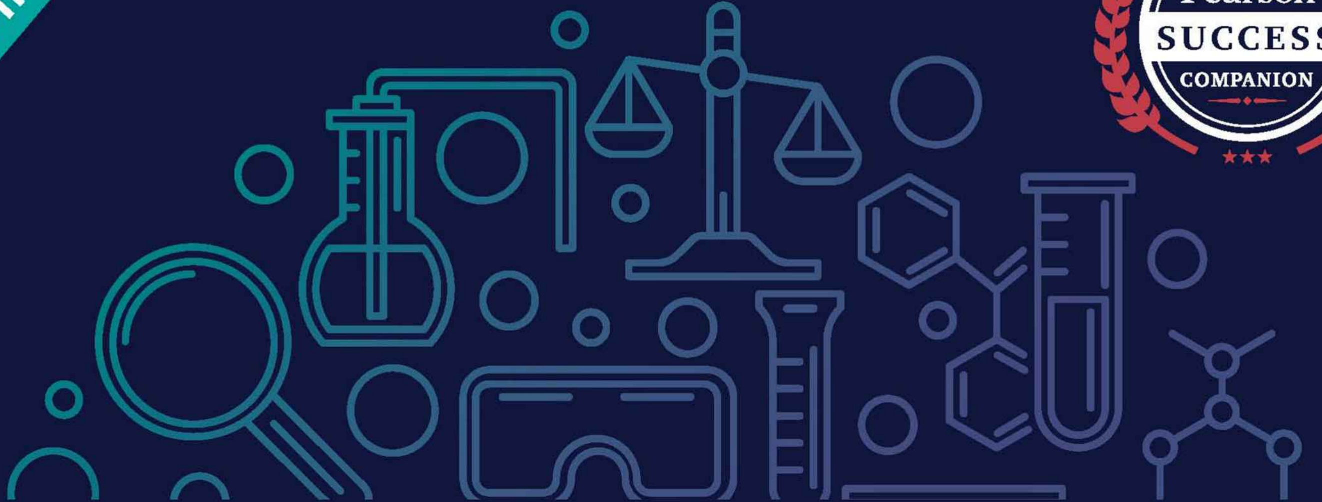
Trishna's

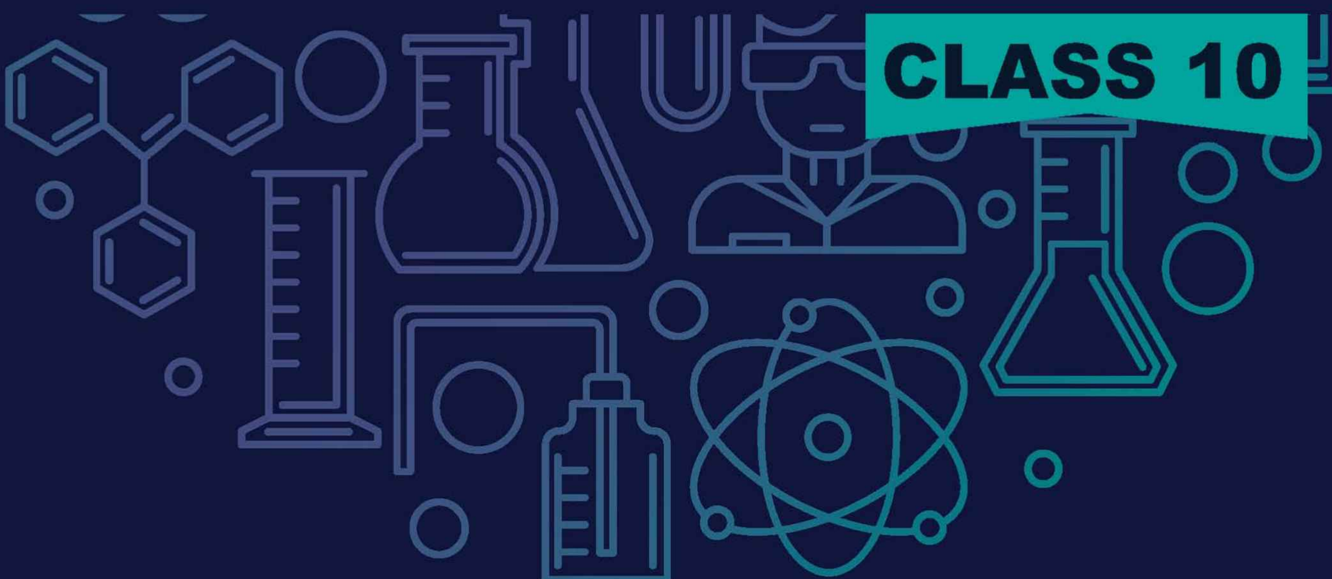


Pearson SUCCESS COMPANION

Pearson IIT Foundation Series

CHEMISTRY

CLASS 10



6e

- Provides student friendly content, 'application based problems' and 'hints and solutions' to master the art of problem solving
- Uses graded approach to generate, build and retain interest in concepts and their applications

Pearson

CLASS

10

Pearson IIT Foundation Series

Chemistry

Sixth Edition

CLASS

10

Pearson IIT Foundation Series

Chemistry

Sixth Edition

Trishna Knowledge Systems

Pearson

Photo Credits

All Chapter Openers: isak55. shutterstock
Icons of Practice Questions: graphixmania. Shutterstock
Icons of Answer Keys: Viktor88. Shutterstock
Icons of Hints and Explanation: graphixmania. Shutterstock

Copyright © 2017 Trishna Knowledge Systems
Copyright © 2012, 2014, 2015, 2016 Trishna Knowledge Systems

No part of this eBook may be used or reproduced in any manner whatsoever without the publisher's prior written consent.

This eBook may or may not include all assets that were part of the print version. The publisher reserves the right to remove any material in this eBook at any time.

ISBN 9789332578999
e-ISBN: 9789332585430

First Impression

Published by Pearson India Education Services Pvt. Ltd, CIN: U72200TN2005PTC057128, formerly known as TutorVista Global Pvt. Ltd, licensee of Pearson Education in South Asia.

Head Office: 15th Floor, Tower-B, World Trade Tower, Plot No. 1, Block-C, Sector-16, Noida 201 301, Uttar Pradesh, India.
Registered Office: 4th Floor, Software Block, Elnet Software City, TS-140, Block 2 & 9, Rajiv Gandhi Salai, Taramani, Chennai 600 113, Tamil Nadu, India.
Fax: 080-30461003, Phone: 080-30461060
www.pearson.co.in, Email: companysecretary.india@pearson.com

Compositor: Chandraprabhu Enterprise Private Limited
Printer in India at

Brief Contents

Contents

Preface

Pearson IIT Foundation Series has developed into a trusted resource for scores of students who have aspired to be a part of the elite undergraduate institutions of India. As a result it has become one of the best selling series, providing authentic and class tested content for effective preparation.

The structure of the content is not only student friendly but is also designed in such a manner that it invigorates the students to go beyond the usual school curriculum and also act as a source of higher learning to strengthen the fundamental concepts of Physics, Chemistry, and Mathematics.

The core objective of the series is to be a one stop solution for students preparing for various competitive examinations. Irrespective of the field of study that the student may choose to take up later, it is important to understand that Mathematics and Science form the basis for most modern day activities Hence, utmost efforts have been made to develop student interest in these basic building blocks via real-life examples and application based problems. Ultimately the aim is to ingrain the art of problem-solving in the minds of the reader.

To ensure high level of accuracy and practicality this series has been authored by a team of highly qualified and experienced faculties involved in grooming the young minds. That said, we believe that there is always scope for doing things in a better manner and hence invite you to provide us with your candid feedback and suggestions on how we can make this series more superior.

Chapter Insights

Remember

Before beginning this chapter, you should be able to:

- define substance, mixture, mass, weight, etc.
- know the states of matter solid, liquid and gas
- basic properties of matter

Remember section will help them to memories and review the previous learning on a particular topics

Key points will help the students to identify the essential points in a chapter

Key Ideas

After completing this chapter, you should be able to:

- define matter, molecule, atom etc.
- know the arrangement of molecules in three different states of matter.

INTRODUCTION

The planet earth has endowed us with the basic necessities of life like air, water, food etc. Among these, air is the most vital for life and hence indispensable.

Layers of Atmosphere

Our atmosphere is divided into five layers on the basis of variations in chemical composition, density, temperature at different heights from the surface of the earth.

(i) Troposphere

(a) The layer of atmosphere which begins at the earth's surface and extends up to 20 km height is called **troposphere**.

Text: concepts are explained in a well structured and lucid manner

Note boxes are some add-on information of related topics

Note: Diluted H_2SO_4 is not used for the preparation of CO_2 because the calcium sulphate formed being insoluble in water forms a layer over marble chips and thus marble chips do not come in contact with dil H_2SO_4 further.

EXAMPLE

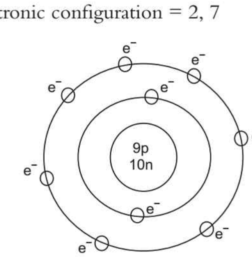
Give the electronic configuration and geometrical representation of the following elements.

(a) Flourine **(b)** Sodium **(c)** Chlorine **(d)** Carbon

SOLUTION

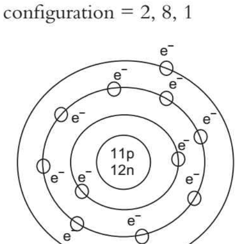
(a) Florine Z = 9

Electronic configuration = 2, 7



(b) Sodium Z = 11

Electronic configuration = 2, 8, 1



Examples given topic-wise to apply the concepts learned in a particular chapter

Illustrative examples solved in a logical and step-wise manner

TEST YOUR CONCEPTS

Very Short Answer Type Questions

Directions for questions 1 to 10: **Fill in the blanks.**

1. In a ______ properties of the constituents are retained.
2. A mixture of alcohol and water is an example of ______ mixture.
3. A substance which is formed by the chemical combination of two or more elements is called a ______.
4. Boiling point is the temperature at which ______ is converted to ______ at one atmospheric pressure.
5. Nonmetals usually exist in ______ state.
6. ______ show the properties of metals and nonmetals.
7. With an increase in the surface area of a liquid, the rate of evaporation______.

16. Which among the following is an element?
 (a) Calcium oxide
 (b) Common salt
 (c) Ozone
 (d) Water
17. Evaporation is the process of conversion of
 (a) a liquid to its gaseous state below the boiling point of the substance
 (b) a liquid to its gaseous state at the boiling point of the substance
 (c) a solid to its liquid state at the melting point of the substance
 (d) a solid to its liquid state below the melting point of the substance

Different levels of questions have been included in the *Test Your Concept* as well as on *Concept Application* which will help students to develop the problem-solving skills

'Test Your Concepts' at the end of the chapter for classroom preparations

CONCEPT APPLICATION

Level 1

True or false

1. Gases have maximum intermolecular spaces.
2. Metals are highly ductile and malleable.
3. Evaporation takes place from the surface of a liquid and hence it is a surface phenomenon.
4. Pure substances are made up of identical molecules and hence are homogeneous in nature.
5. Tellurium is a metalloid and hence it shows properties of both metals and nonmetals.
6. Iodine is a lustrous nonmetal.
7. As the density of sodium is less than that of water it floats on water.
8. Ammonium chloride undergoes sublimation and hence it is a sublimable substance.
9. The constituents of a compound do not retain their properties and hence these cannot be separated by physical methods.
10. Sublimation is the process of the conversion of a solid to its gaseous state.

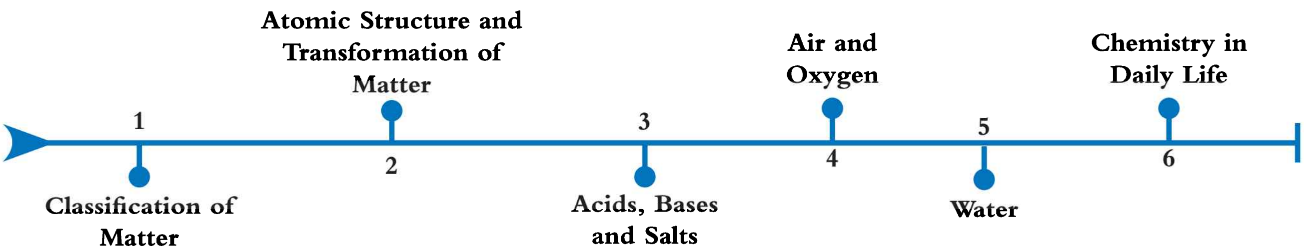
'Concept Application' section with problems divided as per complexity: Level 1; Level 2; and Level 3

38. Carbon fibre, a recently developed allotrope of carbon is ductile and has high tensile strength.
39. Sand is insoluble in water; hence, it can be separated by filtration. Glucone-D is soluble in water; hence, it can be separated by distillation and water is collected separately.
40. Rate of evaporation is directly proportional to surface area of the liquid. This is because more number of surface molecules are exposed to atmosphere which gain kinetic energy and escape into atmosphere.
41. (i) A mixture of sawdust and water is taken in a beaker
 (ii) A filter paper is folded in the form of a cone and fitted into a funnel by moistening it with a few drops of water
 (iii) The mixture is poured gently into the filter cone and collected into another beaker which is called a filtrate.
 (iv) The solid retained on the filter paper is called a residue.

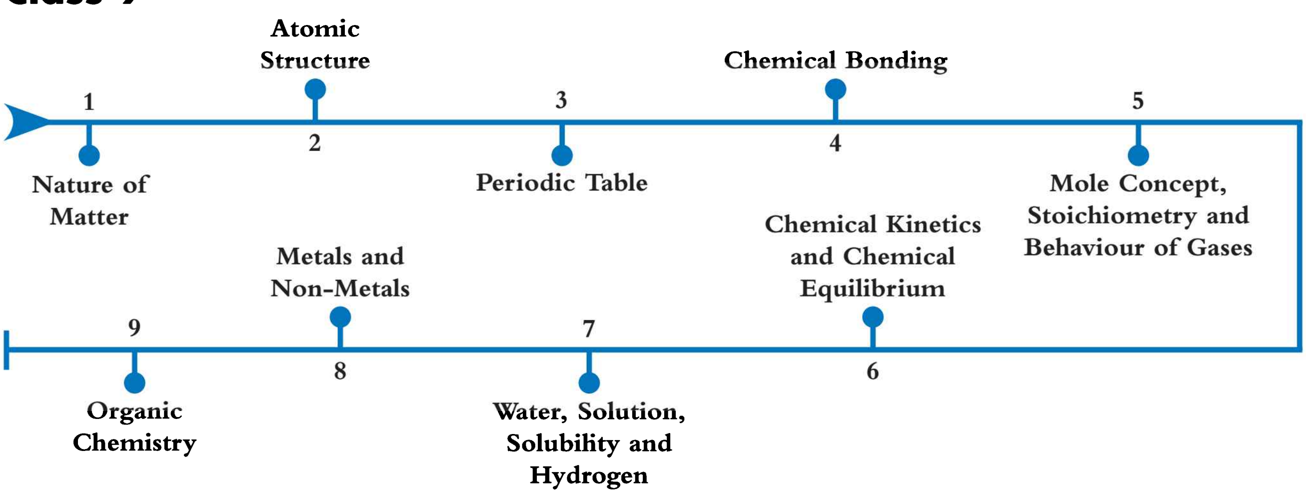
Hints and Explanation for key questions along with highlights on the common mistakes that students usually make in the examinations

Series Chapter Flow

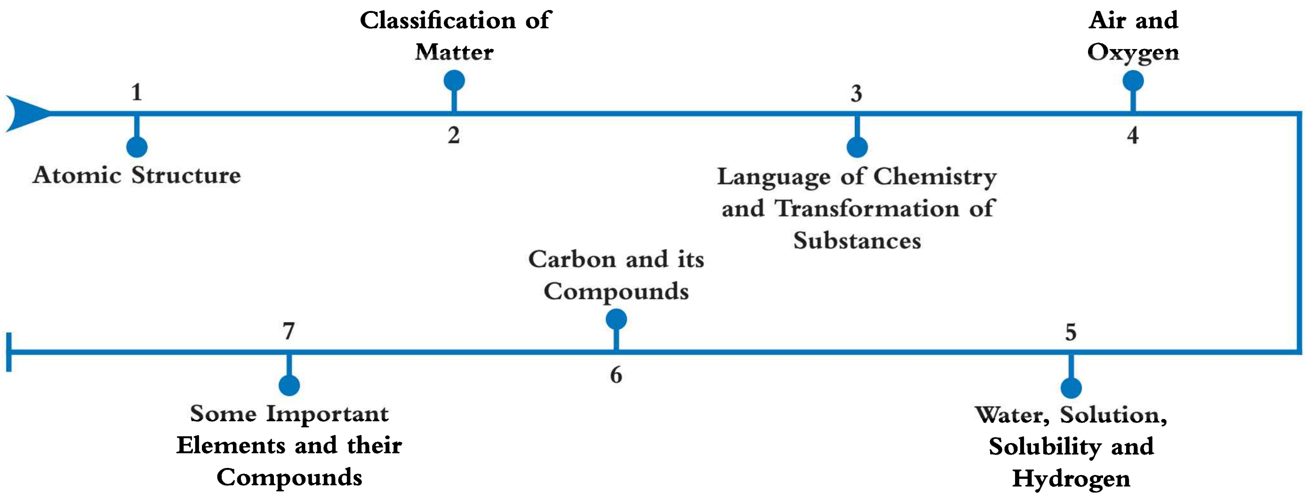
Class 7



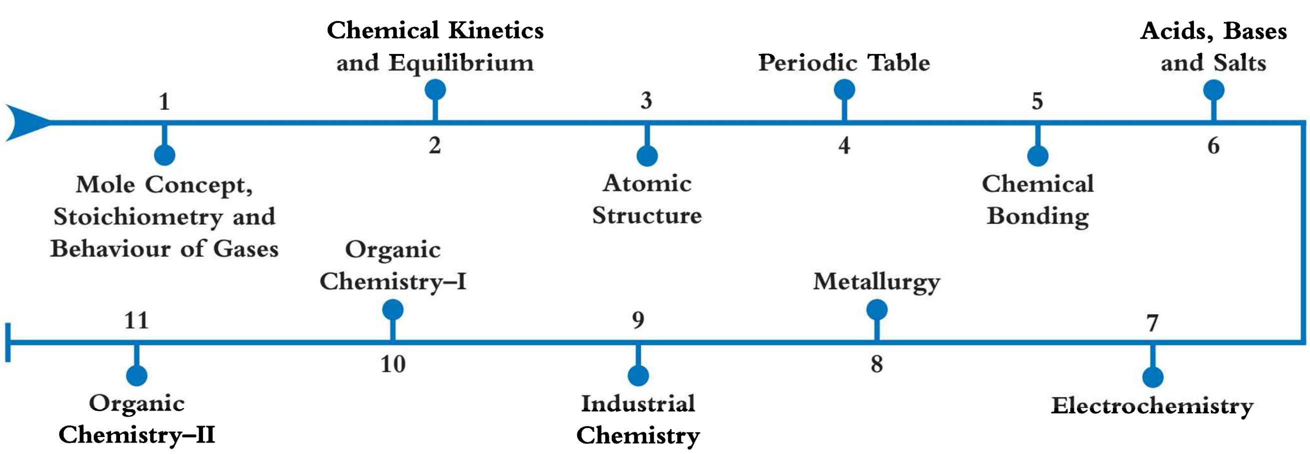
Class 9



Class 8



Class 10



Chapter

1

Mole Concept, Stoichiometry and Behaviour of Gases

Remember

Before beginning this chapter, you should be able to:

- understand the concept of matter and atoms
- review the classification of matter and their atomic structure identify the types of chemical reactions

Key Ideas

After completing this chapter, you should be able to:

- understand the kinetic molecular theory and interrelationship among various measurable properties of gases.
- understand mole as the chemical counting unit
- derive ideal gas equation from Gas Laws and draw a comparison between ideal gas and real gas.
- study the behaviour of gases in a mixture and their relative tendency to diffuse.
- understand and to establish quantitative relationship among reactants and products and develop numerical skills with regard to calculations based on chemical equations.

INTRODUCTION

Chemistry is the branch of science which deals with the study of matter in different perceptions. Matter can be basically classified on the basis of molecular composition as elements, compounds and mixtures. The various elements are given names and symbols and the names and formulae of various compounds have been derived based on certain rules. The study of naming these compounds and derivation of formulae for these is the prerequisite for representing chemical reactions in the form of chemical equations. Therefore, the language of chemistry which involves the study of symbols, formulae and chemical equations with respect to the above aspects is of utmost significance.

SYMBOL

All elements are represented by means of their symbols. A symbol represents the atom of an element which may consist of a single letter or a combination of letters derived either from its English name or from its Latin name.
A symbol is the short hand notation which represents a single atom of an element.

Example

H ⇒ Hydrogen

Hg ⇒ Hydrarg yrum (Latin name for mercury)

He ⇒ Helium

FORMULAE

A molecule of an element or a compound is represented by means of a formula. Formula is written with the help of symbols of the respective constituent element(s) along with the actual number of atoms of the respective elements.
A formula is the short hand notation which represents a single molecule of an element or compound.

Example

Cl ⇒ one molecule of chlorine consists of two atoms.

$CaCO_3$ ⇒ one calcium atom, one carbon atom and three oxygen atoms

Derivation of Formulae of Compounds

A molecule is formed by the combination of a positive radical and a negative radical, but by itself is electrically neutral. Hence the number of positive and negative radicals which form a molecule of the compound depends on the charge(s) on the respective radicals.

Positive Radicals	Negative Radicals	Formulas	Explanation
Na^+	Cl^-	NaCl	One Na^+ neutralizes one Cl^- since both of them are unipositive
H^+	SO_4^{-2}	H_2SO_4	Two H^+ are required to neutralize one SO_4^{-2}
Al^{+3}	CO_3^{-2}	$Al_2(CO_3)_3$	Two Al^{+3} are required to neutralize three CO_3^{-2}
Ca^{+2}	PO_4^{-3}	$Ca_3(PO_4)_2$	Three Ca^{+2} are required to neutralize two PO_4^{-3}

Naming of Inorganic Compounds

Inorganic compounds are classified into three categories, namely, acids, bases and salts. Naming of the respective categories follows certain rules, which we now discuss.

Naming of Acids

Acids usually contain hydrogen ion (H^+) as the positive radical. Hence the name of the acid depends on the constituent(s) of its negative radical.

Types of Acid	Types of Negative Radical	Suffixes
1. Binary acids	Negative radical consists of a single nonmetal Examples: HCl, HBr, etc.	"ic" (prefix hydro) Hydrochloric acid Hydrobromic acid
2. Oxyacid	Negative radical consists of a nonmetal and oxygen. The name of the oxyacid depends on the percentage of the oxygen associated with a specific nonmetal.	
	Acids with comparatively less percentage of oxygen. Examples: H_2SO_3, HNO_3, H_3PO_3, etc.	"ous" Sulphurous acid, nitrous acid, phosphorous acid, etc.
	Acids with comparatively more percentage of oxygen. Examples: H_2SO_4, HNO_3, H_3PO_4, etc.	"ic" Sulphuric acid, nitric acid, phosphoric acid, etc.

If the acid contains lesser number of oxygen atoms than the corresponding "ous" acid, "hypo" prefix is given to the negative radical, whereas "per" prefix is given to the negative radical when the acid contains greater number of oxygen atoms than the corresponding "ic" acid.

Examples

Hypochlorous acid $HClO$
Chlorous acid $HClO_2$
Chloric acid $HClO_3$
Perchloric acid $HClO_4$

Naming of Bases

Bases generally contain hydroxyl radical (OH^-) as the negative radical and a metal ion as its positive radical. While writing the name of the base, the name of the metal is written first followed by hydroxide.

Examples

$Ca(OH)_2$ Calcium hydroxide
$Mg(OH)_2$ Magnesium hydroxide
NaOH Sodium hydroxide
$Al(OH)_3$ Aluminium hydroxide

Naming of Salts

The positive radical present in the salt comes from the corresponding base and the negative radical comes from the corresponding acid.

Name of the salts starts with the name of the metal present as a positive radical which is followed by the name of a negative radical. Name of the negative radical depends on the name of the acid from which the salt is produced.

Acids from which the salt is produced	Suffixes and names of the salt
1. "ous" acid Examples: Sulphurous acid (H_2SO_3) Nitrous acid (HNO_2) Phosphorous acid (H_3PO_3)	"ite" $CaSO_3$ → Calcium sulphite $Zn(NO_2)$ → Zinc nitrite $Mg(PO_3)_2$ → Magnesium phosphite
2. "ic" acid Examples: Sulphuric acid (H_2SO_4) Nitric acid (HNO_3) Phosphoric acid (H_3PO_4)	"ate" $ZnSO_4$ → Zinc sulphate $NaNO_3$ → Sodium nitrate $AlPO_4$ → Aluminium phosphate

If NH_4^+ is present as the positive radical in the base or in the salt, ammonium is written in place of the name of the metal.

EXAMPLE

Ammonium hydroxide (base) → NH_4OH

The formula of a metal phosphide is M_3P_2. Identify formulae of the

(a) metal oxide **(b)** metal nitrite **(c)** metal bicarbonate

SOLUTION

Initial condition **Final condition**

Since the formula of metal phosphide is M_3P_2, metal ion is M^{+2}

(a) Formula of metal oxide is $M^{+2}O^{-2} \Rightarrow MO$

(b) Formula of metal nitrite is $M^{+2}NO_2^{-1} \Rightarrow M(NO_2)_2$

(c) Formula of metal bicarbonate is $M^{+2}\ HCO_3^{-1} \Rightarrow M(HCO_3)_2$

EXAMPLE

Ammonium phosphate (salt) → $(NH_4)_3PO_4$

Metal M forms two oxides A and B in which the ratios of number of oxygen atoms to the total number of atoms present in the molecule are 3 : 5 and 1 : 2 respectively. Determine the formulae of A and B.

SOLUTION

Metal ions present in A and B are M^{+a} and M^{+b} respectively,

$\therefore$ Formula of A is $M^{+a}O^{-2} \Rightarrow M_2O_a$

$\therefore$ Ratio $= \frac{a}{2+a} = \frac{3}{5}$

$\Rightarrow 5a = 6 + 3a \Rightarrow 2a = 6 \Rightarrow a = 3$

$\therefore$ metal oxide A is $M^{+3}O^{-2} \Rightarrow M_2O_3$

Formula of B is $M^{+b}, O^{-2} \Rightarrow M_2O_b$

$\therefore$ Ratio $= \frac{b}{2+b} = \frac{1}{2}$

$\Rightarrow 2b = 2 + b \Rightarrow b = 2$

$\therefore$ metal oxide B is $M^{+2}, O^{-2} \Rightarrow MO$

Another aspect of the study of matter involves the different physical states of matter, i.e., solids, liquids and gases. Existence of matter in three distinct states entirely depends on the arrangement of molecules.

Molecules are closely packed in solids, comparatively loosely packed in liquids but very loosely packed in gases. This type of molecular arrangement, gives the gas molecules maximum freedom of movement which results in the various unique properties that gases exhibit. The gases neither have a definite shape nor a definite volume due to the random movement of the gas molecules. The unique characteristics of gases can be explained with the help of **kinetic molecular theory**.

KINETIC THEORY OF GASES

(i) All gases are made up of tiny particles known as molecules.

(ii) The huge intermolecular spaces make the forces of attraction between the gas molecules negligible.

(iii) The molecules are in constant random motion. During motion, the molecules collide with each other and also with the walls of the container. These collisions are perfectly elastic. The pressure exerted by a gas is due to the collisions of the molecules with the walls of the container.

(iv) The average kinetic energy of gas molecules is proportional to the absolute temperature of the gas.

Characteristics of Gases

Gases are highly compressible and diffusible. They neither have a definite shape nor definite volume. The gases occupy the entire volume available to them. Therefore, the volume of a gas is taken as the volume of the container.

The study of gases is much simpler than that of solids and liquids because the physical properties of all the gases are found to be identical. For example, the compressibility or thermal expansion of all the gases are the same, but this is not so in case of solids and liquids. The properties of solids and liquids differ widely from substance to substance, but the gases generally obey some common rules known as the **gas laws**.

Gas Laws

Gas laws give the interrelationship among the measurable properties of a gas which have been experimentally established.

Boyle's Law

The volume of a given mass of a gas is inversely proportional to the pressure exerted by the gas at constant temperature.

$$V \propto \frac{1}{P} \text{ (T = constant)}$$

$$V = \frac{K}{P}$$

$$PV = K \text{ (constant)}$$

The product of pressure and volume of a given mass of a gas is constant at constant temperature.

If at constant temperature, a gas occupies a volume V_1 at a pressure P_1 and a volume V_2 at a pressure P_2, then $\mathbf{P_1V_1 = P_2V_2}$ **(T = constant).**

Graphical Representation of Boyle's Law

(i) Volume (V) vs Pressure (P)

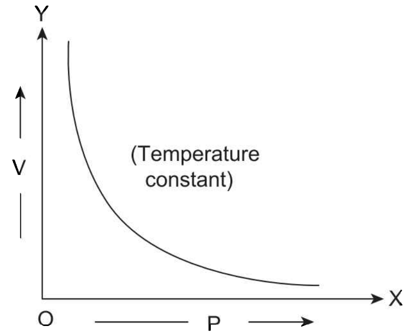


Figure 1.1 Boyle's law graph I

(ii) Volume (V) vs $\frac{1}{\text{Pressure (P)}}$

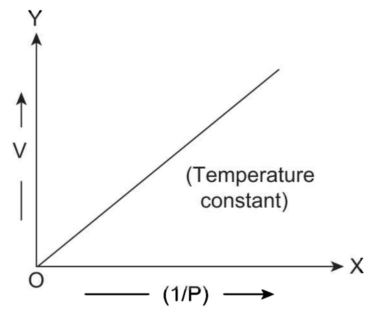


Figure 1.2 Boyle's law graph II

(iii) The product of pressure and volume (PV) vs pressure (P)

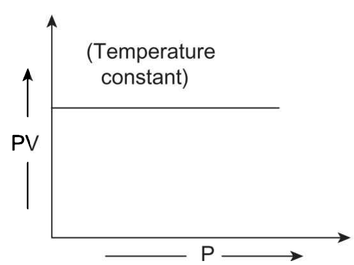


Figure 1.3 Boyle's law graph III

NUMERICAL PROBLEM

1. 5 ℓ of methane gas at 2 atm pressure is compressed to 1.6 ℓ at constant temperature. Calculate the final pressure.

SOLUTION

Initial condition	**Final condition**
$V_1 = 5\ell$	$V_2 = 1.6\ell$
$P_1 = 2\,\text{atm}$	$P_2 = ?$

According to Boyle's law, PV = PV

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2} = \frac{5\times 2}{1.6} = 6.25\,\text{atm}$$

Final pressure = 6.25 atm

2. The pressure of a certain volume of gas is reduced to half of its initial pressure at constant temperature. Calculate its new volume.

SOLUTION

Initial condition | **Final condition**

$V_1 = V$

$P_1 = P\,P_2 = ½P$

$V_2 = ?$

According to Boyle's law,

$$P_1V_1 = P_2V_2$$

$$\Rightarrow V_2 = \frac{V\times P}{\frac{1}{2}P} 2V$$

Final volume = 2V

Charle's Law

At constant pressure, the volume of a given mass of a gas increases or decreases by 1/273 of its original volume at 0°C for every 1°C increase or decrease in temperature respectively. If V_0 is the volume of gas at 0°C and V_t is the volume of gas at t°C, (P = constant)

$$V_t = V_0\left[1+\frac{t}{273}\right]$$

$$V_t = V_0\left[\frac{273+t}{273}\right]$$

$$V_t = V_0\left[\frac{T}{273}\right]; T = \text{absolute temperature}$$

$$\frac{V_0}{273} = \text{Constant}$$

$\therefore \quad V \propto T$

If V_1 and V_2 are the volumes occupied by a given mass of gas at temperatures T_1 and T_2

$$\mathbf{\frac{V_1}{T_1} = \frac{V_2}{T_2}\ (P = constant)}$$

Charle's law can otherwise be stated as the volume occupied by a given mass of a gas is directly proportional to the absolute temperature of the gas at constant pressure.

Graphical representation of Charle's Law

(i) Volume (V) vs absolute temperature (T)

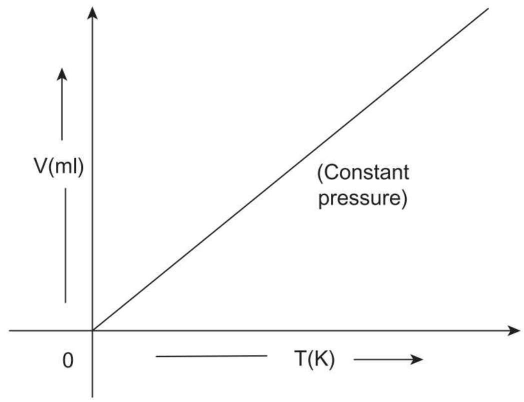


Figure 1.4 Charle's law graph-I

(ii) Volume (V) vs temperature (t) in celsius scale

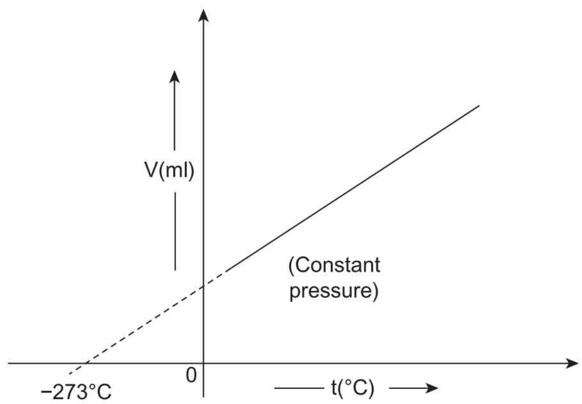


Figure 1.5 Charle's law graph-II

A straight line which intersects the x-axis at −273°C is obtained as V = 0 when t = −273°C

Mathematically, volume at –273°C, $V_t = V_0 + \frac{V_0}{273}(-273)$,

$$\therefore\ V_t = V_0\left[\frac{273-273}{273}\right] = 0$$

Absolute Zero

From the graph (ii) V vs t, the straight line intersects the temperature axis at –273°C showing that the gas occupies zero volume at this temperature. That means it is the lowest temperature that can be attained theoretically. Therefore it is called **absolute zero**.

NUMERICAL PROBLEM

1. At a certain pressure, the volume occupied by a given mass of a gas is 10 ℓ at 0°C, calculate the volume occupied by the gas at 91°C at the same pressure.

SOLUTION

Initial condition	**Final condition**
$V_1 = 10\ell$	$V_2 = ?$
$T_1 = 273K$	$T_2 = (273 + 91)K = 364K$

According to Charle's law, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$$\Rightarrow \frac{10}{273} = \frac{V_2}{364} \Rightarrow V_2 = \frac{10 \times 364}{273} = 13.33\ell$$

2. Calculate the temperature at which the volume of a given mass of gas gets reduced to 3/5th of original volume at 10°C without any change in pressure.

Initial condition	**Final condition**
$V_1 = V$	$V_2 = 3/5V$
$T_1 = (273 + 10)K = 283K$	$T_2 = ?$

According to Charle's law, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$$T_2 = V_2 \times \frac{T_1}{V_1}$$

$$\Rightarrow T_2 = \frac{3V}{5} \times \frac{283}{V}$$

$$\Rightarrow T_2 = 169.8K \Rightarrow T_2 = -103.2°C$$

The volume of a given mass of gas depends on its temperature and the pressure imposed. Hence in order to define the volume of a gas a **standard temperature and pressure** has been accepted all over the world.

Standard Temperature and Pressure (STP)

The conditions of standard temperature and pressure are given below.

Standard temperature = 0°C = 273 K
Standard pressure = 760 mm of Hg (mercury)
= 76 cm of Hg = 1 atm

Gay-Lussac's law of combining volumes of gases: Gay-Lussac proposed a law pertaining to gaseous reactions which ultimately led to another gas law the Avogadro's law.

Gay-Lussac's law states that when gases chemically react, they do so in volumes which bear a simple whole number ratio to each other and to the volumes of the products, provided the products are also in gaseous state under similar conditions of temperature and pressure.

Explanation

In the reaction of carbon monoxide with oxygen, two volumes of carbon monoxide react with one volume of oxygen to give two volumes of carbon dioxide under similar conditions of temperature and pressure.

$$\underset{2\text{vol}}{CO + CO} + \underset{1\text{vol}}{O_2} \rightarrow \underset{2\text{vol}}{CO_2 + CO_2}$$

The volume ratio of carbon monoxide, oxygen and carbon dioxide is 2 : 1 : 2.

Amedo Avogadro, in 1811, gave his hypothesis to explain Gay-Lussac's law. It was experimentally confirmed later and was established as Avogadro's law.

Avogadro's Law

Avogadro's law states that equal volumes of all gases contain equal number of molecules under similar conditions of temperature and pressure.

If n is the number of molecules present in volume V of any gas at temperature T and pressure P, then $V \propto n$ when T and P are constant.

Example: 1 ℓ of hydrogen, helium and hydrogen chloride contain equal number of molecules in them provided their volumes are measured at the same temperature and pressure.

In chemistry, the mass of any substance irrespective of its state is measured in terms of gram molecular weight or gram molecule and gram atomic weight or gram atom. Atomic weight of a substance expressed in grams is called its **gram atomic weight or gram atom**. Molecular weight of a substance expressed in grams is called its **gram molecular weight or gram molecule**.

Gram Molecular Volume (GMV)

One gram molecule of any dry gas at STP occupies the same volume, i.e., 22.4 ℓ or 22.4 dm^3. This is called gram molar volume or GMV.

Example: 1 gram molecule of dry chlorine gas occupies 22.4 ℓ of volume at STP.

Since GMW of chlorine is 71 g, 71 g of chlorine gas occupies 22.4 l of volume at STP.

Vapour Density

Vapour density (VD) of a gas or vapour is the ratio of the mass of a certain volume of gas or vapour to the mass of the same volume of hydrogen gas when their volumes are measured under similar conditions of temperature and pressure.

Relation Between Molecular Weight or Relative Molecular Mass vand Vapour Density

VD of a gas or vapour at a certain temperature and pressure

$$= \frac{\text{Mass of the certain volume of gas or vapour}}{\text{Mass of the same volume of } H_2 \text{ gas}}$$ [Volume of both the gases are measured at that particular temperature and pressure]

$$= \frac{\text{mass of n molecules of the gas or vapour}}{\text{mass of n molecules of } H_2 \text{ gas}}$$ [By applying Avogadro s law]

$$= \frac{\text{mass of 1 molecule of the gas or vapour}}{\text{mass of 1 molecule of } H_2 \text{ gas}} = \frac{1}{2} \times \frac{\text{mass of 1 molecule of the gas or vapour}}{\text{mass of 1 atom of hydrogen gas}}$$

$= \frac{1}{2} \times$ relative molecular mass (Molecular weight)

$\therefore$ Molecular weight or relative molecular mass = 2 × VD

i.e., relative molecular mass is twice the vapour density of the gas or vapour.

EXAMPLE

Gas laws are universally applicable for all gases whereas such universal laws could not be established for solids and liquids. Comment on this statement.

SOLUTION

Gases differ from solids and liquids in the extent of intermolecular forces of attraction. Since gases are characterized by negligible forces of attraction, the molecules behave independent of the neighbouring molecules. Due to large intermolecular spaces, the coefficient of volume expansion is same for all gases. Moreover, in case of gases the molecules are considered as point masses and hence the volume occupied by the molecules is negligible in comparison to the total volume. Therefore, the physical behaviour of all gases being similar, certain laws could be established which are universally applicable. In case of liquids and solids, the molecules are considered as rigid spheres and the coefficient of volume expansion is not uniform for all substances, such universal laws can not be established.

EXAMPLE

Boyle's law says that pressure and volume are inversely proportional to each other. However, when a balloon is blown, both volume and pressure increase continuously. Justify

SOLUTION

When a balloon is blown continuously, more and more air is forced into the balloon which increases the volume as well as the number of collisions of air molecules on the walls of the balloon that is pressure. Boyle's law is applicable for a given mass of a gas. Hence it is not valid in the above case.

EXAMPLE

Why is Kelvin temperature always positive?

SOLUTION

Absolute zero which is equal to −273°C is the minimum possible temperature for a gas. Any centigrade temperature greater than −273°C will become positive when converted to absolute scale. Since centigrade temperature less than −273°C is not possible, Kelvin temperature cannot have a negative value

EXAMPLE

A certain mass of a gas taken in 1 litre cylinder exerts a pressure of 500 mm Hg at a certain temperature. If the gas is transferred to another cylinder where it exerts 20% more pressure, calculate the volume of the cylinder at the same temperature.

SOLUTION

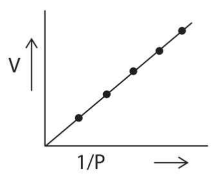
V_1 = 1000 cc, P_1 = 500 mm of Hg,

$$P_2 = P_1 + \frac{20P_1}{100} = 500 + (\frac{20 \times 500}{100}) = 600 \text{ mm of Hg}$$

$$P_2V_2 = P_1V_1,\ V_2 = \frac{P_1V_1}{P_2} = \frac{1000 \times 500}{600} = 833 \text{ cc}$$

EXAMPLE

The slope of a given straight line graph with constant temperature is found to be 0.2 ℓ atm at 5 atmospheric pressure. Calculate the volume of gas at that pressure.



SOLUTION

Slope = 0.2 ℓ atm, P = 5 atm.

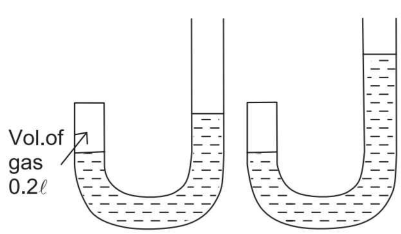
According to Boyle's law,

$$P \propto \frac{1}{V},\ P = \text{constant} \times \frac{1}{V} = \text{slope} \times \frac{1}{V};\ 0.2 \times \frac{1}{V} = 5 \Rightarrow V = \frac{0.2}{5}$$

= 0.04 ℓ

EXAMPLE

J-shaped tube closed at one end was used by Boyle to study the relationship between the pressure of the trapped gas and its volume. Such a set up is given here. Initially some amount of gas is taken in the tube and mercury is poured in it. The volume of gas is 0.2 ℓ and the difference in the height of the mercury column is 760 mm of Hg. Now some more amount of mercury is poured and the difference in the height of the mercury column is found to be 1140 mm of Hg. Calculate the new volume of gas considering the temperature constant.



SOLUTION

V_1 = 0.2 ℓ V_2 = ?

P_1 = 760 mm + 760 mm P_2 = 1140 mm + 760 mm

According to Boyle's law $P_1 V_1 = P_2 V_2$

$$1520 \times 0.2 = 1900 \times V_2 \Rightarrow V_2 = \frac{1520 \times 0.2}{1900} = 0.16\,\ell$$

EXAMPLE

A cylinder was filled with a gas at 2 atm pressure at 27°C and can withstand a pressure of 12 atm. At what temperature the cyliner bursts when the building catches fire?

SOLUTION

$P_1 = 2$ atm, $P_2 = 12$ atm

$T_1 = 27 + 273 = 300$ K, $T_2 = ?$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow T_2 = \frac{T_1P_2}{P_1} \Rightarrow T_2 = \frac{12 \times 300}{2} = 1800\text{ K} = 1527°\text{ C}$$

∴ Cylinder bursts at or above 1527°C

EXAMPLE

After usage for a certain period, a cooking gas cylinder was considered to be empty as no gas was coming out of it. Is the cylinder empty in its true sense? Explain what happens if the cylinder is kept in hot water or shaken vigorously. Explain by applying kinetic molecular theory.

SOLUTION

No. It is not empty in its true sense. In a cooking gas cylinder, the gas was initially at a high pressure. As the gas was drawn out from the cylinder, the amount of gas in the cylinder decreases thereby reducing the pressure inside the cylinder. The gas will come out of the cylinder as long as the pressure of the gas inside the cylinder is more than the atmospheric pressure. When it is kept in hot water or shaken vigorously, kinetic energy of gas molecules increases and number of collisions increases. Thus pressure increases and gas comes out of the cylinder.

Avogadro Number and Mole Concept

Avogadro Number

Scientists experimentally determined that the number of atoms present in 12 g of carbon i.e., 1 g atom of carbon 12 isotope is 6.023×10^{23}.

Different experiments showed that 1 g atom or 1 g molecule of any substance contains the same number (6.023×10^{23}) of elementary particles or chemical units (atoms, molecules or ions). This constant number is called the Avogadro number which is denoted by N_A or L. It also represents the number of molecules present in 1 g molar volume.

The Avogadro number, i.e., 6.023×10^{23} is taken as the unit to measure the amount of substances and is called **mole**.

Mole

A mole is defined as the quantity of substance which contains the same number of elementary particles or chemical units as the number of atoms present in 12 g of C–12 isotope.

Hence, 1 mole of any substance contains the Avogadro number of elementary particles or units. The elementary particles can be atoms, molecules, ions, etc.

Therefore, it can be concluded that

(i) 1 g atom of any substance is equivalent to one mole of atoms of that substance and contains the Avogadro number of atoms.

(ii) 1 g molecule of any substance is equivalent to one mole of molecules of that substance and contains the Avogadro number of molecules.

Examples

1. One mole of hydrogen atoms	6.023×10^{23} hydrogen atoms 1 g atom of hydrogen or 1 g hydrogen
2. One mole of carbon atoms	6.023×10^{23} carbon atoms 1 g atom of carbon or 12 g of carbon
3. One mole of NaCl	6.023×10^{23} Na^+ ions and 6.023×10^{23} Cl^- ions
4. One mole of ammonia gas	1 g molecule of sodium chloride or 58.5 g of NaCl 6.023×10^{23} NH_3 molecules 1 g molecule of ammonia or 17 g of NH_3

Examples

(i) Calculate the number of moles of sodium (Na) atoms present in 11.5 g of sodium.

$$\text{Number of moles of sodium atoms} = \frac{\text{mass of sodium}}{\text{GAW}} = \frac{11.5}{23} = 0.5$$

i.e., 0.5 moles of Na atoms are there in the given 11.5 g sample

(ii) Calculate the number of moles of water (H_2O) present in 4.5 g of water.

$$\text{Number of moles of water molecules} = \frac{\text{mass of water molecules}}{\text{GMW}} = \frac{4.5}{18} = 0.25$$

i.e., 0.25 moles of H_2O are there in 4.5g of water.

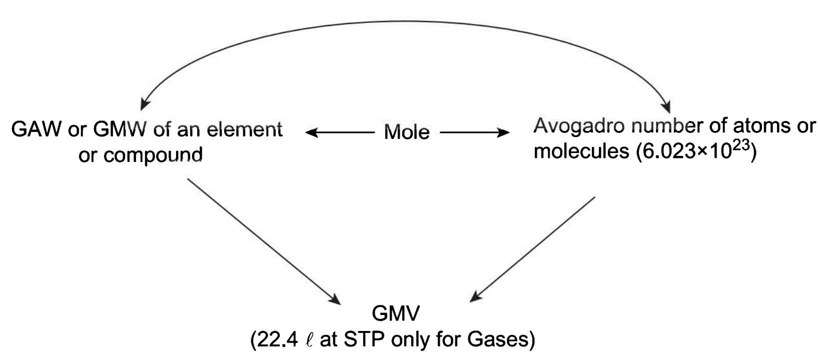
Relation Between GMV, Mole and Avogadro Number

1 g mole of any dry gas occupies 22.4 ℓ volume at STP. Hence 22.4 ℓ of a dry gas at STP contains 6.023×10^{23} molecules, i.e., Avogadro number of molecules.

Example: 32 g or 1 mole of dry oxygen gas occupies 22.4 ℓ volume at STP and contains 6.023×10^{23} molecules of oxygen.

Example: 4 g or 1 mole of dry helium gas occupies 22.4 litres at STP and contains 6.023×10^{23} atoms because helium is a monoatomic gas.

Schematic Representation of Different Relationships for Mole



NUMERICAL PROBLEM

1. Calculate the number of molecules present in 16.8 ℓ of gas "X" at STP. Also determine its gram molecular weight if the above sample weighs 26.625 g.

SOLUTION

Volume of the given gas = 16.8 ℓ at STP

Number of moles present in that volume = 16.8/22.4 = 0.75 mole

Number of molecules in 0.75 moles = $0.75 \times 6.023 \times 10^{23} = 4.52 \times 10^{23}$

Weight of 0.75 moles of the gas X = 26.625 g

Gram molecular weight of "X" = Weight/No. of moles = 26.625/0.75

= 35.5 g

2. Calculate the volume occupied by 200 g of SO_3 gas at STP and the number of molecules present in it.

Weight of SO_3 taken = 200 g

Number of moles of SO_3 = $\frac{200}{\text{GMW of } SO_3} = \frac{200}{80} = 2.5 \text{ moles}$

Volume occupied by 1 mole of gas is 22.4 ℓ, at STP

Volume occupied by the given amount of gas = $2.5 \times 22.4 = 56$ ℓ.

Number of molecules present in 1 mole of gas = 6.023×10^{23}

Number of molecules present in the given amount of gas = $2.5 \times 6.023 \times 10^{23} = 15.05 \times 10^{23}$ molecules

3. What is the volume occupied by 30.1×10^{23} molecules of carbon dioxide gas at STP? Calculate the mass of this gas.

Number of molecules = 30.1×10^{23}

Number of moles of gas = $\frac{30.1 \times 10^{23}}{6.023 \times 10^{23}} = 5 \text{ moles}$

Volume occupied by 5 moles of gas = $22.4 \times 5 = 112$ ℓ.

Mass of the given gas = Number of moles × GMW = $5 \times 44 = 220$ g

Ideal Gas Equation

The behaviour of gases can be described by three laws.

According to Boyle's law, for a given mass of gas, $V \propto \frac{1}{P}$ [T is constant]

According to Charles's law, for a given mass of gas, $V \propto T$ [P is constant]

According to Avogadro's law, $V \propto n$ [P and T are constant]

Combining the three gas laws,

$V \propto \frac{nT}{P}$ [when all the functions vary independently] or $PV \propto nT$

or $PV = nRT$ [R is a constant]

A hypothetical gas called ideal gas obeys the equation under all conditions of temperature and pressure. Hence this equation is called an **ideal gas equation** and R is called universal gas constant.

However, no gas is perfectly ideal. All gases show nearly ideal behaviour under the conditions of low pressure and high temperature and are called real gases.