Ch(5) : pH of strong acid –strong base

I- auto ionization of water (autoprotolysis)

Distilled water is a very weak conductor of electricity, this conductivity is due to the few limited number of ions obtained by the reaction of water with itself, this reaction is called auto ionization of water according to the equation :

$$H_2O_{(l)} + H_2O_{(l)} \overset{H^+}{\leftrightarrow} H_2OH^+_{(aq)} + OH^-_{(aq)}$$

Or simply :

$$2H_2O_{(l)} \leftrightarrow H_3O^+_{(aq)} + OH^-_{(aq)}$$

This reaction is called also autoprotolysis since it transfers proton (H^+) between two molecules of water.

This reaction is very limited, its equilibrium constant K_c is designated by K_w (constant of water).

$$K_w = 10^{-14}$$

$K_w = [H_3O^+] \times [OH^-] = 10^{-14}$ **this constant depends only on the temperature.**

H^+ does not exist in solution as form of proton, it links with water molecules to give H_3O^+.

H_3O^+ is called hydronium ion.

OH^- : hydroxide ion

In pure water (neutral medium) :

$$[H_3O^+] = [OH^-] = 10^{-7}\ mol.L^{-1}$$

$$[H_3O^+] \times [OH^-] = 10^{-7} \times 10^{-7} = 10^{-14} = K_w$$

What is the logarithm function? (math review)

The logarithm of any number written as (10^x) is equal to the power x .

The logarithm is designated by (log).

$Log(10^x) = x$ $\qquad$ $log(10) = 1$

$Log(10^{-x}) = -x$ $\qquad$ $-log(10^{-x}) = x$

if $log(x) = y$ **then** $x = 10^y$

$Log(a^b) = b \times log(a)$

$Log(a \times b) = log(a) + log(b)$

$Log\left(\frac{a}{b}\right) = log(a) - log(b)$

$Log\left(\frac{1}{a}\right) = log(a^{-1}) = -log(a)$

II- Definition and measure of pH

The logarithm function is used to determine the pH and it is designated by p(x) = f(x) = log (x)

The pH of aqueous solution is a logarithm function of $[H^+]$.

$$[H^+] = [H_3O^+]$$

The pH of aqueous solutions depends on both concentration of H_3O^+ and concentration of OH^- :

$$pH = -\log [H_3O^+] \qquad\qquad [H_3O^+] = 10^{-pH}$$

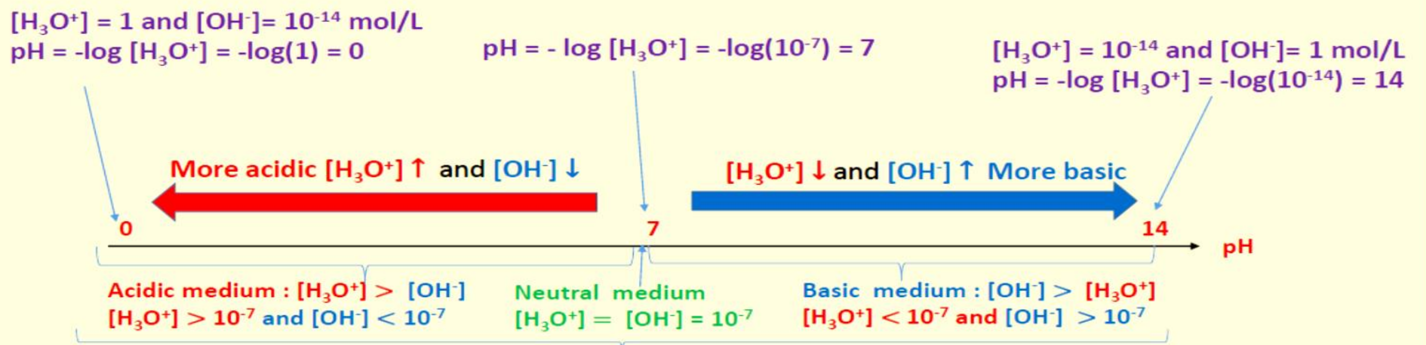
Note : **we put a mines before the log to obtain a positive value of pH**

Since in aqueous solution: $[H_3O^+] = K_w /[OH^-] = 10^{-14}/[OH^-]$,

thus $pH = -\log (10^{-14}/[OH^-])$

$$pH = 14 + \log[OH^-] \qquad\qquad [OH^-] = 10^{(pH -14)}$$

The pH scale is represented as the following :



In all mediums : $K_w = [H_3O^+]\times [OH^-] = 10^{-14}$ = constant (at T = 25℃)

If a base is added to water : $[OH^-]$ ↑ and $[H_3O^+]$ ↓ and $K_w = 10^{-14}$

If an acid is added to water : $[H_3O^+]$ ↑ and $[OH^-]$ ↓ and $K_w = 10^{-14}$

Application 1

Determine the pH of HCl solution having $[H_3O^+] = 10^{-5}$ mol/L and deduce $[OH^-]$ in the same solution.

Answer

$pH = -\log [H_3O^+] = -\log (10^{-5}) = 5 < 7$ (acidic)

$K_w = [H_3O^+] [OH^-] = 10^{-14}$ thus $[OH^-] = 10^{-14}/10^{-5} = 10^{-9}$ mol/L

Or $[OH^-] = 10^{pH-14} = 10^{5-14} = 10^{-9}$ mol/L

Application 2

A solution of sodium hydroxide having a pH = 12

Determine $[H_3O^+]$ and $[OH^-]$ in the solution.

Answer

$[H_3O^+] = 10^{-pH} = 10^{-12}$ mol/L $\qquad [OH^-] = 10^{-14}/10^{-12} = 10^{-2}$ mol/L

III-Definition of strong acids and their pH

A strong acid is a chemical species that dissolves in water or reacts with water in a complete reaction to give H_3O^+ ions.

A strong acid is designated generally by HA , its reaction with water is written as :

$$HA + H_2O \xrightarrow{} H_3O^+ + A^-$$

H_3O^+ **: is the ion that gives the acidic character.**

A^- **: is a spectator ion (has no effect on the pH)**

Examples of strong acids:

HCl : hydrochloric acid ($HCl + H_2O \rightarrow H_3O^+ + Cl^-$)

HNO_3 : nitric acid ($HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$)

HBr : Hydrobromic acid ($HBr + H_2O \rightarrow H_3O^+ + Br^-$)

Calculation of pH of strong acid solution

Consider a solution of strong acid HA having a given concentration C_a

Its reaction with water is : $HA + H_2O \rightarrow H_3O^+ + A^-$

Since the reaction is complete, thus we can write (acc. to.S.R) :

$n(H_3O^+)_{\text{max formed}} = n_0(HA)$ **and therefore by dividing by $V_{solution}$ we obtain:**

$$\boxed{[H_3O^+] = C_a}$$

The pH of this solution is :

$$\boxed{pH = -\log [H_3O^+] = -\log C_a}$$

If the pH of the solution is given, then we can deduce $C_a = 10^{-pH}$

Note : since the reaction of dissociation of strong acid is complete, thus its degree of dissociation $\alpha \approx 1$ ($\alpha \approx 100\ \%$)

Effect of dilution on the pH of strong acids

Suppose we have a solution of strong acid HA of concentration C_a and having a given pH.

The pH of this solution is $pH = -\log C_a$

If the solution is diluted 10 times, its concentration become and its pH becomes: $C'_a = \frac{C_a}{10}$

$pH' = -\log C'_a$

$$= -\log\left(\frac{C_a}{10}\right) = -(\log C_a - \log 10) = -\log C_a + 1 = pH + 1$$

Conclusion:

The dilution 10 times of strong acid solution will increase its pH one unit:

$$\boxed{pH' = pH + 1}$$

The dilution 100 times of strong acid solution will increases its pH two units:

$$\boxed{pH'' = pH + 2}$$

IV- Definition of strong bases and their pH

A strong base is a chemical species that dissolves in water in a complete reaction to give OH^- ions.

A strong base is designated generally by BOH, its reaction with water is written as :

$$BOH \rightarrow B^+ + OH^-$$

OH^- : hydroxide ion that gives the basic character.

B^+ : spectator ion (has no effect on the pH)

Examples of strong bases:

NaOH : sodium hydroxide ($NaOH \rightarrow Na^+ + OH^-$)

KOH : potassium hydroxide ($KOH \rightarrow K^+ + OH^-$)

LiOH : lithium hydroxide ($LiOH \rightarrow Li^+ + OH^-$)

Calculation of pH of strong base solutions

Consider a solution of strong base BOH of concentration C_b .

Its reaction with water is : $BOH \rightarrow B^+ + OH^-$

Since the reaction is complete, then we can write (acc. to. SR) :

$n(OH^-)_{max\ formed} = n_0(BOH)$ and therefore by dividing by $V_{solution}$ we obtain :

$$\boxed{[OH^-]_{formed} = C_b}$$

The pH of this solution is : $\boxed{pH = 14 + \log [OH^-] = 14 + \log C_b}$

If the pH of the solution is given, we can deduce: $C_b = 10^{(pH-14)}$

Since the reaction of strong base is complete, its degree of dissociation $\alpha \approx 1$ ($\approx 100\%$).

Effect of dilution on the pH of strong bases

Suppose we have a solution of strong base BOH of concentration C_b and having a given pH.

The pH of this solution is $pH = 14 + \log C_b$

If the solution is diluted 10 times, its concentration become $C'_b = \frac{C_b}{10}$ and its pH becomes:

$$pH' = 14 + \log C'_b$$

$$= 14 + \log\left(\frac{C_b}{10}\right) = 14 + \log C_b - \log 10 = 14 + \log C_b - 1 = pH - 1$$

Conclusion:

The dilution 10 times of strong base solution will decrease its pH one unit:

$$\boxed{pH' = pH - 1}$$

The dilution 100 times of strong base solution will decrease its pH two units:

$$\boxed{pH'' = pH - 2}$$

Contrast between solutions of strong acids and strong bases

Solution of strong acid of concentration C_a	Solution of strong base of concentration C_b
$pH = -\log C_a$	$pH = 14 + \log C_b$
$[H_3O^+]_{formed} = C_a$ (since its reaction with water is complete).	$[OH^-]_{formed} = C_b$ (since its reaction of dissociation is complete)
Degree of dissociation : $\alpha = 100\ \%$	Degree of dissociation : $\alpha = 100\%$
The dilution 10 times of the solution will rise its pH one unit : pH' = pH +1	The dilution 10 times of the solution will decrease its pH one unit : pH' = pH - 1

V- Reaction of strong acids with strong bases

When a strong acid solution (HA) is added to a strong base solution(BOH), the reaction that occurs is actually the reaction of H_3O^+ with OH^- ions according to the equation :

$$(H_3O^+_{(aq)} + \cancel{A^-_{(aq)}}) + (\cancel{B^+_{(aq)}} + OH^-_{(aq)}) \rightarrow 2H_2O_{(l)} + \cancel{A^-_{(aq)}} + \cancel{B^+_{(aq)}}$$

The net ionic equation of this reaction is always :

$$H_3O^+_{(aq)} + OH^-_{(aq)} \rightarrow 2H_2O_{(l)}$$

This reaction is complete, rapid and exothermic.

The equilibrium constant of this reaction is :

$$K_c = \frac{1}{[H_3O^+]\times[OH^-]} = \frac{1}{K_w} = \frac{1}{10^{-14}} = 10^{14}$$

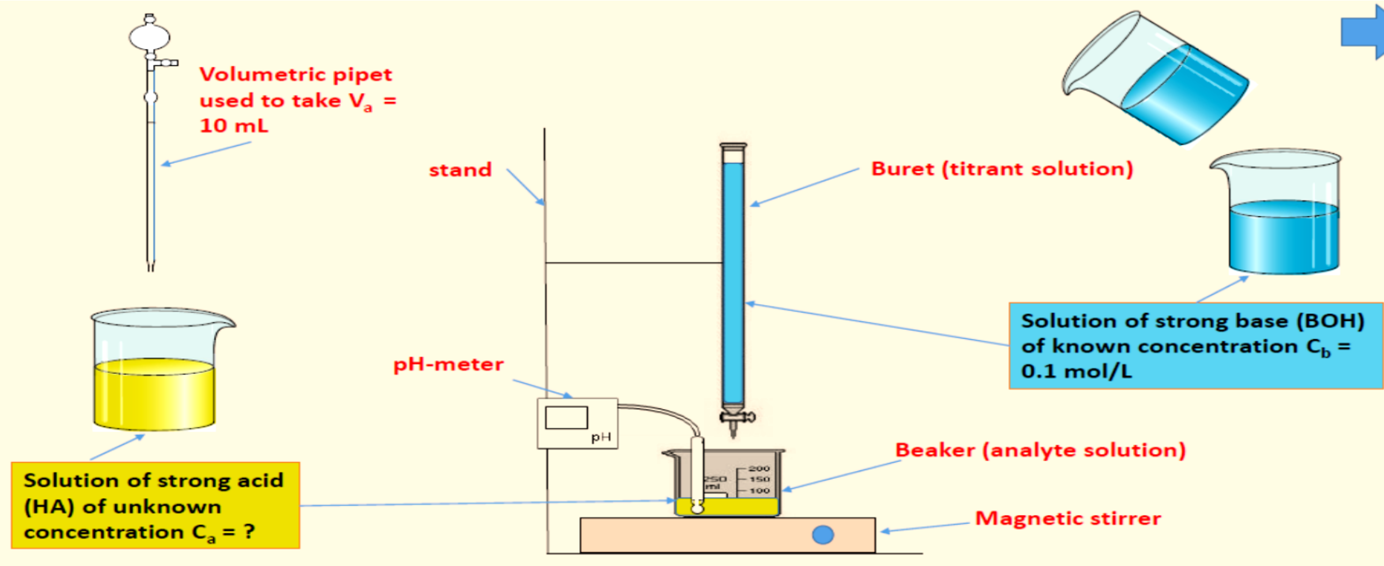
VI- pH –metric titration of strong acid (H_3O^+) acid with strong base (OH^-)

The pH – metric titration aims to determine the concentration of strong acid solution (or strong base) by neutralizing a certain volume taken from this solution by the exact volume of strong base (or strong acid) added from the buret.

The pH of the solution present in the titration beaker is shown by a pH meter after each mL added from the buret.

The materials needed for this titration are :

- Stand
- Glassware
  - Buret
  - Beaker
  - Volumetric pipet (to take a volume from the titrated solution)
- Pipet filler
- pH –meter

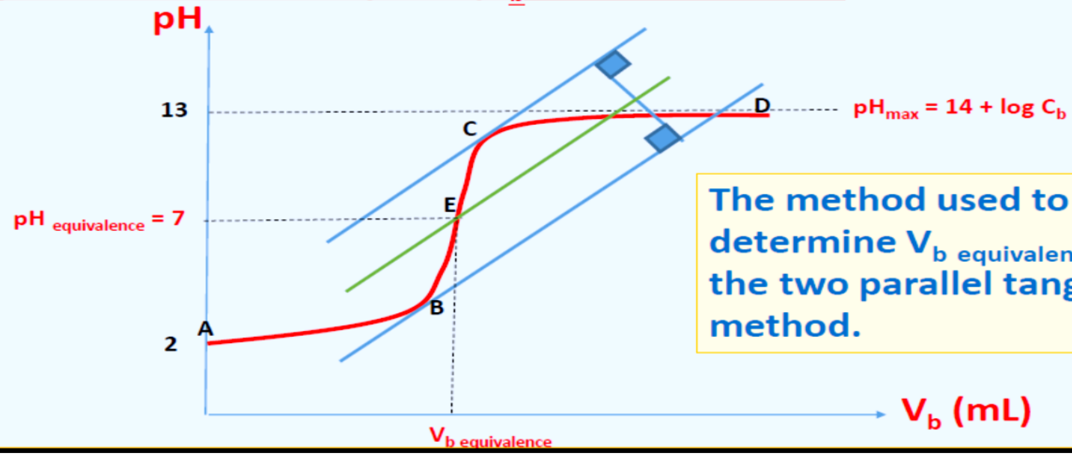


The equation of titration reaction is : $H_3O^+ + OH^- \rightarrow 2H_2O$

The titrant solution in the buret is added progressively and the pH indicated by the pH meter is recorded at each mL added to obtain a data table as the following :

$V_{b\,(mL)}$	0	1	2	..	9	10	...	20	30
pH	2	2.1	2.2	..	6.5	7	...	12.8	12.9

The shape of titration curve pH = f(V_b) is the following :



The method used to determine $V_{b\ equivalence}$ is called the two parallel tangents method.

Calculation of concentration C_a

$$H_3O^+ + OH^- \rightarrow 2H_2O$$

At equivalence , acc. to. SR :

$$n(\text{acid})_{taken} = n(\text{base})_{added}$$

$$n(H_3O^+)_{taken} = n(OH^-)_{added}$$

$$C_a \times V_{a\ taken} = C_b \times V_{b\ eq}$$

$$C_a = \frac{C_b \times V_{b\ eq}}{V_{a\ taken}}$$

Note

$V_{b\ equivalence}$ is determined from the curve pH = f(V_b) by using the two parallel tangents method.

Description of the curve pH = f(V_b)

The curve is an ascending curve that consists of three parts and of one inflection point :

Part AB

The pH increases slightly as the volume of base added increases.

Part BC

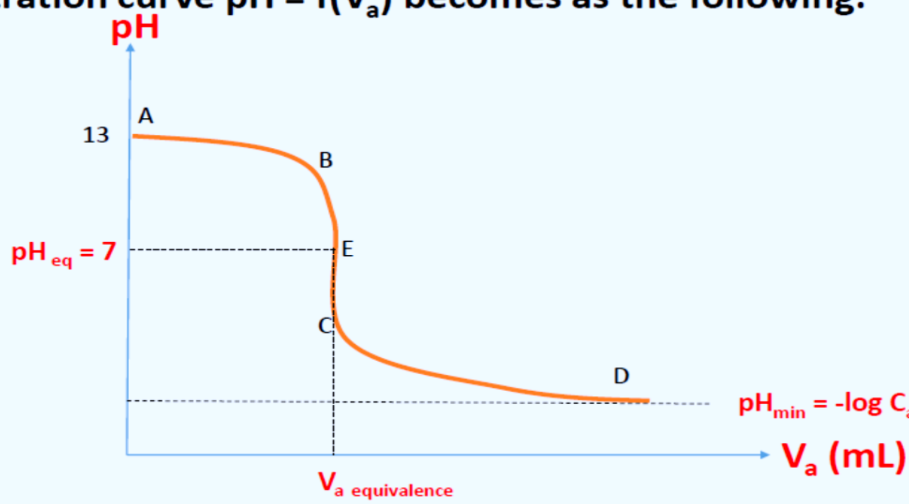
The pH increases rapidly as a little volume of base is added and the curve shows a sudden jump of pH.

This part consist of an inflection point E which is the equivalence point.

Part CD

The pH increases slightly again as the volume of base added increases. The pH tends to reach a limited value equal to 14 + log C_b

If the base is placed in the beaker and the acid is placed in the buret, the shape of the titration curve pH = f(V_a) becomes as the following:



Note : **the description of the curve is the same but we use decrease instead of increase in the variation of pH**