

- 1 **HA** and **HB** are two strong monobasic acids.  
25.0 cm<sup>3</sup> of 6.0 mol dm<sup>-3</sup> **HA** is mixed with 45.0 cm<sup>3</sup> of 3.0 mol dm<sup>-3</sup> **HB**.

What is the H<sup>+</sup>(aq) concentration, in mol dm<sup>-3</sup>, in the resulting solution?

**A** 1.9

**B** 2.1

**C** 4.1

**D** 4.5

Your answer

**[1]**

- 2 This question is about the properties and reactions of ethanoic acid,  $\text{CH}_3\text{COOH}$ . Ethanoic acid is a weak acid with an acid dissociation constant,  $K_a$ , of  $1.75 \times 10^{-5} \text{ mol dm}^{-3}$  at  $25^\circ\text{C}$ .

- (a) A student uses a pH meter to measure the pH of a solution of  $\text{CH}_3\text{COOH}$  at  $25^\circ\text{C}$ . The measured pH is 2.440.

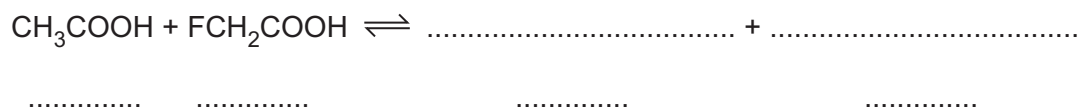
Calculate the concentration of ethanoic acid in the solution.

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

concentration = .....  $\text{mol dm}^{-3}$  [3]

- (b) Ethanoic acid is added to another weak acid, fluoroethanoic acid,  $\text{FCH}_2\text{COOH}$  ( $K_a = 2.19 \times 10^{-3} \text{ mol dm}^{-3}$ ). An equilibrium is set up containing two acid-base pairs.

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



[2]

- (c) The student plans to prepare a buffer solution that has a pH of 4.50. The buffer solution will contain ethanoic acid,  $\text{CH}_3\text{COOH}$ , and sodium ethanoate,  $\text{CH}_3\text{COONa}$ .

The student plans to add 9.08 g  $\text{CH}_3\text{COONa}$  to  $250\text{ cm}^3$  of  $0.800\text{ mol dm}^{-3}$   $\text{CH}_3\text{COOH}$ . The student assumes that the volume of the solution does not change.

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

Show **all** your working.

[5]

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

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

Explain your reasoning.

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..... [2]

- 3 A buffer solution is prepared by mixing  $200\text{ cm}^3$  of  $2.00\text{ mol dm}^{-3}$  propanoic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$ , with  $600\text{ cm}^3$  of  $1.00\text{ mol dm}^{-3}$  sodium propanoate,  $\text{CH}_3\text{CH}_2\text{COONa}$ .

$$K_a \text{ for } \text{CH}_3\text{CH}_2\text{COOH} = 1.32 \times 10^{-5} \text{ mol dm}^{-3}$$

What is the pH of the buffer solution?

**A** 4.58

**B** 4.70

**C** 5.06

**D** 5.18

Your answer

**[1]**

4 This question is about acids and bases found in the home.

(a) Ethanoic acid,  $\text{CH}_3\text{COOH}$ , is the acid present in vinegar.

A student carries out an experiment to determine the  $\text{p}K_{\text{a}}$  value of  $\text{CH}_3\text{COOH}$ .

- The concentration of  $\text{CH}_3\text{COOH}$  in the vinegar is  $0.870 \text{ mol dm}^{-3}$ .
- The pH of the vinegar is 2.41.

(i) Write the expression for the acid dissociation constant,  $K_{\text{a}}$ , of  $\text{CH}_3\text{COOH}$ .

[1]

(ii) Calculate the  $\text{p}K_{\text{a}}$  value of  $\text{CH}_3\text{COOH}$ .

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

$\text{p}K_{\text{a}} = \dots\dots\dots$  [3]

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

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

percentage dissociation =  $\dots\dots\dots$  % [1]

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

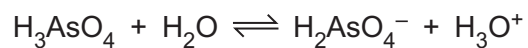
- A student dissolves 1.26 g of a drain cleaner in water and makes up the solution to  $100.0\text{ cm}^3$ .
- The student measures the pH of this solution as 13.48.

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

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

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

- 5 The equation shows the dissociation of the acid  $\text{H}_3\text{AsO}_4$  in water.



Which pair is a conjugate acid–base pair?

- A  $\text{H}_3\text{AsO}_4$  and  $\text{H}_2\text{O}$
- B  $\text{H}_2\text{AsO}_4^-$  and  $\text{H}_3\text{O}^+$
- C  $\text{H}_3\text{AsO}_4$  and  $\text{H}_3\text{O}^+$
- D  $\text{H}_3\text{O}^+$  and  $\text{H}_2\text{O}$

Your answer

[1]

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

**(a)\*** Carbonic acid,  $\text{H}_2\text{CO}_3$ , is a weak acid which, together with hydrogencarbonate ions,  $\text{HCO}_3^-$ , acts as a buffer to maintain the pH of blood.

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

Explain, in terms of equilibrium, how the carbonic acid–hydrogencarbonate mixture acts as a buffer in the control of blood pH, and calculate the  $[\text{HCO}_3^-] : [\text{H}_2\text{CO}_3]$  ratio in healthy blood.

[6]

[illegible]

Additional answer space if required

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- 7 This question is about weak acids.

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

| Weak acid                                                    | $K_a / \text{mol dm}^{-3}$ |
|--------------------------------------------------------------|----------------------------|
| iodic(V) acid, $\text{HIO}_3(\text{aq})$                     | $1.78 \times 10^{-1}$      |
| propanoic acid, $\text{C}_2\text{H}_5\text{COOH}(\text{aq})$ | $1.35 \times 10^{-5}$      |
| hydrocyanic acid, $\text{HCN}(\text{aq})$                    | $6.17 \times 10^{-10}$     |

**Table 20.1**

- (a) Calculate the pH of  $0.0800 \text{ mol dm}^{-3} \text{ C}_2\text{H}_5\text{COOH}(\text{aq})$ .

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

pH = ..... [2]

- (b) A student adds a total of  $45.0 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3} \text{ NaOH}(\text{aq})$  to  $25.0 \text{ cm}^3$  of  $0.0800 \text{ mol dm}^{-3} \text{ C}_2\text{H}_5\text{COOH}(\text{aq})$  and monitors the pH throughout.

- (i) Show by calculation that  $20.0 \text{ cm}^3$  of  $\text{NaOH}(\text{aq})$  is required to reach the end point.

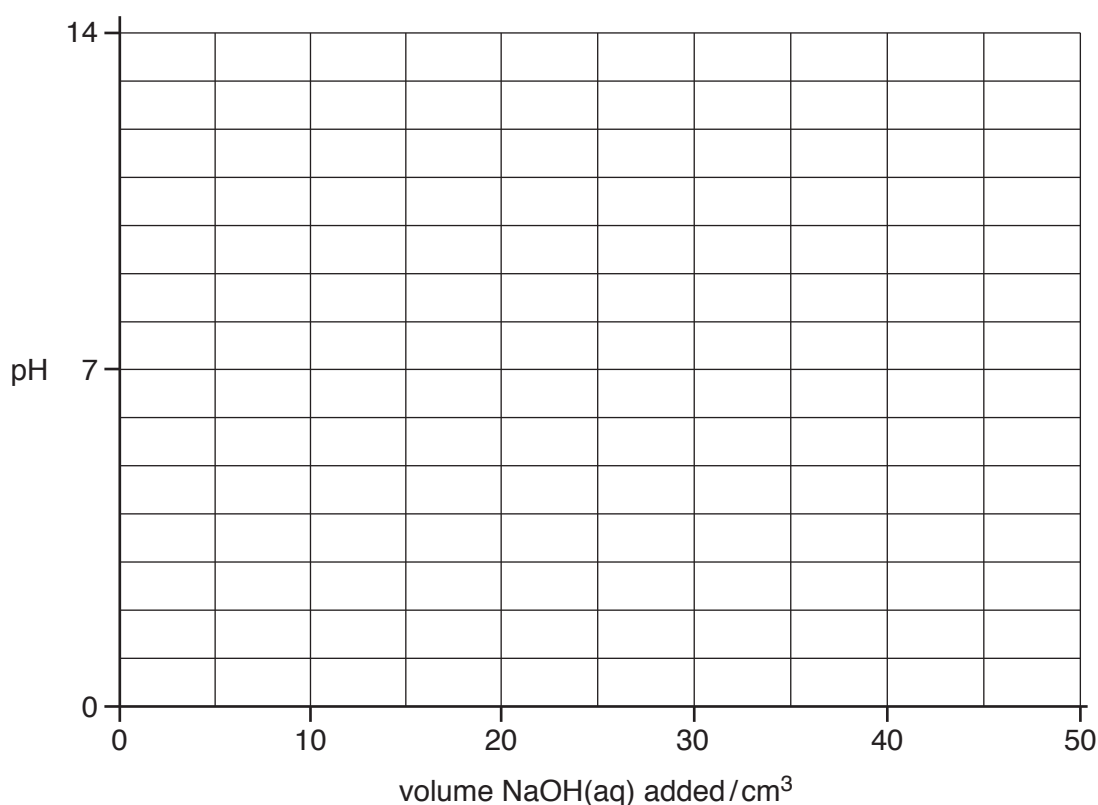
[1]

(ii) Calculate the pH of the final solution.

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

pH = ..... [4]

- (iii) On the axes below, sketch a pH curve for the pH changes during the addition of  $45.0 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3} \text{ NaOH(aq)}$  to  $25.0 \text{ cm}^3$  of  $0.0800 \text{ mol dm}^{-3} \text{ C}_2\text{H}_5\text{COOH(aq)}$ .



[3]

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

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

**Table 20.2**

Explain which indicator would be most suitable for the titration.

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..... [1]

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

Predict **one** similarity and **one** difference between the pH curve with  $\text{C}_2\text{H}_5\text{COOH}(\text{aq})$  and the pH curve with  $\text{HCN}(\text{aq})$ . Use the information in **Table 20.1**, and your answer to (b)(iii).

Similarity .....

.....

Difference .....

.....

**[2]**

- (c) The student calculates the pH of  $0.0800\text{ mol dm}^{-3}$   $\text{HIO}_3(\text{aq})$ . The student assumes that the equilibrium concentration of  $\text{HIO}_3(\text{aq})$  is the same as the initial concentration of  $\text{HIO}_3(\text{aq})$ .

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

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

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..... **[1]**

- 8     $20\text{ cm}^3$  of  $0.10\text{ mol dm}^{-3}$  hydrochloric acid is added to  $10\text{ cm}^3$  of  $0.10\text{ mol dm}^{-3}$  sodium hydroxide.

What is the pH of the resulting mixture?

**A**    1.00

**B**    1.18

**C**    1.30

**D**    1.48

Your answer

**[1]**

- 9(a) The  $K_a$  values of  $\text{HCOOH}$  and  $\text{CH}_3\text{COOH}$  are shown in **Table 18.1**.

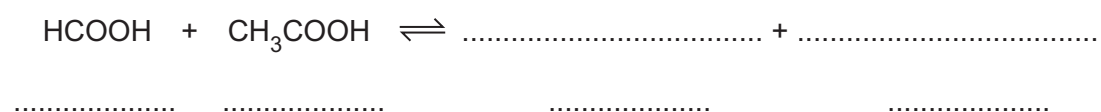
| Weak acid                | $K_a / \text{mol dm}^{-3}$ |
|--------------------------|----------------------------|
| $\text{HCOOH}$           | $1.82 \times 10^{-4}$      |
| $\text{CH}_3\text{COOH}$ | $1.78 \times 10^{-5}$      |

**Table 18.1**

A student adds methanoic acid to ethanoic acid.

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

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



[2]

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

(i) The student measures the pH of  $\text{CH}_3\text{COOH}(\text{aq})$  as 2.72.

Show that the concentration of the  $\text{CH}_3\text{COOH}(\text{aq})$  is  $0.204 \text{ mol dm}^{-3}$ .

[2]

(ii) The student plans to make a buffer solution of pH 4.00 from a mixture of  $\text{CH}_3\text{COOH}(\text{aq})$  and sodium ethanoate,  $\text{CH}_3\text{COONa}(\text{aq})$ .

The student mixes  $400 \text{ cm}^3$  of  $0.204 \text{ mol dm}^{-3}$   $\text{CH}_3\text{COOH}(\text{aq})$  with  $600 \text{ cm}^3$  of  $\text{CH}_3\text{COONa}(\text{aq})$ .

Calculate the concentration of  $\text{CH}_3\text{COONa}(\text{aq})$  needed to prepare this buffer solution of pH 4.00.

concentration = .....  $\text{mol dm}^{-3}$  [4]

- 10 An aqueous solution of ethanoic acid,  $\text{CH}_3\text{COOH}$ , has a concentration of  $0.50 \text{ mol dm}^{-3}$ .  
 $\text{p}K_{\text{a}}$  for  $\text{CH}_3\text{COOH} = 4.76$  at  $25^\circ\text{C}$ .

What is the pH of the ethanoic acid solution at  $25^\circ\text{C}$ ?

A 2.53

B 2.68

C 4.91

D 5.06

Your answer

[1]

**11** This question is about acids, bases and buffers.

**(a)** Sodium hydroxide, NaOH, is a strong base.

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

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

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

- (b)\* Nitrous acid,  $\text{HNO}_2$ , is a weak Brønsted–Lowry acid with a  $\text{p}K_{\text{a}}$  value of 3.34 at room temperature.

$\text{HNO}_2$  can be prepared by reacting  $\text{N}_2\text{O}_3$  with water.  
 $\text{HNO}_2$  is the only product.

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

- Step 1**      The chemist weighs a sample of  $\text{N}_2\text{O}_3$ .  
Water is then added to form  $100\text{ cm}^3$  of  $0.500\text{ mol dm}^{-3}$   $\text{HNO}_2(\text{aq})$ .
- Step 2**      The chemist adds  $100\text{ cm}^3$  of  $0.150\text{ mol dm}^{-3}$   $\text{NaOH}(\text{aq})$  to the  $100\text{ cm}^3$  solution  
of  $0.500\text{ mol dm}^{-3}$  solution of  $\text{HNO}_2(\text{aq})$ .  
The resulting solution is made up to  $1.00\text{ dm}^3$ .

Explain why a buffer solution forms in **Step 2**. Determine the pH of this buffer solution and the mass of  $\text{N}_2\text{O}_3$  that was used in **Step 1**.

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Additional answer space if required.

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- 12** The equilibrium equation for an indicator, HA, is shown below.



Colour:      Blue                                  Yellow

The indicator is added to a solution. The indicator turns a yellow colour.  
An excess of aqueous sodium hydroxide is then added.

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

- A** Colour changes from yellow to blue.
- B** Colour changes from yellow to green.
- C** Colour changes from yellow to green and then to blue.
- D** Colour stays yellow.

Your answer

**[1]**

- 13** Ammonia and water react to set up an acid–base equilibrium.

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

- A**  $\text{H}_2\text{O}$  and  $\text{OH}^-$   
**B**  $\text{OH}^-$  and  $\text{NH}_3$   
**C**  $\text{NH}_4^+$  and  $\text{H}_2\text{O}$   
**D**  $\text{NH}_4^+$  and  $\text{NH}_3$

Your answer

**[1]**

- 14(a)** Glycolic acid,  $\text{HOCH}_2\text{COOH}$ , ( $\text{p}K_{\text{a}} = 3.83$ ) is a weak monobasic acid used in some skincare products.

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

- (i) Explain why a buffer solution is formed.

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.....  
..... [1]

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

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

pH = ..... [4]

- (iii) A small amount of aqueous ammonia,  $\text{NH}_3(\text{aq})$ , is added to the buffer solution.

Explain, in terms of equilibrium, how the buffer solution would respond to the added  $\text{NH}_3(\text{aq})$ .

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..... [2]

**15** What is the percentage dissociation of a  $0.015 \text{ mol dm}^{-3}$  solution of methanoic acid,  $\text{HCOOH}$  ( $K_{\text{a}} = 1.60 \times 10^{-4} \text{ mol dm}^{-3}$ )?

**A** 0.016%

**B** 1.1%

**C** 1.82%

**D** 10.3%

Your answer

**[1]**

16 This question is about acids and bases.

(a) **Table 20.1** shows the ionic product,  $K_w$ , of water at 25 °C and 40 °C.

**Table 20.1**

| Temperature / °C | $K_w / \text{mol}^2 \text{dm}^{-6}$ |
|------------------|-------------------------------------|
| 25               | $1.00 \times 10^{-14}$              |
| 40               | $2.92 \times 10^{-14}$              |

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

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

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

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

Explain why this student is correct.

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.....  
..... **[1]**

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

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

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

Equation .....

Calculation

pH = ..... [5]

(c) Butanoic acid,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ , is a weak monobasic acid.

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

.....  
..... [1]

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

This buffer solution has a pH of 5.07 at  $25^\circ\text{C}$ .

Calculate the acid dissociation constant,  $K_a$ , of butanoic acid at  $25^\circ\text{C}$ .

Assume that the volume of the solution remains constant at  $250\text{ cm}^3$  when the potassium hydroxide is dissolved.

$K_a = \dots\dots\dots \text{mol dm}^{-3}$  [4]

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

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

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

.....  
.....

17 Which solution can be added to  $\text{CH}_3\text{COOH}(\text{aq})$  to make a buffer solution?

A  $\text{CH}_3\text{COONa}(\text{aq})$

B  $\text{HCOOH}(\text{aq})$

C  $\text{HCl}(\text{aq})$

D  $\text{NaCl}(\text{aq})$

Your answer

[1]

**18** This question is about acids and bases.

**(a)** Chloroethanoic acid,  $\text{ClCH}_2\text{COOH}$ , is a weak monobasic acid.

**(i)** Write the expression for the acid dissociation constant,  $K_a$ , of  $\text{ClCH}_2\text{COOH}$ .

**[1]**

**(ii)** The expression for the acid dissociation constant,  $K_a$ , of  $\text{ClCH}_2\text{COOH}$  can be simplified to:

$$K_a = \frac{[\text{H}^+]^2}{[\text{ClCH}_2\text{COOH}]}$$

**Expression 19.1**

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

.....  
 ..... **[1]**

**(iii)** A student carries out an experiment to determine the  $\text{p}K_a$  value of a solution of  $\text{ClCH}_2\text{COOH}$ .

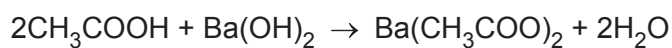
- The concentration of  $\text{ClCH}_2\text{COOH}$  is  $0.090 \text{ mol dm}^{-3}$ .
- The pH of  $\text{ClCH}_2\text{COOH}$  is 1.95.

Use **Expression 19.1** to calculate the  $\text{p}K_a$  value of  $\text{ClCH}_2\text{COOH}$ .

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

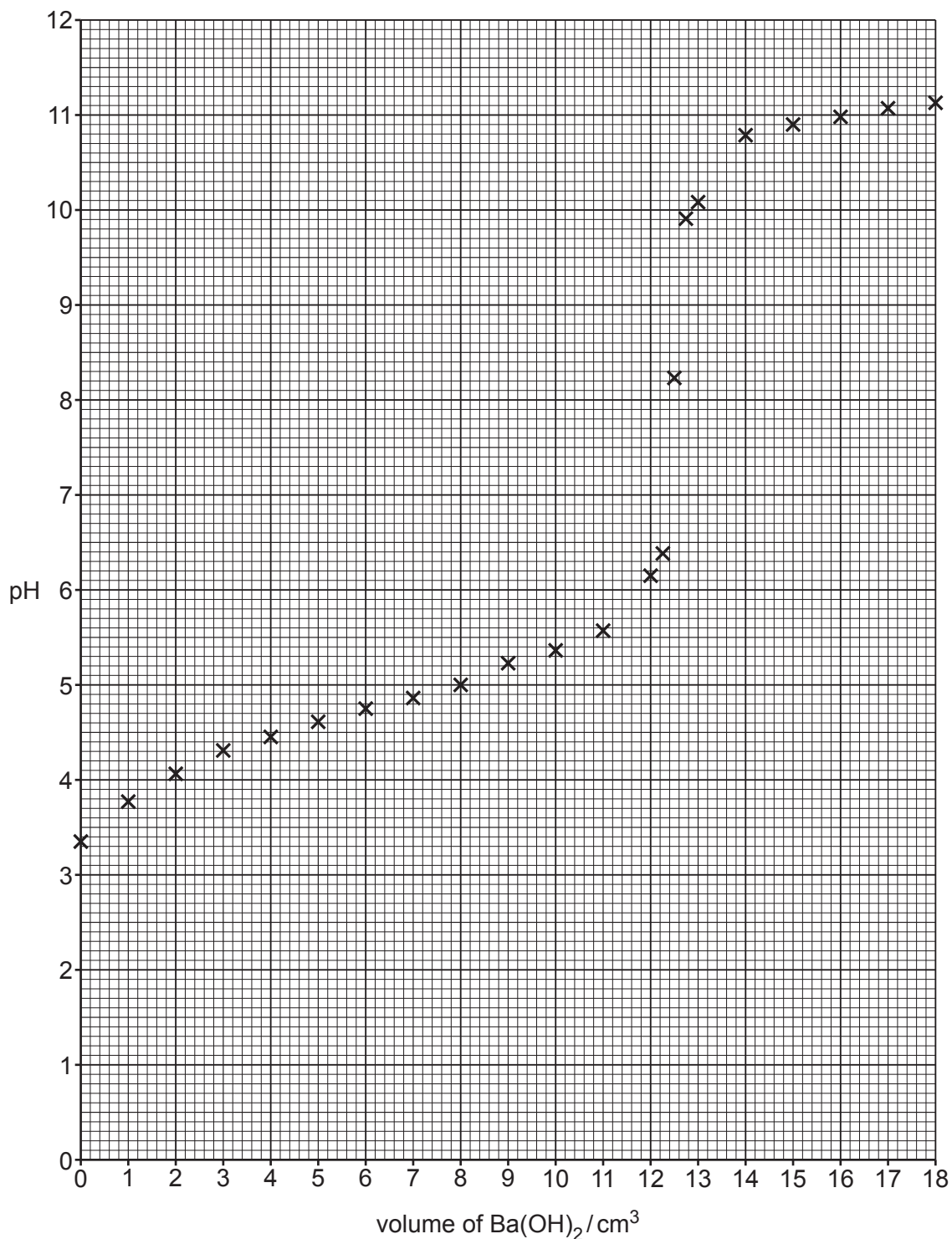
$\text{p}K_a = \dots\dots\dots$  **[3]**

- (b) A student titrates a  $10.0\text{ cm}^3$  sample of ethanoic acid,  $\text{CH}_3\text{COOH}$ , against an aqueous solution of  $0.0560\text{ mol dm}^{-3}$   $\text{Ba}(\text{OH})_2$ .



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

The student's results are shown below.



- (i) Draw a best-fit curve on the graph and calculate the concentration of the  $\text{CH}_3\text{COOH}$  solution.

$\text{CH}_3\text{COOH}$  concentration = .....  $\text{mol dm}^{-3}$  [5]

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

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

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

Identify the indicator in the table that would be suitable to observe the end point of the titration between  $\text{CH}_3\text{COOH}$  and  $\text{Ba}(\text{OH})_2$ .

..... [1]

- 19** A mixture of ethanoic acid and ethanol is left to reach equilibrium.

A student determines the amount of ethanoic acid remaining in the equilibrium mixture by titrating the mixture with a solution of sodium hydroxide.

Which row of the table shows a suitable indicator for the titration?

|          | pH range of the indicator |
|----------|---------------------------|
| <b>A</b> | 1.2 – 2.8                 |
| <b>B</b> | 4.8 – 6.0                 |
| <b>C</b> | 9.4 – 10.6                |
| <b>D</b> | 12.0 – 13.4               |

Your answer

**[1]**

**20** This question is about monobasic acids and buffer solutions.

**(a)** Nitric acid,  $\text{HNO}_3$ , is a strong monobasic acid.

Calculate the pH of  $0.150 \text{ mol dm}^{-3} \text{ HNO}_3$ .

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

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

Nitrous acid,  $\text{HNO}_2$ , is a weak monobasic acid.

Predict whether the pH of  $0.150 \text{ mol dm}^{-3} \text{ HNO}_2$  is higher, lower or the same as the pH of  $0.150 \text{ mol dm}^{-3}$  nitric acid,  $\text{HNO}_3$ .

Explain your answer.

Prediction .....

Explanation .....

.....

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..... **[2]**

(c)\* A student plans to prepare a buffer solution with a pH of 4.85 using propanoic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$ , and sodium propanoate,  $\text{CH}_3\text{CH}_2\text{COONa}$ .

$$K_a \text{ for } \text{CH}_3\text{CH}_2\text{COOH} = 1.32 \times 10^{-5} \text{ mol dm}^{-3}.$$

The student mixes  $125\text{ cm}^3$  of  $0.180\text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{COOH}(\text{aq})$  with a calculated mass of  $\text{CH}_3\text{CH}_2\text{COONa}(\text{s})$ . The student assumes that the volume of the solution does not change.

- Calculate the mass of  $\text{CH}_3\text{CH}_2\text{COONa}$  needed to make  $125\text{ cm}^3$  of a buffer solution with a pH of 4.85.
- Explain why this solution resists changes in pH when a small amount of alkali is added.

[6]

Additional answer space if required.

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