Buffers and pH titration curves

AQA 7405 · Full A-level

Show your working where needed. Check the worked answers when you finish.

Name _____ Date _____

1. An ethanoic acid buffer

An aqueous mixture contains ethanoic acid and sodium ethanoate. Explain how it resists a small pH change if strong acid is added. Then explain what happens if strong base is added to a fresh sample. Include ionic equations.

2. Find a buffer pH

A buffer contains 0.300 mol dm^{-3} HA and 0.150 mol dm^{-3} A^-. The pKa of HA is 4.75. Calculate the pH.

3. Ethanoic acid mixed with sodium hydroxide

Mix 40.0 cm^3 of 0.200 mol dm^{-3} ethanoic acid with 15.0 cm^3 of 0.200 mol dm^{-3} NaOH. For ethanoic acid, pKa = 4.76.

Calculate the pH of the mixture and explain why it can act as an acidic buffer.

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4. A small acid addition

A buffer initially contains 0.00800 mol HA and 0.0120 mol A^-. The pKa of HA is 3.75. Add 0.00100 mol H^+ from a strong acid.

Calculate the pH before and after the addition.

5. Find Ka from titration readings

A weak monoprotic acid is titrated with NaOH. The equivalence volume is 25.0 cm^3. The pH values are 4.30 at 6.25 cm^3, 4.78 at 12.5 cm^3 and 5.26 at 18.75 cm^3.

Select the reading that lets you obtain pKa directly and explain your choice. Calculate Ka.

6. A titration curve and an indicator

Volume of added alkali / cm^3: 0.0, 10.0, 20.0, 24.8, 25.0, 25.2, 30.0. Corresponding pH: 2.9, 4.6, 5.4, 6.9, 8.7, 10.6, 12.0.

Sketch the curve. Use it to choose an indicator from methyl orange (pH 3.1-4.4), methyl red (4.4-6.2) and phenolphthalein (8.3-10.0). Justify your choice.

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7. Compare two acid titrations

Separate samples of equally concentrated monoprotic acids are titrated with the same strong base at 298 K. Curve A has equivalence pH 7.00. Curve B starts at a higher pH and has equivalence pH 8.75.

Identify the curve for the weak acid and explain why its equivalence pH is above 7.00.

8. A buffer at a target pH

Prepare a buffer from 0.0240 mol ethanoic acid and anhydrous sodium ethanoate, M_r = 82.0. The acid has pKa = 4.76.

Calculate the mass of salt needed for pH 5.06. Calculate the new pH after adding 0.00150 mol OH^-.

9. Extra challenge · Prepare a buffer and test an addition

A flask contains 0.0120 mol ethanoic acid (pKa = 4.76). It is partly neutralised with 0.200 mol dm^{-3} NaOH to make a buffer of pH 4.36.

Calculate the volume of NaOH used. Then calculate the pH after adding 0.000600 mol HCl to the entire buffer.

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Worked answers

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1. An ethanoic acid buffer

Acid addition: $CH_3COO^- + H^+ \rightarrow CH_3COOH$. Removing added H^+ limits the fall in pH.

Base addition: $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$. Removing added OH^- limits the rise in pH. Both buffer components must remain present in appreciable amounts.

2. Find a buffer pH

Ka = 10 to the power −4.75 = 1.78×10^{-5} mol dm^{-3}. Rearranging $K_a = [H^+][A^-]/[HA]$ gives $[H^+] \approx K_a \times 0.300/0.150$.

Thus $[H^+] \approx 3.56 \times 10^{-5}$ mol dm^{-3} and pH ≈ 4.45. The pH is below pKa because there is more HA than A^-.

3. Ethanoic acid mixed with sodium hydroxide

OH^- converts 0.00300 mol from the initial 0.00800 mol of ethanoic acid into 0.00300 mol of ethanoate. Both ethanoate and the remaining 0.00500 mol acid are present.

The common volume cancels in $[A^-]/[HA]$. Therefore $pH \approx pK_a + \log_{10}(0.00300/0.00500) = 4.54$.

4. A small acid addition

Initially $pH = 3.75 + \log_{10}(0.0120/0.00800) \approx 3.93$.

Added H^+ converts 0.00100 mol A^- to HA, leaving 0.0110 mol A^- and 0.00900 mol HA. $pH \approx 3.75 + \log_{10}(0.0110/0.00900) = 3.84$.

5. Find Ka from titration readings

At half-equivalence, half of the initial acid has been converted to conjugate base. The amounts of HA and A^- are approximately equal, so $K_a \approx [H^+]$ and $pK_a \approx pH$.

$pK_a \approx 4.78$ and $K_a \approx 1.66 \times 10^{-5}$ mol dm^{-3}.

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Worked answers

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6. A titration curve and an indicator

Put volume on the horizontal axis and pH on the vertical axis. Sketch a gradual rise, a steep section around 25.0 cm^3 and a levelling off above pH 11.

Phenolphthalein has its colour-change range inside the steep section near equivalence. The colour change needs only a small added volume there.

7. Compare two acid titrations

B is the weak acid. At equivalence its conjugate base is present. It accepts protons from water, producing OH^-: $A^- + H_2O \rightleftharpoons HA + OH^-$.

The conjugate base of a strong acid has negligible basicity, so curve A has a neutral equivalence solution.

8. A buffer at a target pH

Target ratio = 10 to the power (5.06 − 4.76) = 1.995… . The sodium ethanoate supplies 0.0240 × 1.995… = 0.04789… mol, giving mass = 3.93 g.

OH^- consumes 0.00150 mol acid and forms 0.00150 mol ethanoate. The new pH ≈ 4.76 + $\log_{10}$(0.04939…/0.02250) = 5.10.

9. Extra challenge · Prepare a buffer and test an addition

At pH 4.36, the ethanoate/ethanoic acid ratio is 10 to the power (4.36 − 4.76), or 0.3981. For x mol NaOH, x/(0.0120 − x) = 0.3981, giving x = 0.003417 mol. The volume is 17.1 cm^3.

The added H^+ converts 0.000600 mol ethanoate to ethanoic acid. Amounts are now 0.002817 mol ethanoate and 0.009183 mol acid. The pH is approximately 4.76 + $\log_{10}$(0.002817/0.009183) = 4.25.

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