Equivalence point and endpoint

Before we visit equivalence point it pays to refresh ourselves with the strength of acid base conjugate. Click here for more information

Strong acids have weak conjugate bases whilst weak acids have strong conjugate bases. Strong bases have weak conjugate acids and weak bases have strong conjugate acid. Diagrams 1 and 2 below summarise these points in an acid base reaction between ethanoic acid and water nitric acid and hydroxide ions.

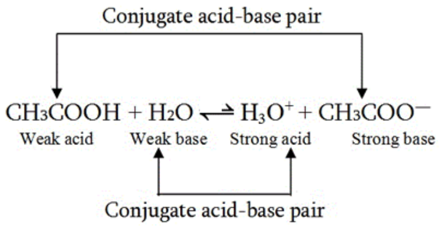


Diagram 1 – acid base reaction between a weak acid and a weak base, such as water

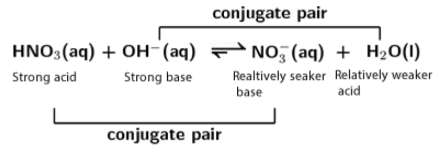


Diagram 2 – acid base reaction between a strong acid and a strong base

The equivalence point in a titration is not always at pH 7 because it depends on the nature of the acid and base involved. The equivalence point is the point at which the amount of titrant added is stoichiometrically equivalent to the amount of substance being titrated. The pH at this point varies depending on the strength of the acid and base:

1. **Strong Acid vs. Strong Base**: In a titration between a strong acid (e.g. HCl) and a strong base (e.g., NaOH), the equivalence point typically occurs at pH 7. This is because the reaction produces water and a neutral salt (e.g. NaCl), and the resulting solution is neutral.

2. **Weak Acid vs. Strong Base**: In a titration between a weak acid (e.g. acetic acid) and a strong base (e.g. NaOH), the equivalence point occurs at a pH greater than 7. This is because the conjugate base of the weak acid (e.g. acetate ion) is formed, which hydrolyzes in water to produce hydroxide ions, making the solution slightly basic.

$$CH_3COO^-(aq) + H_2O(l) \rightarrow OH^-(aq) + CH_3COOH(aq)$$

3. **Strong Acid vs. Weak Base**: In a titration between a strong acid (e.g. HCl) and a weak base (e.g. ammonia), the equivalence point occurs at a pH less than 7. This is because the conjugate acid of the weak base (e.g. ammonium ion) is formed, which hydrolyzes in water to produce hydronium ions, making the solution slightly acidic.

$$HCl(aq) + NH_3(aq) \rightarrow Cl^-(aq) + NH_4^+(aq)$$

4. **Weak Acid vs. Weak Base**: The pH at the equivalence point can vary significantly and is usually not at pH 7. The exact pH depends on the relative strengths of the weak acid and weak base.

Thus, the pH at the equivalence point is determined by the relative strengths of the acid and base involved in the titration.

Using the information in table 1 answer the following questions.

Neutral salts	Strong acid	Weak acid	Strong base	Weak base
$NaNO_3$	HNO_3	H_2CO_3	NaOH	NH_3
NaCl	H_2SO_4	CH_3COOH	$Ca(OH)_2$	Na_2CO_3
KNO_3	HCl	H_3PO_4	LiOH	HCO_3^-

Table 1

1. **Explain why the pH at the equivalence point is not always 7. Provide examples using the following titrations. HNO_3 titrated with NaOH and H_2CO_3 and NaOH.**
   The equivalence point reflects the stoichiometric balance between the acid and base, but the resulting pH is influenced by the strengths of the conjugate acids and bases formed during the reaction.
   Examples:
   HNO_3 titrated with NaOH (Strong Acid vs. Strong Base):
   Reaction: *$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$*
   Equivalence Point: *The pH at the equivalence point in this titration is 7. Both HNO_3 (a strong acid) and NaOH (a strong base) fully dissociate in water. At the equivalence point, the strong acid is completely neutralized by the strong base, forming a neutral salt ($NaNO_3$) and water. Since neither the salt nor the water affects the pH, the solution remains neutral at pH 7.*
   H_2CO_3 titrated with NaOH (Weak Acid vs. Strong Base):
   Reaction: *$H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 + 2H_2O$*
   Equivalence Point: *The pH at the equivalence point in this titration is greater than 7. H_2CO_3 is a weak acid that only partially dissociates in water, while NaOH is a strong base that fully dissociates. At the equivalence point, the weak acid is neutralized by the strong base, forming a salt (Na_2CO_3) and water. The conjugate base (CO_3^{2-}) of H_2CO_3 is relatively weak and it hydrolyzes in water to produce hydroxide ions (OH^-), making the solution basic. Therefore, the pH at the equivalence point is higher than 7, typically in the range of 8-10.*
2. **In a titration of a weak acid (H_2CO_3) with a strong base (NaOH), what is the expected pH range at the equivalence point? Explain your reasoning.**
   *Because CO_3^{2-} generates OH^- ions, the solution at the equivalence point will have a pH greater than 7. The exact pH depends on the concentration of the carbonate ions and how strongly they interact with water, but it typically falls in the range of **8 to 10**. A pH that is representative of a weak base is accepted.*

   Reaction at Equivalence Point:
   The strong base (NaOH) completely neutralizes the weak acid (H_2CO_3) to form water (H_2O) and the conjugate base, the carbonate ion (CO_3^{2-}):
   $H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 + 2H_2O$
   Presence of the Conjugate Base (CO_3^{2-}):
   At the equivalence point, all the H_2CO_3 has been converted to CO_3^{2-}, the conjugate base of the weak acid. The carbonate ion (CO_3^{2-}) is a weak base and reacts with

water to produce hydroxide ions (OH^-):

$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$

This reaction increases the concentration of hydroxide ions in the solution, making the solution basic.

3. **Describe how an indicator is selected for a titration provide an example**

   An indicator is selected based on its pH range of colour change. The indicator's pH range should encompass the pH at the equivalence point to ensure that the endpoint (indicated by the colour change) occurs as close as possible to the equivalence point. This is essential for accurate titration results, as it ensures that the titration is stopped at the point where the stoichiometric amounts of acid and base are present.

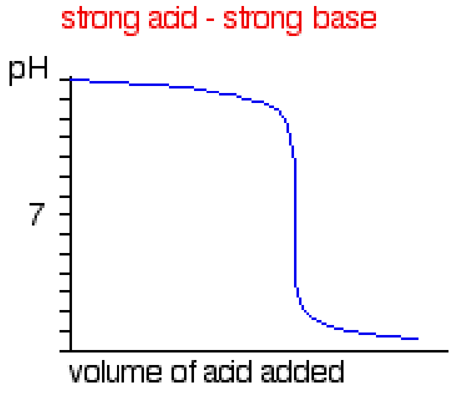
4. **During a titration, the endpoint is observed at pH 8.3. What does this indicate about the strength of the acid and base involved?**

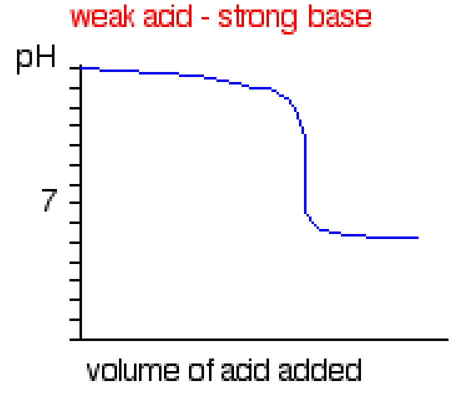
   An endpoint at pH 8.3 suggests that a weak acid is being titrated with a strong base. The weak acid (e.g. acetic acid) is neutralized by the strong base (e.g, NaOH), forming a weak conjugate base (e.g. acetate ion) that makes the solution slightly basic at the equivalence point. The pH at this point reflects the basic nature of the conjugate base formed.

5. **How does the titration curve of a strong acid with a strong base differ from that of a weak acid with a strong base? Discuss the differences in their equivalence points.**

   ***Strong Acid with Strong Base**: The titration curve shows a sharp, nearly vertical rise in pH near the equivalence point, which occurs at pH 7. Both the acid and base are fully dissociated, forming a neutral salt and water.*

   ***Weak Acid with Strong Base**: The titration curve shows a more gradual rise in pH, with the equivalence point occurring at a pH greater than 7. The weak acid is only partially dissociated, and its conjugate base (formed during the reaction) hydrolyzes to produce hydroxide ions, making the solution basic at the equivalence point.*





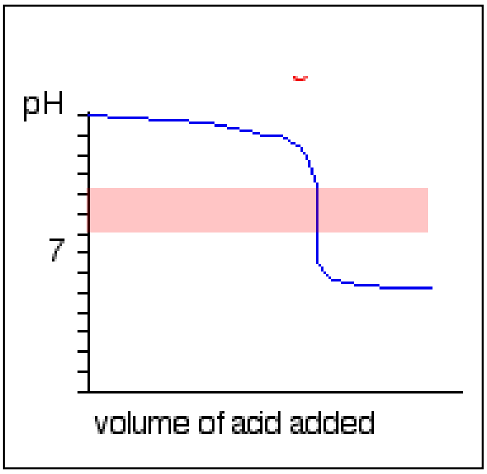
6. **If the pH at the equivalence point of a titration is 5.5, what can you infer about the nature of the acid and base being titrated?**

A pH of 5.5 at the equivalence point suggests that a strong acid (e.g. HCl) is being titrated with a weak base (e.g. NH_3). The strong acid fully dissociates, and the weak base is neutralized, forming a weak conjugate acid (e.g, ammonium ion) that hydrolyzes to produce hydronium ions (H_3O^+), making the solution slightly acidic at the equivalence point.

7. **A titration takes place between carbonic acid (H_2CO_3) and sodium hydroxide (NaOH).**
   a. **Write a balanced chemical equation for the reaction**

      $H_2CO_3(aq) + NaOH(aq) \rightarrow Na_2CO_3(s) + 2H_2O(l)$

   b. **What indicator should be used? Explain your reasoning by drawing an appropriate pH curve for the titration in the space below.**



Phenolphthalein. It changes in the range of the equivalence point (pH 8-10).