

Buffers, titration curves and indicators

AP Chemistry · Worksheet

Name: _____ Date: _____ Class: _____

These problems cover Unit 8 of AP Chemistry: buffers, the Henderson-Hasselbalch equation, buffer capacity, titration curves and indicators. They are also suitable for A Level and first-year university students.

Level 1 problems use the equation directly. Level 2 problems add mole tables for added acid or base and the pH of a solution at several points on a curve. The last five problems are level 3 and combine several steps or ask for derivations and explanations.

Level: AP Chemistry · **Curriculum:** AP Chem Unit 8

Problem 1 Equal amounts of acid and base (easy)

A buffer contains 0.25 mol/dm^3 CH_3COOH and 0.25 mol/dm^3 CH_3COONa ($\text{pK}_a = 4.74$). Calculate its pH.

Problem 2 Unequal buffer ratio (easy)

Chiamaka in Lagos prepares a buffer with 0.40 mol/dm^3 ethanoate and 0.20 mol/dm^3 ethanoic acid ($\text{pK}_a = 4.74$). Calculate its pH.

Problem 3 Spot the buffers (easy)

Decide which mixtures are buffers: (a) HCl and NaCl , (b) HF and NaF , (c) NH_3 and NH_4Cl , (d) NaCl and NaOH .

Problem 4 Choose a buffer pair (easy)

A lab needs a buffer at pH 9.2. The options are $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$ ($\text{pK}_a 4.74$) and $\text{NH}_4^+/\text{NH}_3$ ($\text{pK}_a 9.25$). Choose and justify.

Problem 5 Equivalence volume (easy)

Emma in Leeds titrates 25.0 cm^3 of 0.100 mol/dm^3 HCl with 0.0500 mol/dm^3 NaOH . Calculate the volume of NaOH needed to reach equivalence.

Problem 6 pK_a from half-equivalence (easy)

In the titration of a weak monoprotic acid, the pH is 4.76 when exactly half of the

equivalence volume has been added.

1. State pKa of the acid.
2. Calculate Ka.

Problem 7 Ammonia buffer (medium)

Diego in Texas mixes $0.30 \text{ mol/dm}^3 \text{ NH}_3$ with $0.20 \text{ mol/dm}^3 \text{ NH}_4\text{Cl}$. The pKa of NH_4^+ is 9.25. Calculate the pH.

Problem 8 Adding base to a buffer (medium)

A 100.0 cm^3 buffer contains $0.0200 \text{ mol CH}_3\text{COOH}$ and $0.0200 \text{ mol CH}_3\text{COO}^-$ (pKa 4.74). Then 5.0 cm^3 of $1.0 \text{ mol/dm}^3 \text{ NaOH}$ is added.

1. Calculate the amount of NaOH added.
2. Find the new amounts of HA and A^- .
3. Calculate the new pH.

Problem 9 Adding acid to a buffer (medium)

Wanjiru in Nairobi has 250 cm^3 of buffer containing 0.025 mol NH_3 and 0.025 mol NH_4^+ (pKa of $\text{NH}_4^+ = 9.25$). She adds 0.0050 mol HCl .

1. Write the equation for the reaction of the added acid.
2. Calculate the new amounts of NH_3 and NH_4^+ .
3. Calculate the new pH.

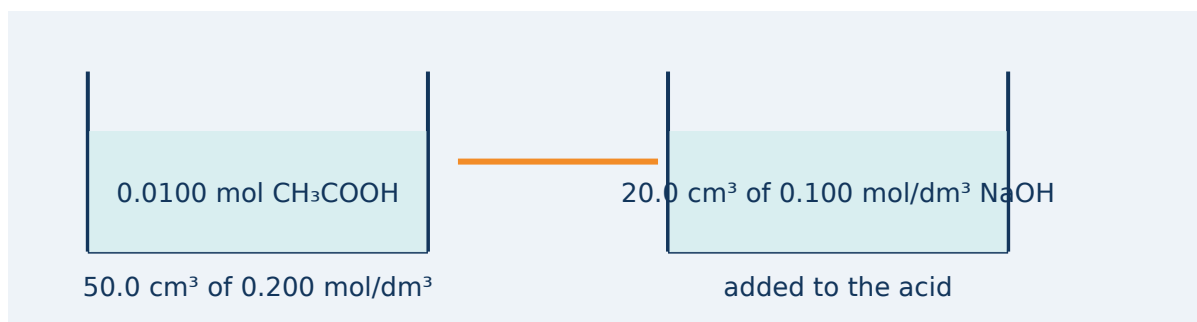
Problem 10 Making a buffer of given pH (medium)

Bilal in Lahore wants a buffer of pH 4.90. He has 0.200 mol of ethanoic acid (pKa 4.74) in solution. $M(\text{CH}_3\text{COONa}) = 82.0 \text{ g/mol}$.

1. Calculate the required ratio $[\text{A}^-]/[\text{HA}]$.
2. Calculate the amount of sodium ethanoate needed.
3. Calculate its mass.

Problem 11 Partial neutralisation (medium)

Mei in Singapore adds 20.0 cm^3 of $0.100 \text{ mol/dm}^3 \text{ NaOH}$ to 50.0 cm^3 of $0.200 \text{ mol/dm}^3 \text{ CH}_3\text{COOH}$.



The base is added to the acid before the pH is measured.

1. Calculate the amount of acid and of hydroxide.
2. Find the amounts of HA and A⁻ after reaction.
3. Calculate the pH (pK_a 4.74).

Problem 12 Before equivalence, strong acid (medium)

In a titration 20.0 cm³ of 0.100 mol/dm³ NaOH has been added to 25.0 cm³ of 0.100 mol/dm³ HCl. Calculate the pH.

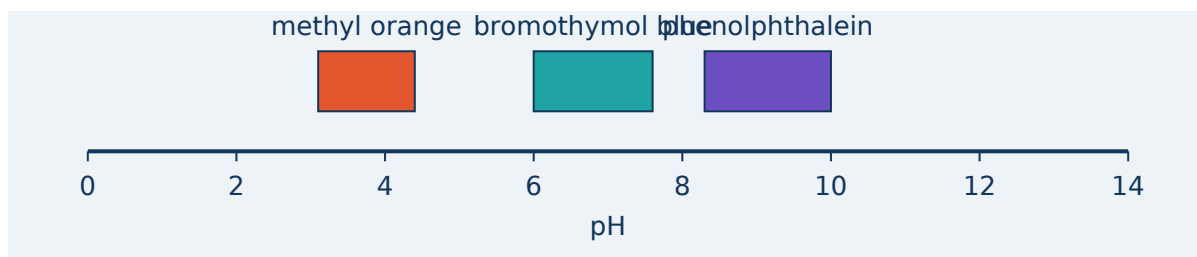
Problem 13 Equivalence of ethanoic acid (medium)

Calculate the pH at equivalence when 25.0 cm³ of 0.100 mol/dm³ CH₃COOH is titrated with 0.100 mol/dm³ NaOH (K_a = 1.8 × 10⁻⁵).

1. Find [CH₃COO⁻] at equivalence.
2. Calculate K_b.
3. Calculate the pH.

Problem 14 Choose the indicator (medium)

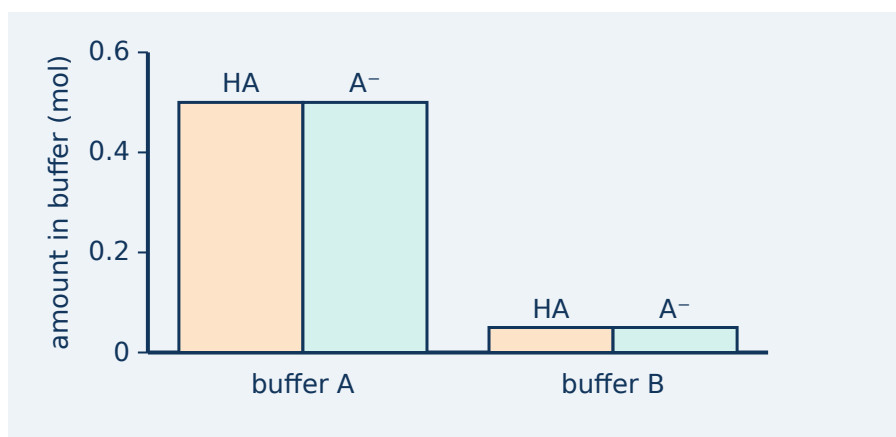
Indicator ranges: methyl orange 3.1–4.4, bromothymol blue 6.0–7.6, phenolphthalein 8.3–10.0. Choose an indicator for (a) HCl with NaOH, (b) CH₃COOH with NaOH.



Colour-change ranges of three indicators.

Problem 15 Comparing capacity (medium)

Two 1.00 dm³ buffers use CH₃COOH/CH₃COO⁻ (pK_a 4.74). Buffer A has 0.50 mol of each; buffer B has 0.050 mol of each. Kofi adds 0.020 mol HCl to each.



Composition of the two buffers.

1. Calculate the new pH of A.
2. Calculate the new pH of B.
3. Explain which has the greater capacity.

Problem 16 Complete titration of methanoic acid (hard)

Aarav in Pune titrates 25.0 cm³ of 0.100 mol/dm³ HCOOH ($K_a = 1.8 \times 10^{-4}$) with 0.100 mol/dm³ NaOH. Calculate the pH after adding (a) 0 cm³, (b) 12.5 cm³, (c) 25.0 cm³, (d) 30.0 cm³.

Problem 17 Derive the buffer equation (hard)

Starting from $K_a = [\text{H}_3\text{O}^+][\text{A}^-]/[\text{HA}]$, derive the Henderson-Hasselbalch equation and calculate pH when $[\text{A}^-]/[\text{HA}] = 0.10$ for an acid with $\text{p}K_a$ 4.74.

Problem 18 Buffer from ammonia and HCl (hard)

Mei in Singapore needs a buffer of pH 9.00. She has 100.0 cm³ of 0.50 mol/dm³ NH₃ and 0.50 mol/dm³ HCl ($\text{p}K_a$ of NH₄⁺ = 9.25).

1. Calculate the required ratio $n(\text{NH}_3)/n(\text{NH}_4^+)$.
2. Calculate the amount of HCl to add.
3. Calculate its volume.

Problem 19 Unknown weak acid (hard)

Diego in Texas titrates 25.0 cm³ of a monoprotic weak acid with 0.100 mol/dm³ NaOH. Equivalence is reached at 31.5 cm³, and the pH after adding 15.75 cm³ is 4.20.

1. Calculate the concentration of the acid.
2. State $\text{p}K_a$ and calculate K_a .
3. Explain how you know $\text{pH} = \text{p}K_a$ at 15.75 cm³.

Problem 20 Capacity limit (hard)

A 1.00 dm³ buffer contains 0.30 mol CH₃COOH and 0.30 mol CH₃COO⁻ ($\text{p}K_a$ 4.74). Wanjiru

will accept a drop of at most 0.10 pH unit.

1. Write the condition on the new ratio $[A^-]/[HA]$.
2. Calculate the maximum amount of HCl that can be added.
3. Calculate the volume of 1.0 mol/dm^3 HCl this represents.