Buffers & Titration Curves

Buffer action, Henderson-Hasselbalch, effective range, the four titration regions, and indicators.

01 What makes a buffer — CORE RULE

A buffer needs appreciable amounts of BOTH a weak acid and its conjugate base (or a weak base and its conjugate acid), with a non-hydrolyzing spectator counter-ion. Strong-acid- or strong-base-only solutions cannot buffer.

02 How it resists — CORE RULE

Added base is neutralized by the weak acid: $HA + OH^- \rightarrow A^- + H_2O$. Added acid by the conjugate base: $A^- + H_3O^+ \rightarrow HA + H_2O$. Each added strong species becomes a weak conjugate-pair member.

03 Henderson-Hasselbalch — CORE RULE

pH = pKa + log([A^-]/[HA]). Basic buffer: pOH = pKb + log([BH^+]/[B]), pH = 14 − pOH. Volume cancels in the ratio, so moles can be used directly.

04 Polyprotic buffer pKa — CORE RULE

Use the pKa of the step whose two species ARE the buffer pair. $H_3PO_4/H_2PO_4^-$ → pKa1 (2.12); $H_2PO_4^-/HPO_4^{2-}$ → pKa2 (7.21); HPO_4^{2-}/PO_4^{3-} → pKa3 (12.32).

05 Ratio for a target pH — CORE RULE

Inverse H-H: [A^-]/[HA] = 10^(pH − pKa). Used for buffer prep and post-perturbation pH. Give the ratio in the direction the problem asks; the reciprocal is a different quantity.

06 Effective range & capacity — CORE RULE

A buffer works over pKa ± 1 (ratio 0.1 to 10). For a target pH, pick a weak acid with pKa ≈ pH. Capacity scales with absolute concentrations: 1.0 M/1.0 M holds ~10× more than 0.1 M/0.1 M at the same pH.

07 Four titration regions — METHOD

(1) Initial: analyte alone. (2) Buffer region (weak analyte only): both analyte + formed conjugate, use H-H. (3) Equivalence: only the salt (strong-strong pH 7; weak acid + strong base pH > 7; weak base + strong acid pH < 7). (4) Post-equivalence: excess titrant.

08 Half-equivalence = pKa — CORE RULE

At V = V_equiv/2, half the weak acid is neutralized so [HA] = [A^-] and pH = pKa. (Weak base + strong acid: pOH = pKb there.) Read pKa straight off the curve.

09 Curve features — CORE RULE

Equivalence point = the volume where pH rises most steeply; half-equivalence = half that volume; the buffer region is the slow-changing pre-equivalence span. A weak-acid curve starts higher and has a smaller equivalence jump than strong-strong.

10 Indicator selection — CORE RULE

An indicator changes colour over pKa(ind) ± 1. Pick one with pKa ≈ equivalence pH. Weak acid + strong base (equiv > 7): phenolphthalein (9.4). Weak base + strong acid (equiv < 7): methyl red (5.1).