Determining pH at the equivalence point of an acid-base titration.

Acid-base titrations are used to determine the acidity or alkalinity of water samples. These determinations can be used to evaluate the health of the water in the lakes and rivers and thus to identify the effects of pollution and acid rain.
A titration is a sequential addition of a reactant to a solution containing the other reactants. In a acid-base titration a basic solution of known concentration is added to an acidic solution of known concentration or vice versa. The basic solution is added until the complete neutralization of the acid takes place.
The titration is complete when all of the acid originally present has reacted. The volume of the basic solution added from a buret, will determine the concentration of the unknown acid. The concentration of one of the solution must be known.
The solution of known concentration is called the **titrant**.
The **equivalence point** of a titration is when the moles of base added equals the moles of acid originally present in solution. The equivalence point of a titration is determined using a **pH meter** or an **indicator**. An indicator is a compound that changes colour depending upon the pH of the solution. Acid-base indicators are weak acids or weak bases:

$$HI_{n\,(aq)} \rightleftharpoons H^{+1}_{(aq)} + I_n^{-1}{}_{(aq)}$$

Acidic form	Basic form
(colour 1)	(colour 2)

Indicators usually change colour over a pH range of between 1 and 2 pH units, with an end-point somewhere in the middle, the mid-point of the pH. The **end-point** is the point where the indicator is most clearly seen to be between the two extremes of its colour.

At the midpoint: $[HI_n] = [I_n^{-1}]$, then $pH = pK_{HIn}$

The eye does not detect this midpoint when $[HI_n] = [I_n^{-1}]$, but instead detects the first permanent colour change. This may occur when one form has 10 times the concentration of the other form, i.e. the eye detects the colour change over a range of about one pH unit on either side of the midpoint. Thus, the range of an indicator is given by: $pH = pK_{HIn} \pm 1$
For example, bromothymol blue is yellow in acidic solution and blue in alkaline solution. The colour change takes place from pH 6.0 to pH 7.6 and the end-point occurs when the pH is 7.0.

The equivalence point of a titration may also be determined by means of **thermometric** measurements.

Steps to Solving for pH at the equivalence point of an acid-base reaction.
1. Calculate the moles of acid, the moles of base reacted, and therefore use stoichiometric ratios to determine the moles of the strong conjugate ion formed. Determine if the conjugate ion is an acid or a base (of the parent), .: determine if hydrolysis by the conjugate ion will form a basic or an acidic reaction, i.e. will it be a K_a or a K_b problem. (Be careful in choosing whether you will use K_a or a K_b to determine the pH. Make this decision based on whether the dominant species in solution is acidic or basic, respectively.)
2. Calculate the concentration of the conjugate ion, from the moles and the total volume of the solution.
3. Write a balanced equation for the hydrolysis of the conjugate ion, and prepare an ICE chart, using the concentration of the conjugate ion to determine the value of 'x', i.e. the $[OH^{-1}]$ or the $[H_3O^{+1}]$, and hence the pH of the resulting solution.

Problems

1. In a titration of 10.0 mL of 0.30 M HNO_3 with 0.50 M NaOH, the following volume of titrant has been added. Calculate the pH of the solution when the following have been added:

a. 0.00 mL of NaOH **(Answer: pH = 0.52)**
b. 3.00 mL of NaOH **(Answer: pH = 0.94)**
c. 5.90 mL of NaOH **(Answer: pH = 2.50)**
d. 6.00 mL of NaOH **(Answer: pH = 7.00)**
e. 7.00 mL of NaOH **(Answer: pH = 2.47)**

2. 25.0 mL of standardized 0.45 mol/L NaOH is titrated with 21.0 mL of 0.35 mol/L acetic acid. Calculate the pH of the solution. **(Answer: pH = 12.93)**

3. 28.0 mL of standardized 0.43 mol/L NaOH is titrated with 23.0 mL of 0.36 mol/L acetic acid. Calculate the pH of the solution. **(Answer: pH = 12.87)**

4. 28.0 mL of 0.36 mol/L acetic acid is titrated with a standardized 0.43 mol/L KOH solution. Calculate the pH of the solution after 21.0 mL of the KOH solution has been added. (Ka of acetic acid is 1.8×10^{-5}) **(Answer: pH = 3.21)**

5. 24.0 mL of 0.39 mol/L acetic acid, CH_3COOH, is titrated with a standardized 0.33 mol/L KOH solution. Calculate the pH of the solution after 17.0 mL of the KOH solution has been added. (Ka of acetic acid is 1.8×10^{-5}). **(Answer: pH = 2.89)**

6. In a thermometric titration, 100.0 cm^3 of 2.00 mol dm^{-3} HCl, initially at a temperature of 19.5 ^{O}C is neutralized by 100.0 cm^3 of 2.00 mol dm^{-3} NaOH also at a temperature of 19.5 ^{O}C. The temperature at the equivalence point of the final mixture was determined to be 33.0 ^{O}C. Calculate the enthalpy change of neutralization. **(Answer: ? H_n = –56.7kJ mol^{-1})**

7. A student mixes 100 cm^3 of 0.100 mol dm^{-3} $HCl_{(aq)}$ with exactly 50.0 cm^3 of 0.200 mol dm^{-3} of $NH_{3(aq)}$. What is the pH of the resulting solution? (Ka of NH_4^{+1} is 5.6×10^{-10})
(Answer: pH = 5.21)

8. Aniline, $C_6H_5NH_2$, is a weak organic base. If you mix exactly 50.0 cm^3 of 0.20 mol dm^{-3} $HCl_{(aq)}$ with 0.93 g of aniline, what is the pH of the resulting solution? (Ka of $C_6H_5NH_3^{+1}$ is 2.4×10^{-5}) **(Answer: pH = 2.66)**

9. A student mixes 50.0 cm^3 of 0.100 mol dm^{-3} $NaOH_{(aq)}$ with exactly 50.0 cm^3 of 0.100 mol dm^{-3} of formic acid, $HCOOH_{(aq)}$. What is the pH of the resulting solution? (K_b of formate ion, $HCOO^{-1}$ is 5.6×10^{-11}) **(Answer: pH = 8.23)**

10. Calculate the pH at equivalence point in the titration of 100.0 cm^3 of 0.100 mol dm^{-3} NH_3 with 0.100 mol dm^{-3} HCl. **(Answer: pH = 5.78)**

11. a. What volume of 0.100 mol dm^{-3} $NaOH_{(aq)}$ is required to react completely with 0.976 g of weak monoprotic acid, benzoic acid, C_6H_5COOH ? **(Answer: volume = 8.00)**

b. What is the pH of the resulting solution after reaction? **(Answer: pH = 8.60)**
(K_b of benzoate ion, $C_6H_5COO^{-1}$ is 1.6×10^{-10})