Year 13 Science: Titration curves and indicators

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. 25.0 mL of 0.120 mol L^{-1} CH_3COOH is titrated with 0.150 mol L^{-1} NaOH. What volume of NaOH reaches equivalence?

2. What is the pH at the half-equivalence point when NH_3 is titrated with HCl? $pKa(NH_4^+) = 9.24$.

3. Which indicator suits NH_3 titrated with HCl: methyl red or phenolphthalein?

4. What is the pH at the equivalence point when HCl is titrated with NaOH?

5. Name the two carbon-containing species in the buffer region of CH_3COOH titrated with NaOH.

6. 20.0 mL of 0.0850 mol L^{-1} methanoic acid, HCOOH, is titrated with 0.100 mol L^{-1} NaOH. $Ka(HCOOH) = 1.78 \times 10^{-4}$, pKa = 3.75. Calculate the volume of NaOH needed to reach equivalence.

7. Calculate the pH before any NaOH is added.

8. State the pH after 8.50 mL of NaOH has been added, and explain why.

9. Calculate the pH at the equivalence point.

10. Choose phenolphthalein or methyl orange for this titration, and justify your choice.

11. Calculate the pH after 20.0 mL of NaOH has been added.

Fix the mistake

12. Correct this statement: "The pH at the equivalence point is always 7."

13. Correct this statement: "At the half-equivalence point, pH = ½ pKa."

14. Correct this statement: "At equivalence, $[CH_3COO^-] = 0.100$ mol L^{-1}, the same as the acid."

15. Correct this statement: "Choose an indicator whose pKa equals the pKa of the acid."

Answer key (for parents and tutors)

1. 25.0 mL of 0.120 mol L^{-1} CH_3COOH is titrated with 0.150 mol L^{-1} NaOH. What volume of NaOH reaches equivalence?
   $n = 0.120 \times 0.0250 = 3.00 \times 10^{-3}$ mol; $V = 3.00 \times 10^{-3} \div 0.150 = 0.0200$ L = 20.0 mL.
2. What is the pH at the half-equivalence point when NH_3 is titrated with HCl? pKa(NH_4^+) = 9.24.
   pH = pKa = 9.24.
3. Which indicator suits NH_3 titrated with HCl: methyl red or phenolphthalein?
   Methyl red: the equivalence point is about pH 5.3, inside its range of 4.4 to 6.2.
4. What is the pH at the equivalence point when HCl is titrated with NaOH?
   pH 7.00: NaCl does not react with water.
5. Name the two carbon-containing species in the buffer region of CH_3COOH titrated with NaOH.
   CH_3COOH and CH_3COO^-.
6. 20.0 mL of 0.0850 mol L^{-1} methanoic acid, HCOOH, is titrated with 0.100 mol L^{-1} NaOH. Ka(HCOOH) = 1.78×10^{-4}, pKa = 3.75. Calculate the volume of NaOH needed to reach equivalence.
   $n(HCOOH) = 0.0850 \times 0.0200 = 1.70 \times 10^{-3}$ mol, so $V = 1.70 \times 10^{-3} \div 0.100 = 17.0$ mL (Achieved).
7. Calculate the pH before any NaOH is added.
   $[H_3O^+] = \sqrt{(1.78 \times 10^{-4} \times 0.0850)} = 3.89 \times 10^{-3}$ mol L^{-1}, so pH = 2.41 (Merit).
8. State the pH after 8.50 mL of NaOH has been added, and explain why.
   pH = 3.75: 8.50 mL is half of 17.0 mL, so half the HCOOH has become $HCOO^-$; [HCOOH] = $[HCOO^-]$, so $[H_3O^+]$ = Ka and pH = pKa (Merit).
9. Calculate the pH at the equivalence point.
   $[HCOO^-] = 1.70 \times 10^{-3} \div 0.0370 = 0.0459$ mol L^{-1}; $[H_3O^+] = \sqrt{(1.78 \times 10^{-4} \times 1.0 \times 10^{-14} \div 0.0459)} = 6.23 \times 10^{-9}$ mol L^{-1}, so pH = 8.21 (Excellence).
10. Choose phenolphthalein or methyl orange for this titration, and justify your choice.
    Phenolphthalein: $HCOO^-$ is a weak base, so the equivalence point is above 7 (8.21). The steep section runs from about pH 6.3 one drop (0.05 mL) before equivalence to about 10.1 one drop after, and phenolphthalein's range, 8.3 to 10.0, lies inside it, so although 8.3 is just above 8.21, the first lasting pink appears within one drop of equivalence. Methyl orange, 3.1 to 4.4, would change in the buffer region around pH 3.75, long before equivalence (Excellence).
11. Calculate the pH after 20.0 mL of NaOH has been added.
    Excess OH^- = $0.100 \times 0.0030 = 3.0 \times 10^{-4}$ mol in 40.0 mL, so $[OH^-] = 7.5 \times 10^{-3}$ mol L^{-1}, $[H_3O^+] = 1.33 \times 10^{-12}$ mol L^{-1} and pH = 11.88 (Merit).
12. Correct this statement: "The pH at the equivalence point is always 7."
    Only for strong with strong; a weak acid gives a basic salt (pH above 7) and a weak base an acidic salt (pH below 7).
13. Correct this statement: "At the half-equivalence point, pH = ½ pKa."
    At half-equivalence [HA] = $[A^-]$, so $[H_3O^+]$ = Ka and pH = pKa.
14. Correct this statement: "At equivalence, $[CH_3COO^-]$ = 0.100 mol L^{-1}, the same as the acid."
    The volume has doubled to 40.0 mL, so $[CH_3COO^-] = 0.0500$ mol L^{-1}; always use the total volume.
15. Correct this statement: "Choose an indicator whose pKa equals the pKa of the acid."
    Choose one whose range lies in the steep section around the equivalence point, not near the acid's pKa, which is in the buffer region.