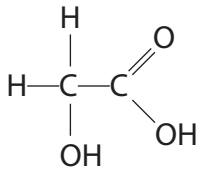
8 2-Hydroxyethanoic acid, also known as glycolic acid, $CH_2OHCOOH$, is an alpha hydroxy acid used in some skincare products.
It has a K_a value of 1.5×10^{-4} mol dm^{-3}.

The structure of glycolic acid is



(a) A solution of glycolic acid of concentration 0.1 mol dm^{-3} has a pH of 2.4

What is the approximate pH of the resulting solution after it has been diluted by a factor of 100?

(1)

☒ **A** 1.4

☒ **B** 2.4

☒ **C** 3.4

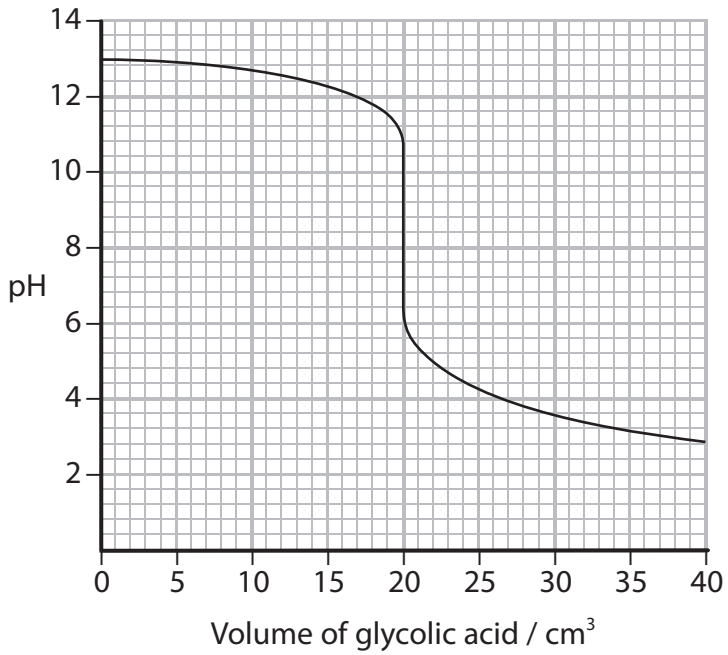
☒ **D** 4.4

(b) Another solution of glycolic acid has a pH of 2.0

Calculate the concentration of this solution.

(3)

(c) 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)

(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

(d) Glycolic acid has an acid dissociation constant of 1.5×10^{-4} mol dm^{-3} compared with a value of 1.7×10^{-5} mol dm^{-3} for ethanoic acid.

(i) Give a possible explanation as to why the value of K_a for glycolic acid is approximately ten times larger than that of ethanoic acid.

(2)

.....

.....

.....

.....

.....

.....

(ii) Complete the equation to show the conjugate acid-base pairs that would be produced when pure samples of glycolic acid and ethanoic acid are mixed.

(1)

$CH_2OHCOOH + CH_3COOH \rightarrow$ ..... + ...

(Total for Question 8 = 12 marks)

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

8 Acids can be classified as weak or strong acids.

(a) A mixture of concentrated sulfuric and nitric acids is used in the nitration of benzene.

The following equilibrium is set up:

$$H_2SO_4 + HNO_3 \rightleftharpoons H_2NO_3^+ + HSO_4^-$$

Which statement about this equilibrium is correct?

(1)

☒ **A** HNO_3 and $H_2NO_3^+$ are a conjugate acid-base pair

☒ **B** the nitric acid acts as an acid

☒ **C** the nitric acid acts as an oxidising agent

☒ **D** the sulfuric acid acts as a dehydrating agent

(b) Sulfuric acid ionises in two stages.

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

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

(i) Explain, with reference to the equations, why the HSO_4^- ion is classified as a weak acid.

(2)

(ii) A 0.100 mol dm^{-3} solution of sulfuric acid has a pH of 0.97.

Calculate the concentration of hydrogen ions in this solution.

(1)

(c) Ethanoic acid, CH_3COOH, is a weak acid.

A student prepares 600 cm^3 of a buffer solution by mixing 400 cm^3 of 0.500 mol dm^{-3} ethanoic acid solution with 200 cm^3 of 0.500 mol dm^{-3} sodium ethanoate solution, CH_3COONa.

Calculate the pH of the buffer solution produced.

(K_a for ethanoic acid = 1.74×10^{-5} mol dm^{-3})

(4)

(Total for Question 8 = 8 marks)

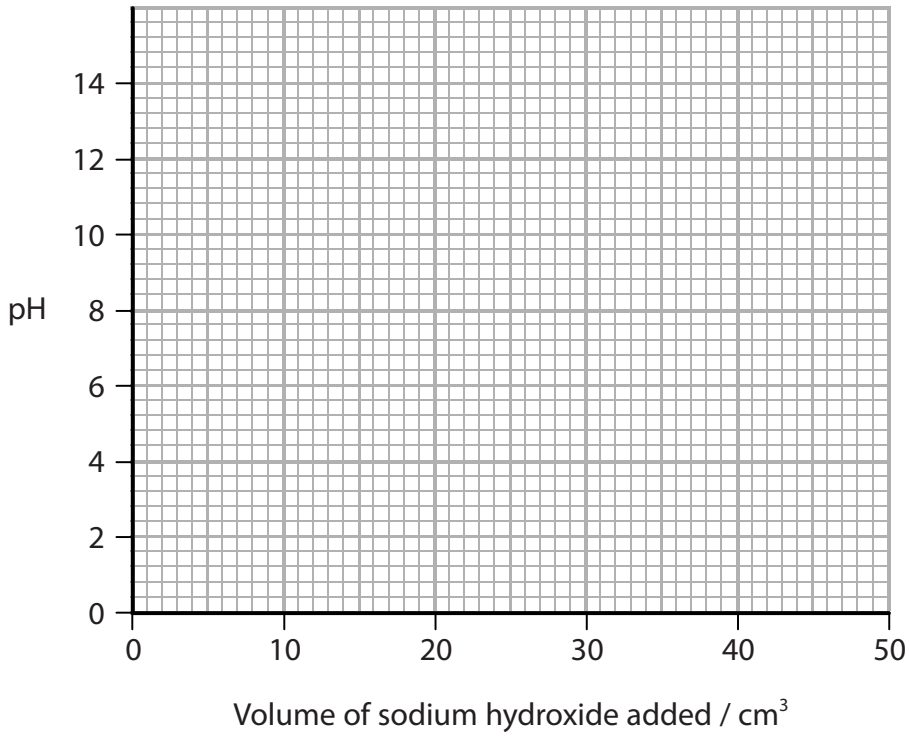
7 This question is about weak acids.

(a) A weak acid, HX, has a K_a value of 5.25×10^{-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)

(b) (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 (b)(i) to obtain the value of the acid dissociation constant, K_a, for propanoic acid.
You are **not** expected to calculate this value.

(2)

(Total for Question 7 = 11 marks)

9 This question is about buffer solutions.

(a) 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)

(b) Another 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 9 = 7 marks)

Question Number	Answer	Mark
8(a)	**The only correct answer is C** ***A*** *is not correct because this is for a 100-fold increase in concentration* ***B*** *is not correct because this is for no change in concentration* ***D*** *is not correct because this is for a 10000-fold decrease in concentration*	**(1)**

Question Number	Answer	Additional Guidance	Mark
8(b)	• calculation of $[H^+]$ **(1)** • expression relating K_a, $[H^+]$ and $[CH_2OHCOOH]$ **(1)** • calculation of $[CH_2OHCOOH]$ **(1)**	Example of calculation $[H^+] = 10^{-pH} = 0.01 / 1 \times 10^{-2} / 10^{-2}$ (mol dm^{-3}) $K_a = \frac{[H^+]^2}{[CH_2OHCOOH]}$ **or** $[CH_2OHCOOH] = \frac{[H^+]^2}{K_a}$ Allow [HA] in M2 and M3 $[CH_2OHCOOH] = \frac{0.01^2}{1.5 \times 10^{-4}}$ $= 0.667 / 0.67$ (mol dm^{-3}) Ignore SF except 1 SF Ignore units Correct answer with no working scores (3)	**(3)**

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

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

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

Question Number	Answer	Additional Guidance	Mark
8(d)(i)	An explanation that makes reference to the following points: • the O of the (extra) OH / hydroxyl group (in the 2 / alpha position / CH_2OH) withdraws / attracts electrons **(1)** • stabilises the anion / CH_2OHCOO^- ion **or** weakens O-H bond in acid so hydrogen **ion** / H^+ lost more easily **(1)**	Allow reference to intramolecular hydrogen bonding Allow hydrogen **ion** / H^+ more easily dissociates	**(2)**

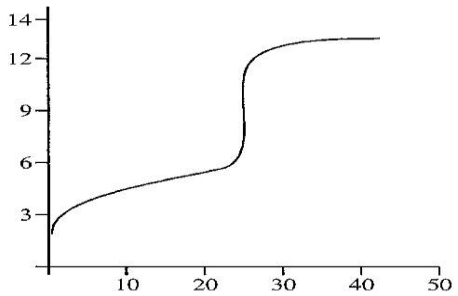
Question Number	Answer	Additional Guidance	Mark
8(d)(ii)	($CH_2OHCOOH + CH_3COOH \rightarrow$) • $CH_2OHCOO^- + CH_3COOH_2^+$	Both correct for the mark Allow formulae in either order Allow formulae in brackets with charge outside Allow displayed formulae Do not allow $CH_3C(OH)_2^+$	**(1)**

(Total for Question 8 = 12 marks)

Question number	Answer	Additional guidance	Marks
8(a)	A		**1**
8(b)(i)	An explanation that makes reference to the following points: • stage 2 is an equilibrium reaction / only partial ionisation occurs (1) • therefore fewer hydrogen ions are formed (1)	Accept dissociation for ionisation	**2**
8(b)(ii)	• rearrangement of equation pH = - log $[H^+]$ and substitution to give final answer (1)	Example calculation: $[H^+] = 10^{-pH}$ $10^{-0.97} = 0.107$ (mol dm^{-3}) Allow 0.11 (mol dm^{-3}) Correct answer with no working scores 1 mark	**1**
8(c)	• rearrangement of K_a expression (1) • calculation of $[CH_3COOH]$ and $[CH_3COO^-]$ (1) • substitution, and evaluation of $[H^+]$ in the buffer solution (1) • conversion of $[H^+]$ to pH for buffer solution (1)	Example of calculation : $[H^+] = K_a \frac{[CH_3COOH]}{[CH_3COO^-]}$ $[CH_3COOH] = 0.333$ mol dm^{-3} and $[CH_3COO^-] = 0.167$ mol dm^{-3} $[H^+] = 1.74 \times 10^{-5} \times 0.333 / 0.167$ $= 3.48 \times 10^{-5}$ (mol dm^{-3}) so pH = -lg $3.48 \times 10^{-5} = 4.46$ Accept answers that use forms of the Henderson-Hasselbach equation Correct answer with no working scores 4 marks	**4**

(Total for Question 8 = 8 marks)

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

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

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

(Total for Question 7 = 11 marks)

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

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

		Allow alternative methods, for example pH = pK_a – log $\frac{[acid]}{[salt]}$ pH = – log 1.74 x 10^{-5} – log $\frac{0.0389}{0.0444}$ pH = 4.817 / 4.82 / 4.8 scores M4 and M5 **or** pH = pK_a + log$\frac{[salt]}{[acid]}$ pH = −log1.74 x 10^{-5} + log $\frac{0.0444}{0.0389}$ pH = 4.817 / 4.82 / 4.8 scores M4 and M5	

(Total for Question 9 = 7 marks)