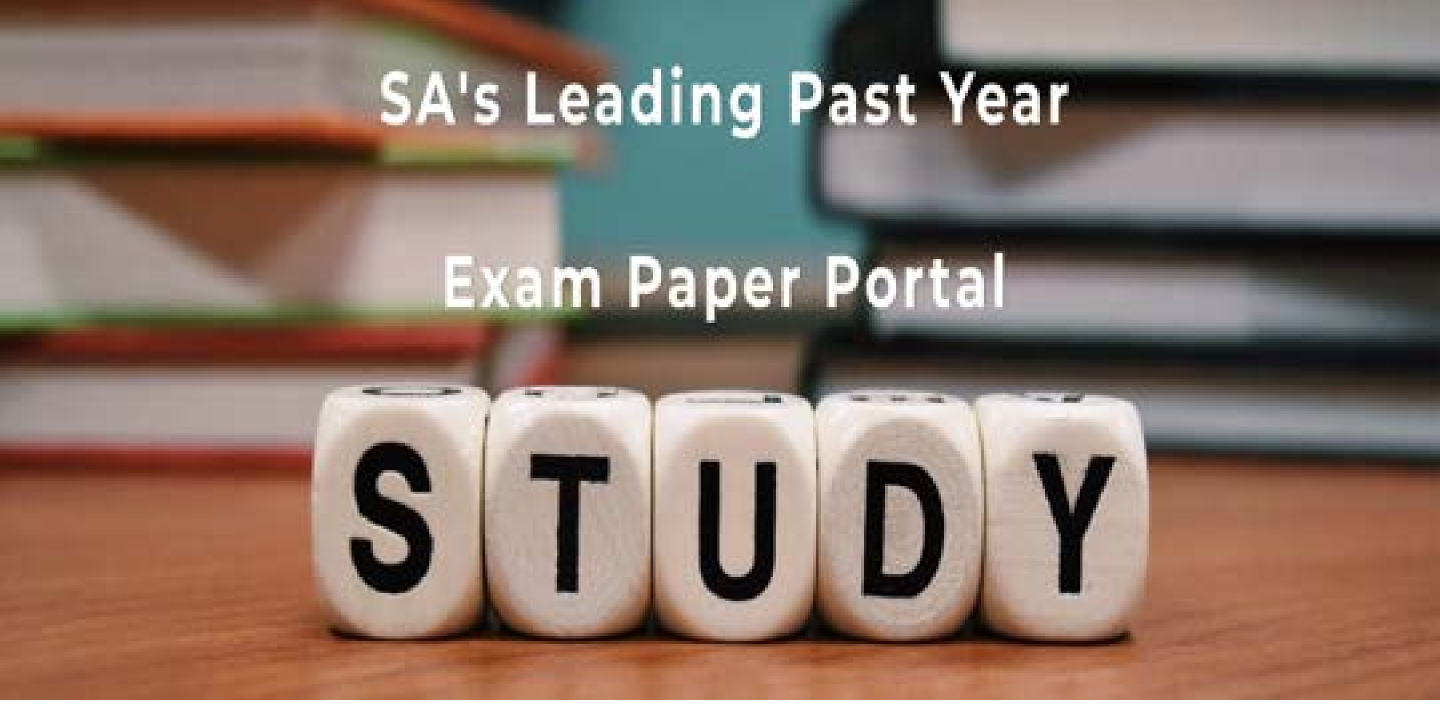

SA's Leading Past Year
Exam Paper Portal
STUDY

TABLE OF CONTENTS

1 Introduction

The declaration of COVID-19 as a global pandemic by the World Health Organisation led to the disruption of effective teaching and learning in many schools in South Africa. The majority of learners in various grades spent less time in class due to the phased-in approach and rotational/ alternate attendance system that was implemented by various provinces. Consequently, the majority of schools were not able to complete all the relevant content designed for specific grades in accordance with the Curriculum and Assessment Policy Statements in most subjects.

As part of mitigating against the impact of COVID-19 on the current Grade 12, the Department of Basic Education (DBE) worked in collaboration with subject specialists from various Provincial Education Departments (PEDs) developed this Self-Study Guide. The Study Guide covers those topics, skills and concepts that are located in Grade 12, that are critical to lay the foundation for Grade 12. The main aim is to close the pre-existing content gaps in order to strengthen the mastery of subject knowledge in Grade 12. More importantly, the Study Guide will engender the attitudes in the learners to learning independently while mastering the core cross-cutting concepts.

2 How to use the booklet

This booklet is meant to help you improve your understanding of the subject Physical Sciences. It summarises the work that must be studied for examination purposes. This guide does not give full explanations of all the concepts. Its aim is to assist you in the understanding of the important facts as highlighted in the examination guidelines, it gives tips and suggested methods of solving problems, and on how to answer certain questions, your textbook will explain the work in depth, thus it does not replace your textbook, it should be used in conjunction with your preferred textbook. The authors wrote this booklet using their experience in a classroom situation.

This guide aims to help you improve your performance, or to help you score marks in Acids and Bases. Examples are given with solutions/answers, some explanations are provided next to the solution/answer to enhance your understanding. After studying a certain example, using a blank paper/cardboard shield the solution/answer for that example and try to solve it on your own without looking at the answer. Use the provided solutions to mark your own work. If you fail to get it right on the first attempt, do not give up, keep on trying until you can solve it successfully.

Solutions to the exercises are provided in this booklet. Attempt the exercises without looking at the solutions. After doing an exercise compare your solution to the one provided and go through the provided solutions carefully and make sure you understand the steps taken to solve the problem/question. If you cannot do a certain exercise, go back to the relevant section/theory and study it again.

3. Acids and Bases

3.1 Extracts from the Examination Guidelines

Acid-base reactions

- Define acids and bases according to Arrhenius and Lowry-Brønsted:
  Arrhenius theory: Acids produce hydrogen ions (H^+) in solution. Bases produce hydroxide ions (OH^-) in solution.
  Lowry-Brønsted theory: An acid is a proton (H^+ ion) donor. A base is a proton (H^+ ion) acceptor.
- Distinguish between *strong* acids/bases and *weak* acids/bases with examples. *Strong acids* ionise completely in water to form a high concentration of H_3O^+ ions. Examples of strong acids are hydrochloric acid; sulphuric acid and nitric acid.
  Weak acids ionise incompletely in water to form a low concentration of H_3O^+ ions. Examples of weak acids are ethanoic acid and oxalic acid.
  Strong bases dissociate completely in water to form a high concentration of OH^- ions. Examples of strong bases are sodium hydroxide and potassium hydroxide.
  Weak bases dissociate/ionise incompletely in water to form a low concentration of OH^- ions. Examples of weak bases are ammonia, calcium carbonate, potassium carbonate, calcium carbonate, sodium hydrogen carbonate.
- Distinguish between *concentrated* and *dilute* acids/bases.
  Concentrated acids/bases contain a large amount (number of moles) of acid/base in proportion to volume of water.
  Dilute acids/bases contain a small amount (number of moles) of acid/base in proportion to volume of water.
- Write down the reaction equations of aqueous solutions of acids and bases.
  Examples: $HC\ell(g) + H_2O(\ell) \rightarrow H_3O^+(aq) + C\ell^-(aq)$ ($HC\ell$ is a monoprotic acid.)
  $NH_3(g) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$
  $H_2SO_4(aq) + 2H_2O(\ell) \rightarrow 2H_3O^+(aq) + SO_4^{2-}(aq)$ (H_2SO_4 is a diprotic acid.)
- Identify conjugate acid-base pairs for given compounds. When the acid, HA, loses a proton, its conjugate base, A^-, is formed. When the base, A^-, accepts a proton, its conjugate acid, HA, is formed. These two are a conjugate acid-base pair.
- Describe a substance that can act as either acid or base as *ampholyte*. Water is a good example of an ampholyte substance. Write equations to show how an ampholyte substance can act as acid or base.

- Write down neutralisation reactions of common laboratory acids and bases.

  Examples: $HC\ell(aq) + NaOH(aq)/KOH(aq) \rightarrow NaC\ell(aq)/KC\ell(aq) + H_2O(\ell)$

  $HC\ell(aq) + Na_2CO_3(aq) \rightarrow NaC\ell(aq) + H_2O(\ell) + CO_2(g)$

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

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

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

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

  Note: The above are examples of equations that learners will be expected to write from given information. However, any other neutralisation reaction can be given in a question paper and used to assess e.g. stoichiometry.

Hydrolysis

- Define *hydrolysis* as the reaction of a salt with water.
- Determine the approximate pH (equal to, smaller than or larger than 7) of salts in salt hydrolysis.
  - Hydrolysis of the salt of a weak acid and a strong base results in an alkaline solution i.e. the pH > 7. Examples of such salts are sodium ethanoate, sodium oxalate and sodium carbonate.
  - Hydrolysis of the salt of a strong acid and a weak base results in an acidic solution i.e. the pH < 7. An example of such a salt is ammonium chloride.
  - The salt of a strong acid and a strong bases does not undergo hydrolysis and the solution of the salt will be neutral i.e. pH = 7.

Acid-base titrations

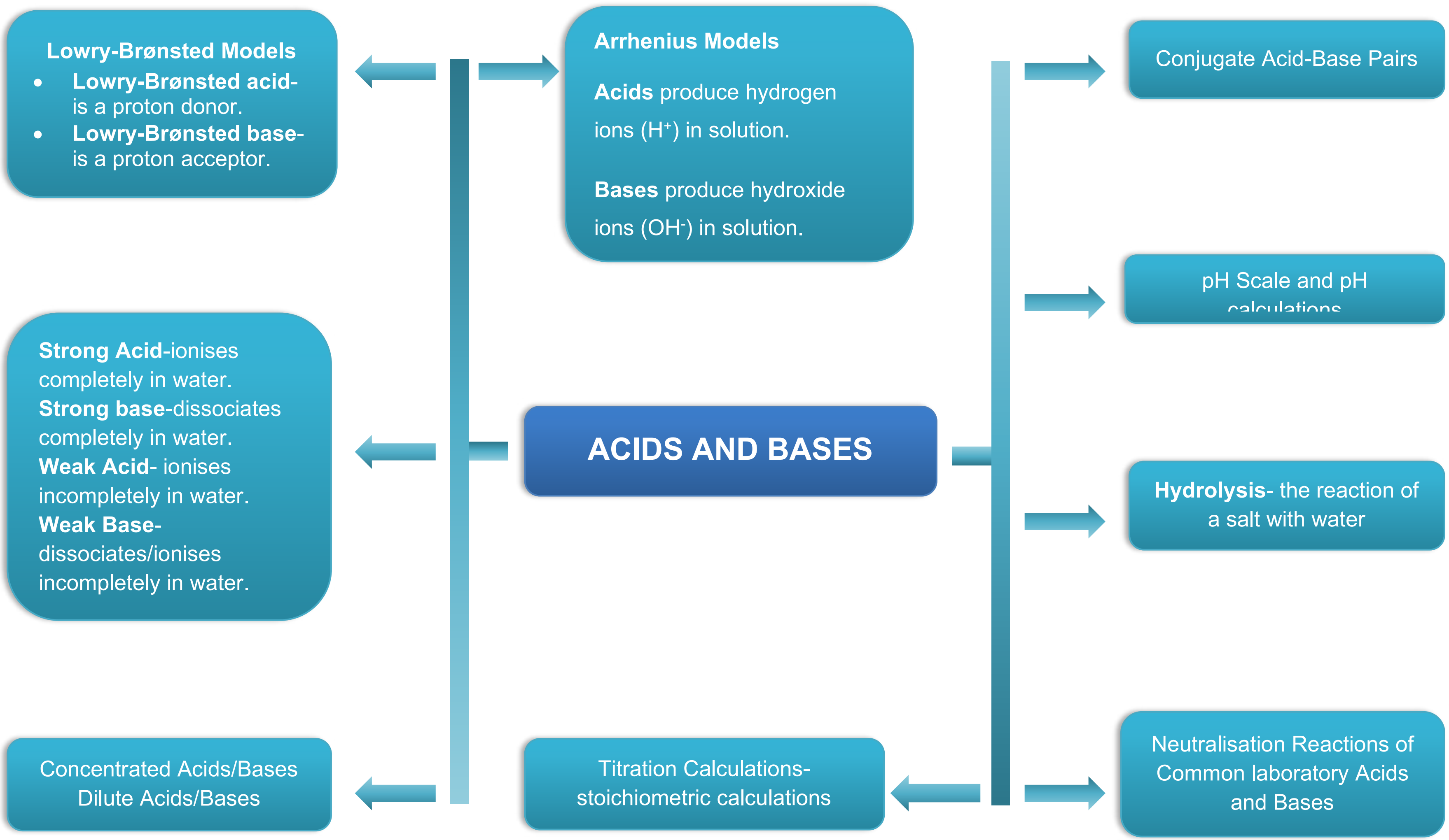
- Motivate the choice of a specific indicator in a titration. Choose from methyl orange, phenolphthalein & bromothymol blue.
- Define the equivalence point of a titration as the point at which the acid /base has completely reacted with the base/acid.
- Define the *endpoint* of a titration as the point where the indicator changes colour.
- Perform stoichiometric calculations based on titrations of a strong acid with a strong base, a strong acid with a weak base and a weak acid with a strong base. Calculations may include percentage purity.
- For a titration e.g. the titration of oxalic acid with sodium hydroxide:
  - List the apparatus needed or identify the apparatus from a diagram.
  - Describe the procedure to prepare a standard oxalic acid solution.
  - Describe the procedure to conduct the titration.
  - Describe safety precautions .

- Describe measures that need to be in place to ensure reliable results.
- Interpret given results to determine the unknown concentration.

pH and pH scale

- Explain the pH scale as a scale of numbers from 0 to 14 used to express the acidity or alkalinity of a solution.
- Calculate pH values of strong acids and strong bases using $pH = -\log[H_3O^+]$.
- Define K_w as the equilibrium constant for the ionisation of water or the ionic product of water, i.e. $K_w = [H_3O^+][OH^-] = 1 \times 10^{14}$ at 298 K.
- Explain the *auto-ionisation* of water i.e. the reaction of water with itself to form H_3O^+ ions and OH^- ions.
- Interpret K_a values of acids to determine the relative strength of given acids. Interpret K_b values of bases to determine the relative strength of given bases.
- Compare strong and weak acids by looking at:
  - pH (monoprotic and diprotic acids)
  - Conductivity
  - Reaction rate

3.2 Mind Map


ACIDS AND BASES
Lowry-Brønsted Models
Lowry-Brønsted acid- is a proton donor.
Lowry-Brønsted base- is a proton acceptor.
Arrhenius Models
Acids produce hydrogen ions (H⁺) in solution.
Bases produce hydroxide ions (OH⁻) in solution.
Strong Acid-ionises completely in water.
Strong base-dissociates completely in water.
Weak Acid- ionises incompletely in water.
Weak Base- dissociates/ionises incompletely in water.
Concentrated Acids/Bases
Dilute Acids/Bases
Titration Calculations- stoichiometric calculations
Conjugate Acid-Base Pairs
pH Scale and pH calculations
Hydrolysis- the reaction of a salt with water
Neutralisation Reactions of Common laboratory Acids and Bases

3.3 Definitions

TERM	DEFINITION/EXPLANATION
Arrhenius Acid	Acids produce hydrogen ions (H^+) in solution
Arrhenius Base	Bases produce hydroxide ions (OH^-) in solution
Lowry-Brønsted Acid	Is a proton (H^+ ion) donor
Lowry-Brønsted Base	Is a proton (H^+ ion) acceptor.
Strong Acid	Strong acids ionise completely in water to form a high concentration of H_3O^+ ions.
Weak Acid	Weak acids ionise incompletely in water to form a low concentration of H_3O^+ ions
Strong Base	Strong bases dissociate completely in water to form a high concentration of OH^- ions
Weak Base	Weak bases dissociate/ionise incompletely in water to form a low concentration of OH^- ions
Concentrated Acid	Concentrated acids contain a large amount (number of moles) of acid in proportion to volume of water
Concentrated Base	Concentrated bases contain a large amount (number of moles) of base in proportion to volume of water
Dilute Acid	Dilute acids contain a small amount (number of moles) of acid in proportion to volume of water.
Dilute Base	Dilute acids contain a small amount (number of moles) of acid in proportion to volume of water.
Ampholyte	A substance that can act as acid or base.
Hydrolysis	Is the reaction of a salt with water
Equivalence Point of a titration	Is the point at which the acid /base has completely reacted with the base/acid
End Point of a titration	Is the point where the indicator changes colour
Ionisation Constant of Water (K_w)	Is the equilibrium constant for the ionisation of water
Standard solution	A solution of known concentration

3.4 Arrhenius and Lowry-Brønsted Models

Examination Guidelines

Arrhenius theory: Acids produce hydrogen ions (H^+) in solution.
Bases produce hydroxide ions (OH^-) in solution.

Lowry-Brønsted theory: An acid is a proton (H^+ ion) donor.
A base is a proton (H^+ ion) acceptor.

According to the Arrhenius theory Acids produce hydrogen ions (H^+) in solution.

e.g. $HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$, **$H^+$** was produced thus it's an Arrhenius acid,

Bases produce hydroxide ions (OH^-) in solution.

e.g. $KOH(aq) \rightarrow K^+(aq) + OH^-(aq)$, **$OH^-$** was produced, thus it's an Arrhenius base.

According to the Lowry-Brønsted theory, an acid is a proton (H^+ ion) donor, and a base is a proton (H^+ ion) acceptor.

H^+

e.g $HNO_3(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + NO_3^-(aq)$

HNO_3 donated a proton to H_2O, it is a Lowry-Brønsted acid, and H_2O accepted the proton, so it is a Lowry-Brønsted base.

3.5 Strong acids/bases and weak acids/bases

Examination Guidelines

***Strong** acids* ionise **completely** in water to form a high concentration of H_3O^+ ions.

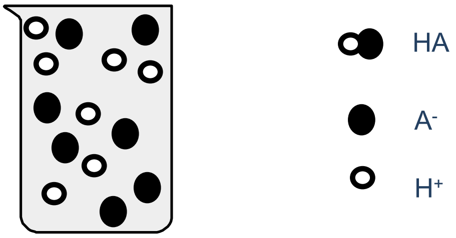
***Weak** acids* ionise **incompletely** in water to form a low concentration of H_3O^+ ions.

***Strong** bases* dissociate **completely** in water to form a high concentration of OH^- ions.

***Weak** bases* dissociate/ionise **incompletely** in water to form a low concentration of OH^- ions.

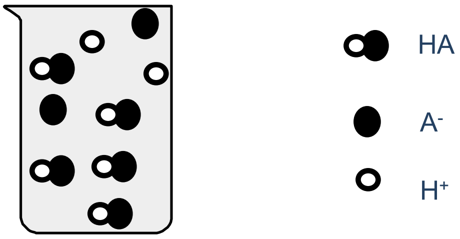
Acids

Strong acids *ionise completely* in water to form a high concentration of H_3O^+ ions.



The acid HA ionised completely. There are **no** HA molecules present. Only ions are present.

Weak acids *ionise incompletely* in water to form a low concentration of H_3O^+ ions.



The acid HA ionised incompletely.
HA molecules are still present.
Very few ions are present.

Bases

Strong bases *dissociate completely* in water to form a high concentration of OH^- ions. (In a NaOH solution, all the base dissociate to form ions, there are now Na^+ and OH^- ions in the container)

Weak bases *dissociate/ionise incompletely* in water to form a low concentration of OH^- ions. (There are fewer ions in the solution compared to the base itself, e.g. in a $Zn(OH)_2$ solution there is a low amount of Zn^{2+} and OH^- ions compared to the $Zn(OH)_2$ molecules)

Please familiarise yourself with the list/table given below.

STRONG ACIDS	STRONG BASES
HCℓ - Hydrochloric acid (monoprotic) **HNO3 – Nitric acid (monoprotic)** **H2SO4 – Sulphuric acid (diprotic)** **H3PO4 – Phosphoric acid (triprotic)**	NaOH – Sodium hydroxide KOH – Potassium hydroxide LiOH – Lithium hydroxide Ba(OH)2 – Barium hydroxide
WEAK ACIDS	**WEAK BASES**
CH3COOH – Acetic acid **(COOH)2 – Oxalic acid**	NH3 - Ammonia Zn(OH)2 – Zinc hydroxide

Note:

A **monoprotic** acid is an acid that can donate one proton only.

e.g. **H** Cℓ

Only **ONE** proton is available/can be donated.

A **diprotic acid** is an acid that can donate a maximum of two protons.

e.g. $\mathbf{H_2}$ SO_4

TWO protons are available/can be donated.

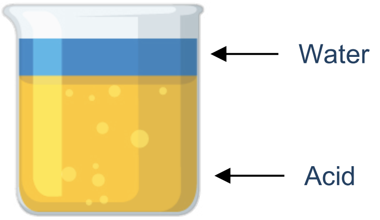
3.6 Concentrated/Dilute Acids/Bases

Examination Guidelines

Concentrated acids/bases contain a large amount (number of moles) of acid/base in proportion to volume of water.

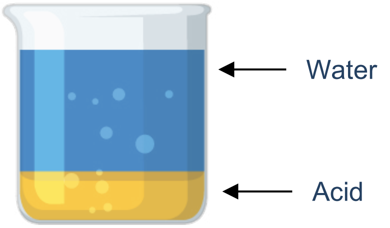
Dilute acids/bases contain a small amount (number of moles) of acid/base in proportion to volume of water.

Concentrated acids/bases contain a large amount (number of moles) of acid/base in proportion to volume of water.



There is 'more' acid than water in the solution, i.e., there is a large amount of acid in proportion to the volume of water.

Dilute acids/bases contain a small amount (number of moles) of acid/base in proportion to volume of water.



There is 'less' acid than water in the solution, i.e., there is a small amount of acid in proportion to the volume of water.

Note: The diagrams just show the proportion of acid to volume of water in the solution, not that the water is above the acid, or they have different densities and they cannot mix.

Note:

A **dilute** acid is **not** a **weak** acid, a weak acid can either be concentrated or dilute.

A **concentrated** acid is **not** a **strong** acid, a strong acid can be concentrated or dilute.

A **strong** acid/base conducts electricity better than a **weak** acid/base because of the greater number of ions in solutions, since the strong acid ionises/ the strong base dissociates completely, provided the strong acid/base and the weak acid/base have equal concentrations.

A strong acid/base reacts very fast due to the high concentration of ions (the acid ionises or the base dissociates completely in water)

3.7 Conjugate acid-base pairs

Examination Guidelines

Identify conjugate acid-base pairs for given compounds. When the acid, HA, loses a proton, its conjugate base, A^-, is formed. When the base, A^-, accepts a proton, its conjugate acid, HA, is formed. These two are a conjugate acid-base pair.

Describe a substance that can act as either acid or base as *ampholyte*. Water is a good example of an *ampholyte* substance. Write equations to show how an *ampholyte* substance can act as acid or base.

You must be able to write balanced equations of aqueous solutions of acids and bases and be able to identify conjugate acid-base pairs.

Conjugate acid-base pairs are compounds that differ from each other by a proton (H^+ ion)

To form a conjugate acid, *add a proton*.

This may assist especially when answering multiple choice questions.

Example

The conjugate acid of:

(a) NH_3 is NH_4^+ (A proton (H^+) was added to NH_3)

(b) HCO_3^- is H_2CO_3 (A proton (H^+) was added to HCO_3^-)

To form a conjugate base, *remove a proton*.

Example

The conjugate base of:

(a) HCO_3^- is CO_3^{2-} (A proton was removed from HCO_3)

(b) H_2O is OH^- (A proton was removed from H_2O)

Example

Identify conjugate acid base pairs.

Base 1 Acid 1

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

Acid 2 Base

2

The conjugate acid-base pairs are:

NH_3 and NH_4^+ and, H_2O and H_3O^+.

Forward reaction

NH_3 is a base because it accepts a proton from H_2O, and H_2O is an acid because it donates a proton to NH_3.

Reverse reaction

NH_4^+ is an acid because it donates a proton to OH^-, and OH^- is a base because it accepts a proton from NH_4^+.

Exercise

Identify conjugate acid-base pairs in the following balanced equations.

(a) $HCO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$

(b) $HCO_3^-(aq) + H_2O(\ell) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$

Hydroxide ion

Hydronium ion

Solution

(a) H_2CO_3 is the conjugate acid of HCO_3^- (base)

OH^- is the conjugate base of H_2O (acid)

(b) CO_3^{2-} is the conjugate base of HCO_3^- (acid)

H_3O^+ is the conjugate acid of H_2O (base)

In both equations, it can be noted that in (a) HCO_3^- is a base and in (b) it is an acid, thus HCO_3^- is an **ampholyte**, i.e., it can act as either an acid or a base. H_2O is also an **ampholyte** as can be seen in both (a) and (b).

3.8 Hydrolysis

Examination Guidelines

Define hydrolysis as the reaction of a salt with water.
Determine the approximate pH (equal to, smaller than or larger than 7) of salts in salt hydrolysis.

- Hydrolysis of the salt of a weak acid and a strong base results in an alkaline solution i.e. the pH > 7. Examples of such salts are sodium ethanoate, sodium oxalate and sodium carbonate.
- Hydrolysis of the salt of a strong acid and a weak base results in an acidic solution i.e. the pH < 7. An example of such a salt is ammonium chloride.
- The salt of a strong acid and a strong bases does not undergo hydrolysis and the solution of the salt will be neutral i.e. pH = 7.

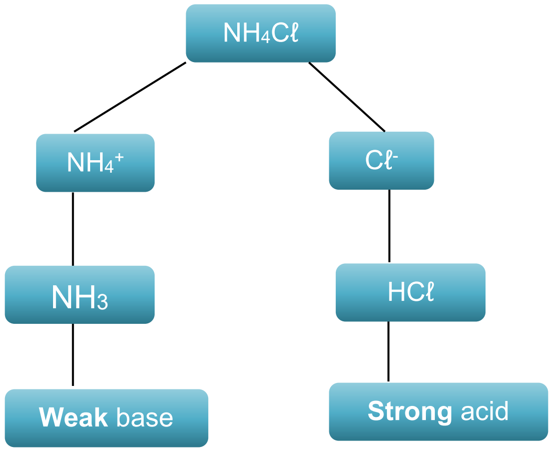
Hydrolysis is the reaction of a salt with water.

The salt of a *strong acid* and a *weak base* is acidic, pH < 7.

The salt of a *weak acid* and a *strong base* is basic, pH > 7.

The salt of a strong acid and a strong base does not undergo hydrolysis.

EXAMPLE 1



Hydrolysis No Hydrolysis

$NH_4^+(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + NH_3(aq)$

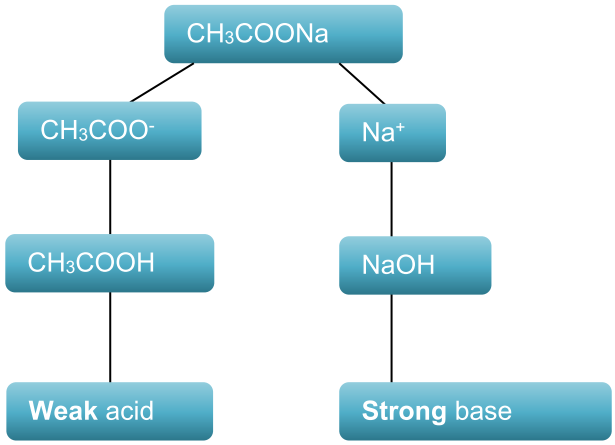
The salt is **acidic**, a **strong acid** reacted with a weak base OR H_3O^+ which is an acid is formed.

STEPS

- Split the salt into ions.
- Identify the acid and the base that formed the salt.

  i.e. $NH_3(aq) + HC\ell(aq) \rightarrow NH_4C\ell(aq)$
- Classify the acid and the base as strong or weak.
- The ion of the **weak** species OR acid/base will undergo hydrolysis.
- It forms the original acid/base and a hydronium or hydroxide ion when it reacts with water.

EXAMPLE 2



Hydrolysis No hydrolysis

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

The salt is **basic**, a **strong base** reacted with a weak acid OR OH^- which is a base is formed.

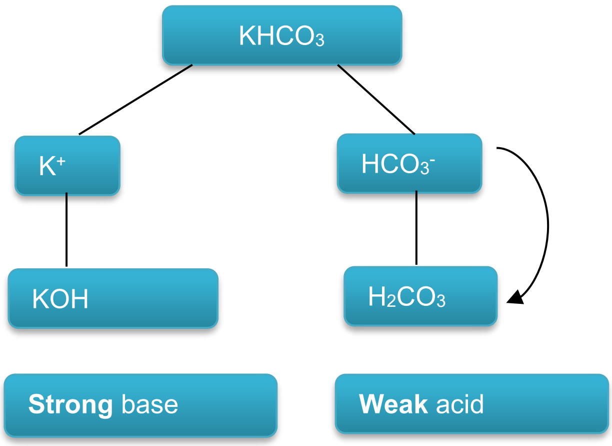
STEPS

- Split the salt into ions.
- Identify the acid and the base that formed the salt.
  i.e. $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COOH(aq) + H_2O(\ell)$
- Identify the strength of the acid and the base.
- The ion of the weak species OR acid/base will undergo hydrolysis.
- It forms the original acid/base and a hydronium or hydroxide ion when it reacts with water

Exercise

Is the salt $KHCO_3$ acidic or basic? Explain with the aid of a balanced chemical equation.

Solution



$HCO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$

The salt is **basic**, OH^- is formed which is a base (A strong base reacted with a weak acid)

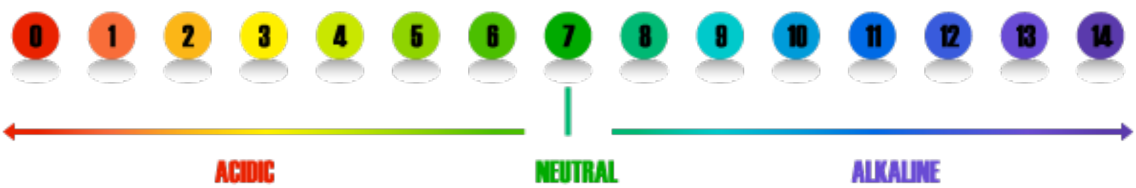
3.9 pH and the pH scale and pH calculations

Examination Guidelines

- Explain the pH scale as a scale of numbers from 0 to 14 used to express the acidity or alkalinity of a solution.
- Calculate pH values of strong acids and strong bases using pH = $-\log[H_3O^+]$.
- Define the concept of K_w as the equilibrium constant for the ionisation of water – the ionic product of water (ionisation constant of water).
- Explain the auto-ionisation of water i.e. the reaction of water with itself to form H_3O^+ ions and OH^- ions.

The pH scale is a scale of numbers from 0 to 14 used to express the acidity or alkalinity of a solution.

Acids have a pH less than 7 (pH<7), a neutral solution has a pH equal to 7 (pH=7), bases have a pH greater than 7 (pH>7).



Acid-base indicators are used to test the pH of solutions, the common indicators are:

- Methyl orange (red in an acidic solution and yellow in a basic solution)
- Bromothymol blue (yellow in an acidic solution and blue in a basic solution)
- Phenolphthalein (colourless in an acidic solution and pink in a basic solution)

Calculation of pH

To calculate the pH of a solution the concentration of H_3O^+ must be known or be determined. The reaction of water with itself produces H_3O^+ and OH^- ions, it is called the auto-ionisation of water. The equation is given below:

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

The expression for the equilibrium constant of the chemical equation given above is:

$$k_w = \frac{[H_3O^+][OH^-]}{[H_2O]^2}$$

the concentration of water is very large (constant) compared to the concentrations of H_3O^+ and OH^- /water is a pure liquid so its concentration will be 1 $mol.dm^{-3}$, it can therefore be omitted from the equilibrium expression, thus $k_w = \frac{[H_3O^+][OH^-]}{1}$, this expression is called the **ionic product** of water, the symbol K_w is used, $K_w = [H_3O^+][OH^-]$. $K_w = 1\times10^{-14}$ at 25°C.

For a **neutral** solution $[H_3O^+] = [OH^-] = 1\times10^{-7}$ $mol\cdot dm^{-3}$.

For an **acidic** solution $[H_3O^+] > 1\times10^{-7}$ $mol\cdot dm^{-3}$ and $[H_3O^+] > [OH^-]$.

For a **basic** solution $[H_3O^+] < 1\times10^{-7}$and $[H_3O^+] < [OH^-]$.

Copy and complete the following table, use $K_w = [H_3O^+][OH^-] = 1\times10^{-14}$

pH	**2**	**3**	**5**	**6**	**7**	**9**	**10**	**12**	**13**
$[H_3O^+]$ $mol\cdot dm^{-3}$	1×10^{-2}	1×10^{-3}		1×10^{-6}		1×10^{-9}		1×10^{-12}	1×10^{-13}
$[OH^-]$ $mol\cdot dm^{-3}$			1×10^{-9}	1×10^{-8}	1×10^{-7}	1×10^{-5}	1×10^{-4}		

Solution

Use the expression $[H_3O^+][OH^-]=1\times10^{-14}$ to calculate the unknown value,

e.g. $[H_3O^+][OH^-]=1\times10^{-14}$

$[H_3O^+](1\times10^{-13})=1\times10^{-14}$

Therefore, $[H_3O^+]=1\times10^{-1}$ $mol\cdot dm^{-3}$

pH	**2**	**3**	**5**	**6**	**7**	**9**	**10**	**12**	**13**
$[H_3O^+]$ $mol\cdot dm^{-3}$	1×10^{-2}	1×10^{-3}	1×10^{-5}	1×10^{-6}	1×10^{-7}	1×10^{-9}	1×10^{-10}	1×10^{-12}	1×10^{-13}
$[OH^-]$ $mol\cdot dm^{-3}$	1×10^{-12}	1×10^{-11}	1×10^{-9}	1×10^{-8}	1×10^{-7}	1×10^{-5}	1×10^{-4}	1×10^{-2}	1×10^{-1}

For pH calculations the formula $pH = -\log[H_3O^+]$ is used.

You are expected to calculate the pH of solutions of **strong acids** and **strong bases** only.

Steps to follow when calculating the pH of an acid.

- Write down a balanced equation for the ionisation reaction of the acid (reaction with water)
- Use ratios to determine the concentration of $[H_3O^+]$.
- Substitute the concentration of $[H_3O^+]$ in the formula $pH = -\log[H_3O^+]$.

Examples

1. Calculate the pH of a 0,2 mol·dm^{-3} HNO_3 solution.

$HNO_3(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + NO_3^-(aq)$

0,2 mol·dm^{-3} 0,2 mol·dm^{-3} (**1:1 ratio**) (monoprotic acid)

$\therefore [H_3O^+] = 0,2$ mol·dm^{-3}

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

$= -\log (0,2)$

$= 0,699$ (**Note:** pH does not have a unit)

2. Calculate the pH of a 0,25 mol·dm^{-3} H_2SO_4 solution.

$H_2SO_4(aq) + H_2O(\ell) \rightleftharpoons 2H_3O^+(aq) + SO_4^{2-}(aq)$

0,25 mol·dm^{-3} 2(0,25) mol·dm^{-3} (**1:2 ratio**) (diprotic acid)

$[H_3O^+] = 0,5$ mol·dm^{-3}

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

$= -\log (0,5)$

$= 0,301$

Steps to follow when calculating the pH of a base.

- Write down a balanced equation for the dissociation reaction of the base.
- Use ratios to determine the **concentration of $[OH^-]$.**
- **Use k_w to calculate the concentration of $[H_3O^+]$**
- Substitute the concentration of $[H_3O^+]$ in the formula $pH = -\log[H_3O^+]$.

Examples

1. Calculate the pH of a 0,4 $mol \cdot dm^{-3}$ NaOH solution.

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

0,4 $mol \cdot dm^{-3}$ 0,4 $mol \cdot dm^{-3}$ (**1:1 ratio**)

$\therefore [OH^{-}] = 0{,}4\ mol \cdot dm^{-3}$

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

$[H_3O^{+}](0{,}4) = 1 \times 10^{-14}$

$\therefore [H_3O^{+}] = 2{,}5 \times 10^{-14}\ mol \cdot dm^{-3}$

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

$= -\log (2{,}5 \times 10^{-14})$

$= 13{,}602$

2. Calculate the pH of a 0,01 $mol \cdot dm^{-3}$ $Ba(OH)_2$ solution.

$Ba(OH)_2(aq) \rightleftharpoons Ba^{2+}(aq) + 2OH^{-}(aq)$

0,01 $mol \cdot dm^{-3}$ 2(0,01) $mol \cdot dm^{-3}$ (**1:2 ratio**)

$\therefore [OH^{-}] = 0{,}02\ mol \cdot dm^{-3}$

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

$[H_3O^{+}](0{,}02) = 1 \times 10^{-14}$

$\therefore [H_3O^{+}] = 5 \times 10^{-13}\ mol \cdot dm^{-3}$

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

$= -\log (5 \times 10^{-13})$

$= 12{,}301$

Calculating the concentration of an acid or base if given the pH

1. Calculate the concentration of the acid HCℓ with a pH = 4,5

   Solution

   - Write down a balanced equation for the ionisation reaction of the acid (reaction with water)

   - Substitute the pH value in the formula pH = $-\log[H_3O^+]$ and calculate the concentration of $[H_3O^+]$ using antilog, use the button 10 on your calculator, i.e., press 2nd F/SHIFT then log

   - Use ratios to determine the concentration of the acid.

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

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

$$4,5 = -\log [H_3O^+]$$

$$[H_3O^+] = 10^{-4,5}$$

$$= 3,162 \times 10^{-5} \text{ mol·dm}^{-3}$$

Therefore $[HC\ell] = 3,162 \times 10^{-5}$ mol·dm^{-3} (**1:1 ratio**)

2. Calculate the concentration of the base $Ca(OH)_2$ with a pH of 11,2.

Solution

- Write down a balanced equation for the dissociation reaction of the base.
- Substitute the pH value in the formula pH = -log[H_3O^+] and calculate the concentration of [H_3O^+] using antilog, use the button 10 on your calculator, i.e., press 2nd F/SHIFT then log
- **Use k_w to calculate the concentration of OH^-.**
- Use ratios to determine the concentration of the base.

$$Ca(OH)_2(aq) \rightleftharpoons Ca^{2+}(aq) + 2OH^-(aq)$$

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

$$11{,}2 = -\log [H_3O^+]$$

$$[H_3O^+] = 10^{-11{,}2}$$

$$= 6{,}310 \times 10^{-12} \text{ mol·dm}^{-3}$$

$$[H_3O^+][OH^-]=1\times10^{-14}$$

$$(6{,}310 \times 10^{-12})\ [OH^-]=1\times10^{-14}$$

$$[OH^-]=0{,}00158 \text{ mol·dm}^{-3}$$

Therefore [$Ca(OH)_2$] = ½ (0,00158) = 0,0007924 ($7{,}924 \times 10^{-4}$) mol·dm^{-3} (**ratio 2:1**)

3.10 Titrations and Stoichiometric Calculations

Examination Guidelines

Write down neutralisation reactions of common laboratory acids and bases.

Examples: $HC\ell(aq) + NaOH(aq)/KOH(aq) \rightarrow NaC\ell(aq)/KC\ell(aq) + H_2O(\ell)$
$HC\ell(aq) + Na_2CO_3(aq) \rightarrow NaC\ell(aq) + H_2O(\ell) + CO_2(g)$
$HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(\ell)$
$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$
$(COOH)_2(aq) + NaOH(aq) \rightarrow (COO)_2Na_2(aq) + H_2O(\ell)$
$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$

Note: The above are examples of equations that learners will be expected to write from given information. However, any other neutralisation reaction can be given in a question paper and used to assess e.g. stoichiometry calculations.

- Motivate the choice of a specific indicator in a titration. Choose from methyl orange, phenolphthalein & bromothymol blue.
- The equivalence point of a titration as the point at which the acid /base has completely reacted with the base/acid.
- The endpoint of a titration as the point where the indicator changes colour.
- Perform stoichiometric calculations based on titrations of a strong acid with a strong base, a strong acid with a weak base and a weak acid with a strong base. Calculations may include percentage purity.

Terms

Neutralisation is a chemical reaction in which an acid and a base interact, with the formation of a salt and water, carbon dioxide will also be formed if a carbonate is used. **(see table below)**

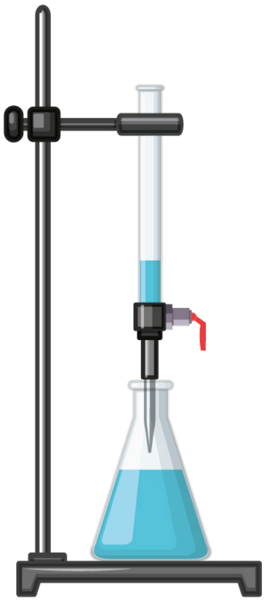
A **titration** is when a standard solution (solution of known concentration) is added to the sample solution (unknown concentration) until the **end point** (the point where the indicator changes colour) is reached.

Examples

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

$HC\ell(aq) + Na_2CO_3(aq) \rightarrow NaC\ell(aq) + H_2O(\ell) + CO_2(g)$

The following setup is used in a titration:



An **acid-base indicator** is used to determine the **end point** of a titration. You must be able to choose the correct indicator for a titration.

ACID	BASE	INDICATOR	pH colour change range
Strong	Strong	Bromothymol blue	6,0 – 7,6
Strong	Weak	Methyl Orange	3,2 – 4.4
Weak	Strong	Phenolphthalein	8,2 – 10,0

e.g., For a titration of NaOH (strong base) against HCℓ (strong acid), bromothymol blue is used. The equivalence point for the reaction of a strong acid and a strong base is approximately 7.

3.10.1 Basic Calculations

Tips

1. Calculate the number of moles, if given volume and concentration of a substance using n = cV OR $n=\frac{m}{M}$ if given a mass.
2. Use the mole ratio from the balanced equation to calculate the number of moles of the other substance required.
3. Simply calculate the concentration, volume or mass of the substance depending on what is asked, using $c=\frac{n}{v}$ OR $n=\frac{m}{M}$.

Examples

1. Calculate the concentration of 4 g magnesium hydroxide dissolved in 24 ml of distilled water.

$M[Mg(OH)_2] = 24 + 2(16) + 2(1) = 58\ g\cdot mol^{-1}$

- Calculate the molar mass of $Mg(OH)_2$
- Calculate the number of moles using $n=\frac{m}{M}$,
- Convert ml/cm³ to dm³ by dividing the volume by 1000.
- Calculate the concentration using the formula $c=\frac{n}{V}$

$$n=\frac{m}{M}$$

$$n=\frac{4}{58}$$

$$=0{,}06896\ \text{mol}$$

$$c=\frac{n}{V}$$

$$=\frac{0{,}06896}{0{,}024}$$

$$=2{,}873\ mol\cdot dm^{-3}$$

$1\ cm^3 = 1\ ml$

$1000\ cm^3 = 1\ dm^3$

$1\ dm^3 = 1\ L$

2. Calculate the mass of H_2SO_4 in 30 cm^3 of a 0,02 $mol\cdot dm^{-3}$ solution.

$$c=\frac{n}{V}$$

$$0{,}02=\frac{n}{0{,}03}$$

$$n=0{,}0006\ \text{mol}$$

$$n=\frac{m}{M}$$

$$0{,}0006=\frac{m}{98}$$

$$m=0{,}0588\ g$$

- Convert ml/cm³ to dm³ by dividing the volume by 1000.
- Calculate the number of moles using the formula $c=\frac{n}{V}$
- Calculate the molar mass of H_2SO_4.
- Calculate the mass using the formula $n=\frac{m}{M}$,

3.10.2 Dilution Calculations

Dilution is required when we prepare a certain concentration of a solution from a more concentrated solution. When diluting a solution, the **number of moles does NOT CHANGE**, the number of moles before dilution(n_1) = number of moles after dilution(n_2).

From $n_1=c_1V_1$ (before dilution) and $n_2=c_2V_2$ (after dilution), it can be deduced that $c_1V_1= c_2V_2$

Example

Calculate the volume of 0,5 mol·dm^{-3} H_2SO_4 that must be added to give 50 cm^3 of the H_2SO_4 with concentration 0,025 mol·dm^{-3}.

Solution

$$c_1V_1=c_2V_2$$
$$(0{,}5)V_1=(0{,}025)(50)$$
$$V_1=2{,}5\ \mathrm{cm}^3$$

3.10.3 Stoichiometric Calculations

If given a mass use $n=\frac{m}{M}$ to calculate the number of moles, the same formula will be used to calculate a required mass.

If given concentration and volume use $c=\frac{n}{V}$ to calculate the number of moles

Use mol ratios to calculate the number of moles of the required substance or solution.

Calculate the required concentration or volume by using $c=\frac{n}{V}$

If **initial** or **excess** amounts are mentioned, the formulae $n_{excess} = n_{initial} – n_{reacted}$,

$n_{initial} = n_{reacted} + n_{excess}$ or $n_{reacted} = n_{initial} - n_{excess}$ should be used.

Example

1. 10 ml of a 0,25 mol·dm^{-3} sodium hydroxide solution reacts with 0,40 mol·dm^{-3} H_2SO_4 according to the balanced chemical equation given below. Calculate the volume of acid needed to react with the base.

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

Solution

Calculate the number of moles of NaOH first.

$\frac{10}{1000} = 0{,}01$

(1000 ml/cm^3 = 1 L/dm^3)

$n(NaOH)=cV$

$= (0{,}25)(0{,}010)$

$=0{,}0025$ mol

Calculate the number of moles using $c=\frac{n}{V}$.

$\frac{n(H_2SO_4)}{n(NaOH)}=\frac{1}{2}$

Use mole ratios to calculate the number of moles.

$\frac{n(H_2SO_4)}{0{,}0025}=\frac{1}{2}$

$n(H_2SO_4)=\frac{1}{2}\times 0{,}0025$

$=0{,}00125$ mol

Calculate the volume using $c=\frac{n}{V}$.

$c=\frac{n}{V}$

$0{,}40=\frac{0{,}00125}{V}$

$V=0{,}003125$ dm^3

$=3{,}125$ cm^3

OR

$\frac{c_aV_a}{c_bV_b}=\frac{n_a}{n_b}$

$\frac{0{,}4\times V_a}{0{,}25\times 0.010}=\frac{1}{2}$

$V_a=0{,}003125$ dm^3

A learner adds a sample of calcium carbonate to 50,0 cm^3 of hydrochloric acid of concentration 1,0 mol.dm^{-3}. The hydrochloric acid is in **excess**.

The balanced equation for the reaction that takes place is:

$CaCO_3 + 2HC\ell \rightarrow CaC\ell_2 + CO_2 + H_2O$

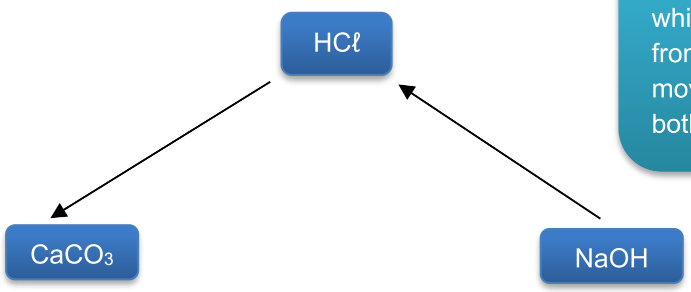
The **excess** HCℓ is now neutralised by 28,0 cm^3 of a 0,5 mol.dm^{-3} sodium hydroxide solution.

The balanced equation for this reaction is:

$HC\ell + NaOH \rightarrow NaC\ell + H_2O$

Calculate the mass of calcium carbonate in this sample.

Solution



The information given will indicate from which side to start. In this one we will start from NaOH reacting with the acid, then move to $CaCO_3$. **Note**: $HC\ell$ reacts with both.

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

$c_b = 0,5$

$V_b = 0,028$

Write down the data/values below each reagent, it will become easy to see which reagent has complete/incomplete information/data.

Step 1: Calculate the total number of moles of $HC\ell$ (**initial**)

$n(HCl)_{initial} = cV$

$= (1,0)(0,050)$

$= 0,05$ mol

Step 2: Calculate the number of moles of NaOH.

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

$c_b = 0,5$

$V_b = 0,028$

Write down the data/values below each reagent, it will become easy to see which reagent has complete/ incomplete information/data.

$n(NaOH) = cV$

$= (0,5)(0,028)$

$= 0,014$ mol

Step 3: Calculate the number of moles HCℓ in **excess** (reacted with NaOH).

$$\frac{n(HCl)}{n(NaOH)}=\frac{1}{1}$$

$$\frac{n(HCl)}{0,014}=\frac{1}{1}$$

$$n(HCl)_{excess}=0,014\text{ mol}$$

Step 4: Calculate the total number of moles of HCℓ **reacted** (reacted with $CaCO_3$)

$n(HC\ell)_{reacted} = n(HC\ell)_{initial} - n(HC\ell)_{excess}$

$= 0,05 – 0,014$

$= 0,036$ mol

Step 5: Calculate the number of moles of $CaCO_3$ reacted with HCℓ.

$CaCO_3 + 2HC\ell \rightarrow CaC\ell_2 + CO_2 + H_2O$

$n_a = 0,036$

$$\frac{n(CaCO_3)}{n(HCl)}=\frac{1}{2}$$

$$\frac{n(CaCO_3)}{0,036}=\frac{1}{2}$$

$$=\frac{1}{2}\times 0,036$$

$$=0,018\text{ mol}$$

Step 6: Calculate the mass of $CaCO_3$.

$$n=\frac{m}{M}$$

$$0,018=\frac{m}{100}$$

$$=0,018\times 100$$

$$=1,8\text{ g}$$

Calculate the molar mass of $CaCO_3$.

$M[CaCO_3] = 40+12+3(16)$

$= 100\ g\cdot mol^{-1}$

3.11 K_a and K_b values

- Interpret K_a values of acids to determine the relative strength of given acids. Interpret K_b values of bases to determine the relative strength of given bases.
- Compare strong and weak acids by looking at:
  - pH (monoprotic and diprotic acids)
  - Conductivity
  - Reaction rate

K_a is the ionisation constant of an acid and k_b is the dissociation/ionisation constant of a base. The ionisation constants are a measure of the relative strength of an acid or base. Strong acids have large k_a values, because they ionise completely, and weak acids have small k_a values since they ionise incompletely/partially.
Strong bases have large k_b values, because they dissociate completely, and weak bases have small k_b values since they ionise/dissociate incompletely/partially.

Strong acids have K_a values larger than 1
Weak acids have K_a values smaller than 1

Table: Ka values of some common acids

Formula	Name	K_a values	Type
HBr	Hydrobromic acid	1×10^9	Strong acid
HCℓ	Hydrochloric acid	$1,3\times10^6$	Strong acid
H_2SO_4	Sulphuric acid	1st H^+ :1×10^3 2nd H^+ :1×10^{-2}	Strong acid
HNO_3	Nitric acid	1×10^9	Strong acid
$(COOH)_2$	Oxalic acid	1st H^+ :$5,5\times10^{-2}$ 2nd H^+ :1×10^{-5}	Weak acid
CH_3COOH	Ethanoic acid	$1,7\times10^{-7}$	Weak acid

Examples

1. Write down the k_a or k_b expressions of the following acids/bases.

(a) NH_3 (aq) + H_2O (ℓ) $\rightleftharpoons$ NH_4^+ (aq) + OH^- (aq)

(b) HNO_3 (aq) + H_2O (ℓ) $\rightleftharpoons$ H_3O^+ (aq) + NO_3^- (aq)

Use the same principles as used when writing k_c in chemical equilibrium, i.e. liquids and solids are not included in the expression.

Solution

(a) $k_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$

Since NH_3 is a weak base, its k_b value will be small.

(b) $k_a = \frac{[H_3O^+][NO_3^-]}{[HNO_3]}$

Since HNO_3 is a strong acid, its k_a value will be large.

2. The K_a values for two weak acids are as follows:

NAME	FORMULA	K_A
Oxalic acid	$(COOH)_2$	$5{,}5\times10^{-2}$
Carbonic acid	H_2CO_3	$4{,}5\times10^{-7}$

Which acid, Oxalic acid or Carbonic acid, is stronger? Give a reason for the answer.

Solution

Oxalic acid has a higher K_a value/Carbonic acid has a lower K_a value.

4. Exercises

4.1 Multiple Choice Questions

1 Which ONE of the following solutions has the highest conductivity?

A $0,1\ mol\cdot dm^{-3}\ H_2CO_3$

B $0,1\ mol\cdot dm^{-3}\ (COOH)_2$

C $0,1\ mol\cdot dm^{-3}\ HNO_3$

D $0,1\ mol\cdot dm^{-3}\ CH_3COOH$ (2)

2 Consider the following acids:

ACID A	ACID B
0,1 mol·dm^{-3} hydrochloric acid	1,0 mol·dm^{-3} ethanoic (acetic) acid

Which ONE of the following statements about the acids is CORRECT?

A Acid A is weaker and more dilute than acid B.

B Acid A is stronger and more concentrated than acid B.

C Acid A is stronger but more dilute than acid B

D Acid A is weaker and more concentrated than acid B.

3 Ammonium sulphate ($(NH_4)_2SO_4$) is dissolved in water. Which ONE of the following statements regarding the solution which is formed, is CORRECT?

A pH = 7

B $[H_3O^+] \cdot [OH^-] < 1 \times 10^{-14}$

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

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

4 A solution of ethanoic acid (acetic acid) is titrated against a standard sodium hydroxide solution. Which ONE of the following indicators would be the most suitable for this titration?

	Indicator	pH range of the indicator
A	Phenolphthalein	8,3 - 10
B	Methyl orange	3,1 – 4,4
C	Bromothymol blue	6,0 – 7,6
D	Universal indicator	Changes colour over a wide range of pH values

(2)

5 Which ONE is the conjugated acid of $HC_2O_4^-$?

A $C_2O_4^{2-}$

B OH^-

C $H_2C_2O_4$

D $H_2C_2O_4^-$ (2)

6 An aqueous solution that contains more hydronium ions than hydroxide ions is a(n)

A Basic solution

B Acidic solution

C Neutral solution

D None of the above (2)

7 According to the Brønsted-Lowry theory, a base ……..

A dissociates in aqueous solution

B raises the hydrogen ion concentration of an aqueous solution above 1.0×10^{-7} mol.dm^{-3}.

C tastes bitter and feels slippery

D accepts a proton during a collision with an acid (2)

8 Which ONE of the following species CANNOT act as a Brønsted-Lowry acid and a Brønsted-Lowry base?

A $H_2PO_4^-$

B H_2O

C HSO_4^-

D CH_3COOH (2)

9 A sodium hydroxide (NaOH) solution of concentration 0,1 mol·dm^{-3} is added dropwise to an ethanoic acid (CH_3COOH) solution of concentration 0,1 mol·dm^{-3}. Which ONE of the following substances will increase in concentration as sodium hydroxide is added dropwise?

A H_3O^+

B OH^-

C CH_3COO^-

D H_2O (2)

10 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:

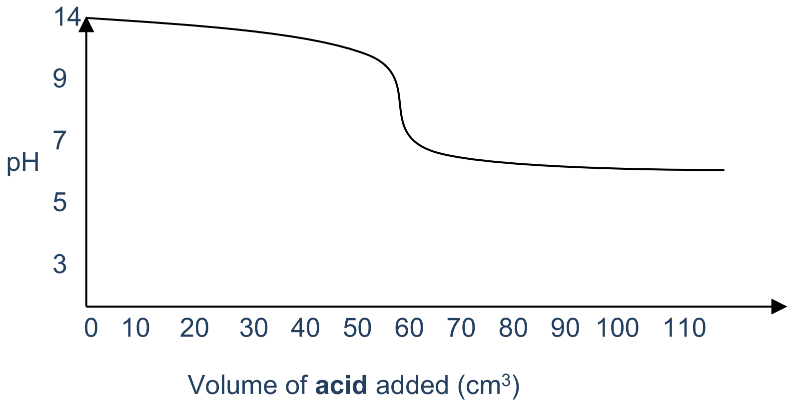
A CH_3COOH and CH_3COO^-

B CH_3COOH and OH^-

C CH_3COO^- and H_2O

D CH_3COOH and H_2O (2)

11 The graph (not drawn to scale) for pH versus volume for the titration of an unknown acid with a base was obtained, which ONE of the following combinations of base and acid best fits the graph?



A Strong acid – weak base

B Weak acid – strong base

C Strong acid – strong base

D Weak acid – weak base (2)

4.2 Structured Questions

1. Classify each of the following as strong acid or weak acid. Sulphuric acid, hydrochloric acid, carbonic acid.
2. State whether each of the following solutions can act as a Lowry-Brønsted acid or Lowry-Brønsted base. Give a reason for the answer.
   (a) $Ca(OH)_2$
   (b) HBr
3. Give the formula of the conjugate acid or conjugate base for each of the following, indicate whether it is an acid (conjugate) or base (conjugate).
   (a) H_3O^+
   (b) $C\ell^-$
4. The K_a value of benzoic acid (C_6H_5COOH) at 25°C is $6{,}3 \times 10^{-5}$. Can the acid be classified as a STRONG ACID or WEAK ACID? Explain.
5. Is the salt K_2CO_3 acidic or basic? Use a balanced equation to explain/support the answer.
6. A student wishes to prepare 400 cm^3 of a 0,1 $mol{\cdot}dm^{-3}$ LiOH solution from a 0,25 $mol{\cdot}dm^{-3}$ solution. What volume of the 0,25 $mol{\cdot}dm^{-3}$ solution must be diluted?
7. The pH of a blood sample was measured using a pH meter, the pH was found to be 7,45. Calculate the concentration of the hydroxide ions in the blood.
8. Sulphuric acid reacts with sodium hydroxide according to the balanced equation given below:

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

   25 cm^3 of 0,3 $mol{\cdot}dm^{-3}$ sulphuric acid is mixed with 25 cm^3 0,3 $mol{\cdot}dm^{-3}$ sodium hydroxide. Calculate the pH of the resulting mixture.
9. A 0,48 g sample of calcium carbonate reacts with 50 cm^3 of a 0,11 $mol{\cdot}dm^{-3}$ of nitric acid solution according to the balanced equation given below:
   $CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O + CO_2$
   Calculate the percentage purity of the $CaCO_3$.

4.3 Typical Examination Questions

QUESTION 1

1.1 A bottle in a laboratory contains dilute sulphuric acid of unknown concentration. Learners wish to determine the concentration of the sulphuric acid solution. To do this they titrate the sulphuric acid against a standard potassium hydroxide solution of concentration 0.2 mol·dm^{-3}.

The balanced equation for the reaction taking place is:

$2KOH + H_2SO_4 \rightarrow K_2SO_4 + 2H_2O$

1.1.1 What is a standard solution? (1)

1.1.2 Calculate the mass of KOH which he must use to make 300 cm^3 of a 0.2 mol·dm^{-3} KOH solution. (3)

1.1.3 Calculate the pH of the 0.2 mol·dm^{-3} KOH solution. (5)

1.1.4 Which one of the indicators listed in the table below should he use in this titration? Explain your answer.

INDICATOR	pH
Methyl orange	2.9 – 4.0
Methyl red	4.4 – 6.0
Bromothymol blue	6.0 – 10.0
phenolpthalein	8.3 – 10.0

(2)

1.1.5 During the titration the learners find that 15 cm^3 of the KOH solution neutralises 20 cm^3 of the H_2SO_4 solution. Calculate the concentration of the H_2SO_4 solution. (4)

1.2 An impure sample of calcium oxalate, CaC_2O_4, with a mass of 0.803 g, is titrated with 15.70 cm^3 of a 0.101 mol·dm^{-3} $KMnO_4$.

The net reaction is…

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

Calculate the percentage purity of the CaC_2O_4 in the original sample. (6)

[21]

QUESTION 2

2.1 Sulphuric acid is a **strong** diprotic acid.

Define the term *strong acid* (2)

2.2 HSO_4^- can behave either as an acid or a base.

2.2.1 Give the term that is used for substances such as HSO_4^- (1)

2.2.2 Write down the balanced equation for the reaction of HSO_4^- with H_2O in which it acts as an acid. (2)

2.3 Calculate the pH of a $Mg(OH)_2$ solution with a concentration of 0,2 $mol \cdot dm^{-3}$.
Assume that $Mg(OH)_2$ dissociates completely. (4)

2.4 Vinegar is (3 – 5) % ethanoic acid by mass, with the remaining mass being a solvent. To determine the percentage of ethanoic acid in a vinegar sample, it is titrated against a NaOH solution. The balanced equation for the reaction is:

$$CH_3COOH\ (aq) + NaOH\ (aq) \rightarrow CH_3COONa\ (aq) + H_20\ (\ell)$$

A 10 g sample of vinegar is titrated against a 0,309 $mol.dm^{-3}$ NaOH solution.19,57 cm^3 of NaOH is required to reach end point.

2.4.1 Determine the mass of the ethanoic acid in the 10 g sample. (5)

2.4.2 Show by calculation that the percentage of the ethanoic acid is within the given range. (2)

The table below provides information of three different indicators:

INDICATOR	COLOUR CHANGE	COLOUR CHANGE pH RANGE
Methyl orange	Red – yellow	3,0 – 4,4
Bromothymol blue	Yellow – blue	6,0 – 7,6
Phenolphthalein	Colourless - pink	8,2 – 9,8

2.4.3 Use the information in the table above and choose a suitable indicator to use in the above titration. Give a reason for the answer. (2)

2.4.4 The ethanoate ions that form during the reaction, <u>react with water</u> according to the balanced equation below:

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

Write down the name of the process described by the underlined phrase. (1)

[19]

QUESTION 3

3.1 The acid HF ionises according to the following equation:

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

When a 0,10 mol·dm^{-3} solution of HF is prepared, it is found that the concentration of the F^- (aq) ions is 0,018 mol·dm^{-3}. The temperature of the solution is 25 °C.

3.1.1 Is HF a strong acid? (Write down only YES or NO.) (1)

3.1.2 Give a reason for the answer to QUESTION 3.1.1. (2)

3.2 0,50 dm^3 of a $HC\ell$ solution of concentration **x** mol.dm^{-3} is added to 0,80 dm^3 of a 0,25 mol·dm^{-3} solution of NaOH. At the completion of the reaction, it is found that 0,12 mol of hydroxide ions (OH^-) is present in the solution. The balanced equation for the reaction is:

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

3.2.1 Name the apparatus you will use to measure out the acid solution. (2)

3.2.2 Calculate **x**, the concentration of the $HC\ell$ solution. (6)

3.2.3 Calculate the concentration of the hydroxide ions (OH^-) at the completion of the reaction. (3)

3.2.4 Calculate the pH of the solution at the completion of the reaction. (4)

[18]

QUESTION 4

4.1 During a lesson on acids and bases, a teacher wrote the following equations on the board:

$HC\ell(g) + H_2O(g) \rightarrow H_3O^+(aq) + C\ell^-(aq)$……………...……..(I)

$NH_3(aq) + H_2O(g) \rightleftarrows NH_4^+(aq) + OH^-(aq)$……………………..(II)

4.1.1 Give the Lowry-Brönsted definition of a base. (2)

4.1.2 Which ONE of the compounds in reactions (I) and (II) is an ampholyte? (2)

4.2 Write down

4.2.1 the meaning of the term *diprotic acid*. (2)

4.2.2 the formula of a common *diprotic acid*. (2)

[8]

5. Solutions to Exercises

5.1 Solutions to Multiple Choice Questions

1 C, It's a strong acid it ionises completely, there will be more ions in the solution.
2 C, Acid A is a strong acid, Acid B is a weak acid and the concentration of Acid B is higher than the concentration of Acid A
3 C, a strong acid reacted with a weak base. (Hydrolysis)
4 A, a weak acid is titrated against a strong base.
5 C, H^+ was 'added' to make it an acid
6 B, it has a high concentration of hydronium ions.
7 D, a base is a proton acceptor.
8 D, it can only donate a proton, it cannot accept a proton.
9 B, the hydroxide ions are added.
10 A, $CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$
11 B, the end point is above the pH of 7, a strong base reacted with a weak acid.

5.2 Solutions to Structured Questions

1 Sulphuric acid – strong acid ✓
Hydrochloric acid – strong acid ✓
Carbonic acid – weak acid ✓ (3)

2 (a) It is a base✓, it can accept a proton✓, $OH^- + H^+ \rightleftharpoons H_2O$
(b) It is an acid✓, it can donate a proton✓, $HBr + H_2O \rightleftharpoons H_3O^+ + Br^-$ (4)

3 (a) H_2O✓ (conjugate base) a proton was 'removed', i.e., can accept a proton✓
(b) $HC\ell$✓ (conjugate acid) a proton was 'added', i.e., can donate a proton. ✓ (4)

4 Weak acid✓, it has a low k_a value✓, it ionises incompletely. (2)

5 $CO_3^{2-} + H_2O$ ✓$\rightleftharpoons HCO_3^- + OH^-$ ✓
A strong base (OH^-) was formed✓ (A strong base reacted with a weak acid) (3)

6 $c_1V_1=c_2V_2$
$(0,1)(400)$✓$=(0,25)V_2$ ✓
$V_2=\frac{(0,1)(400)}{0,25}$
$=160\ cm^3$✓ (3)

7 pH = -log $[H_3O^+]$✓

7,45✓= -log $[H_3O^+]$

$[H_3O^+] = 10^{-7,45}$

$= 3,548 \times 10^{-8}$ mol·dm^{-3}✓

$[H_3O^+][OH^-] = 1\times10^{-14}$

$(3,548 \times 10^{-8})\ [OH^-] = 1\times10^{-14}$✓

$[OH^-] = 2,818 \times 10^{-7}$ mol·dm^{-3}✓

(5)

8 $n(NaOH)=cV$✓ $n(H_2SO_4)=cV$ (10)

$=(0,2)(0,025)$✓ $=(0,3)(0,025)$✓

$=0,005$ mol $=0,0075$ mol

NaOH is the limiting reactant.

$$\frac{n(H_2SO_4)_{reacted}}{n(NaOH)}=\frac{1}{2}✓$$

$$n(H_2SO_4)_{reacted}=\frac{1}{2}\times0,005$$

Use mol ratios to find the number of moles H_2SO_4 reacted.

$=0,0025$ mol

$n(H_2SO_4)_{excess} = 0,0075 – 0,0025$✓ $= 0,005$ mol

$$c(H_2SO_4)=\frac{n}{V}✓$$

$$=\frac{0,005}{0,05✓}$$

$=0,1$ mol

The new volume is now 50 cm^3, i.e.

25 + 25 =50

$H_2SO_4 + 2H_2O \rightleftharpoons 2H_3O^+ + SO_4^{2-}$

0,1 2(0,1)

$[H_3O^+] = 0.2$ mol·dm^{-3}

pH = -log $[H_3O^+]$✓

= -log (0,2) ✓

= 0,7✓

9 $n(HNO_3)=cV$✓

$=(0,11)(0,05)$✓

$=0,0055$ mol (7)

$n(CaCO_3)=\frac{1}{2}✓\times 0{,}0055$

$=0{,}00275$ mol

$n=\frac{m}{M}$

$0{,}00275=\frac{m}{100✓}$

$m=0{,}275$ g

$\%\ purity=\frac{\text{mass pure substance}}{\text{mass impure substance}}\times 100✓$

$=\frac{0{,}275}{0{,}48}✓\times 100$

$=57{,}292\ \%$✓

5.3 Solutions to Typical Examination Questions

QUESTION 1

1.1.1 A solution of known concentration.✓ (1)

1.1.2 **OPTION 1**

$M(KOH) = 56\ g\cdot mol^{-1}$
$m = cMV$✓
$= 0{,}2 \times 56 \times 0{,}3$✓
$= 3{,}36$ g✓

OPTION 2

$M(KOH) = 56\ g\cdot mol^{-1}$

$n = cV$
$= 0{,}2 \times 0{,}3$
$= 0{,}06$ ✓
$m = nM$
$= 0{,}06 \times 56$ ✓
$= 3{,}36$ g✓ (3)

1.1.3 0,2 mol KOH yields 0,2 mol OH^-

$K_w = [H_3O^+][OH^-]$✓

$10^{-14} = [H_3O^+](0{,}2)$

$[H_3O^+] = 5 \times 10^{-14}$✓

$pH = -\log[H_3O^+]$✓

$= -\log(5 \times 10^{-14})$ ✓

$= 13{,}3$✓

1.1.4 Bromothymol blue;✓ H_2SO_4 is a strong acid and KOH is a strong base✓ The equivalence point will be at approximately pH = 7 which is the endpoint of bromothymol blue. (2)

1.1.5 **OPTION 1**

$$\left(\frac{n_a}{n_b}\right) = \left(\frac{C_aV_a}{C_bV_b}✓\right)$$

$$\left(\frac{1}{2}\right)✓ = \frac{C_a \times 20}{0,2\times 15}✓$$

$$C_a = 0,075 mol\cdot dm^{-3}✓$$

OPTION 2

$$n(NaOH) = cV ✓$$
$$= 0,2\times 0,015$$
$$= 0,003 \text{ mol}$$
$$\frac{n(H_2SO_4)}{n(NaOH)} = \frac{1}{2}$$
$$n(H_2SO_4) = \frac{1}{2}(0,003)✓$$
$$= 0,0015 \text{ mol}$$
$$c = \frac{n}{V}$$
$$= \frac{0,0015}{0,020}✓$$
$$= 0,075 \text{ mol}\cdot dm^{-3}✓$$

(4)

1.2 Moles of MnO_4^- : $n = cV$✓

$$= \frac{15,70 \times 0,101}{1000}$$

$$= 1,5857 \times 10^{-3} \text{ mol}✓$$

Moles of $C_2O_4^{2-}$ $= \frac{5}{2} \times 1,5875 \times 10^{-3}$

$$= 3,9643 \times 10^{-3}\ mol✓$$

$$n(CaC_2O_4) = n(C_2O_4^{2-})$$

$$m = nM$$

Mass of CaC_2O_4 = $3,9643 \times 10^{-3} \times 128$✓

$$= 0,50743 g$$

Percentage of CaC_2O_4 = $\frac{0,50743}{0,803} \times 100$✓

$$= 63,19\%✓$$

(6)

[21]

QUESTION 2

2.1 A strong acid is an acid that ionises completely in water ✓ to form a high concentration of H_3O^+ ions. ✓ (2)

2.2.1 Ampholyte ✓ (1)

2.2.2 $HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$ ✓✓ (2)

2.3 **OPTION 1**

$[OH^-] = 0{,}4\ mol{\cdot}dm^{-3}$ ✓ *(ratio 1:2)* ($Mg(OH)_2 \rightarrow Mg^{2+} + 2OH^-$)

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

$[H_3O^+]\ (0{,}4) = 1 \times 10^{-14}$

$$[H_3O^+] = \frac{1\times10^{14}}{0{,}4}$$

$= 2{,}5 \times 10^{-14}\ mol.dm^{-3}$

$pH = -\log\ [H_3O^+]$ ✓

$= -\log\ (2{,}5 \times 10^{-14})$

$= 13{,}6$ ✓

OPTION 2

$[OH^-] = 0{,}4\ mol{\cdot}dm^{-3}$ ✓ (ratio)

$pOH = -\log[OH^-]$ ✓ $= -\log(0{,}4) = 0{,}4$

$pH + pOH = 14$ ✓ (4)

$\therefore pH = 13{,}6$ ✓

2.4.1 $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

$c = 0{,}309\ mol{\cdot}dm^{-3}$

$V = 0{,}01957\ dm^{-3}$

$n_{NaOH} = c \times V$ ✓

$= 0{,}309 \times 0{,}01957$

$= 6{,}05 \times 10^{-3}\ mol$ ✓

$m = n \times M_{CH_3COOH}$ ✓ *(ratio 1:1)*

$= (6{,}05 \times 10^{-3}) \times 60$ ✓

$= 0{,}363\ g$ ✓ (5)

2.4.2 % = 0,363 / 10 x 100 = 3,63% ✓ Yes ✓ (2)

2.4.3 Phenolphthalein✓

A weak acid reacted with a strong base ✓.

OR

pH of solution $\approx \frac{6+13}{2} \approx 9,5$

(2)

2.4.4 Hydrolysis✓ (1)

[19]

QUESTION 3

3.1.1 No✓ (1)

3.1.2 The acid did not ionise completely/it ionised incompletely, since $0,018\ mol\cdot dm^{-3} < 0,10\ mol\cdot dm^{-3}$.✓✓ (2)

3.2.1 Burette ✓✓ (2)

3.2.2 $HC\ell(aq) + NaOH(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$

$c_a = ?$ $c_b = 0,25$

$V_a = 0,50$ $V_b = 0,80$

$n(NaOH)_{initial} = cV$ ✓

$= (0,25)(0,80)$ ✓

$= 0,2$ mol

$n(NaOH)_{reacted} = n(NaOH)_{initial} - n(NaOH)_{excess}$

$= 0,20 - 0,12$ ✓

$= 0,08$ mol

$n(HC\ell) = n(NaOH)_{reacted} = 0,08$ mol ✓

$$c = \frac{n}{V}$$

$$= \frac{0,08}{0,50}\ ✓$$

$= 1,6\ mol{\cdot}dm^{-3}$ ✓ (6)

3.2.3 $c = \frac{n}{V}$ ✓

$$= \frac{0,12}{1.3\ ✓}$$

$= 0,0923\ mol{\cdot}dm^{-3}$ ✓ (3)

3.2.4 $[H_3O^+][OH^-] = 1\times10^{-14}$

$[H_3O](0,0923) = 1\times10^{-14}$

$[H_3O^+] = 1,0834\times10^{-13}\ mol{\cdot}dm^{-3}$

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

$= -\log(1,0834\times10^{-13})$

$= 12,965$ (4)

[16]

QUESTION 4

4.1.1 Is a proton donor (2)

4.1.2 H_2O (2)

4.2.1 An acid which can donate a maximum of two protons.✓✓ (2)

4.2.2 H_2SO_4 ✓✓ (2)

[8]

6. Examination guidance (Acids and Bases)

- In Acids and Bases a lot of stoichiometry which was learned in Grades 10 and 11 is used, for instance, calculating the number of moles if given masses, concentration, number of particles or gas volumes and using ratios in calculations of product formed, reactant used, etc. You must be able to use the formulae, $n=\frac{m}{M}$, $n=\frac{V}{V_m}$, $n=\frac{N}{N_A}$, $c=\frac{n}{V}$ to calculate the number of moles. You must revise your work on limiting reactants because some questions might involve limiting reactants.
- When doing multistep calculations e.g., when calculating the number of moles of NaOH, the formula should be as follows:

  n(NaOH) = cV NOT just n = cV

- When there are excess number of moles, initial number of moles, number of moles used/reacted, number of moles remaining, you should write a descriptor/label, e.g., $n(NaOH)_{initial}$, $n(NaOH)_{reacted/used}$, $n(NaOH)_{excess/remaining}$, this will make it easy to identify what you have and what must be calculated/determined.
- When substituting values given in the question paper they should not be rounded off, they should be used as they were given in the question paper. E.g. if given 0,00687, substitute 0,00687 not 0,01.
- The formula $c=\frac{m}{VM}$ should only be used when dealing with solutions, it should NOT be used for solids. Preferably use $n=\frac{m}{M}$ first and then $c=\frac{n}{V}$ (only for solutions).
- Always calculate the number of moles using relevant formulae, use ratios to find the unknown number of moles, one will always earn a mark for calculating the number of moles and using the ratios (**Easy to Score Marks**).
- To calculate the antilog, i.e., to calculate the concentration of $[H_3O^+]$ in the pH formula, use 10 to the power of, e.g. $10^{-7,6}$. Most calculators have the button

  10 , which should be used, i.e., press 2nd F/SHIFT then log

7. Study and Examination Tips: Physical Sciences

- Always copy formulae correctly from the data sheet, do not rely on your memory.
- Substitute directly into the original formula, do not manipulate the formula before substituting.
- Rounding off should only be done at the final answer of a calculation. One should not round off in each step as it leads to an incorrect answer. The instruction in the paper reads a 'MINIMUM of TWO decimal digits' and NOT a 'MAXIMUM of TWO decimal digits', you may leave your answer with more than TWO decimal digits.
- Always start with a question you feel you will manage or in which you will score good marks.
- Learn the definitions as given in the examination guidelines.
- Practice definitions by writing all the terms down and then try to write the correct definitions without referring to your examination guidelines. Do that until you can write the definitions correctly without omitting key words.

8 References

The following documents were used in the Development of this booklet:

- Physical Sciences Grade 10-12 CAPS document (DBE)
- Physical Sciences Examination Guidelines 2021 (DBE)
- Previous Grade 12 Question Papers (DBE)
- Grade 12 Preparatory Examination Papers (PEDs)

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