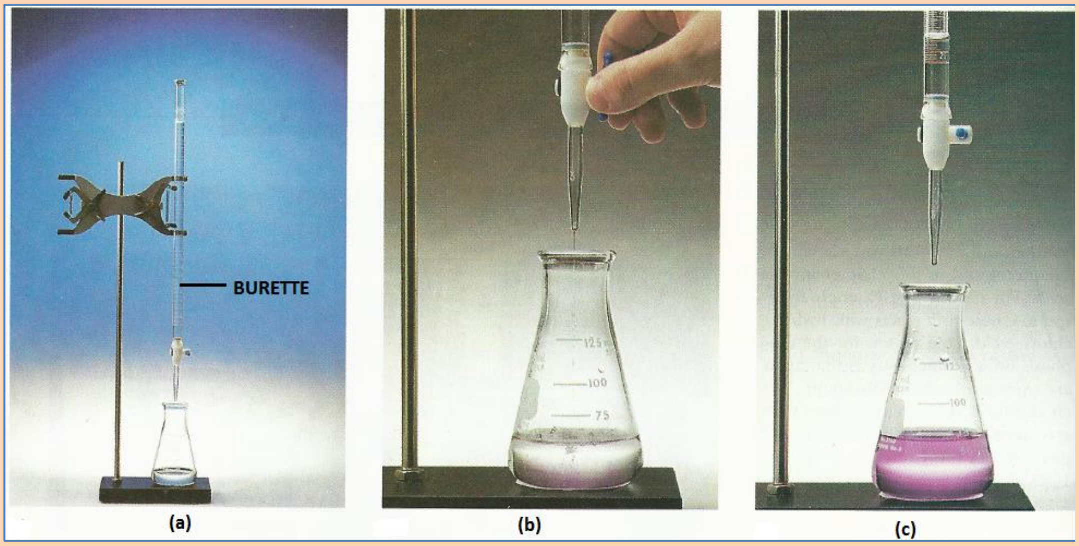
NORTHERN CAPE DEPARTMENT OF EDUCATION

PHISICAL SCIENCES
GRADE 12
CHEMISTRY



TERM 2
CONSOLIDATION
ACIDS AND BASES

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ACIDS AND BASES

Arrhenius theory:

- **Acid** is a substance which produces H^+/H_3O^+ ions when it dissolves in water.

$$HC\ell \xrightarrow{H_2O} H^+(aq) + C\ell^-(aq)$$

- **Base** is a substance which produces OH^- ions when it dissolves in water.

$$NaOH \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

Lowry-Brønsted theory:

- **Acid** is a proton(H^+) donor.
- **Base** is a proton(H^+) acceptor.

Eg: $\underset{A_1}{HC\ell\,(\ell)} + \underset{B_2}{H_2O\,(\ell)} \rightarrow \underset{A_2}{H_3O^+(aq)} + \underset{B_1}{C\ell^-(aq)}$

$\underset{B_2}{NH_3\,(g)} + \underset{A_1}{H_2O\,(\ell)} \rightarrow \underset{A_2}{NH_4^+(aq)} + \underset{B_1}{OH^-(aq)}$

Where A_1, B_1 and A_2, B_2 are the corresponding acid-base conjugate pairs.

This process of an acid or a base splitting into ions is called **ionisation**.

Remember: Every reaction between a Brønsted acid and Brønsted base involves H^+ transfer and has two conjugate acid-base pairs. Acid and its conjugate base differ only by an H^+.

Conjugate acid-base pairs

Name	Acid 1	Base 2	Base 1	Acid 2
Nitric acid	HNO_3 +	$H_2O \rightleftharpoons$	NO_3^- +	H_3O^+
Sulphuric acid	H_2SO_4 +	$H_2O \rightleftharpoons$	SO_4^{2-} +	$2H_3O^+$
Hydrogen fluoride	HF +	$H_2O \rightleftharpoons$	F^- +	H_3O^+
Hydrogen sulphide	H_2S +	$H_2O \rightleftharpoons$	HS^- +	H_3O^+
Hydrogen sulphate ion	HSO_4^- +	$NH_3 \rightleftharpoons$	SO_4^{2-} +	NH_4^+
Hydrogen carbonate	HCO_3^- +	$H_2O \rightleftharpoons$	CO_3^{2-} +	H_3O^+

Acid 1 and base 1 are conjugate pairs as base 2 and acid 2

Monoprotic and polyprotic acids

Acids such as $HC\ell$, HF, HNO_3 etc are capable of donating one proton and are called monoprotic acids.

H_2SO_4 , H_3PO_4, H_2CO_3 etc can donate more than one proton and are called polyprotic acids.

H_2SO_4 can donate 2 protons and hence it is diprotic acid.

H_3PO_4 can donate 3 protons and hence it is triprotic acid.

Ampholytes (Amphiprotic substance)

A substance that can act either as an acid or base is called an ampholyte or amphiprotic.

Water is a good example.

$HC\ell\ (\ell) + H_2O\ (\ell) \rightleftharpoons H_3O^+(aq) + C\ell^-\ (aq)$

In the above reaction water is acting as an acid.

$NH_3\ (g) + H_2O\ (\ell) \rightleftharpoons NH_4^+(aq) + OH^-$

But in this reaction water is acting as a base.

Another example is hydrogen phosphate ion (HPO_4^{2-}).

It can donate a proton (acting as an acid) according to the reaction,

$$HPO_4^{2-} + H_2O \rightleftharpoons H_3O^+ + PO_4^{3-}$$

It can accept a proton (acting as a base) according to the reaction,

$$HPO_4^{2-} + H_2O \rightleftharpoons H_2PO_4^- + OH^-$$

You can also notice that in the above reactions water also acts as an ampholyte.

Strong acids/bases and weak acids/bases

Strong acids ionises completely in water to form a high concentration of H_3O^+ ions. eg: Hydrochloric acid, Nitric acid etc.

Weak acids ionises incompletely in water to form a low concentration of H_3O^+ ions. eg: Ethanoic acid, Oxalic acid etc.

Strong bases ionise completely in water to form a high concentration of OH^- ions. eg. potassium hydroxide, sodium hydroxide etc.

Weak bases ionise incompletely in water to form a low concentration of OH^- ions. eg: Calcium carbonate, Ammonia etc.

Strong acids/bases have high concentration of ions in it making it good conductors of electricity than weak acids/bases

Concentrated acids/bases and dilute acids/bases

Concentrated acids contain a large amount of acid in proportion to the volume of water.

Dilute acids contain a small amount of acid in proportion to the volume of water.

Concentrated bases contain a large amount of base in proportion to the volume of water.

Dilute bases contain a small amount of base in proportion to the volume of water.

Neutralisation Reactions

A **neutralization reaction** is when an acid and a base react to form water and a salt and involves the combination of H^+ ions and OH^- ions to generate water.

Examples

$HC\ell (aq) + NaOH (aq) \rightarrow NaC\ell (aq) + H_2O(\ell)$

$HC\ell (aq) + KOH (aq) \rightarrow KC\ell^- (aq) + H_2O(\ell)$

$HNO_3(aq) + NaOH (aq) \rightarrow NaNO_3(aq) + H_2O(\ell)$

$H_2SO_4(aq) + 2NaOH (aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$

$CH_3COOH(aq) + NaOH (aq) \rightarrow CH_3COONa(aq) + 2H_2O(\ell)$

$(COOH)_2(aq) + 2NaOH (aq) \rightarrow (COO)_2Na_2(aq) + 2H_2O(\ell)$

Acid ionisation constant (K_a)

Consider the ionisation reaction of an acid HA.

$HA(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + A^- (aq)$

Now the acid ionisation constant is $K_a = \frac{[H_3O^+][A^-]}{[HA]}$ For strong acids $K_a > 1$.

Base ionisation constant (K_a)

Consider the ionisation reaction of a base B.

$B(aq) + H_2O(\ell) \rightleftharpoons BH^+(aq) + OH^- (aq)$

Now the base ionisation constant $K_b = \frac{[BH^+][OH^-]}{[B]}$ For strong bases $K_b > 1$.

Ionisation of water (Auto ionisation)

Consider the following reaction between two water molecules.

$H_2O(\ell) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^- (aq)$

This reaction of water with itself to form H_3O^+ and OH^- ions is called auto ionisation. Now the equilibrium constant for this reaction is represented by K_w.

$$K_w = [H_3O^+][OH^-]$$

K_w is called the water ionisation constant and its value is 10^{-14}.

- In neutral solution $[H_3O^+] = [OH^-] = 10^{-7}$
- In acidic solution $[H_3O^+] > [OH^-]$
  $\therefore [H_3O^+] > 10^{-7}$ and $[OH^-] < 10^{-7}$
- In basic solution $[OH^-] > [H_3O^+]$
  $\therefore [OH^-] > 10^{-7}$ and $[H_3O^+] < 10^{-7}$

pH scale

pH of a solution is defined as the negative of the (base 10) logarithm of its hydronium ion concentration.

$$pH = -\log[H_3O^+]$$

In pure water (neutral) $[H_3O^+] = 10^{-7}$

$$\therefore\ pH = -\log[H_3O^+] = -\log[10^{-7}]$$

$$= 7$$

$pOH = -\log[OH^-]$ **NOTE**: This formula is not in the curriculum and in the formula sheet. But very useful to do problems together with the equation, $pOH + pH = 14$

Hydrolysis

When an acid react with a base a salt is formed. Reaction of this salt with water is called hydrolysis.

eg 1: Na_2CO_3 (Sodium carbonate)

Na_2CO_3 is produced by the reaction of NaOH (strong base) and H_2CO_3 (weak acid)

$Na_2CO_3 \rightleftharpoons 2Na^+ + CO_3^{2-}$

Now hydrolysis of Na_2CO_3 can be shown as

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

Solution contains extra OH- ions makes the solution basic (alkaline).(pH>7)

So the hydrolysis of a salt of a strong base and a weak acid results in an alkaline solution.

eg 2: $NH_4C\ell$ (Ammonium chloride)

$NH_4C\ell$ is produced by the reaction of $HC\ell$ (strong acid) and NH_4 (weak base).

Now hydrolysis of $NH_4C\ell$ can be shown as

$NH_4C\ell + H_2O \rightleftharpoons NH_3 + H_3O^+ + C\ell^-$

Solution contains extra H_3O^+ ions which makes it acidic.(pH<7)

The hydrolysis of a salt of a strong acid and a weak base results in a acidic solution.

eg 3: $NaC\ell$ (Sodium chloride)

$NaC\ell$ produced by the reaction of $HC\ell$ (strong acid) and NaOH (strong base).

hydrolysis of $NaC\ell$ of is as shown below.

$NaC\ell\,(S) + H_2O\,(\ell) \rightleftharpoons Na^+(aq) + C\ell^-(aq)$ pH = 7

The hydrolysis of a salt of a strong acid and a strong base results in a nuetral solution.

Remember:

- Anions that are conjugate bases of strong acids (eg. Cl^-, NO_3^- etc) are very weak bases and their presence have no effect on the pH of the solution.
- Alkali metal and alkaline earth metal cations (Na^+, Mg^{2+} etc) have no effect on the pH of the solution.

Acid - base titration

An acid - base titration can be used to determine the concentration of an acid or base by exactly neutralising the acid or base with a base or an acid of known concentration.

$$\frac{C_a V_a}{C_b V_b} = \frac{n_a}{n_b}$$

Equivalence point - of a titration is the point at which the acid/base has completely reacted with the base/acid.

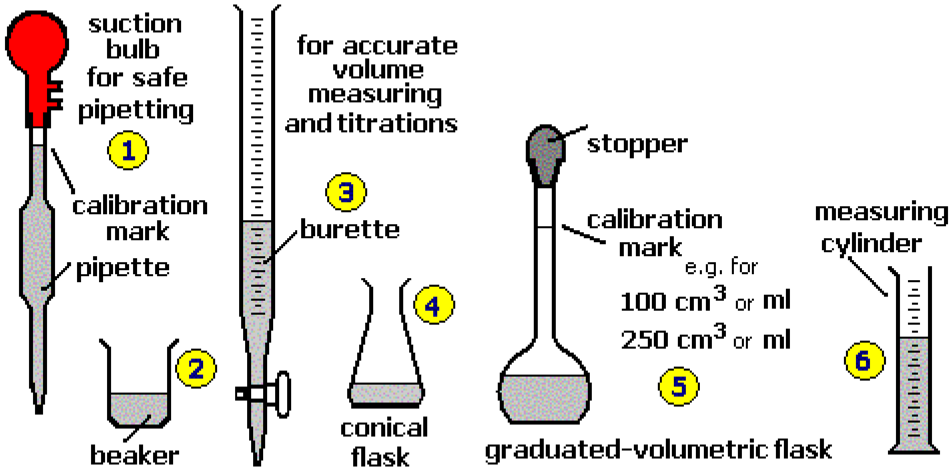
Endpoint- of a titration is the point where the indicator changes colour.

Indicators

Solution	Indicator used	pH range
Strong acid/ strong base Yellow blue	bromothymol blue	6-8
Strong acid/ weak base Red yellow	Methyl orange	3-4
Weak acid/ strong base Clear Red	Phenolphthalein	8-10

- When a strong base is titrated against a strong acid the salt formed at the equivalence point will be neutral (pH 7). So bromothymol blue having a pH range of 7 is used.
- When a strong acid is titrated against a weak base, the salt formed at the equivalence point will have a pH less than 7. So methyl orange of pH range 3-4 is used.
- When a weak acid is titrated against a strong base, the salt formed at the equivalence point will have a pH greater than 7. So phenolphthalein of pH range 8-10 is used.

Following are some of the apparatus used for titration.



Or Erlynmeyer flask

ACTIVITY 1

1 Consider the reversible reaction represented below:

$CH_3COOH(aq) + OH^-(aq) \rightleftharpoons CH_3COO^-(aq) + H_2O(\ell)$

The correct conjugate acid-base pair is:

A CH_3COOH and H_2O

B CH_3COOH and OH^-

C CH_3COO^- and H_2O

D CH_3COOH and CH_3COO^- (2)

ACTIVITY 2

2 Consider the reaction represented by the equation below:

$H_3PO_4(aq) + HCO_3^-(aq) \rightleftharpoons H_2PO_4^-(aq) + H_2CO_3(aq)$ $K_a > 1$

The strongest base in the above reaction is:

A $H_2PO_4^-$

B HCO_3^-

C H_3PO_4

D H_2CO_3 (2)

ACTIVITY 3

3 The approximate pH range for colour change of a certain indicator is 8,3 - 10,0. This indicator is suitable to indicate the endpoint during the titration of …

A $HC\ell(aq)$ and $NaOH(aq)$.

B $CH_3COOH(aq)$ and $NaOH(aq)$.

C $CH_3COOH(aq)$ and $Na_2CO_3(aq)$.

D $HC\ell(aq)$ and $Na_2CO_3(aq)$. (2)

ACTIVITY 4

4 Which ONE of the following is a CORRECT description for a 0,1 $mol{\cdot}dm^{-3}$ hydrochloric acid solution?

A Dilute strong acid

B Dilute weak acid

C Concentrated weak acid

D Concentrated strong acid (2)

ACTIVITY 5

5 The pH of a solution of NaOH is 10,5. Which one of the following statements is CORRECT?

A $[OH^-] = [H_3O^+]$

B $[Na^+] > [OH^-]$

C $[H_3O^+] < [OH^-]$

D $[OH^-] < [H_3O^+]$ (2)

ACTIVITY 6

6 A small quantity of concentrated hydrochloric acid is gradually added to 1 dm^3 of distilled water at 25 °C. In the resultant solution, the value of K_w, $[H_3O^+]$ and $[OH^-]$ in $mol{\cdot}dm^{-3}$ would be:

A	$K_w = 10^{-14}$	$[H_3O^+] < 10^{-7}$	$[OH^-] > 10^{-7}$
B	$K_w < 10^{-14}$	$[H_3O^+] < 10^{-7}$	$[OH^-] < 10^{-7}$
C	$K_w = 10^{-14}$	$[H_3O^+] > 10^{-7}$	$[OH^-] < 10^{-7}$
D	$K_w = 10^{-14}$	$[H_3O^+] = 10^{-7}$	$[OH^-] = 10^{-7}$

(2)

ACTIVITY 7

Calculate the pH of the following solution

7.1 2 g of NaOH dissolved in water to give 2 dm^3 solution.

7.2 1 g of $Mg(OH)_2$ in 0,50 dm^3 solution.

7.3 Calculate the pH of 0,2 $mol\cdot dm^{-3}$ H_2SO_4

7.4 Calculate the pH of ethanoic acid of concentration 0,02 $mol\cdot dm^3$ and $K_a = 1,8 \times 10^{-5}$.

STRUCTURED QUESTIONS

QUESTION 1

1.1 A certain species of fish cannot survive in a river where the water has a pH of less than 5,5. The hydrogen ion concentration of the water in the river was measured to be $3,2 \times 10^{-5}$ $mol\cdot dm^{-3}$.
Will this species of fish survive in the river? Support your answer with a relevant calculation. (4)

1.2 Write down the *Brönsted- Lowry* definition of an acid. (2)

1.3 The following list of solutions is available in the laboratory:

A 0,1 mol·dm-3 HCℓ

B 0,2 mol·dm-3 NaOH

C 0,5 mol·dm-3 Na2CO3

D 0,5 mol·dm-3 CH3COOH

From the above list choose ----

1.3.1 a weak base. (1)

1.3.2 a strong acid. (1)

1.3.3 an acid with the highest concentration. (1)

QUESTION 2

A bottle containing dil H_2SO_4 of unknown concentration. In order to determine the concentration of the acid, a learner titrates the acid against a standard solution of KOH according to the equation

H_2SO_4 (aq) + KOH(aq) → K_2SO_4 (aq) + H_2O (ℓ)

2.1 Calculate the mass of KOH that must be used to prepare 300 cm^3 of a 0,2 mol·dm^{-3} KOH solution.

2.2 pH of the 0,2 mol·dm^{-3} KOH solution.

2.3 During the titration the learner finds that exactly 15 cm^3 of the KOH solution neutralises exactly 20 cm^3 of the H_2SO_4 solution. Calculate the concentration of the H_2SO_4 solution.

QUESTION 3

Milk of magnesia has been used over the ages to relieve stomach ailments. Its active ingredient is magnesium hydroxide. A group of learners prepare a solution of magnesium hydroxide.

3.1 What mass of magnesium hydroxide must be dissolved in distilled water to prepare 500 cm^3 of a solution with a concentration of 0,2 mol·dm^{-3}?

3.2 What will the concentration of the hydroxide ions in the solution be?

3.3 pH of any medicine safe for human consumption is between 4 and 9. Will this solution of the learners be safe for human consumption?

3.4 The learners now run a titration using hydrochloric acid of concentration 0,1 mol·dm^{-3}. They transfer 25 cm^3 of magnesium hydroxide solution into the conical flask. A reaction occurs according to the equation:

$Mg(OH)_2$ (aq) + 2HCℓ (aq) → $MgCℓ_2$ (aq) + $2H_2O$ (ℓ)

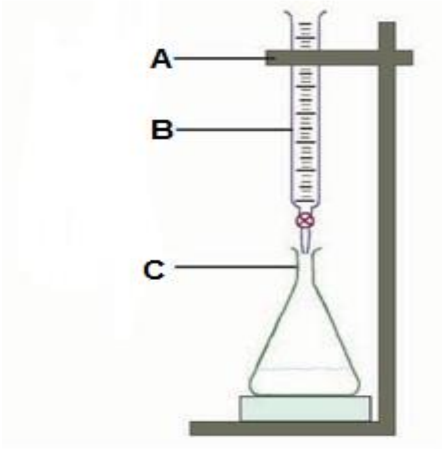
Determine what volume of HCℓ will be needed to fully neutralise the milk of magnesia if its concentration still be 0,2 mol·dm^{-3}.

QUESTION 4

Commercial vinegar contains a small percentage of ethanoic acid. A laboratory technician wishes to determine the concentration of ethanoic acid in vinegar. He titrates a solution of ethanoic acid against a standard solution of sodium hydroxide of concentration 0,009 mol.dm^{-3}. The equation for the reaction is:

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(aq)$$

The apparatus shown below was used during the titration.



25,00 cm^3 of vinegar was diluted with distilled water and made up to a volume of 250,00 cm^3. Some of the diluted solution was added to apparatus B. 25,00 cm^3 of sodium hydroxide solution was added to apparatus C and few drops of an indicator added.

4.1 What is the name of apparatus B?

4.2 Ethanoic is considered a weak acid. What is meant by term 'weak acid'?

A titration was carried out and the results tabulated as shown below:

Experiment	Volume of CH_3COOH (cm^3)
1	21,1
2	21,1
3	20,9

4.3 What observation is made to identify the end point for the acid-base titration?

4.4 Which one of the indicators listed in the table below is suitable to be used for the above titration? Give a reason for the answer.

Indicator	pH range
Methyl orange	2,9 – 4,0
Bromothymol blue	6,0 – 7,6
Phenolphthalein	8,3 – 10,0

4.5 Calculate the concentration of dilute ethanoic acid.

4.6 Calculate the concentration of ethanoic acid in vinegar.

QUESTION 5

In an acid -base reaction 0,5 dm^3 of a 0,1 $mol \cdot dm^{-3}$ hydrogen flouride solution is added to 0,8 dm^3 of 0,25 $mol \cdot dm^{-3}$ solution of NaOH. The reaction runs to completion according to the following equation.
$HF(aq) + NaOH(aq) \rightarrow NaF(aq) + H_2O(\ell)$

5.1 Calculate the number of moles of hydroxide ions remaining in the solution at the completion of the reaction.

5.2 Calculate the pH of the solution at the completion of the reaction.

QUESTION 6

A solution of magnesium hydroxide was prepared by dissolving 2,56 g of impure sample of magnesium hydroxide in 250 cm^3 distilled water. 20 cm3 of this solution is neutralized by 15 cm^3 of hydrochloric acid of 0,1 $mol.dm^{-3}$ according to the reaction
$Mg(OH)_2 + 2\,HC\ell \rightarrow MgC\ell_2 + H_2O$
Assume that the impurities do not react.
Calculate the percentage purity of the sample of magnesium hydroxide.

QUESTION 7

You are asked to determine the percentage of ethanoic acid in vinegar. 7,5 g of commercial vinegar is dissolved in 100 cm^3 of water. 25 cm^3 of this solution is neutralised by 28,5 cm^3 of NaOH of concentration 0, 11 $mol{\cdot}dm^{-3}$. The equation is

$NaOH (aq) + CH_3COOH (aq) \rightarrow CH_3COONa (aq) + H_2O (\ell)$

7.1 Calculate the pH of the sodium hydroxide solution.

7.2 Calculate the number of moles of sodium hydroxide used to nuetralise the 25 cm^3 of etahnoic acid.

7.3 Calculate the percentage of ethanoic acid by mass in 100 cm^3 vinegar. (Assume that 1 mℓ of vinegar has a mass of 1 g.)

QUESTION 8

A Grade 12 class wants to determine the percentage of ethanoic acid in a certain bottle of vinegar. They titrate a sample taken from the bottle of vinegar with a standard solution of sodium hydroxide. The equation for the reaction is:

$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$

8.1 Define an *acid* in terms of the Arrhenius theory. (2)

8.2 Give a reason why ethanoic acid is classified as a weak acid. (1)

8.3 Explain the meaning of *standard solution*. (1)

8.4 Write down the names of TWO items of apparatus needed to measure accurate volumes of the acid and the base in this titration. (2)

8.5 It is found that 40 mℓ of a 0,5 $mol{\cdot}dm^{-3}$ sodium hydroxide solution is needed to neutralise 20 mℓ of the vinegar
Calculate the;

8.5.1 pH of the sodium hydroxide solution (4)

8.5.1 Percentage of ethanoic acid by mass present in the vinegar
(Assume that 1 mℓ of vinegar has a mass of 1 g.) (7)

8.5 The sodium ethanoate (CH_3COONa) formed during the above neutralisation reaction undergoes hydrolysis to form an alkaline solution. Write down an equation for this hydrolysis reaction. (3)