Buffers and pH titration curves

OCR A H432 · 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. Carbonic acid and hydrogencarbonate

Blood plasma contains a carbonic acid-hydrogencarbonate buffer. Write the equilibrium for the conjugate pair.

Explain how the buffer limits a pH decrease when an acid is added and a pH increase when a base is added. Give an ionic equation for each addition.

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 · Two buffers with the same starting pH

Two buffers use HA with pKa = 4.76. Buffer X contains 0.00400 mol HA and 0.00800 mol A^-. Buffer Y contains 0.0200 mol HA and 0.0400 mol A^-.

Calculate their initial pH and their pH after adding 0.00250 mol H^+ to each. Use the results to explain which buffer better resists the pH change.

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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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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. Carbonic acid and hydrogencarbonate

$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$. HCO_3^- uses up added acid: $HCO_3^- + H^+ \rightarrow H_2CO_3$.

H_2CO_3 uses up added hydroxide ions: $H_2CO_3 + OH^- \rightarrow HCO_3^- + H_2O$. Both reactions limit the change in $[H^+]$ and therefore in pH.

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 · Two buffers with the same starting pH

Both have an initial A^-/HA ratio of 2, so pH ≈ 4.76 + $\log_{10}(2)$ = 5.06.

Added H^+ converts A^- into HA. In X the ratio becomes 0.00550/0.00650 and pH ≈ 4.69. In Y it becomes 0.03750/0.02250 and pH ≈ 4.98.

Y loses a smaller fraction of its A^- to the same acid addition, so its concentration ratio changes less and the pH drop is smaller.

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