

Question Number	Answer	Mark
9	<p>The only correct answer is D (4, 3, 1, 2)</p> <p><i>A is not correct because Beaker 4 has the highest pH</i></p> <p><i>B is not correct because Beaker 4 has the highest pH</i></p> <p><i>C is not correct because Beaker 4 has the highest pH</i></p>	(1)

Question Number	Answer	Mark
8	<p>The only correct answer is C (the dissociation of water is endothermic, so the concentration of hydrogen ions is higher at 100°C than at 25°C)</p> <p><i>A is incorrect because at lower pH the concentration of hydrogen ions is higher</i></p> <p><i>B is incorrect because at lower pH the concentration of hydrogen ions is higher and the reaction is endothermic</i></p> <p><i>D is incorrect because the forward reaction is endothermic</i></p>	(1)

Question Number	Answer	Mark
7	<p>The only correct answer is B (neutral with a pH of 6.6)</p> <p><i>A is incorrect because this is the pH of water at 25 °C</i></p> <p><i>C is incorrect because the water is neutral $[H^+] = [OH^-]$</i></p> <p><i>D is incorrect because the water is neutral and the pH has been calculated incorrectly</i></p>	(1)

Question Number	Answer	Mark
11	<p>The only correct answer is B (13.53)</p> <p><i>A is incorrect because this is the pH determined using the value of pK_w at 298 K</i></p> <p><i>C is incorrect because this is the value of pK_w minus the concentration</i></p> <p><i>D is incorrect because this is the value of pK_w</i></p>	(1)

Question Number	Answer	Mark
5	<p>The only correct answer is C (the dissociation of water is endothermic so the concentration of hydrogen ions is higher at 75°C)</p> <p><i>A is not correct because in pure water the concentrations of hydrogen ions and hydroxide ions are always equal</i></p> <p><i>B is not correct because the concentration of hydrogen ions increases</i></p> <p><i>D is not correct because the reaction is endothermic</i></p>	(1)

Question number	Answer	Mark
11	<p>The only correct answer is A(increases, increases)</p> <p><i>B is incorrect because the solution becomes less acidic with dilution so pH increases</i></p> <p><i>C is incorrect because the proportion of acid molecules dissociating increases with dilution</i></p> <p><i>D is incorrect because the proportion of acid molecules dissociating increases with dilution and the solution becomes less acidic with dilution so pH increases</i></p>	(1)

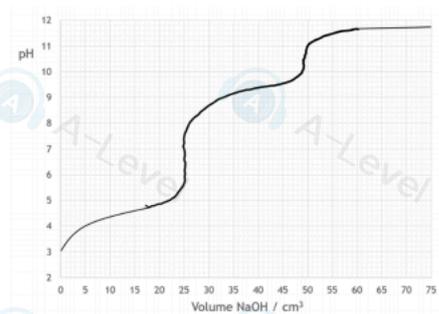
Question Number	Answer	Additional Guidance	Mark
19(a)(i)	<p>$C_5H_5NH^+$ K_a:</p> <ul style="list-style-type: none"> calculation of inverse $\log(-5.25)$ to 2SF (1) <p>$CHCl_2COOH$ pK_a:</p> <ul style="list-style-type: none"> calculation of $-\log(4.5 \times 10^{-2})$ to 3SF (1) 	<p><u>Example of calculation:</u></p> <p>$(5.6234 \times 10^{-6} \Rightarrow) 5.6 \times 10^{-6}$ Do not award 6×10^{-6}</p> <p>$(1.3468 \Rightarrow) 1.35$ Do not award 1.4 or 1.34</p> <p>Penalise inconsistent SF once only Penalise incorrect rounding once only</p>	2

Question Number	Answer	Additional Guidance	Mark
19(a)(ii)	<p>An answer that makes reference to the following point:</p> <ul style="list-style-type: none"> $(K_a \Rightarrow) \frac{[H^+][C_5H_5N]}{[C_5H_5NH^+]}$ 	<p>Do not award C_6 for C_5 Do not award non-square brackets</p> <p>Allow $[H_3O^+]$ for $[H^+]$</p> <p>Allow use of  for C_5H_5N</p> <p>Do not award C_5H_4NH for C_5H_5N Do not award charged C_5H_5N, eg $C_5H_5N^-$</p> <p>Allow use of  for $C_5H_5NH^+$</p> <p>Allow $C_5H_6N^+$ for $C_5H_5NH^+$ Do not award omission of charge from $C_5H_5NH^+$</p>	1

Question Number	Answer	Additional Guidance	Mark
19(a)(iii)	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> $CH_3CH_2COOH_2^+$ and $HCOO^-$ (1) $HCOOH$ A1 and $HCOO^{(-)}$ B1 and CH_3CH_2COOH B2 and $CH_3CH_2COOH_2^{(+)}$ A2 (1) 	<p>Allow $COOH^-$</p> <p>Allow A2 and B2 for A1 and B1</p> <p>Allow B1 and A1 for B2 and A2</p> <p>TE on M1 for $HCOOH_2^{(+)}$ and $CH_3CH_2COO^{(-)}$ only</p>	2

Question Number	Answer	Additional Guidance	Mark																				
19(a)(iv)	<p>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.</p> <p>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.</p> <p>The following table shows how the marks should be awarded for indicative content.</p> <table border="1"> <thead> <tr> <th>Number of indicative marking points seen in answer</th> <th>Number of marks awarded for indicative marking points</th> </tr> </thead> <tbody> <tr> <td>6</td> <td>4</td> </tr> <tr> <td>5-4</td> <td>3</td> </tr> <tr> <td>3-2</td> <td>2</td> </tr> <tr> <td>1</td> <td>1</td> </tr> <tr> <td>0</td> <td>0</td> </tr> </tbody> </table> <p>The following table shows how the marks should be awarded for structure and lines of reasoning.</p> <table border="1"> <thead> <tr> <th></th> <th>Number of marks awarded for structure and sustained lines of reasoning</th> </tr> </thead> <tbody> <tr> <td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.</td> <td>2</td> </tr> <tr> <td>Answer is partially structured with some linkages and lines of reasoning.</td> <td>1</td> </tr> <tr> <td>Answer has no linkages between points and is unstructured.</td> <td>0</td> </tr> </tbody> </table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5-4	3	3-2	2	1	1	0	0		Number of marks awarded for structure and sustained lines of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.	2	Answer is partially structured with some linkages and lines of reasoning.	1	Answer has no linkages between points and is unstructured.	0	<p>The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).</p> <p>If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).</p> <p>If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded, do not deduct mark(s).</p> <p>Comment: Look for the indicative marking points first, then consider the mark for the structure of the answer and sustained line of reasoning.</p>	6
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																						
6	4																						
5-4	3																						
3-2	2																						
1	1																						
0	0																						
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Answer is partially structured with some linkages and lines of reasoning.	1																						
Answer has no linkages between points and is unstructured.	0																						

<p>Indicative points:</p> <ul style="list-style-type: none"> IP1: use of $[H^+] = \sqrt{K_a \times [HA]}$ IP2: use of $pH = -\log[H^+]$ IP3: indication that $[HA]_{\text{equilibrium}}$ is lower than $[HA]_{\text{initial}}$ IP4: (because) dissociation (of both acids) is significant IP5: (calculated pH values lower than measured pH values because) $[HA]$ is overestimated in the calculations IP6: (difference greatest for) $CHCl_2COOH$ (as is) stronger acid or two Cl atoms in $CHCl_2COOH$ are more electron withdrawing than one / stabilise anion more / weaken O-H bond more 	<p>If calculations shown, pH values are 2.0775 and 1.3239</p> <p>Ignore $[H^+] = [A^-]$ assumption is not valid Ignore $[H^+] > [A^-]$ Do not award $[A^-] > [H^+]$</p> <p>Allow dissociation is not negligible Allow dissociation occurs Do not award dissociation is negligible Do not award dissociation is complete</p> <p>Do not award $[H^+]$ overestimated in calculation due to dissociation of water</p> <p>Allow more dissociated for stronger Ignore strong acid for stronger acid Ignore $CHCl_2COOH$ has larger K_a / smaller pK_a</p>	
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Question Number	Answer	Additional Guidance	Mark
19(b)	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> vertical section at 25 cm³ and with height in the range of 1 to 4 pH units (1) vertical section at 50 cm³ and with height greater than 0.4 pH units (1) (buffered section with) pH 9.3 at 37.5 cm³ (1) 	<p><u>Example of completed titration curve:</u></p>  <p>Allow slight slope in range of 24 cm³ to 26 cm³</p> <p>Allow any pH between 9.0 and 9.6 Allow reading of pH from midpoint volume between two vertical sections as TE on M1/M2</p>	3

Question Number	Answer	Additional Guidance	Mark
19(c)	<p>M1 and M2:</p> <ul style="list-style-type: none"> calculation of [H⁺] at both pH values or calculation of pOH at both pH values (1) calculation of [OH⁻] at both pH values (1) <p>M3, M4 and M5 (Method 1):</p> <ul style="list-style-type: none"> calculation of moles of NaOH in 50.0 cm³ at pH 12.43 (1) calculation of volume of NaOH required at pH 12.00 (1) volume of water required in cm³ (1) <p>M3, M4 and M5 (Method 2):</p> <ul style="list-style-type: none"> expression for dilution (1) calculation of volume of NaOH required at pH 12.00 (1) volume of water required in cm³ (1) 	<p><u>Example of calculation:</u></p> <p>[H⁺] = 10^{-12.43} = 3.7154 × 10⁻¹³, [H⁺] = 10^{-12.00} = 1 × 10⁻¹² or pOH = 14 - 12.43 = 1.57; pOH = 14 - 12.00 = 2.00</p> <p>[OH⁻] = 1 × 10⁻¹⁴ ÷ 3.7154 × 10⁻¹³ = 10^{-1.57} = 0.026915 [OH⁻] = 1 × 10⁻¹⁴ ÷ 1 × 10⁻¹² = 10^{-2.00} = 0.01</p> <p>0.026915 × $\frac{50.0}{1000}$ = 1.3458 × 10⁻³</p> <p>1.3458 × 10⁻³ ÷ 0.01 = 0.13458 dm³ = 134.58 cm³</p> <p>134.58 - 50.0 = 84.58 / 84.6 / 85 (cm³) TE on M4</p> <p>c₁v₁ = c₂v₂</p> <p>v₂ = $\frac{c_1 v_1}{c_2} = \frac{0.026915}{0.01} \times 50.0 = 134.58 \text{ cm}^3$</p> <p>134.58 - 50.0 = 84.58 / 84.6 / 85 (cm³)</p>	5

<p>M3, M4 and M5 (Method 3):</p> <ul style="list-style-type: none"> calculation of moles of NaOH in 50.0 cm³ at pH 12.43 (1) calculation of moles of NaOH in 50.0 cm³ at pH 12.00 (1) and difference in moles of NaOH (1) calculation of volume of NaOH required (1) <p>M3, M4 and M5 (Method 4):</p> <ul style="list-style-type: none"> difference in concentrations of NaOH (1) difference in moles of NaOH (1) calculation of volume of NaOH required (1) <div style="border: 1px solid black; padding: 2px; width: fit-content; margin: 10px auto;">OTHER METHODS MAY BE POSSIBLE</div>	$0.026915 \times \frac{50.0}{1000} = 1.3458 \times 10^{-3}$ $0.01 \times \frac{50.0}{1000} = 5 \times 10^{-4}$ <p>and</p> $1.3458 \times 10^{-3} - 5 \times 10^{-4} = 8.458 \times 10^{-4}$ $8.458 \times 10^{-4} \div 0.01 = 84.58 \text{ (cm}^3\text{)}$ $0.026915 - 0.01 = 0.016915$ $0.016915 \times \frac{50.0}{1000} = 8.458 \times 10^{-4}$ $8.458 \times 10^{-4} \div 0.01 = 84.58 \text{ (cm}^3\text{)}$ <p>If no other marks awarded, calculation of [H⁺]/pOH and calculation of [OH⁻] at either pH scores (1)</p>	
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Question Number	Answer	Additional Guidance	Mark
17(a)(i)	<ul style="list-style-type: none"> correct expression for K_a 	<p>Example of expression:</p> $K_a = \frac{[\text{CH}_3\text{COO}^-][\text{H}^+]}{[\text{CH}_3\text{COOH}]}$ <p>Allow H₃O⁺ Ignore state symbols even if incorrect Do not award curly brackets Do not award HA etc</p>	(1)

Question Number	Answer	Additional Guidance	Mark
17(a)(ii)	<ul style="list-style-type: none"> calculation of [H⁺] (1) calculation of pH (1) 	<p>Example of calculation: No TE from wrong K_a expression in i for M1</p> $\sqrt{(1.7 \times 10^{-5} \times 0.25)} = 2.0616 \times 10^{-3} / 0.0020616 \text{ (mol dm}^{-3}\text{)}$ $-\log 2.0616 \times 10^{-3} = 2.6858/2.69/2.7$ <p>TE from [H⁺] as long as the pH is below 7 Ignore SF except 1 Correct answer without working scores 2</p>	(2)

Question Number	Answer	Additional Guidance	Mark
17(a)(iii)	<p>An answer that makes reference to the following point:</p> <ul style="list-style-type: none"> degree of ionisation/dissociation of the acid is very small / negligible/ <p>Or</p> $[\text{CH}_3\text{COOH}]_{\text{eqm}} = [\text{CH}_3\text{COOH}]_{\text{initial}}$ <p>Or</p> $[\text{H}^+] = [\text{CH}_3\text{COO}^-]$ <p>Or</p> <p>all of the hydrogen ions come from the acid</p>	<p>Allow HA and A⁻</p> <p>Allow H₃O⁺</p> <p>Allow no hydrogen ions come from the water</p>	(1)

Question Number	Answer	Additional Guidance	Mark
17(b)(i)	<p>An answer that makes reference to the following point:</p> <ul style="list-style-type: none"> the Cl is electron withdrawing / (highly) electronegative/ negatively inductive <p>and</p> <p>so stabilises the COO⁻ anion/ weakens the O-H bond (causing the H⁺ to be removed more easily)</p>		(1)

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17(b)(ii)	<ul style="list-style-type: none"> correct equation (1) correct conjugate acids and bases (1) 	<p>Example of equation:</p> $\text{CH}_3\text{COOH} + \text{CH}_2\text{ClCOOH} \rightleftharpoons \text{CH}_3\text{COOH}_2^+ + \text{CH}_2\text{ClCOO}^-$ <p>Or</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 25%;">B1</td> <td style="width: 25%;">A2</td> <td style="width: 25%;">A1</td> <td style="width: 25%;">B2</td> </tr> <tr> <td>B2</td> <td>A1</td> <td>A2</td> <td>B1</td> </tr> </table> <p>M2 dependent on M1 or near miss such as missing a charge or a subscript 2</p> <p>Allow any indication of linkage eg lines</p>	B1	A2	A1	B2	B2	A1	A2	B1	(2)
B1	A2	A1	B2								
B2	A1	A2	B1								

Question Number	Answer	Additional Guidance	Mark
17(e)	<p>concentration route</p> <ul style="list-style-type: none"> • calculation of $[\text{CH}_3\text{COONa}]$ • rearrangement of K_a equation • calculation of $[\text{H}^+]$ • calculation of pH <p>moles route</p> <ul style="list-style-type: none"> • calculation of moles CH_3COONa and calculation of moles CH_3COOH • rearrangement to get $[\text{H}^+]$ • calculation of $[\text{H}^+]$ • calculation of pH 	<p>Example of calculation:</p> <p>$8.2 \div 82 \times 1000 / 250 = 0.4 \text{ (mol dm}^{-3}\text{)}$</p> <p>$[\text{H}^+] = K_a \times \frac{[\text{HA}]}{[\text{A}^-]}$ OR $\frac{[\text{H}^+]}{K_a} = \frac{[\text{HA}]}{[\text{A}^-]}$</p> <p>$[\text{H}^+] = 1.7 \times 10^{-5} \times \frac{0.7}{0.4} = 2.975 \times 10^{-5} \text{ (mol dm}^{-3}\text{)}$</p> <p>$-\log 2.975 \times 10^{-5} = 4.5265$</p> <p>$8.2 \div 82 = 0.1 \text{ (mol)}$</p> <p>and $250 \times 0.7 \div 1000 = 0.175 \text{ (mol)}$</p> <p>$[\text{H}^+] = K_a \times 0.175 \div 0.1$</p> <p>$[\text{H}^+] = 1.7 \times 10^{-5} \times 0.175 \div 0.1 = 2.975 \times 10^{-5} \text{ (mol dm}^{-3}\text{)}$</p> <p>$-\log 2.975 \times 10^{-5} = 4.5265$</p> <p>Correct answer with or without working scores 4 Allow TE throughout but if final answer is above pH 7, do not award M4.</p>	(4)

	<p>Henderson-Hasselbalch route</p> <ul style="list-style-type: none"> • calculation of $[\text{CH}_3\text{COONa}]$ or moles of CH_3COONa and CH_3COOH • HH equation • calculation of $\text{p}K_a$ • calculation of pH 	<p>$8.2 \div 82 \times 1000 / 250 = 0.4 \text{ (mol dm}^{-3}\text{)}$</p> <p>$8.2 \div 82 = 0.1 \text{ (mol)}$</p> <p>and $250 \times 0.7 \div 1000 = 0.175 \text{ (mol)}$</p> <p>$\text{pH} = \text{p}K_a - \log \frac{[\text{HA}]}{[\text{A}^-]}$ or $\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$</p> <p>$-\log 1.7 \times 10^{-5} = 4.76955$</p> <p>Put the numbers into HH = 4.5265</p> <p>Correct answer with or without working scores 4 Allow TE throughout but if final answer is above pH 7, do not award M4.</p>	
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Question Number	Answer	Additional Guidance	Mark
17(d)	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> • (because of the weak acid) the pH of the bubble bath is lower (or equal) than 3.8 at the start so (the bromocresol green) is yellow • when diluted/ water added (to the bath) and the $[H^+]$ decreases/ the pH increases/less acidic • (the bromocresol green) turns (green then) blue as the pH is equal or higher than 5.4 	<p>Allow just yellow in acidic solution/low pH</p> <p>(1)</p> <p>Do not award any mention of water acting as a base/ acid being neutralised/reacting with OH^-</p> <p>(1)</p> <p>Allow at a pH of 4.7 the colour will be green Do not award if they state that pH 5.4 is alkaline</p> <p>(1)</p> <p>Ignore any reference to acid dissociating</p>	(3)