 mol dm\(^{-3} \) solution of HX at this temperature. Give your answer to 2 d.p. (3)
(e) An acid–base buffer solution is formed when 10.0 cm\(^3 \) of 0.125 mol dm\(^{-3} \) aqueous sodium hydroxide are added to 15.0 cm\(^3 \) of 0.174 mol dm\(^{-3} \) aqueous HX. The value of \( K_a \) for the weak acid HX is \( 3.01 \times 10^{-5} \) mol dm\(^{-3} \). Calculate the pH of this buffer solution at 298 K. Give your answer to 2 decimal places. (6) (Total 18 marks)

Q5. Ammonia and ethylamine are examples of weak Brønsted–Lowry bases.
(a) State the meaning of the term Brønsted–Lowry base. (1)
(b) (i) Write an equation for the reaction of ethylamine \( (\text{CH}_3\text{CH}_2\text{NH}_2) \) with water to form weakly alkaline solution. (1)
(ii) In terms of this reaction, state why the solution formed is weakly alkaline. (1)
(c) State which is the stronger base, ammonia or ethylamine. Explain your answer. (3)
(d) Give the formula of an organic compound that forms an alkaline buffer solution when added to a solution of ethylamine. (1)
(e) Explain qualitatively how the buffer solution in part (d) maintains an almost constant pH when a small amount of hydrochloric acid is added to it. (2) (Total 9 marks)
Q6. This question involves calculations about two strong acids and one weak acid. All measurements were carried out at 25 °C.
(a) A 25.0 cm³ sample of 0.0850 mol dm⁻³ hydrochloric acid was placed in a beaker and 100 cm³ of distilled water were added. Calculate the pH of the new solution formed. Give your answer to 2 decimal places. (2)
(b) HX is a weak monobasic acid.
(i) Write an expression for the acid dissociation constant, K_a, for HX. (1)
(ii) The pH of a 0.0850 mol dm⁻³ solution of HX is 2.79. Calculate a value for the acid dissociation constant, K_a, of this acid. Give your answer to 3 significant figures. (3)
(c) A 25.0 cm³ sample of 0.620 mol dm⁻³ nitric acid was placed in a beaker and 38.2 cm³ of 0.550 mol dm⁻³ aqueous sodium hydroxide were added. Calculate the pH of the solution formed. Give your answer to 2 decimal places. The ionic product of water K_w = 1.00 × 10⁻¹⁴ mol² dm⁻⁶ at 25 °C. (6) (Total 12 marks)

Q7. Titration curves labelled A, B, C and D for combinations of different aqueous solutions of acids and bases are shown below. All solutions have a concentration of 0.1 mol dm⁻³.
(a) In this part of the question write the appropriate letter in each box. From the curves A, B, C and D, choose the curve produced by the addition of:
• NH₃ to 25 cm³ of HCl
• NaOH to 25 cm³ of CH₃COOH
• HNO₃ to 25 cm³ of KOH [total 3 marks]
(b) A table of acid-base indicators is shown below. The pH ranges over which the indicators change colour and their colours in acid and alkali are also shown.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>pH range (in acid)</th>
<th>Colour in acid</th>
<th>Colour in alkali</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapaeolin yellow</td>
<td>1.3 – 3.0</td>
<td>red</td>
<td>yellow</td>
</tr>
<tr>
<td>Bromocresol green</td>
<td>3.8 – 5.4</td>
<td>yellow blue</td>
<td>blue</td>
</tr>
<tr>
<td>Cresol purple</td>
<td>7.6 – 9.2</td>
<td>yellow purple</td>
<td>purple</td>
</tr>
<tr>
<td>Alizarin yellow</td>
<td>10.1 – 12.0</td>
<td>yellow orange</td>
<td></td>
</tr>
</tbody>
</table>

(i) Select the indicator that could be used in the titration B but not in the titration A. (1)
(ii) Give the colour change at the end point of the titration D when cresol purple is used. (1) (Total 5 marks)

Q8. This question is about the pH of some solutions containing potassium hydroxide and ethanoic acid.

(a) (i) Write an expression for pH. (1)
(ii) Write an expression for the ionic product of water, K_w (1)
(iii) At 10 °C, a 0.154 mol dm⁻³ solution of potassium hydroxide has a pH of 13.72. Calculate K_w at 10 °C. (2)
(b) At 25 °C, the acid dissociation constant K_a for ethanoic acid has the value 1.75 × 10⁻⁵ mol dm⁻³. (1)
(i) Write an expression for K_a for ethanoic acid. (1)
(ii) Calculate the pH of a 0.154 mol dm⁻³ solution of ethanoic acid at 25 °C. (3)
(iii) At 25 °C, the acid dissociation constant K_a for ethanoic acid has the value 1.75 × 10⁻⁵ mol dm⁻³. (1)
(iv) Calculate the pH of the solution formed when 10.0 cm³ of 0.154 mol dm⁻³ potassium hydroxide are added to 20.0 cm³ of 0.154 mol dm⁻³ ethanoic acid at 25 °C. (4)
(v) Calculate the pH of the solution formed when 40.0 cm³ of 0.154 mol dm⁻³ KOH are added to 20.0 cm³ of 0.154 mol dm⁻³ ethanoic acid at 25 °C. At 25 °C, K_w has the value 1.00 × 10⁻¹⁴ mol² dm⁻⁶. (4) (Total 16 marks)

Q9. This question is about the pH of several solutions. Give all values of pH to 2 decimal places.

(a) (i) Write an expression for pH. (1)
(ii) Calculate the pH of 0.154 mol dm⁻³ hydrochloric acid. (1)
(iii) Calculate the pH of the solution formed when 10.0 cm³ of 0.154 mol dm⁻³ hydrochloric acid are added to 990 cm³ of water. (2)
(b) The acid dissociation constant, K_a, for the weak acid HX has the value 4.83 × 10⁻⁵ mol dm⁻³ at 25 °C. A solution of HX has a pH of 2.48. Calculate the concentration of HX in the solution. (4)
(c) Explain why the pH of an acidic buffer solution remains almost constant despite the addition of a small amount of sodium hydroxide. (2)
(d) The acid dissociation constant, K_a, for the weak acid HY has the value 1.35 × 10⁻⁵ mol dm⁻³ at 25 °C. A buffer solution was prepared by dissolving 0.0236 mol of the salt NaY in 50.0 cm³ of a 0.428 mol dm⁻³ solution of the weak acid HY. (4)
(i) Calculate the pH of this buffer solution. (4)
(ii) A 5.00 × 10⁻⁴ mol sample of sodium hydroxide was added to this buffer solution. Calculate the pH of the buffer solution after the sodium hydroxide was added. (4) (Total 18 marks).
Q10. In this question, give all values of pH to two decimal places.
Calculating the pH of aqueous solutions can involve the use of equilibrium constants such as $K_w$ and $K_a$.

$K_a$ is the ionization product of water. The value of $K_w$ is $5.48 \times 10^{-14}$ mol$^2$ dm$^{-3}$ at 50 °C.

(a) (i) Write an expression for pH. (1)
(ii) Write an expression for $K_w$. (1)

(b) (i) Calculate the pH of pure water at 50 °C. (2)
(ii) Suggest why this pure water is not acidic. (1)

(iii) Calculate the pH of 0.140 mol dm$^{-3}$ aqueous solution of ethanoic acid at 50 °C. (3)

(c) Calculate the pH of the solution formed when 25.00 cm$^3$ of 0.150 mol dm$^{-3}$ aqueous sulfuric acid are added to 30.0 cm$^3$ of 0.200 mol dm$^{-3}$ aqueous potassium hydroxide at 25 °C. Assume that the sulfuric acid is fully dissociated. (6)

(d) (i) Write an expression for the acid dissociation constant, $K_a$, for ethanoic acid. (1)
(ii) The value of $K_a$ for ethanoic acid is $1.74 \times 10^{-5}$ mol dm$^{-3}$ at 25 °C. Calculate the pH of a 0.136 mol dm$^{-3}$ aqueous solution of ethanoic acid at this temperature. (3) (Total 18 marks)

Q11. In this question, give all values of pH to 2 decimal places.

(a) (i) Write an expression for the term pH. (1)
(ii) Calculate the concentration, in mol dm$^{-3}$, of an aqueous solution of sulfuric acid that has a pH of 0.25. (2)

(b) A student carried out a titration by adding an aqueous solution of sodium hydroxide from a burette to an aqueous solution of ethanoic acid. The end-point was reached when 22.60 cm$^3$ of the sodium hydroxide solution had been added to 25.00 cm$^3$ of 0.410 mol dm$^{-3}$ ethanoic acid.

(i) Write an equation for the reaction between sodium hydroxide and ethanoic acid. (1)
(ii) Calculate the concentration, in mol dm$^{-3}$, of the sodium hydroxide solution used. (2)
(iii) A list of indicators is shown below.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thymol blue</td>
<td>1.2–2.8</td>
</tr>
<tr>
<td>Bromophenol blue</td>
<td>3.0–4.6</td>
</tr>
<tr>
<td>Litmus</td>
<td>5.0–8.0</td>
</tr>
<tr>
<td>Cresol purple</td>
<td>7.6–9.2</td>
</tr>
</tbody>
</table>

(c) At 298 K, the value of the acid dissociation constant, $K_a$, for ethanoic acid in (aq) is $1.74 \times 10^{-5}$ mol dm$^{-3}$.

(i) Write an expression for the acid dissociation constant, $K_a$, for ethanoic acid. (1)
(ii) Calculate the pH of 0.410 mol dm$^{-3}$ ethanoic acid at this temperature. (3)
(iii) Calculate the pH of the buffer solution formed when 10.00 cm$^3$ of 0.100 mol dm$^{-3}$ potassium hydroxide are added to 25.00 cm$^3$ of 0.410 mol dm$^{-3}$ ethanoic acid. (6) (Total 18 marks)

Q12. Indicators and pH curves can be used to determine the end point in a titration.

(a) The pH curves labelled J, K, L and M for combinations of different acids and bases are shown below. All solutions have a concentration of 0.1 mol dm$^{-3}$.

(i) Select from J, K, L and M the curve produced by the addition of ammonia to 25 cm$^3$ hydrochloric acid.

(ii) A table of acid–base indicators and the pH ranges over which they change colour is shown below.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Thymol blue</td>
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<td>3.0–4.6</td>
</tr>
<tr>
<td>Methyl red</td>
<td>4.2–6.3</td>
</tr>
<tr>
<td>Cresolphthalein</td>
<td>8.2–9.8</td>
</tr>
<tr>
<td>Thymolphthalein</td>
<td>9.3–10.5</td>
</tr>
</tbody>
</table>

Select from the list above an indicator which could be used in the titration which produces curve J but not in the titration which produces curve K. (4)

(b) The acid dissociation constant, $K_a$, for the weak acid, ethanoic acid is $1.74 \times 10^{-5}$ mol dm$^{-3}$ at 25 °C.

$K_a =$

$$
\frac{[H^+][CH_3COO^-]}{[CH_3COOH]}
$$

(i) Write an expression for the term pH.
(ii) Calculate the pH of a 0.15 mol dm$^{-3}$ solution of ethanoic acid. (4) (Total 8 marks)
Q13. Buffer solutions are important in biological systems and in industry to maintain almost constant pH values.

(a) In the human body, one important buffer system in blood involves the hydrogencarbonate ion, \( \text{HCO}_3^- \), and carbonic acid, \( \text{H}_2\text{CO}_3 \), which is formed when carbon dioxide dissolves in water.

(i) Use the following equation to explain how this buffer maintains a constant pH of 7.41 even if a small amount of acid enters the bloodstream.

\[
\text{H}_2\text{CO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{HCO}_3^-(aq)
\]

(ii) In a sample of blood with a pH of 7.41, the concentration of \( \text{HCO}_3^- \) ions is \( 2.50 \times 10^{-2} \text{ mol dm}^{-3} \) and the concentration of \( \text{H}_2\text{CO}_3(aq) \) is \( 1.25 \times 10^{-5} \text{ mol dm}^{-3} \). Calculate a value for the acid dissociation constant, \( K_a \), for carbonic acid at this temperature. (5)

(b) In industry, the pH of a solution used to dye cloth must be controlled or else the colour varies.

A solution of dye in a beaker is buffered by the presence of ethanoic acid and sodium ethanoate. In the solution, the concentration of ethanoic acid is 0.15 mol dm\(^{-3}\) and the concentration of sodium ethanoate is 0.10 mol dm\(^{-3}\). The value of \( K_a \) for ethanoic acid is \( 1.74 \times 10^{-5} \text{ mol dm}^{-3} \) at 298 K.

(i) A 10.0 cm\(^3\) portion of 1.00 mol dm\(^{-3}\) hydrochloric acid is added to 1000 cm\(^3\) of this buffered solution. Calculate the number of moles of hydrochloric acid added.

(ii) Calculate the number of moles of ethanoic acid and the number of moles of sodium ethanoate in the solution after addition of the hydrochloric acid.

\text{Mol of ethanoic acid after addition} ..................................................

\text{Mol of sodium ethanoate after addition} ..................................................

(iii) Hence calculate the pH of this new solution. Give your answer to 2 decimal places. (6) (Total 11 marks)

Q14. (a) A sample of hydrochloric acid has a pH of 2.34

Write an expression for pH and calculate the concentration of this acid.

\[ \text{pH} \]

(b) A 0.150 mol dm\(^{-3}\) solution of a weak acid, HX, also has a pH of 2.34

(i) Write an expression for the acid dissociation constant, \( K_a \), for the acid HX.

(ii) Calculate the \textit{value} of \( K_a \) for this acid and \textit{state its units}.

(iii) Calculate the value of \( pK_a \) for the acid HX. Give your answer to two decimal places. (5)

(c) A 30.0 cm\(^3\) sample of a 0.480 mol dm\(^{-3}\) solution of potassium hydroxide was partially neutralised by the addition of 18.0 cm\(^3\) of a 0.350 mol dm\(^{-3}\) solution of sulphuric acid.

(i) Calculate the initial number of moles of potassium hydroxide.

(ii) Calculate the number of moles of sulphuric acid added.

(iii) Calculate the number of moles of potassium hydroxide remaining in excess in the solution formed.

(iv) Calculate the concentration of hydroxide ions in the solution formed.

(v) Hence calculate the pH of the solution formed. Give your answer to two decimal places. (6) (Total 13 marks)

Q15. In this question, give all pH values to 2 decimal places.

(a) (i) Write expressions for the ionic product of water, \( K_w \), and for pH.

\[ K_w = \quad \text{pH} = \]

(ii) At 318 \(^\circ\)K, the value of \( K_w \) is \( 4.02 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6} \) and hence the pH of pure water is 6.70. State why pure water is not acidic at 318 K.

(iii) Calculate the number of moles of sodium hydroxide in 2.00 cm\(^3\) of 0.500 mol dm\(^{-3}\) aqueous sodium hydroxide.

(iv) Use the value of \( K_w \) given above and your answer to part (a)(iii) to calculate the pH of the solution formed when 2.00 cm\(^3\) of 0.500 mol dm\(^{-3}\) aqueous sodium hydroxide are added to 998 cm\(^3\) of pure water at 318 K. (6)

(b) At 298 K, the acid dissociation constant, \( K_a \), for propanoic acid, \( \text{CH}_3\text{CH}_2\text{COOH} \), has the value \( 1.35 \times 10^{-5} \text{ mol dm}^{-3} \).

(i) Write an expression for \( K_a \) for propanoic acid.

(ii) Calculate the pH of 0.125 mol dm\(^{-3}\) aqueous propanoic acid at 298 K. (4)

(c) Sodium hydroxide reacts with propanoic acid as shown in the following equation.

\[ \text{NaOH} + \text{CH}_3\text{CH}_2\text{COOH} \rightarrow \text{CH}_3\text{CH}_2\text{COONa} + \text{H}_2\text{O} \]

A buffer solution is formed when sodium hydroxide is added to an excess of aqueous propanoic acid.

(i) Calculate the number of moles of propanoic acid in 50.0 cm\(^3\) of 0.125 mol dm\(^{-3}\) aqueous propanoic acid.

(ii) Use your answers to part (a)(iii) and part (c)(i) to calculate the number of moles of propanoic acid in the buffer solution formed when 2.00 cm\(^3\) of 0.500 mol dm\(^{-3}\) aqueous sodium hydroxide are added to 50.0 cm\(^3\) of 0.125 mol dm\(^{-3}\) aqueous propanoic acid.

(iii) Hence calculate the pH of this buffer solution at 298 K. (6) (Total 16 marks)
Q16. (a) Titration curves labelled A, B, C and D for combinations of different acids and bases are shown below. All solutions have a concentration of 0.1 mol dm⁻³.

(i) Select from A, B, C and D the curve produced by the addition of ammonia to 25 cm³ of hydrochloric acid ethanoic acid to 25 cm³ of sodium hydroxide sodium hydroxide to 25 cm³ of hydrochloric acid

(ii) A table of acid–base indicators and the pH ranges over which they change colour is shown below.

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</tr>
<tr>
<td>Methyl red</td>
<td>4.2 – 6.3</td>
</tr>
<tr>
<td>Cresolphthalein</td>
<td>8.2 – 9.8</td>
</tr>
<tr>
<td>Thymolphthalein</td>
<td>9.3 – 10.5</td>
</tr>
</tbody>
</table>

Select from the table an indicator which could be used in the titration which produces curve A but not in the titration which produces curve B.

(b) (i) Write an expression for the term pH.

(ii) A solution of potassium hydroxide has a pH of 11.90 at 25°C. Calculate the concentration of potassium hydroxide in the solution.

(iii) The acid dissociation constant, $K_a$, for propanoic acid has the value of $1.35 \times 10^{-5}$ mol dm⁻³ at 25 °C.

(a) Use the information to calculate the concentration of the acid.

(b) (i) Write an expression for the acid dissociation constant, $K_a$, for HA.

(ii) Write an expression for $pK_a$.

(iii) Using your answers to parts (b)(i) and (b)(ii), show that when sufficient sodium hydroxide has been added to neutralise half of the acid, pH of the solution = $pK_a$ for the acid HA

(c) Explain why dilution with a small volume of water does not affect the pH of a buffer solution.

(d) (i) Calculate the change in pH when 0.250 mol dm⁻³ hydrochloric acid is diluted with water to produce 0.150 mol dm⁻³ hydrochloric acid.

(ii) Calculate the volume of water which must be added to 30.0 cm³ of 0.250 mol dm⁻³ hydrochloric acid in order to reduce its concentration to 0.150 mol dm⁻³.

Q17. The pH curve shown below was obtained when a 0.150 mol dm⁻³ solution of sodium hydroxide was added to 25.0 cm³ of an aqueous solution of a weak monoprotic acid, HA.

(a) Use the information to calculate the concentration of the acid.

(b) (i) Write an expression for the acid dissociation constant, $K_a$, for HA.

(ii) Write an expression for $pK_a$.

(iii) Explain what is meant by the term buffer solution.

(c) In a buffer solution, the concentration of ethanoic acid is 0.150 mol dm⁻³ and the concentration of sodium ethanoate is 0.100 mol dm⁻³. Calculate the pH of this buffer solution.

(d) (i) Calculate the pH of this buffer solution.

(ii) A 10.0 cm³ portion of 1.00 mol dm⁻³ hydrochloric acid is added to 1000 cm³ of this buffer solution. Calculate the number of moles of ethanoic acid and the number of moles of sodium ethanoate in the solution after addition of the hydrochloric acid. Hence, find the pH of this new solution.

Q18. This question concerns the weak acid, ethanoic acid, for which the acid dissociation constant, $K_a$, has a value of $1.74 \times 10^{-5}$ mol dm⁻³ at 25 °C. In each of the calculations below, give your answer to 2 decimal places.

(a) Write an expression for the term $pH$. Calculate the pH of a 0.150 mol dm⁻³ solution of ethanoic acid.

(b) A buffer solution is prepared by mixing a solution of ethanoic acid with a solution of sodium ethanoate.

(i) Write an equation for the reaction which occurs when a small amount of HCl is added to this buffer solution.

(c) In a buffer solution, the concentration of ethanoic acid is 0.150 mol dm⁻³ and the concentration of sodium ethanoate is 0.100 mol dm⁻³. Calculate the pH of this buffer solution.

(i) Calculate the pH of this buffer solution.

(ii) A 10.0 cm³ portion of 1.00 mol dm⁻³ hydrochloric acid is added to 1000 cm³ of this buffer solution. Calculate the number of moles of ethanoic acid and the number of moles of sodium ethanoate in the solution after addition of the hydrochloric acid. Hence, find the pH of this new solution.
Q19. The value of the acid dissociation constant, $K_a$, for the weak acid HA, at 298 K, is 1.45 $\times$ 10^{-4} mol dm^{-3}.
(a) Write an expression for the term $K_a$ for the weak acid HA. (1)
(b) Calculate the pH of a 0.250 mol dm^{-3} solution of HA at 298 K. (4)
(c) A mixture of the acid HA and the sodium salt of this acid, NaA, can be used to prepare a buffer solution.
(i) State and explain the effect on the pH of this buffer solution when a small amount of hydrochloric acid is added.
(ii) The concentration of HA in a buffer solution is 0.250 mol dm^{-3}. Calculate the concentration of A^- in this buffer solution when the pH is 3.59 (6) (Total 11 marks)

Q20. (a) The pH of a 0.120 mol dm^{-3} solution of the weak monoprotic acid, HX, is 2.56 at 298 K.
(i) Write an expression for the term pH. (3)
(ii) Write an expression for the dissociation constant, $K_d$, for the weak acid HX and calculate its value at 298 K. (5)
(b) (i) Write an expression for the ionic product of water, $K_w$, and give its value at 298 K. (2)
(ii) Hence, calculate the pH of a 0.0450 mol dm^{-3} solution of sodium hydroxide at 298 K. (4)
(c) A titration curve is plotted showing the change in pH as a 0.0450 mol dm^{-3} solution of NaOH is added to 25.0 cm$^3$ of a solution of ethanedioic acid, H$_2$C$_2$O$_4$. The titration curve obtained has two equivalence points (end points).
(i) Write an equation for the reaction which is completed at the first equivalence point.
(ii) When the second equivalence point is reached, a total of 41.6 cm$^3$ of 0.0450 mol dm^{-3} sodium hydroxide has been added. Calculate the concentration of the ethanedioic acid solution. (4)
(d) Draw the structure of the organic product formed in each case when, in the presence of a small amount of concentrated sulphuric acid, ethanedioic acid reacts with
(i) an excess of methanol,
(ii) an equimolar amount of ethane-1,2-diol. (2) (Total 15 marks)

Q21. (a) By reference to the forces between molecules, explain why ammonia is very soluble in water. (2)
(b) Aqueous solutions of ammonia have a pH greater than 7.
(i) Write an equation for the reaction of ammonia with water.
(ii) Explain why the pH of a solution containing 1.0 mol dm^{-3} of ammonia is less than 14 at 298 K. (3)
(c) An ammonium ion in aqueous solution can behave as a Brønsted–Lowry acid. State what is meant by the term Brønsted–Lowry acid. (1)
(d) State what is meant by the term buffer solution. Identify a reagent which could be added to a solution of ammonia in order to form a buffer solution. (3)
(e) An acidic buffer solution is obtained when sodium ethanoate is dissolved in aqueous ethanoic acid.
(i) Calculate the pH of the buffer solution formed at 298 K when 0.125 mol of sodium ethanoate is dissolved in 250 cm$^3$ of a 1.00 mol dm^{-3} solution of ethanoic acid.
The acid dissociation constant, $K_a$, for ethanoic acid is 1.70 $\times$ 10^{-5} mol dm^{-3} at 298 K.
(ii) Write an ionic equation for the reaction which occurs when a small volume of dilute hydrochloric acid is added to
this buffer solution. (5) (Total 14 marks)

Q22. (a) At 50°C, the ionic product of water, $K_w$, has the value 5.48 $\times$ 10^{-14} mol$^2$ dm$^{-6}$.
(i) Define the term $K_w$
(ii) Define the term pH
(iii) Calculate the pH of pure H$_2$O at 50°C. Explain why pure H$_2$O at 50 °C is neutral even though its pH is not 7. (5)
(b) At 25°C, $K_w$ has the value 1.00 $\times$ 10^{-14} mol$^2$ dm$^{-6}$. Calculate the pH at 25 °C of
(i) a 0.150 mol dm$^{-3}$ solution of sodium hydroxide,
(ii) 35.0 cm$^3$ of this solution of NaOH is mixed with 40.0 cm$^3$ of 0.120 mol dm$^{-3}$ HCl. (8)
(c) In a 0.150 mol dm$^{-3}$ solution of a weak acid HX at 25 °C, 1.80% of the acid molecules are dissociated into ions.
(i) Write an expression for $K_a$ for the acid HX.
(ii) Calculate the value of $K_a$ for the acid HX at this temperature and state its units. (5) (Total 18 marks)
The sketch below shows the change in pH when a 0.200 mol dm$^{-3}$ solution of sodium hydroxide is added from a burette to 25.0 cm$^3$ of a 0.150 mol dm$^{-3}$ solution of the weak acid HA at 25 °C.

(a) The volume of sodium hydroxide solution added at the equivalence point is $x$ cm$^3$. Calculate the value of $x$. (2)

(b) (i) Define the term pH.
(ii) The pH at the equivalence point is $c$. Suggest a value for $c$.
(iii) Identify a suitable indicator for detecting the equivalence point of the titration. (3)
(c) The value of $K_a$ for the weak acid HA at 25 °C is $2.75 \times 10^{-5}$ mol dm$^{-3}$.
(i) Explain the term weak as applied to the acid HA.
(ii) Write an expression for $K_a$ for the acid HA.

Q24. (a) Methylamine is a weak Bronsted-Lowry base and can be used in aqueous solution with one other substance to prepare a basic buffer.
(i) Explain the term Bronsted-Lowry base and write an equation for the reaction of methylamine with water to produce an alkaline solution.

Bronsted-Lowry base

Equation

(ii) Suggest a substance that could be added to aqueous methylamine to produce a basic buffer.
(iii) Explain how the buffer in part (a)(ii) is able to resist a change in pH when a small amount of NaOH is added. (5)

(b) Explain why methylamine is a stronger base than ammonia. (2)

(c) A cation is formed when methylamine reacts with a large excess of bromoethane. Name the mechanism involved in the reaction and draw the structure of the cation formed. (2)(Total 9 marks)

Q25. A 0.210 mol dm$^{-3}$ solution of potassium hydroxide was added from a burette to 25.0 cm$^3$ of a 0.160 mol dm$^{-3}$ solution of ethanoic acid in a conical flask.

Given that the value of the acid dissociation constant, $K_a$, for ethanoic acid is $1.74 \times 10^{-5}$ mol dm$^{-3}$, calculate the pH at 25 °C of the solution in the conical flask at the following three points:
1) before any potassium hydroxide had been added;
2) after 8.0 cm$^3$ of potassium hydroxide solution had been added;
3) after 40.0 cm$^3$ of potassium hydroxide solution had been added. (Total 16 marks)

Q26. The value of the acid dissociation constant, $K_a$, for ethanoic acid is $1.74 \times 10^{-5}$ mol dm$^{-3}$ at 298 K.

(a) (i) Write an expression for $K_a$ for ethanoic acid.
(ii) Calculate the pH at 298 K of a 0.220 mol dm$^{-3}$ solution of ethanoic acid. (5)

(b) A sample of the 0.220 mol dm$^{-3}$ solution of ethanoic acid was titrated against sodium hydroxide solution.
(i) Calculate the volume of a 0.150 mol dm$^{-3}$ solution of sodium hydroxide required to neutralise 25.0 cm$^3$ of the ethanoic acid solution.
(ii) From the list below, select the best indicator for this titration and explain your choice.

Name of indicator | pH range
---|---
Bromophenol blue | 3.0 – 4.6
Methyl red | 4.2 – 6.3
Bromothymol blue | 6.0 – 7.6
Thymol blue | 8.0 – 9.6

(c) A buffer solution is formed when 2.00 g of sodium hydroxide are added to 1.00 dm$^3$ of a 0.220 mol dm$^{-3}$ solution of ethanoic acid. Calculate the pH at 298 K of this buffer solution. (6)(Total 16 marks)
Mini Mock ANSWERS A2 CHEMISTRY UNIT 4 ACIDS, BASES AND BUFFERS

Q1. (a) Proton donor or H⁺ donor

\[ K_a = \frac{[\text{CH}_3\text{COO}^-][\text{H}^+] }{[\text{CH}_3\text{COOH}]} \]

(b) (i) Must be ethanoic acid not HA; Must have square brackets (penalise here only) but mark on in (b)(ii). 1

(ii) \[ M_1 [\text{H}^+] = 10^{-2.69} \ OR \ 2.042 \times 10^{-3} \ (\text{mol dm}^{-3}) \]

\[ \text{CH}_3\text{COOH} = \frac{[\text{H}^+]^2}{K_a} \]

\[ M_2 \]

\[ M_3 \]

\[ = \frac{(2.042 \times 10^{-3})^2}{1.75 \times 10^{-5}} \]

\[ M_4 = 0.238 \ (\text{mol dm}^{-3}) \ Allow \ 0.229 \sim 0.24 \]

(c) (i) \[ \text{ClCH}_2\text{COOH} \ Leftrightarrow \text{ClCH}_2\text{COO}^- + \text{H}^+ \]

OR

\[ \text{ClCH}_2\text{COOH} + \text{H}_2\text{O} \ Leftrightarrow \text{ClCH}_2\text{COO}^- + \text{H}_3\text{O}^+ \]

Allow \ ClCH_2COH and ClCH_2CO^- 1

(ii) \[ M_1 \text{ Cl is (more electronegative so) withdraws electrons OR negative inductive effect of Cl} \]

Allow Cl reduces +ve inductive effect of methyl group. 1

M2 Weakens O–H bond OR O–H bond is more polar OR reduces negative charge on COO^- 1

OR stabilizes COO^- (more) 1

(d) (i) A 1

(ii) C 1

(iii) D 1

(e) \[ M_1 \text{ Mol NaOH} = \text{mol OH}^- = (19.6 \times 10^{-3}) \times 0.720 = 1.41(1) \times 10^{-2} \]

\[ M_2 \text{ Mol H}_2\text{SO}_4 = (26.4 \times 10^{-3}) \times 0.550 = 1.45(2) \times 10^{-2} \]

\[ M_3 \text{ Mol H}^+ \text{ added} = 2 \times (1.452 \times 10^{-2}) = 2.90(4) \times 10^{-2} \]

OR

\[ \text{XS mol H}_2\text{SO}_4 = 7.46(4) \times 10^{-3} \]

\[ M_4 \text{ XS mol H}^+ = 0.0149(3) \]

M5 For dividing by volume

\[ [\text{H}^+] = 0.0149(3) \times (1000 / 46.0) = 0.324 \sim 0.325 \text{ mol dm}^{-3} \]

M6 \[ \text{pH} = 0.49 \]

1[18]

Q2. (a) (i) 2-hydroxypropanoic acid OR 2-hydroxypropan(1-)oic acid 1

(ii) \[ \text{C}_6\text{H}_2\text{O}_11 + \text{H}_2\text{O} \rightarrow 4\text{CH}_3\text{CH(OH)COOH} \]

OR

\[ \text{C}_6\text{H}_2\text{O}_11 + \text{H}_2\text{O} \rightarrow 2\text{CH}_3\text{CH(OH)COOH} + \text{C}_6\text{H}_2\text{O}_6 \]

(b) (i) Nucleophilic addition

M2

M1

M3

5

(ii) Equal mixture of enantiomers / (optical) isomers 1

(iii) (Plane) polarized light 1

(Polarised light) rotated by single enantiomer but unaffected by racemate 1
(c) (i)  $\text{CH}_3\text{CH}($OH$)$COOH + NaOH $\rightarrow$ CH$_3$CH(OH)COONa + H$_2$O \\
**OR** $\text{CH}_3\text{CH}($OH$)$COOH + OH$^-\rightarrow$ CH$_3$CH(OH)COO$^-\rightarrow$ H$_2$O  
1  
(ii)  $[\text{H}^+] = K_a \ OR \ p\text{H} = pK_a$  
1  
P$\text{H} = 3.86$  
1  
(iii) M1 buffer  
1  

Any two out of the three marks M2, M3 & M4  
M2 Large lactate concentration in buffer **OR** sodium lactate completely ionised  
M3 added acid reacts with / is removed by lactate ion or A$^-$ or sodium lactate or salt **OR** equation H$^+ + A^- \rightarrow$ HA  
Ignore reaction of H$^+$ with OH$^-$  
Ignore reference to equilibrium unless it is shown.  
M4 ratio [HA] / [A$^-$] stays almost constant. *Ignore H$^+$ or pH remains constant.*  

(d) (i)  

OR  

(ii) (Poly)ester ie allow ester  
1  
(iii)  

Allow any cyclic C$_6$H$_8$O$_4$  
1  
(iv)  

(v) In landfill, no air or UV, to assist decay **OR** not enough water or moisture (to hydrolyse polyester)  
Allow landfill has / contains: no or few bacteria / micro-organisms / enzymes compared with compost heap  
**OR** less oxygen **OR** lower temperature.  
[22]  

Q3. (a) (i)  

OR $[\text{H}_3\text{O}^+] [\text{OH}^-]$  
1  
(ii)  $\sqrt{3.46 \times 10^{-14}} \ (= 1.86 \times 10^{-7})$  
1  
P$\text{H} = 6.73$  
1  
(iii) $[\text{H}^+] = 10^{-11.36} \ (= 4.365 \times 10^{-12} \ OR \ 4.37 \times 10^{-12})$  
1  

$K_w = [4.365 \times 10^{-12} \ OR \ 4.37 \times 10^{-12} \times 0.047] = 2.05 \times 10^{-13}$  
1  
(b) (i)  

$\text{HCOOH} \rightleftharpoons \text{HCOO}^- + \text{H}^+$  
1  
**OR**  

$\text{HCOOH} + \text{H}_2\text{O} \rightleftharpoons \text{HCOO}^- + \text{H}_3\text{O}^+$  
1
(ii) \[ K_a = \frac{[H^+][HCOO^-]}{[HCOOH]} \text{ OR } \frac{[H_3O^+][HCOO^-]}{[HCOOH]} \]

(iii) M1

\[
K_a = \frac{[H^+]^2}{[HCOOH]} \quad \left( \left[\frac{H^+}{HCOOH}\right]^2 = 1.78 \times 10^{-4} \times 0.056 = 9.97 \times 10^{-5} \right)
\]

Allow HA or HX etc. Allow \([H^+] = \sqrt{(K_a \times [HA])}\) for M1

M2 \([H^+] = 3.16 \times 10^{-3}\)

M3 \(\text{pH} = 2.50; \) allow more than 2 dp but not fewer

(iv) M1 Decrease

M2 Eqn shifts / moves to RHS \text{ OR } more \(H^+\) \text{ OR } \(K_a\) increases \text{ OR } more dissociation

M3 To reduce temperature or oppose increase / change in temperature

\[ [H^+] = \frac{K_a \times [HX]}{[X^-]} \text{ OR } \text{pH} = \text{p}K_a - \log \frac{[HX]}{[X^-]} \]

(c) (i) M1

\[
\frac{1.78 \times 10^{-4} \times 2.35 \times 10^{-2}}{1.84 \times 10^{-2}} \text{ OR } \text{pH} = 3.75 - \log \frac{2.35 \times 10^{-2}}{1.84 \times 10^{-2}}
\]

M3 \(\text{pH} = 3.64 \) allow more than 2 dp but not fewer

(ii) M1 Mol \(H^+\) added = \(5.00 \times 10^{-4}\)

M2 Mol HCOOH = \(2.40 \times 10^{-2}\) \text{ and } Mol HCOO\(^-\) = \(1.79 \times 10^{-2}\)

\[ [H^+] = \frac{-K_a \times [XH]}{[X^-]} = \frac{1.78 \times 10^{-4} \times 2.40 \times 10^{-2}}{1.79 \times 10^{-2}} \]

\( = 2.39 \times 10^{-4} \)

M3 \(\text{Vol} = 0.0378 \text{ dm}^3 \text{ or } 37.8 \text{ cm}^3 \)

If \([HX]/[X^-]\) upside down here after correct expression in (c)(i), no further marks

\text{OR} \quad \text{pH} = 3.75 - \log \frac{2.40 \times 10^{-2}}{1.79 \times 10^{-2}}

If \([HX]/[X^-]\) upside down here and is repeat error from (c)(i), max 3 \((\text{pH} = 3.88 \text{ after } 3.86 \text{ in (c)(i)})\)

M4 \(\text{pH} = 3.62 \) allow more than 2 dp but not fewer \(1 \text{ [20]}\)

Q4.(a) Proton donor or \(H^+\) donor \text{ Allow donator} \(1\)

(b) (i) B B Both need to be correct to score the mark \(1\)

(ii) A A Both need to be correct to score the mark \(1\)

(iii) B A Both need to be correct to score the mark \(1\)

(c) M1 \([H^+] = 10^{-1.25}\) OR \(0.05623\) \(1\)

M2 \(\text{mol HCl} = (25 \times 10^{-3}) \times 0.0850 = (2.125 \times 10^{-3})\)

\[
\left( \frac{2.125 \times 10^{-3}}{0.05623} \right) = 0.0378 \text{ dm}^3 \text{ or } 37.8 \text{ cm}^3
\]

M3 \(\text{Vol} = 4.52\)

(d) (i) \(4.52\) \(1\)

(ii) \(K_a = \frac{[H^+]^2}{[HX]}\) \text{ ignore } \frac{[H^+]^2}{[HX]} \text{ but this may score M1 in (d)(iii)} \(1\)
M3  pH = 2.64  (allow more than 2dp but not fewer)  

M2  mol OH⁻ = (10.0 × 10⁻³) × 0.125 = 1.25 × 10⁻³  

M3  mol HX in buffer = orig mol HX – mol OH⁻ = 2.61 × 10⁻³ – 1.25 × 10⁻³ = 1.36 × 10⁻³  
   ((HX) = 1.36 × 10⁻³/25 × 10⁻³ = 0.0544)  

M4  mol X⁻ in buffer = mol OH⁻ = 1.25 × 10⁻³  
   ([X⁻] = 1.25 × 10⁻³/25 × 10⁻³ = 0.05)  

M5  If use \( K_a = \frac{[H^+]^2}{[HX]} \) no further marks  
   \[ \frac{3.01 \times 10^{-5} \times 1.36 \times 10^{-3}}{3.01 \times 10^{-5} \times 0.0544} = \frac{1.25 \times 10^{-3}}{0.05} \]  
   (= 3.27 × 10⁻⁵)  

M6  pH = 4.48 or 4.49  (allow more than 2dp but not fewer)  

Q5.(a)  Proton acceptor  

(b)  (i)  CH₃CH₂NH₂ + H₂O → CH₃CH₂NH₃⁺ + OH⁻  

(ii) Mark independently of (b)(i)  
   Allow Ethylamine is only partly/slightly dissociated OR Ethylamine is only partly/slightly ionized  
   reaction/equilibrium lies to left or low [OH⁻] OR little OH⁻ formed OR little ethylamine has reacted  
   Ignore "not fully dissociated" or "not fully ionized"; Ignore reference to ionisation or dissociation of water  

(c)  M1  Ethylamine  

M2  alkyl group is electron releasing/donating OR alkyl group has (positive) inductive effect  

M3  increases electron density on N(H₂) OR increased availability of lp OR increases ability of lp (to accept H(+))  

(d)  CH₃CH₂NH₃Cl OR any amine hydrochloride allow name (ethylammonium chloride or ethylamine hydrochloride) or other halide for Cl or a strong organic acid NOT NH₄Cl  

(e)  Extra H⁺ reacts with ethylamine or OH⁻ OR makes reference to Equilibrium (in (b)(i)) with amine on LHS  
   OR CH₃CH₂NH₂ + H⁺ → CH₃CH₂NH₃⁺ OR H⁺ + OH⁻ → H₂O  
   Equilibrium shifts to RHS OR ratio \([\text{CH}_3\text{CH}_2\text{NH}_3^+] / \text{[CH}_3\text{CH}_2\text{NH}_2] \) remains almost constant  

Q6.(a)  M1  \([H^+] = 0.0170\)  

M2  pH = 1.77  

(b)  (i)  Ignore  
   Allow HA instead of HX  

(ii)  M1  \([H^+] = 10^{-2.79}\) OR 1.6218... × 10⁻³  
   \[ K_a = \frac{[H^+]^2}{[HX]} \]  

M2  OR 1.62 × 10⁻³ \[ \frac{0.0850}{[HX]} \]  
   Allow HA instead of HX  

M3  \( K_a = 3.09 \times 10^{-5}\)  

(c)  M1  mol OH⁻ (= 38.2 × 10⁻³) × 0.550 = 2.10(1) × 10⁻² or 0.0210(1)  

M2  Mol H⁺ (= 25.0 × 10⁻³) × 0.620 = 1.55 × 10⁻² or 0.0155  

M3  excess mol OH⁻ = 5.5(1) × 10⁻³
1. \( \text{M4} \) \( [\text{OH}^-] = 5.5 \times 10^{-3} \times \frac{10^3}{63.2} \) [\( = 0.08718 \) (0.0872)] OR \( [\text{OH}^-] = 5.5 \times 10^{-3} \times \frac{10^3}{63.2} = 0.0870(2) \)

2. \( \text{M5} \) \( [\text{H}^+] = \frac{0.08718}{0.0870} = 1.147 \times 10^{-13} \) OR \( [\text{H}^+] = 1.149 \times 10^{-13} \) pOH = 1.06

3. \( \text{M6} \) pH = 12.9(4)

4. Q7. (a) C 1
   A 1
   D 1

   (b) (i) Bromocresol green 1
   (ii) Purple to yellow Must have both colours: Purple start – yellow finish 1

5. Q8. (a) (i) \( -\log[\text{H}^+] \) 1
   (ii) \( [\text{H}^+] [\text{OH}^-] \) 1
   (iii) \( [\text{H}^+] = 1.905 \times 10^{-14} \times 0.154 = (2.93 - 2.94) \times 10^{-15} \)

6. (b) (i) \( K_a = \frac{[\text{H}^+][\text{CH}_3\text{COO}^-]}{[\text{CH}_3\text{COOH}] \) 1
   (ii) \( K_a = \frac{[\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]} \) Allow HA 1
   \( ([\text{H}^+]^2 = 1.75 \times 10^{-5} \times 0.154 = 2.695 \times 10^{-6} = 2.70 \times 10^{-6} \)
   \( [\text{H}^+] = 1.64 \times 10^{-3} \) 1
   pH = 2.78 or 2.79 1

7. (c) (i) M1 Initially mol OH\(^-\) = (10 \times 10^{-3}) \times 0.154 and mol HA = (20 \times 10^{-3}) \times 0.154 or mol OH\(^-\) = 1.54 \times 10^{-3} and mol HA = 3.08 \times 10^{-3} 1

8. M2 \( [\text{H}^+] = K_a \) \[\frac{[\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]} \) Allow Henderson Hasselbach pH = \( pK_a \) + log \[
   \text{M3} \) mol ethanoic acid left = (mol ethanoate ions) = 1.54 \times 10^{-3}
   \( K_a = [\text{H}^+] \) or pH = \( pK_a \) scores M1, M2 and M3 1

9. M4 pH = \( -\log 1.75 \times 10^{-6} = 4.76 \) or 4.757 1

10. M5 \[\text{M4} \) \[\text{OH}^-] = 3.08 \times 10^{-3} \times \frac{10^3}{60} = 0.0513(3) \]

11. M3 \[\text{M4} \) \[\text{OH}^-] \) = \( 0.05133 \) (= \( 1.948 \times 10^{-13} \) to \( 1.95 \times 10^{-13} \)) or pOH = 1.29 1

12. M4 pH = 12.7(1) 1 [16]
\[
\frac{[H^+]^2}{K_a} = \frac{(3.31 \times 10^{-3})^2}{4.83 \times 10^{-6}}
\]

M3 \[ [HX] = \frac{1}{K_a} \]
M4 \[ [HX] = 0.227 \]

(c) M1 extra/added OH\(^-\) removed by reaction with H\(^+\) or the acid 1
M2 correct discussion of eqn shift i.e. \( HX \rightleftharpoons H^+ + X^- \) moves to right 1

OR

ratio \( [X^-] \) remains almost constant

(d) (i) M1 mol HY = \( (50 \times 10^{-3}) \times 0.428 = 0.0214 \) OR \[ [Y] = 0.0236 \times \frac{1000}{50} = 0.472 \]
M2 \[ [H^+] = 1.35 \times 10^{-5} \times \frac{0.0236}{0.472} \]
OR \[ 1.35 \times 10^{-5} = [H^+] \times \frac{0.0214}{0.472} \]
\[ [H^+] = 1.35 \times 10^{-5} \times \frac{0.428}{0.472} \]

M3 \[ [H^+] = 1.22 \times 10^{-5} \] 1
M4 pH = 4.91 1

If Henderson Hasselbalch equation used:

M1 mol HY = \( (50 \times 10^{-3}) \times 0.428 = 0.0214 \) OR \[ [Y] = 0.0236 \times \frac{1000}{50} = 0.472 \]
M2 pKa = 4.87 1
\[
\log \left( \frac{0.0214}{0.0236} \right) = -0.043
\]
M3 \[
\log \left( \frac{0.428}{0.472} \right) = -0.043
\]

If either HY value or \( Y^- \) value wrong, (apart from AE-1) lose M3 and M4 1
M4 pH = 4.87 - (-0.043) = 4.91 1

(ii) Can score full marks for correct consequential use of their HY and \( Y^- \) values from d(i)
M1 Mol HY after adding NaOH = 0.0214 - 5.0 \times 10^{-4} = 0.0209 1
M2 Mol \( Y^- \) after adding NaOH = 0.0236 + 5.0 \times 10^{-4} = 0.0241 1
\[ 0.0209 \]
M3 \[ [H^+] = 1.35 \times 10^{-5} \times \frac{0.0241}{0.418} \] (= 1.17 \times 10^{-5} )
if convert to concentrations
\[ [H^+] = 1.35 \times 10^{-5} \times \frac{0.482}{0.418} \] (= 1.17 \times 10^{-5} )
M4 pH = 4.93 1

If Henderson Hasselbalch equation used:
Can score full marks for correct consequential use of their HY and \( Y^- \) values from d(i)
M1 Mol HY after adding NaOH = 0.0214 - 5.0 \times 10^{-4} = 0.0209 1
M2 Mol \( Y^- \) after adding NaOH = 0.0236 + 5.0 \times 10^{-4} = 0.0241 1
\[ 0.0209 \]
M3 \[
\log \left( \frac{0.0241}{0.0209} \right) = -0.062
\]
M4 pH = 4.87 - (-0.062) = 4.93 1[18]
### Q10.

(a)  
(i) \(-\log[H^+]\)  
(ii) \([H^+][OH^-]\)  

(b)  
(i) \([H^+] = 2.34 \times 10^{-7}\)  
(ii) \(\text{pH} = 6.63\)  

(ii) \([H^+] = [OH^-]\)  

(iii)  
\[
\begin{align*}
M1 & \quad [H^+] = K_w/\text{[OH\textsuperscript{-}] } \\
M2 & \quad (= 5.48 \times 10^{-14}/0.140) = 3.91 \times 10^{-13} \\
M3 & \quad \text{pH} = 12.4(1) \\
M4 & \quad \text{pH} = 1.56 \\
M5 & \quad \text{pH} = 3.91 \times 10^{-13} \\
M6 & \quad \text{pH} = 0.0273 \\
\end{align*}
\]

(c)  
(i) \(\text{mol NaOH } = \text{mol OH}\textsuperscript{-} = (30 \times 10^{-3}) \times 0.20 = 6.0 \times 10^{-3}\)  
(ii) \(\text{mol } H_2SO_4 = (25 \times 10^{-3}) \times 0.15 = 3.75 \times 10^{-3}\)  

\(\text{OR XS mol } H_2SO_4 = 0.75 \times 10^{-3}\)  

(iii) \(M1\) \(\text{mol } H^+ = (25 \times 10^{-3}) \times 2 = 7.5 \times 10^{-3}\)  

\(\text{OR XS mol } H_2SO_4 = 0.0273\)  

(d)  
(i) \(K_a = \frac{[H^+][CH_3COO\textsuperscript{-}]}{[CH_3COOH]}\)  

(ii) \(K_a = \frac{[H^+]}{[CH_3COOH]}\) \text{ or with numbers or } [H\textsuperscript{+}] = [CH\textsubscript{3}COO\textsuperscript{-}] \text{ allow HA here}  

\([H^+] = (\sqrt{1.74 \times 10^{-5} \times 0.136}) = \sqrt{2.366 \times 10^{-6}} \times 1.54 \times 10^{-3}\)  

\(\text{pH} = 2.81\)  

### Q11.

(a)  
(i) \(-\log[H^+]\)  

(ii) \([H^+] = 0.56\)  

\([H_2SO_4] = \frac{1}{2} \times 0.56 = 0.28\)  

(b)  
(i) \(\text{CH}_3\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{COONa} + \text{H}_2\text{O} \quad \text{OR} \quad \text{CH}_3\text{COOH} + \text{OH}\textsuperscript{-} \rightarrow \text{CH}_3\text{COO}\textsuperscript{-} + \text{H}_2\text{O}\)  

\(\text{Allow } \text{CH}_3\text{CO}_2\text{H etc}\)  

(ii) \(\text{mol acid } = (25.0 \times 10^{-3}) \times 0.41 = 1.025 \times 10^{-2}\) or \(1.03 \times 10^{-2}\)  

\([\text{NaOH}] = 1.025 \times 10^{-2}/22.6 \times 10^{-3} = 0.45(4)\)  

\(\text{OR} \quad [\text{NaOH}] = 1.03 \times 10^{-2}/22.6 \times 10^{-3} = 0.456\) or 0.46  

(iii) \(\text{cresol purple}\)  

(iv) \(\text{NaOH reacts with carbon dioxide (in the air)}\)  

\([H^+] = \sqrt{(1.74 \times 10^{-5} \times 0.136)} = \sqrt{(2.366 \times 10^{-6})} \times 1.54 \times 10^{-3}\)  

\(\text{pH} = 2.81\)  

(c)  
(i) \(K_a = \frac{[H^+][\text{CH}_3\text{COO}\textsuperscript{-}]}{[\text{CH}_3\text{COOH}]}\)  

(ii) \(K_a = \frac{[H^+]^2}{[\text{CH}_3\text{COOH}]}\) \text{ or with numbers}  

\([H^+] = (\sqrt{1.74 \times 10^{-5} \times 0.410}) = (\sqrt{7.13 \times 10^{-6}}) = 2.67 \times 10^{-3}\)  

\(\text{pH} = 2.57\)  

(iii)  
\[
\begin{align*}
M1 & \quad \text{mol } \text{OH}\textsuperscript{-} = (10.0 \times 10^{-3}) \times 0.10 = 1.0 \times 10^{-3} \\
M2 & \quad \text{orig mol HA } = (25.0 \times 10^{-3}) \times 0.41 = 0.01025 \\
& \quad \text{or } 1.025 \times 10^{-2} \text{ or } 1.03 \times 10^{-2} \\
M3 & \quad \text{mol HA in buffer } = \text{orig mol HA } - \text{mol } \text{OH}\textsuperscript{-} \\
& \quad = 0.00925 \text{ or } 0.0093 \\
M4 & \quad \text{pH } = pK_a - \log \frac{[HA]/{[A^-]}}{} \\
& \quad = 1.56 \\
\end{align*}
\]

\(\text{pH} = 0.0273\)  

\(\text{mol } A^- \text{ in buffer } = \text{mol } \text{OH}\textsuperscript{-} = 1.0 \times 10^{-3}\)
\[
M5 \quad [H^+] = \frac{K_a \times [CH_3COCH]}{[CH_3COO^-]} = 1
\]
\[
\frac{(1.74 \times 10^{-5})(0.00925)}{0.0010} \quad \text{or} \quad \frac{(1.74 \times 10^{-5})(0.00930)}{0.0010}
\]
\[
= 1.61 \times 10^{-4} \quad \text{or} \quad 1.62 \times 10^{-4}
\]

\[
M6 \quad pH = 3.79 \quad 1 \quad [18]
\]

Q12.
(a) \( (i) \) B \quad 1
\( (ii) \) cresolphthalein or thymolphthalein \quad 1
(b) \( pH = \log[H^+] \)

\[
K_a = \frac{[CH_3COOH]}{[H^+][CH_3COO^-]} = 1
\]
\[
[H^+] = \sqrt{1.74 \times 10^{-5} \times 0.15} \quad (or) \quad 1.62 \times 10^{-4}
\]
\( pH = 2.79 \quad 1[8] \)

Q13.
(a) \( (i) \) addition of small amounts of acid send eqm to left or extra H\(^+\)removed by reaction with HCO\(_3^-\) \quad 1
\( (ii) \) pH = 7.41 \quad [H^+] = 3.89 \times 10^{-8} \text{ mol dm}^{-3} \quad 1
\]
\[
[H^+][HCO_3^-] = (3.89 \times 10^{-8})(2.5 \times 10^{-2})
\]
\[
= 1.25 \times 10^{-9} = 7.78 \times 10^{-8} \text{ mol dm}^{-3} \quad 1
\]

(b) \( (i) \) moles H\(^+\) added = 10 \times 10^{-3} \times 1.0 = 0.01 \quad 1
\( (ii) \) moles ethanoic acid after addition = 0.15 + 0.01 = 0.16 \quad 1
\( (iii) \) moles ethanoate ions after addition = 0.10 – 0.01 = 0.09 \quad 1

\[
K_a = \frac{[CH_3COOH]}{[H^+][CH_3COO^-]} = 1
\]
\[
= 0.16 / \sqrt{0.09} \quad 1
\]
\( pH = 4.51 \quad 1[11] \)

Q14.
(a) \( -\log[H^+] \quad 1 \quad 4.57 \times 10^{-3} \quad 1 \)

\[
[H^+][X^-] = \frac{[H^+][X^-]}{[H^+][X^-]}
\]

\( (ii) \) \( [H^+]^2 \quad (4.57 \times 10^{-3})^2 \quad 1 \quad If \ use \ 4.6 \times 10^{-3} \)
\( K_a = 1.4(1) \times 10^{-4} \text{ and } pKa = 3.85 = 1.39 \times 10^{-4}; \text{ allow } 1.39 – 1.41 \times 10^{-4} \text{ mol dm}^{-3} \quad 1 \)

\( (iii) \) \( pK_a = 3.86 \quad 1 \)
(c) (i) \[ \frac{30}{1000} \times 0.480 = 0.0144 \text{ or } 1.4(4) \times 10^{-2} \]

(ii) \[ \frac{1000}{18} \times 0.350 = 0.0063 \text{ or } 6.3 \times 10^{-3} \]

(iii) \[ 0.0144 - 2(0.0063) = 1.80 \times 10^{-3} \]

(iv) \[ 1.80 \times 10^{-3} \times \frac{48}{1000} = 0.0375 \text{ (0.038)} \]

(v) \[ 10^{-14} / 0.0375 \quad (10^{-14} / 0.038) \]

\[ \text{M5 for } K_w/[OH^-] \]

\[ = 2.66 \times 10^{-13} \quad (= 2.63 \times 10^{-12}) \]

\[ \text{or } pOH \text{ or } pOH = 1.426 \quad (or \ pOH = 1.420) \]

\[ \text{pH} = 12.57 \quad (12.58) \]

Q15. (a) (i) \[ [H^+][OH^-] \]

\[ - \log [H^+] \]

(ii) \[ [H^+] = [OH^-] \]

(iii) \[ (2.0 \times 10^{-3}) \times 0.5 = 1.0 \times 10^{-3} \]

\[ \frac{4.02 \times 10^{-14}}{1.0 \times 10^{-3}} \]

(iv) \[ [H^+] = \frac{1.0 \times 10^{-3}}{4.02 \times 10^{-14}} \]

\[ \text{pH} = 10.40 \]

(b) (i) \[ K_a = \frac{[H^+][CH_3CH_2COO^-]}{[CH_3CH_2COOH]} \]

\[ = \frac{[H^+]}{[CH_3CH_2COOH]} \]

\[ \frac{[H^+]}{\sqrt{1.35 \times 10^{-5}}} \times 0.125 \]

\[ \text{pH} = 2.89 \]

(c) (i) \[ 50.0 \times 10^{-3} \times 0.125 = 6.25 \times 10^{-3} \]

(ii) \[ 6.25 \times 10^{-3} - (1.0 \times 10^{-3}) = 5.25 \times 10^{-3} \]

(iii) \[ \text{mol salt formed} = 1.0 \times 10^{-3} \]

\[ [H^+] = K_a \times \frac{[CH_3CH_2COOH]}{[CH_3CH_2COO^-]} \]

\[ \frac{(5.25 \times 10^{-3})}{\sqrt{1.35 \times 10^{-5} \times 0.117}} \]

\[ \text{pH} = 4.15 \]

Q16. (a) (i) B; \quad 1

C; \quad 1

A; \quad 1

(ii) cresolphthalein \quad \text{OR} \quad \text{thymolphthalein}; \quad 1

(b) (i) \[ -\log[H^+]; \quad 1 \]

(ii) \[ [H^+] = 1.259 \times 10^{-12} \text{ (or 1.26 or 1.3)} \quad \text{OR} \quad \text{OH} = 14 - \text{pH}; \quad 1 \]

\[ \frac{10^{-14}}{1.259 \times 10^{-12}} \]

\[ \text{OR} = 2.10; \quad 1 \]

\[ = 7.9(4) \times 10^{-3}; \quad 1 \]

(c) (i) \[ K_a = [H^+]^2/[CH_3CH_2COOH] \quad \text{OR} \quad [H^+]^2/[HA] \quad \text{OR} \quad [H^+] = \text{A}^- \text{ etc}; \quad 1 \]

\[ [H^+] = \sqrt{1.35 \times 10^{-5} \times 0.117} \text{ or expression without numbers}; \quad 1 \]

\[ = 1.257 \times 10^{-3}; \quad \text{pH} = 2.90; \quad 1 \]

(iii) \[ K_a = [H^+] \quad \text{OR} \quad pK_a = \text{pH}; \quad 1 \]

\[ \text{pH} = 4.87; \quad 1 \quad [13] \]
Q17.  
(a) Concentration of acid: \( m_1v_1 = m_2v_2 \) hence \( 25 \times m_1 = 18.2 \times 0.150 \)

\[
\text{OR}
\begin{align*}
\text{moles NaOH} &= 2.73 \times 10^{-3}; \\
m_1 &= 18.2 \times 0.150/25 = 0.109;
\end{align*}
\]

(b) (i) 
\[
K_a = [H^+][A^-]/[HA] \quad \text{not} \quad K_a = [H^+]^2/ [HA];
\]

(ii) \( pK_a = -\log K_a; \)

(iii) \([A^-] = [HA];\) hence \(K_a = [H^+] [A^-]/ [HA] = [H^+]\) and \(-\log K_a = -\log[H^+];\)

(c) ratio \([A^-] : [HA]\) remains constant; hence as \([H^+] = K_a [HA]/[A^-]; [H^+]\) remains constant; \(1\)

(d) (i) \text{pH of 0.250 mol dm}^{-3} \text{HCl} = 0.60 \text{ and pH of 0.150 mol dm}^{-3} \text{HCl} = 0.82; \quad 1\)

\[
\text{pH change} = 0.22; \quad 1
\]

(ii) \text{moles HCl} = 30 \times 0.250 \times 10^{-3} = v \times 0.150 \times 10^{-3} = 7.50 \times 10^{-3}\n
\[
v = 30 \times 0.250 \times 10^{-3}/0.150 \times 10^{-3} = 50; \quad 1
\]

\text{water added} = 50 - 30 = 20 \text{ cm}^3; \quad 1 \quad [12]

Q18.  
(a) \[ \text{pH} = -\log[H^+] \]

\[
K_a = \frac{[H^+]^2}{[CH_3COOH]} \quad \text{or} \quad [H^+] = [A^-]
\]

\[
[H^+] = \sqrt{1.74 \times 10^{-5}} \times 0.15 \quad \text{(or} \quad 1.62 \times 10^{-3}) \quad 1
\]

\[
\text{pH} = 2.79 \quad \text{(penalise 1 dp or more than 2dp once in the qu)} \quad 1
\]

(b) (i) Solution which resists change in pH /maintains pH despite the addition of (small amounts of) acid/base (or dilution) \(1\)

(ii) \( \text{CH}_3\text{COO}^- + H^+ \rightarrow \text{CH}_3\text{COOH} \) must show an equation full or ionic in which ethanoate ions are converted to ethanoic acid \(1\)

\[
[H^+] = \frac{K_a [CH_3COOH]}{[CH_3COO^-]} \quad \text{if rearrangement incorrect, no further marks} \quad 1
\]

\[
= 1.74 \times 10^{-5} \times \frac{0.15}{0.10} \quad 1
\]

\[
(= 2.61 \times 10^{-5}) \quad 1
\]

\[
\text{pH} = 4.58 \quad 1
\]

(ii) M1 \text{moles } H^+ \text{ added} = 10 \times 10^{-3} \times 1.0 = 0.01 \quad 1

M2 \text{moles ethanoic acid after addition} = 0.15 + 0.01 = 0.16 \quad 1

M3 \text{moles ethanoate ions after addition} = 0.10 - 0.01 = 0.09 \quad 1

\[
M4 [H^+] = \frac{K_a [CH_3COOH]}{[CH_3COO^-]} = 1.74 \times 10^{-5} \times \frac{0.16}{0.09} \quad 1
\]

\[
(\approx 3.09 \times 10^{-5}) \quad 1[15]
\]

alternative scheme for part (c)(i)

\[
\text{pH} \quad \text{pK}_a = -\log\frac{[CH_3COOH]}{[CH_3COO^-]} \quad 1
\]

\[
pK_a = 4.76 \quad 1
\]

\[
\text{pH} = (4.76 - \log\frac{0.15}{0.10}) = 4.58 \quad 1
\]

alternative for penultimate mark of part (c)(ii)

\[
\text{pH} = 4.76 - \log\frac{0.16}{0.09} \quad 1
\]

18
Q19. (a) \( K_a = \frac{[H^+][A^-]}{[HA]} \)

(b) \( K_a = \frac{[H^+]^2}{[HA]} \) or \([H^+] = [A^-] \)

\[ [H^+] = \sqrt{(1.45 \times 10^{-4}) \times 0.25} = 6.02 \times 10^{-3} \]

\( \text{pH} = 2.22 \)

(c) (i) pH (almost) unchanged

H\(^+\) removed by A\(^-\) forming HA or acid reacts with salt or more HA formed

(ii) \([H^+] = 10^{-3.59} = 2.57 \times 10^{-4} \) or \(2.6 \times 10^{-4} \)

\[ K_a \frac{[HA]}{[A^-]} = \frac{[H^+]^2}{[HA]} = \frac{2.57 \times 10^{-4}}{0.141 \text{ (mol dm}^{-3})} \]

(ii) Alternative scheme for first three marks of part (c)(ii)

\[ \text{pH} = \text{pK}_a - \log [A^-] \]

\( \text{pK}_a = 3.84 \)

\[ 3.59 = 3.84 - \log [A^-] \]

M20. (a) (i) \( \text{pH} = -\log [H^+] \) (1)

(ii) Expression for \( K_w \): \( K_w = \frac{[H^+][OH^-]}{[H^+][OH^-]} \) (1)

Calculation: \( \text{pH} = 2.56 \) \( [H^+] = 2.75 \times 10^{-3} \) (1)

\[ K_w = \frac{[H^+]^2}{[H^+][OH^-]} = \frac{2.75 \times 10^{-3}}{0.12} = 6.32 \times 10^{-5} \text{ (mol dm}^{-3}) \]

depending on approximate made, values of \( K_w = 10^{-5} \times \\)

using \([H^+] = 0.12 \) 6.30 – 6.32

using \([H^+] = 0.12 – 2.75… \) 6.45 – 6.47

using 2.8 and \([H^+] = 0.12 \) 6.53

using 2.8 and \([H^+] = 0.12 – 2.8 \) 6.69

upside down \( K_a \)

5

(b) (i) Expression for \( K_w \): \( K_w = [H^+] [OH^-] \) (1)

Value of \( K_w \): \( 1.0 \times 10^{-14} \) (mol\(^2\) dm\(^{-6}\)) (1)

\( 1.0 \times 10^{-14} \)

(ii) \([H^+] = \frac{0.045}{0.045} = 2.22 \times 10^{-13} \) or \( \text{pOH} = 1.35 \) (1) \( \therefore \) \( \text{pH} = 12.65 \) (1)

4

(c) (i) \( \text{H}_2\text{C}_2\text{O}_4 + \text{OH}^- \rightarrow \text{HC}_2\text{O}_4^- + \text{H}_2\text{O} \) (1)

(ii) \( \text{mol OH}^- = (41.6 \times 10^{-3}) \times 0.0450 \) (1) \( = 1.87 \times 10^{-3} \) \( \therefore \) \( \text{mol } \text{H}_2\text{C}_2\text{O}_4 = 9.36 \times 10^{-4} \) (1)

\( \frac{\text{mol } \text{H}_2\text{C}_2\text{O}_4}{9.36 \times 10^{-4} \times 10^{-3}} = 0.0374 \) (1)

4

(d) (i) \( \text{CH}_3\text{OOCOOCH}_{3} \) or \( \text{CH}_2\text{O}_{2}\text{CCO}_{2}\text{CH}_3 \) and similarly in (ii)
(ii)  
\[ \text{OCH}_2\text{CH}_2\text{O} - \text{C} - \text{C} \] or  
\[ \text{HOCH}_2\text{CH}_2\text{O} - \text{C} - \text{C} - \text{OH} \]

must be 1:1 proportion allow repeating until alone (i.e. n not essential) 2 [15]

M21.  
(a) Hydrogen bonding (1) between H\(_2\)O and NH\(_3\) (1) 2

(b) (i) NH\(_3\) + H\(_2\)O \rightleftharpoons NH\(_4^+\) + OH\(^-\) (1)

(ii) Ammonia is weak base (1) NOT partially ionized Equilibrium to left or incomplete reaction (1) 3

(c) A proton donor (1)

(d) Buffer solution: A solution which resists change in pH (1) when small amounts of acid or base added or on dilution (1)

Reagent: NH\(_4\)Cl (1) ; Allow a correct strong acid 3

(e) (i) \[ K_a = \frac{[H^+][A^-]}{[HA]} \] = [H\(^+\)] [0.125 \times 4] (1) / 1.00  
\[ [H^+] = 1.70 \times 10^{-5} / 0.125 \times 4 = 3.40 \times 10^{-5} \]  (1)  
\[ pH = -\log_{10} [H^+] = 4.74 \] (1)

(ii) H\(^+\) + CH\(_3\)COO\(^-\) \rightarrow CH\(_3\)COOH (1) 5 [14]

M22.  
(a) (i) \[ K_w = [H^+][OH^-] \]  (1)

(ii) pH = \(-\log [H^+]\) (1)

(iii) Calculation:  
\[ [H^+] = \sqrt{5.46 \times 10^{-14}} \] (1) = 2.34 \times 10^{-7} \遮(pH = 6.63 or 6.64) (1)  
Explain: pure water \[ : [H^+] = [OH^-] \] (1) 5

(b) (i) \[ [OH^-] = 0.150 \] \遮([H\(^+\)] = 10^{-14}/0.15 = 6.66 \times 10^{-14} \或者 \text{pOH} = 0.82 \遮(pH = 13.18) (1)  
or pH = 13.17

(ii) moles OH\(^-\) = (35 \times 10^{-3}) \times 0.15 = 5.25 \times 10^{-3} \遮(1)\(^a\)  
moles H\(^+\) = (40 \times 10^{-3}) \times 0.120 = 4.80 \times 10^{-3} \遮(1)\(^b\)  
\遮 excess moles of OH\(^-\) = 4.5 \times 10^{-4} \遮(1)\(^c\)  
\遮 [OH\(^-\)] = (4.5(0) \times 10^{-4}) \times 1000/75 \遮(1)\(^d\)  
= 6.0(0) \times 10^{-3} \遮(1)\(^e\)

\[ [H^+] = \frac{6.0 \times 10^{-3}}{10^{-14}} = 1.66 \times 10^{-12} \text{ or } \text{pOH} = 2.22 \遮(pH = 11.78) (1)\(^f\) \遮(1)\(^g\)  
or pH = 11.77 8

(c) (i) \[ K_a = \frac{[H^+]}{[HA]} \]  (1)

(ii) \[ [H^+] = 1.80 \times 10^{-2} \times 0.150 = 2.70 \times 10^{-3} \] (1)

\[ [H^+] = \frac{2.70 \times 10^{-3}}{0.150} = 4.86 \times 10^{-5} \text{ (1) mol dm}^{-3} \] (1)

or \[ 0.1473 \] = 4.95 \times 10^{-5} 5
ORGANIC NOTES

Curly arrows: must show movement of a pair of electrons, i.e. from bond to atom or from lp to atom / space e.g.

Structures

penalise sticks (i.e. ) once per paper

Penalise once per paper

allow CH₃ or -CH₃ or or CH₃ or H₂C- [18]

M23. (a) moles HA = \frac{25}{10^3} \times 0.150 = 3.75 \times 10^{-3} \text{ (1)} \therefore \text{ vol NaOH} = \frac{3.75 \times 10^{-3}}{0.20} = 1.875 \times 10^{-2} \text{ dm}^3 \text{ (1) or 18.75 cm}^3 \text{ (1) (1)}

(b) (i) pH = -\log[H^+]
(ii) Value above 7 but below 11
(iii) phenol red / thymol blue / phenolphthalein / thymolphthalein i.e. indicator with 7 < pKᵢn < 11

(c) (i) Only slightly dissociated/ionised \[ [H^+] [A^-] \text{ (1)} \]
(ii) \[ K_a = \frac{[H^+]^2}{[HA]} \text{ (1)} \]
(iii) For weak acid alone: \[ K_a = \frac{[H^+]^2}{[HA]} \text{ (1)} \]
\[ [H^+] = \sqrt{(2.75 \times 10^{-6}) \times 0.15} = 2.03 \times 10^{-3} \text{ (1)} \therefore \text{ pH} = 2.69 \text{ (1)5} \]

(d) moles OH⁻ added = 1.875 \times 10^{-3} = moles A⁻ = moles HA left \text{ (1)} \therefore [A⁻] = [HA]
\[ K_a = [H^+] \text{ or } \text{pH} = pK_a \text{ (1)} \therefore \text{ pH} = 4.56 \text{ (1)3 [13]} \]

M24. (a) (i) H⁺ or proton acceptor \[ \text{CH}_3\text{NH}_2 + \text{H}_2\text{O} (\rightleftharpoons) \text{CH}_3\text{NH}_3^+ \text{OH}^- \text{ (1)} \]

(ii) CH₃NH₃Cl or HCl \text{ (1) Or any ammonium compound or strong acid name or formula}

(iii) extra OH⁻ reacts with CH₃\text{NH}_2; or reaction / equilibrium moves to left or ratio salt / base remains almost constant \text{ (1)} \therefore

(b) lone pair (on N accepts H⁺) \text{ (1)}
CH₃ increases electron density (on N); donates / pushes electrons; has positive inductive effect \text{ (1)} \therefore

(c) nucleophilic substitution \text{ (1)}
\[ \text{C}_2\text{H}_5 \]
\[ \text{CH}_3 \quad \text{N}-\text{C}_2\text{H}_5 \]
\[ \text{C}_2\text{H}_5 \quad \text{(1)} \quad 2[9] \]
M25.  

(a) before any KOH added:  
\[
K_a = \frac{[H^+][A^-]}{[HA]} \quad \text{or} \quad \frac{[H^+][\text{CH}_3\text{COO}^-]}{[\text{CH}_3\text{COOH}]} \quad (1)
\]

\[
\therefore K_a = \frac{[\text{CH}_3\text{COOH}]}{[H^+]^2} \quad (1)
\]

\[
[H^+] = \sqrt[1.74 \times 10^{-5} \times 0.160} = 1.67 \times 10^{-3} \quad (1)
\]

\[
pH = 2.78 \quad (1)
\]

(b) at 8 cm³ KOH: moles KOH added = \( (8 \times 10^{-3}) \times 0.210 = 1.68 \times 10^{-3} \)  

\[
\text{moles of } \text{CH}_3\text{COO}^- \text{ formed} = 1.68 \times 10^{-3} \quad (1)
\]

\[
\text{moles of } \text{CH}_3\text{COOH left} = (4.0 \times 10^{-3}) - (1.68 \times 10^{-3}) = 2.32 \times 10^{-3} \quad (1)
\]

\[
[H^+] = \frac{K_a \times [\text{CH}_3\text{COO}^-]}{2.32 \times 10^{-3} / V} = \frac{1.74 \times 10^{-5} \times 1.68 \times 10^{-3} / V}{2.40 \times 10^{-5}} \quad (1) \quad \therefore pH = 4.62 \quad (1)
\]

(c) at 40 cm³ of KOH:  

\[
\text{Total moles of KOH} = (40 \times 10^{-3}) \times 0.21 = 8.4 \times 10^{-3} \quad (1)
\]

\[
\text{excess moles of KOH} = (8.4 \times 10^{-3}) - (4.0 \times 10^{-3}) = 4.4 \times 10^{-3} \quad (1)
\]

\[
in \text{total volume} = 40 + 25 = 65 \text{ cm}^3 \quad (1)
\]

\[
[\text{OH}^-] = \frac{4.4 \times 10^{-3} \times 0.0677}{0.150} = 0.0677 \quad (1)
\]

\[
\therefore pH = 12.83 \quad (1)
\]

or \( \text{H}_2\text{O}^- \)

M26.  

(a) (i) \( K_a = \frac{[H^+] \cdot [\text{CH}_3\text{COO}^-]}{[\text{CH}_3\text{COOH}]} \quad (1)
\]

(ii) \( K_a = \frac{[H^+] \cdot [\text{CH}_3\text{COO}^-]}{[\text{CH}_3\text{COOH}]} \quad (1)
\]

\[
[H^+] = \sqrt{1.74 \times 10^{-5} \times 0.220} = 1.96 \times 10^{-3} \quad (1)
\]

\[
pH = -\log[H^+] \quad (1)
\]

\[
pH = 2.71 \quad (1) \quad 5
\]

(b) (i) moles acid = \( \frac{25}{1000} \times 0.220 \quad (1) = 5.50 \times 10^{-3} \)

\[
\times 0.150 = 0.220 \times \frac{1000}{10^{-3}} \quad \therefore x = 25 \times 0.150 \quad \text{or} \quad 5.50 \times 10^{-3} \times 0.150 = 36.7 \text{ (or 37)} \text{ cm}^3 \text{ (or 36.6)} \quad (1)
\]

(ii) \text{Indicator:} \text{ thymol blue} \quad (1)

\text{Explanation:} \text{ weak acid – strong base} \quad (1) \text{ equivalent at pH > 7} \quad (1) \text{ or high pH}

\[
\text{or} \quad \frac{2.0}{2} \quad (1)
\]

(c) (1) mol NaOH added = \( 40.0 \div 0.050 \) \quad (1)

(2) mol CH₃COOH left = 0.220 – 0.050 = 0.170 \quad (1)

(3) mol CH₃COO⁻ formed = 0.050 \quad (1)

\[
\log [\text{A}^-] \quad OR \quad pH = pK_a + \log(\frac{[\text{salt}]}{[\text{acid}]} \quad (1)
\]

\[
[H^+] = Ka \quad OR \quad pH = pKa + \log(\frac{[\text{salt}]}{[\text{acid}]}) \quad (1)
\]

(5) \( [H^+] = 1.74 \times 10^{-5} \times \frac{0.05}{0.17} \quad OR \quad pH = 4.76 + \log(\frac{0.05}{0.17}) \quad (1)
\]

(6) \( pH = 4.23 \quad (1) \quad 6 \quad [16] \)