GOVERNMENT OF TAMIL NADU

DIPLOMA COURSE IN ENGINEERING & TECHNOLOGY

BASIC PHYSICS

FIRST SEMESTER

A publication under Government of Tamilnadu
Distribution of Free Text book Programme
(NOT FOR SALE)

Untouchability is a sin
Untouchability is a crime
Untouchability is inhuman

**DIRECTORATE OF TECHNICAL EDUCATION
GOVERNMENT OF TAMILNADU**

CHAIRPERSON

THIRU. K. VEERA RAGHAVA RAO, I.A.S
Commissioner of Technical Education
Directorate of Technical Education
Guindy, Chennai – 600025.

CONVENER:

Dr. E.M. SRINIVASAN
Principal (FAC),
Central Polytechnic College,
Chennai.

CO-ORDINATOR:

Dr. C. JOSEPH PRABAGAR
Lecturer,
Central Polytechnic College,
Chennai.

REVIEWERS

Dr. S. DEVASHANKAR
Assistant Professor, P.G Department of Physics, Loganatha Narayanasamy Government College (Autonomous), Ponneri.

Dr. R. BALAJI
Associate Professor, Department of Physics, PSG College of Technology, Coimbatore.

Dr. K. CHINNAIYAN
HOD(Retd), Muthiah Polytechnic College, Annamalai nagar, Chidambarm.

AUTHORS:

THIRUMATHI S. ANITHA
Lecturer (Sr.G), PSG Polytechnic College, Coimbatore.

Dr. A.S. PUGALENTHI
Lecturer (Sr.G), PSG Polytechnic College, Coimbatore.

Dr. R. SUBBIAH
Lecturer (Sr.G), Government Polytechnic College, Srirangam.

THIRU. V. KRISHNAKUMAR
Lecturer,
Bharathiyar Centenary Memorial Government Women's Polytechnic College, Ettayapuram.

THIRU. T. RASAPPAN
Lecturer, Government Polytechnic College, Nagercoil.

Dr. K. RAVIKUMAR
Lecturer, Institute Of Printing Technology, Chennai.

Dr. K. SARAVANAKUMAR
Lecturer, Government Polytechnic College, Perundurai.

Dr. C. JOSEPH PRABAGAR
Lecturer, Central Polytechnic College, Chennai.

Government of Tamil Nadu

First Edition - 2024

(Published Under Regulation 2023)

Content Creation

Directorate of Technical Education

https://dte.tn.gov.in/

Printing & Publishing

This book has been printed on 60 G.S.M. paper.
Printed by web offset at:

THE NATIONAL ANTHEM
FULL VERSION

Jana-gana-mana-adhinayaka jaya he
Bharata-bhagya-vidhata
Punjaba-Sindhu-Gujarata-Maratha-
Dravida-Utkala-Banga
Vindhya-Himachala-Yamuna-Ganga
Uchchhala-jaladhi-taranga
Tava Subha name jage, TavaSubhaasisa mage,
Gahe tava jaya-gatha.
Jana-gana-mangala-dayaka jaya he
Bharata-bhagya-vidhata.
Jaya he, jaya he, jaya he,
Jaya jaya jaya jaya he.

-Rabindranath Tagore

SHORT VERSION

Jana-gana-mana-adhinayaka jaya he
Bharata-bhagya-vidhata.
Jaya he, jaya he, jaya he,
Jaya jaya jaya jaya he.

AUTHENTIC ENGLISH TRANSLATION OF THE NATIONAL ANTHEM

Thou art the ruler of the minds of all people,
Thou dispenser of India's destiny.
Thy name rouses the hearts of the Punjab, Sind,
Gujarat and Maratha, of Dravida, Orissa and Bengal
It echoes in the hills of the Vindhyas and Himalayas,
mingles in the music of the Yamuna and Ganges
and is chanted by the waves of the Indian Sea.
They pray for Thy blessings and sing Thy praise
The saving of all people waits in Thy hand,
Thou dispenser of India's destiny.
Victory. Victory, Victory to Thee

THE NATIONAL INTEGRATION PLEDGE

"I solemnly pledge to work with dedication to preserve and strengthen the freedom and integrity of the nation."

"I further affirm that I shall never resort to violence and that all differences and disputes relating to religion, language, region or other political or economic grievances should be settled by peaceful and constitutional means."

INVOCATION TO GODDESS TAMIL

Bharat is like the face beauteous of Earth clad in wavy seas;
Deccan is her brow crescent-like on which the fragrant 'Tilak' is the blessed Dravidian land.
Like the fragrance of that 'Tilak' plunging the world in joy supreme reigns Goddess Tamil with
renown spread far and wide.
Praise unto You, Goddess Tamil, whose majestic youthfulness, inspires awe and ecstasy

PREFACE

Physics is a fundamental science that underpins many technological advancements shaping our world today. Yet, the transition from understanding basic physical principles to applying them in practical technological fields can be challenging. This book, "Basic Physics" is crafted to serve as a bridge between these realms, offering a comprehensive yet accessible guide to the application of physics in technology.

Divided into five units, this book covers essential topics that form the backbone of technological understanding. The first unit, "Units &Measurements," lays the groundwork by elucidating the importance of accurate measurement in scientific and technological endeavours. It sets the stage for subsequent units by emphasizing precision and reliability in experimentation and analysis.

Moving forward, "Statics" delves into the study of bodies at rest or in constant motion, a crucial aspect in engineering and construction. "Dynamics" extends this understanding to bodies in motion, exploring concepts such as velocity, acceleration, and force, which are vital in designing moving systems.

The unit on "Elastic Properties of Solids" delves into the behaviour of materials under various loads, providing insights into how materials deform and return to their original shape, critical knowledge for designing structures and machines. Finally, "Heat &Thermodynamics" introduces students to the principles governing heat, energy, and work, essential in fields like mechanical engineering and energy systems.

Throughout this book, we aim to not only explain these concepts but also to illustrate their practical applications. Real-world examples and case studies are included to demonstrate how these principles are utilized in technology, providing a deeper understanding and appreciation for the role of physics in our everyday lives.As the authors, we hope is that "Basic Physics" serves as a valuable resource for students, to bridge the gap between theory and practice, and fostering a deeper understanding and appreciation for the application of physics principles in technology.

- AUTHORS

CONTENTS

SYLLABUS

1000231330	Basic Physics	L	T	P	C
Practicum		2	0	2	3

Introduction

Any technological innovation happens through a firm understanding of basic science. Knowing and developing proper understanding of the scientific principles behind every technological gadget or instrument is inevitable to a polytechnic student. This course systematically introduces the laws of physics which gives correct perspectives of dealing with technology and its societal uses.

Course Objectives

The objective of this course is to enable the student to

1. Outline the definitions of physical quantities, units, dimensions and error analysis
2. Explain the basics of vectors, forces and its vectorial properties
3. State Newton's laws and its application into day-to-day life and covers basics of periodic motion
4. Describe the elastic properties of any solid material
5. Explain the heat, work, modes of heat transfer, laws of thermodynamics

Course Outcomes

On successful completion of this course, the student will be able to

CO1: Apply the knowledge of measuring tools used in the Engineering fields

CO2: Demonstrate the applications of Lami's theorem and principle of moment into real world problems

CO3: Correlate the Newton's laws into to day-to-day applications and measure the value of g

CO4: Illustrate the elastic properties of material for engineering applications

CO5: Relate the heat and laws of thermodynamics in technological fields

Pre-requisites

High School Science

Instructional Strategy

- It is advised that teachers take steps to pique pupils' attention and boost their learning confidence.
- To help students learn and appreciate numerous concepts and principles in each area, teachers should provide examples from daily life, realistic situations, and real-world engineering and technological applications. Try to give source examples from where the students would be familiar - like sports, or an activity that they usually engage in frequently.

- The demonstration can make the subject exciting and foster in the students a scientific mindset. Student activities should be planned on all the topics.
- Throughout the course, a theory-demonstrate-practice-activity strategy may be used to ensure that learning is outcome- and employability-based.
- All demonstrations/Hand-on practices are under a simulated environment (may be followed by a real environment as far as possible).
- Do not let students work on an activity or an experiment with the expected outcome, rather allow students to be honest about whatever the results of the experiment are. If the results are different from the expectations, students should do an analysis where could be the source of error, if any.

Assessment Methodology

	Continuous Assessment (40 marks)				End Semester Examination (60 marks)
	CA1	CA2	CA3	CA4	
Mode	Written Test	Lab Assessment	Written Test	Lab Assessment	Written Examination
Duration	2 hours				3 hours
Exam Marks	30	20	30	20	100
Converted to	10	10	10	10	60
Marks	20		20		60

1000231330	Basic Physics	L	T	P	C
Practicum		2	0	2	3

Unit I	UNITS AND MEASUREMENTS	
	Introduction – Science & Technology –Units and dimensions – definition – fundamental quantities – definition and their SI units, symbols – Derived physical quantities – Dimensional formula for length, mass and time, SI unit multiples and submultiples and prefixes of units. Measurements: Need & limitations of measuring instruments, least count, types of measurement, – screw gauge – Vernier calliper- Applications into industries. Errors in measurement (systematic and random), absolute error, relative error, error propagation (no derivation) –precautions to avoid systematic and random errors- Engineering applications. Physical quantities: velocity, momentum, acceleration, force, impulse, work, energy and power, Horsepower, watt, Calorie and Joule – Conversions.	7

Ex. 1 SCREW GAUGE: Using Screw Gauge: (i) Find the thickness and volume of given gauge wires (5,6,7,8,9) by measuring its length and diameter and error estimation (ii) Find the volume of the glass plate by measuring its thickness and area **Ex. 2 VERNIER CALIPER:** Using Vernier Caliper: (i) Find the volume of a given hollow and solid cylinder by measuring its length and diameter (ii) Find the volume of a given rectangular block by measuring its length, breadth and thickness and error estimation		**4** **4**
Unit II	**STATICS**	
Scalar and vector quantities: Definition and examples – Resolution of vector into two perpendicular components – Concurrent forces & coplanar forces: Examples – Resultant and Equilibrant force – Triangle and Parallelogram law for two forces: Statement only (no derivation), Examples – Lami's theorem – statement and explanation – Experimental verification of parallelogram of forces and Lami's theorem – Engineering applications - Moment of force, Couple – Principle of moment – Determination of mass of the given body		**6**
Ex. 3 VERIFICATION OF LAMI'S THEOREM: Verification of parallelogram and Lami's theorem for concurrent forces **Ex. 4 PRINCIPLE OF MOMENT:** Using the principle of moment, determine the unknown mass of the given object		**4** **2**
Unit III	**DYNAMICS**	
Newton laws, kinematic equations – Examples (horizontal, freely falling, vertically thrown) – Projectile motion (qualitative discussion) – Circular motion – angular velocity – period – frequency – relation between linear and angular velocity – centripetal and centrifugal force: application of centripetal and centrifugal forces (working of a centrifuge device) - Simple harmonic motion – amplitude – frequency – period – Simple pendulum – Acceleration due to gravity		**6**
Ex. 5 SIMPLE PENDULUM: Determination of acceleration due to gravity using simple pendulum		**4**
Unit IV	**ELASTIC PROPERTIES OF SOLIDS**	
Elastic and plastic bodies – stress–strain – definitions – Hooke's law – three types of strain – stress-strain curve - elastic and plastic limit – Three modulus of elasticity and its relations (no derivation)- Uniform and non-uniform bending of beams – Experimental determination of Y by uniform bending – Poisson ratio – Engineering applications of elasticity		**5**
Ex. 6 YOUNG'S MODULUS: Determination of young's modulus of a given object (one-meter wood scale) using pin and microscope **Ex. 7 HELICAL SPRING:** Verification of Hooke's law and determination of Spring constant of helical spring		**4** **4**
Unit V	**HEAT**	
Concept of heat – temperature – centigrade, Fahrenheit and Kelvin scales – conduction, convection –radiation – Good and bad thermal conductors – Properties of thermal radiation – Heat conversion – Specific heat capacity – Laws of thermodynamics – different types of process – Examples – Ideal gas – Boyle's law.		**6**
Ex. 8 BOYLE'S LAW: Verification of Boyle's law using Quill Tube		**4**
TOTAL HOURS		**60**

Suggested List of Students Activity (Ungraded)

- Presentation/Seminars by students on any recent technological developments based on fundamental physics
- Periodic class quizzes conducted on a weekly/fortnightly basis to reinforce the basic physic concepts
- Micro project that shall be an extension of any practical lab exercise to real-world application
- Connecting sports to physics concepts:
    - Basketball or football with vectors - projectile motion (horizontal and vertical component). Intuitive understanding of the vectors. Students try out different angles of shooting the ball. For example, asking students through different combinations what angle of throw gives the farthest range, then later compare their answer with a mathematical equation.
- Factors affecting pendulum parameters - does length or mass affect the time period of the pendulum? Does the value of g depend on the setup of the pendulum?
- For STATICS unit - understanding forces involved in the game of human pyramid - can do a demonstration or an activity where cards or paper cups can be used for constructing a pyramid and understand how each cup is in equilibrium despite many forces acting on them.

Reference

- XIth standard Tamilnadu State Board Physics Text Book, 2023 edition, Textbook Corporation Tamil Nadu
- H.C.Verma, Concepts of Physics Vol 1 & Vol 2, Bharathi Bhavan Publishers, 1st edition, 2021

Web-based/Online Resources

- https://www.youtube.com/@Ch22PhysicsIITPAL
- https://www.youtube.com/playlist?list=PLyQSN7X0ro203puVhQsmCj9qhlFQ-As8e
- https://youtube.com/playlist?list=PLFE3074A4CB751B2

UNIT 1

UNITS AND MEASUREMENTS

Objectives

- To define physical quantity and their types
- To understand different system of units
- To recognize the importance of SI unit system
- To convert a physical quantity from one system of unit into other system of units.
- To express physical parameters such as length, mass, time in proper units with proper symbols.
- To recognize that a quantity can be described in terms of its dimensions
- To establish dimensional formula for derived quantities
- To measure the dimensions of given object using a micrometer and Venire caliper
- To understand the source of errors and corrections in measurements

INTRODUCTION

The word physics comes from the Greek word meaning "nature". Today physics is treated as the most fundamental branch of science and finds numerous applications in life. Physics deals with matter in relation to energy and the accurate measurement of the same. Thus, physics is inherently a science of measurement. The fundamentals of physics form the basis for the study and development of engineering and technology.

1.1 SCIENCE & TECHNOLOGY

Engineering is an art of using scientific principle to create Technology. Science, as the systematic pursuit of knowledge through observation, experimentation, and analysis, unveils the mysteries of the universe and unveils the underlying laws governing nature. It is the foundation upon which technological advancements are built. Technology, on the other hand, represents the application of scientific knowledge to create practical solutions, tools, and innovations that enhance our lives and industry standards. Together, science and technology drive innovation across diverse fields, from medicine and communication to transportation and energy. They empower us to tackle complex challenges, improve living standards, and foster global connectivity. As we stand at the intersection of these realms, our ability to harness the fruits of scientific discovery and channel them into technological breakthroughs promises a future marked by boundless opportunities and remarkable transformations.

1.2 UNIT AND DIMENSIONS

A physical quantity is a property of a material or system that can be quantified by measurement. Some physical quantities are length, mass, velocity, momentum, force and energy. *To measure a physical quantity, we need a standard measurement or well-defined small part is known as unit.* For example, if the length of a wooden stick is measured as 60 cm., then cm is the unit of length and 60 is the numerical part.

Systems of unit

System of units is a complete set of fundamental and derived units. Here are some common systems of units used in Physics.

1. F.P.S. system: It is a British system of units, which uses foot, pound and second as the three basic units for measuring length, mass and time respectively.
2. C.G.S. system: It is the Gaussian system of units, which uses centimeter, gram and second for measuring length, mass and time respectively.
3. M.K.S. system: It uses meter, kilogram and second for measuring length, mass and time respectively.

The F.P.S system is not a metric system, whereas M.K.S. and C.G.S. systems are metric systems also known as decimal systems, because multiples and submultiples are related by powers of 10. Example: 1km =1000 m = 10^3 m. The major drawback of the C.G.S. system is that the derived units become unnecessarily small.

1.2.1 Fundamental quantities

Physical quantities are classified into two categories, fundamental quantities and derived quantities. *Physical quantities are independent of any other quantities are known as fundamental or base quantities.* There are seven fundamental quantities and two supplementary quantities are given in the **table 1.1** along with their SI units.

Table 1.1 Fundamental quantities with their SI units

S. No	Physical quantities	Name of Unit	Symbol of the unit (SI)
1	Length	meter	M
2	Mass	kilogram	Kg
3	Time	second	S
4	Electric current	ampere	A
5	Temperature	kelvin	K
6	Luminous intensity	candela	Cd
7	Amount of substance	mole	Mol
Supplementary quantities with their SI units			
1	Plane angle	Radian	Rad
2	Solid angle	steradian	Sr

1.2.2 Derived physical quantities

Quantities that can be expressed in terms of fundamental quantities are called derived quantities. some of the examples for derived quantities arearea, volume, velocity, acceleration, momentum, force and pressure etc.

1.2.3 Dimensional formula

The dimensions of a physical quantity (Q) are the powers to which fundamental units are raised to represent the quantity.

$$Q = [M^a L^b T^c]$$

where, M, L, T are the dimensions of mass, length, and time respectively whereas a, b, c are their respective exponents. **Table 1.2** shows the dimensional formulae for some of the physical quantities.

Table 1.2 Dimensional formula of some physical quantities

Physical quantity	Unit (SI)	Dimensional formula
Length	m	L
Mass	kg	M
Time	s	T

The dimensional formula for some of derived quantities are given below.

Velocity - LT^{-1}, Momentum MLT^{-1} and Force - MLT^{-2}

1.2.4 SI (International System or Système International in French) units

The main drawback of both M.K.S and C.G.S systems that they are confined to mechanics only. However, several physical quantities in physics cannot be described by these systems. Hence a new system, SI system was introduced in 1971 that takes care of all the physical quantities.

SI units are also called as the rationalized and modified form of the M.K.S system. It is relatively better than the M.K.S system for example it assigns only one unit to various forms of a particular physical quantity. Unit of all kinds of energy is joule in SI system. But in the M.K.S system, unit of mechanical energy is joule, unit of heat energy is calorie and unit of electric energy is watt hour.

SI system consists of seven fundamental units and two supplementary units as shown in Table. 1.1

1.2.5 SI unit multiples and submultiples and prefixes of units

When dealing with very small and the very large physical quantities, for example, the distance between two cities or thickness of a wire. Meter is too small for distance and too big for the thickness. Hence, multiples and submultiples of units are required. For example, a kilometer is a multiple of a meter and millimeter is a submultiple. Most commonly used multiples and submultiples along with prefixes which is used in SI units are given in **Table 1.3**

1.3 MEASUREMENTS

The comparison of any physical quantity with the standard unit is called a measurement. Measurement is the basis of all scientific and industrial research hand experiment.

Measurements are playing a key role in both production and quality the industrial products. Some of the physical quantities and their measuring instruments are given in **table 1.4**

Table 1.3 Prefixes for Powers of Ten

Multiples	Prefix	Symbol	Sub multiple	Prefix	Symbol
10^1	deca	da	10^{-1}	deci	d
10^2	hector	h	10^{-2}	centi	c
10^3	kilo	k	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	µ
10^9	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	Exa	E	10^{-18}	atto	a
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{24}	yotta	Y	10^{-24}	yocto	y

Table 1.4 Physical quantities and their measuring devices

S. No	Physical quantity	Measuring devices
1	Length	Meter scale, Screw gauge, Vernier caliper
2	Mass	Physical balance
3	Time	Clock, stop watch
4	Temperature	Thermometer

1.3.1 Need and limitations of a measurements

Measurement is the basis of all scientific and engineering investigations. Based on the result obtained from a measurement, we can manufacture components in appropriate size and shape. Measurements also play an important role in our everyday life.

There are some physical limitations in measurements, which are linked to the instrument used in the measured quantity. The variation in the value of the measured quantity, which can be small or large, is called 'uncertainty or error'. It is because of the accuracy of the device and the operation of the tool

1.3.2 Least count (LC)

The smallest value that can be measured by a measuring instrument is called its least count. The least count is related to the precision of an instrument. The least count of some of the common devices is given below.

meter scale	Vernier caliper	Screw gauge
0.1 cm	0.01 cm	0.01 mm

1.3.3 Types of Measurement

There are three types of measurements are used which are direct method, indirect method and fundamental method

(a) Direct measurement: Measuring exactly the same quantity you want to measure is called direct measurement. For examples, measuring the length of a class room by using measuring tape.

(b) Indirect measurement: Measuring other quantity and required value is determined by mathematical relationship. For example, Measurement of Volume of an object by measuring its mass and density.

(c) Fundamental method: The quantity estimated directly from observation. That is the base quantities used to define the quantity. For example, the measurement of small lengths screw gauge and vernier caliper are used.

1.3.4 Screw gauge (micrometer)

The screw gauge is an instrument used for measuring accurately the dimensions of objects up to about 0.01 mm or 10 micrometers. It works on the principle of transforming rotational movement to linear movement.

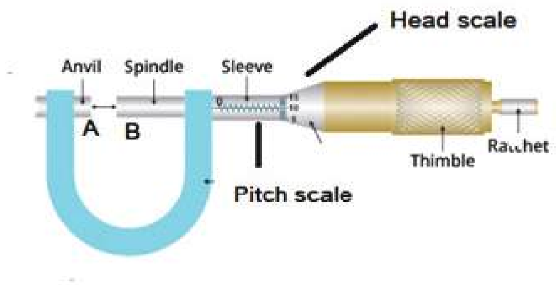


Figure 1.1 Screw gauge and its parts

Construction

A Screw Gauge consists of a U - shaped metal frame as shown in the **Fig 1.1**. The smaller stud (A) is known as the anvil and the longer one (B) is known as the spindle. The anvil is the fixed part, whereas the spindle moves as when the head scale (HC) is moved. A hollow cylindrical nut attached to one end of a frame is called the pitch scale (PS). 100 divisions are marked are marked head scale (HS). The Screw gauge head is having a ratchet arrangement, to avoid over-working the screw.

Least count (LC)

Least count is the minimum length measured by the given instrument and for screw gauge, it is defined as

$$LC = \frac{\text{moved in pitch scale for one complete rotation of head scale}\,(mm)}{\text{Number of divisions in head scale}\,(division)}$$

$$LC = \frac{1\,mm}{100} = 0.01\,mm$$

Zero Error and Zero Correction

When the two stud A and B are brought into contact with out the object, if the zero of the head-scale coincides with the pitch scale axis (**Fig 1.2 a**), there is no zero error (ZE) and hence no need for any zero correction (ZC).

In case, zero of the head scales lie below the pitch scale axis (**Fig 1.2 b**), the zero error is positive and zero correction is negative.

ZE = +5 divisions and the Zero Correction is (ZC)= – (+5 × LC) = –0.05 mm

If zero of the head-scale lie above the pitch scale axis (Fig 1.2 c), the zero error is negative and the zero correction is positive.

ZE = – 5 divisions and the Zero Correction ZC= – (–5 × L.C) = + 0.05 mm

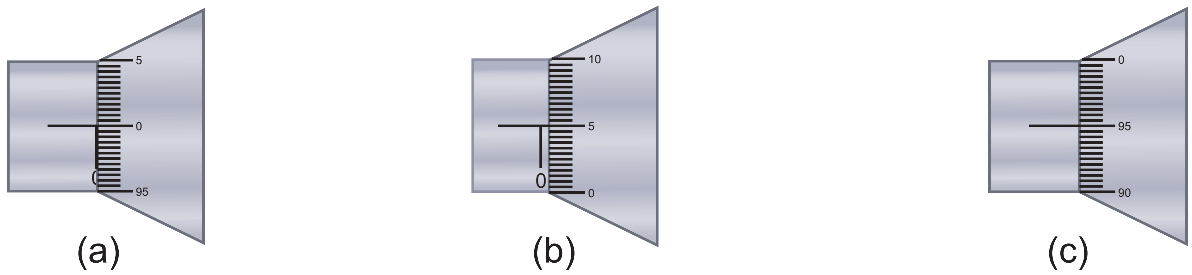


Figure 1.2 (a) No zero error (b) Positive zero error (c) Negative zero error

1.3.5 Finding the thickness of a thin wire by using Screw gauge:

The given thin wire is placed gently in between the two studs A and B and the ratchet is rotated till the wire is firmly but gently gripped as shown in the **Fig 1.3**. Note the number of completed divisions in mm on the pitch scale as Pitch scale reading (PSR) and the divisions on the head scale, which coincides with the index line as head scale coincidence (HSC). The PSR and HSC are entered in the tabular column. Then the head scale reading (HSR), observed reading (OR) and correct reading (CR) are calculated. The procedure is repeated for different positions of the wire and reading are entered in **table 1.5** and the average thickness is calculated.

Figure 1.3 Measuring thickness of a given wire

The average thickens = ____ mm (or) ____ $\times 10^{-3}$ m

1.3.6 Vernier caliper

A Vernier caliper is a measuring device which is used to measure precisely the linear dimensions such as inner and outer diameter, length and depth of specimen.

Table 1.5 Thickness of the thin wire

LC =____ mm **ZE =____ mm** **ZC =____ mm**

S.No	PSR mm	HSC div	HSR = HSC × LC mm	OR = PSR + HSR mm	CR= PSR + HSR ± ZE mm

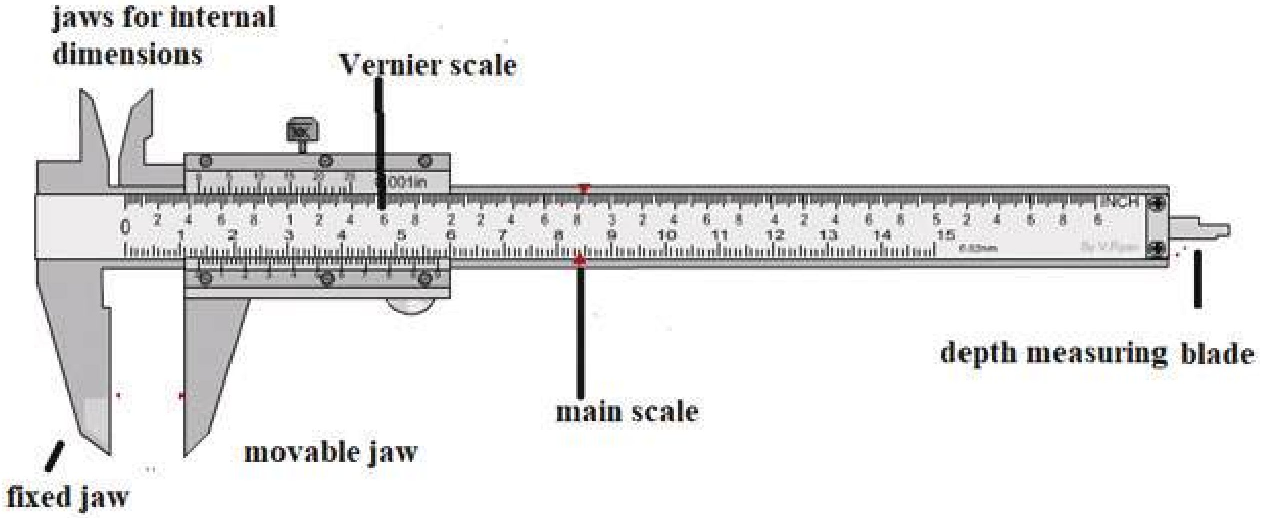


Figure 1.4 (a) Vernier caliper and its parts.

Construction

Vernier caliper consists of two scales. One is fixed and the other is movable. The fixed scale which is graduated in centimeters is called the main scale. The movable scale, which consists of only divisions is called the Vernier scale. Vernier scale slides over the main scale and carries a movable jaw. These movable and fixed jaws are fixed to measure the tips for internal and external measurements. Generally, the Vernier scale is provided with N divisions matching with (N – 1) divisions of the main scale.

Least count (LC)

The value of 1 main scale division (MSD) and number of divisions (n) on the vernier scale are determined. For basic laboratory vernier caliper, 1 MSD is 1mm i.e, 0.1 cm and number of divisions on the vernier scale (n) is 50. The least count of the vernier caliper is calculated using the formula

LC = 1 MSD – 1 VSD

Value of 50 VSD = 49 mm; 1VSD = 49/50 = 0.98 mm

Hence, LC = 1 mm - 0.98 mm = 0.02 mm

Note The L.C of Screw gauge is smaller than Vernier caliper. It implies that screw gauge can be used to measure smaller thickness than vernier caliper with high precision

1.3.7 Finding the thickness (diameter) of a cylinder using Vernier caliper

Figure 1.5 Measuring thickness of the cylinder using vernier caliper

The given cylindrical object (solid or hollow cylinder) is gently placed in between the two lower jaws of the vernier calipers as shown in **Fig 1.5**. The main scale reading (MSR) is taken by noting the position of zero of the vernier scale which coincides with the main scale

Table 1.6 Thickness of the cylinder LC =0.01 cm

S.No	MSR cm	VSC div	VSR = VSC × LC cm	TR = MSR + VSR cm

division. The vernier scale coincidence (VSC) is then noted by particular division in vernier scale which coincides with any one of the main scale divisions. The MSR and VSC are noted in the **table 1.6** for different settings of the cylinder. Then the Vernier Scale Reading (VSR) obtained by multiplying VSC and LC, Total Reading (TR) is calculated using the formula given. The average value of TR is obtained, which gives the thickness of the given cylinder.

The average thickness = ____ cm (or) ____ $\times 10^{-2}$ m

1.3.8 Application in industries

Since the beginning of industrial revolution screw gauge and vernier caliper became an essential tool for precision engineering work.Both are commonly used measuring devices in various engineering field.

Vernier calipers can be used to make both internal and external measurements of complicated structures such as diameter of crankshaft, the diameter of bore of the cylinder, depth of the bore and height of the spring installed in internal combustion engine. It is also used to measure the tooth thickness & profile and addendum of gear tooth (**Fig.1.6a**).

Dimension of surgical instrument are needed to be measured with high precision, because they have to work in very limited space and sensitive parts. Example, the distance between its two sides and length of jaw of forceps is measured by Vernier caliper (**Fig.1.6b**).

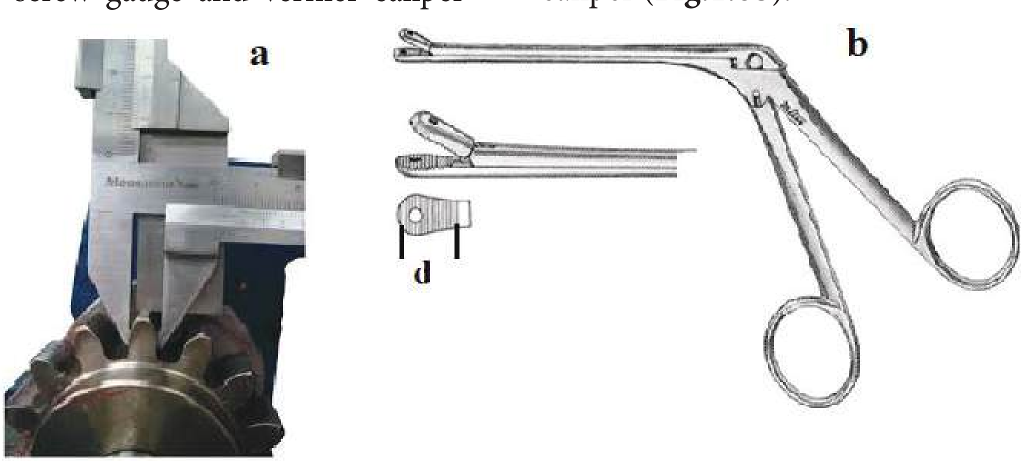


Figure 1.6 Various applications of Vernier caliper

Figure 1.7 Various applications of Screw gauge

Micrometers are used to precisely measure the thickness of thin wires and sheets up to several microns. Thickness of polymers insulation coating (10 microns range) of a winding wire can be measured by micrometers.

Thickness of balls are measured by screw gauge in regular intervals in order to estimate the wear and tear properties of a ball bearing. Size of the balls should be measured accurately, off sized balls makes excess or unwanted contact stresses, stiffness, damping and friction between bearing components and leads to failure of product (**Fig.1.7a**).

Mechanical strength, resistance to bending moment are more significant parameters in heavy industries such as pipe construction frame, beams, etc. Micrometer offers superior design and workmanship to ensure high precision and long life to the final product (**Fig.1.7b**)

1.4 ERRORS IN MEASUREMENTS

Measurement is the heart of science, engineering and technology. For any type of measurement, there will be always some errors and avoiding or minimizing those errors are important to ensure the accuracy and precision of any final product. The uncertainty in a measurement is called an error. Errors can be classified into two types namely systematic errors and random errors.

1.4.1 Systematic errors

Errors whose causes are known is called systematic errors and they are reproducible. These errors can be minimized by applying some corrections. Systematic errors can be classified as follows.

a) Errors due to External Factors.

These errors are due to changes in the external conditions during an experiment which can cause errors in measurement. For example, changes in atmospheric conditions like temperature, pressure, and humidity during measurements may affect the result of the measurement

b) Errors due to Imperfection

These errors are introduced due to limitations in the experimental arrangement. For example, error in weighing a body arising out of buoyancy is usually ignored.

c) Personal errors

These errors are due to lack of proper care by the observer. For example, lack of proper initial setting of the apparatus or recording the reading without proper precautions.

d) Instrumental Errors

These errors are due to improper design at the time of manufacturing of the instrument. For example, a meter scale may be worn off at the end of the zero mark, The instrumental errors can be reduced by choosing the most accurate instruments and applying zero correction.

e) Least count error

The error due to the Least count (LC) of an instrument is called as the least count error. The instrument's resolution is the cause of this error.

1.4.2 Random errors

The causes of errors which are not known precisely are called random errors. It is not possible to eliminate random error completely. For example, consider the case of the length of a rod measured using a vernier. The readings taken may be different for different trials. These errors are also known as trial/chance errors.

If n number of trial readings are taken in an experiment, and the readings are X_1, X_2, X_3 ………………… X_n. The arithmetic mean (X_m) is

$$X_m = \frac{X_1 + X_2 + X_3 + \ldots\ldots\ldots\ldots + X_n.}{n}$$

Usually, this arithmetic mean is taken as the best possible true value of the physical quantity obtained from a measurement.

1.4.3 Absolute Error

It is the magnitude of difference between the true value and the measured value of a physical quantity. Let X_1, X_2, X_3 ………………… X_n are the measured values of any quantity 'X' in an experiment performed n times, then the arithmetic mean of these values is called the true value (X_m) of the quantity.

The absolute error in measured values is given by

$$|\Delta X_1| = |X_m - X_1|$$
$$|\Delta X_2| = |X_m - X_2|$$
$$\ldots\ldots\ldots\ldots$$
$$\ldots\ldots\ldots\ldots$$
$$|\Delta X_n| = |X_m - X_n|$$

Mean Absolute error

The arithmetic mean of absolute errors in all the measurements is called the mean absolute error.

$$|\Delta X_m| = \frac{|\Delta X_1| + |\Delta X_2| + |\Delta X_3| + \ldots\ldots\ldots\ldots + |\Delta X_n|}{n}$$

If X_m is the true value and ΔX_m is the mean absolute error then the magnitude of the quantity may lie between $X_m + \Delta X_m$ and $X_m - \Delta X_m$

Relative error

The ratio of the mean absolute error ($|\Delta X_m|$) to the mean value (ΔX_m) is called relative error. This is also called fractional error and it is given by

$$\text{Relative error} = \frac{\text{Mean absolute error}}{\text{Mean value}}$$

$$\text{Relative error} = \frac{|\Delta X_m|}{|X_m|}$$

Percentage error

The relative error expressed as a percentage is called percentage error.

$$\text{Relative error} = \frac{|\Delta X_m|}{|X_m|} \times 100\%$$

If the percentage error is very close to zero means, the given measured value is very close to the actual value.

1.4.4 Error propagation

If we do calculations with measurements which themselves contain error, the values will certainly be error in the final result. In order to calculate the net error in the final result, we should know how the error propagates in the final calculations.

The error in the final result depends on

(i) The errors in the individual measurements

(ii) On the nature of mathematical operations performed to get the final result.

So, we should know the rules to combine the errors. The various possibilities of the propagation or combination of errors in different mathematical operations are discussed below:

Let us consider ΔA and ΔB are the absolute errors of quantities A and B respectively.

Then, measured value of A is A ± ΔA and measured value of B = B ± ΔB

i) Error in Summation

Consider a physical quantity Z which is sum of A and B.

$$Z = A + B$$

The error ΔZ in Z is then given by

The error ΔZ in Z is then given by

$$\Delta Z = \Delta A + \Delta B$$

The maximum absolute error in the sum of two quantities is equal to the sum of the absolute errors in the individual quantities.

EXAMPLE 1

Consider a building which has ground and first floor and its total height to be measured. One student measures height of ground floor and gives (4±0.05) m and another student measures the height of first floor and he gives (4.7±0.03) m. What is the total height of the building and calculate the error in total height.

Solution:

Height of ground floor h_0 = 4 m and uncertainty or error = 0.05 m

Height of first floor h_1 = 4.7 m and uncertainty or error = 0.03 m

The total height = $h_0 + h_1$ = 8.7 m

Error in total height = 0.08 m

Therefore, the total height is expressed as (8.7 ± 0.08) m

ii) Error in Difference

Consider a physical quantity Z which is difference of A and B.

$$Z = A - B$$

The error ΔZ in Z is then given by

$$\Delta Z = \Delta A + \Delta B$$

The Maximum absolute error in difference of two quantities is equal to sum of the absolute errors in the individual quantities.

EXAMPLE 2

Consider two sticks of different lengths and its difference in length is to be measured. One student measures length of first stick and gives (1±0.001) m and another student measures the length of second stick and he gives (1.5±0.002) m. What is the difference in their length and calculate the error involved in it.

Solution:

length of first stick l_1 = 1 m and uncertainty or error = 0.001 m

Height of first floor l_2 = 1.5 m and uncertainty or error = 0.002 m

The difference in their length = l_1 - l_2 = 0.5 m

Error involved in their difference = 0.03 m

Therefore, the difference in their length is expressed as (0.5 ± 0.03) m

iii) Error in Product

Consider a physical quantity Z which is the product of A and B

$$Z = AB$$

The error ΔZ in Z is given by

$$\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B} \text{ or } \Delta Z = \left(\frac{\Delta A}{A} + \frac{\Delta B}{B}\right) Z$$

The maximum value of fractional or relative error in the division of qualities is equal to the slim of the fractional or relative errors in the individual quantities.

EXAMPLE 3

The length and breadth of a rectangle slab are (4.7 ± 0 .1) cm and (3.4 ± 0 .1) cm respectively. Calculate the area of the rectangle with error limits.

Solution:

Length L = (4.7 ± 0 .1) cm Breadth B = (3.4 ± 0 .1) cm

Area A with error limit = A ± ΔA = ?

Area A = L × B = 4.7 × 3.4 = 15.98 cm^2

The fractional error in the area is given by

ΔA/A = ΔL/L ± ΔB/B

Or

ΔA = (ΔL/L ± ΔB/B) A

ΔA = (0.1/4.7 + 0.1/3.4) 15.98

ΔA = (0.0212 + 0.0294) 15.98

ΔA = (0.0506) 15.98

ΔA = 0.8085

Area with error limit is A ± ΔA

A = (15.98± 0.81) cm^2

iv) Error in Division

Consider a physical quantity Z which is the division of A and B

$$Z = A/B,$$

The error ΔZ in Z is given by

$$\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B} \text{ or } \Delta Z = \left(\frac{\Delta A}{A} + \frac{\Delta B}{B}\right) Z.$$

The Maximum value of fractional or relative error in division of quantities is equal to the slim of the fractional or relative errors in the individual quantities.

v) Error in Power of a Quantity

Consider a physical quantity *Z* which is n^{th} power of *A*

$$Z = A^n$$

The error ΔZ in Z is given by

$$\frac{\Delta Z}{Z} = n\frac{\Delta A}{A}$$

The Fractional error or relative error in the quantity is equal to sum of the fractional or relative error of the individual quantities multiplied by their powers.

EXAMPLE 4

A disc is given to a student to determine its area. He measures the radius and found out (0.5±0.001) m. What is the area of the disc and calculate the error involved in it.

Solution:

Radius r = 0.5 m uncertainty or error $\Delta r = 0.001$ m

The area of the disc

$$A = \pi r^2 = 3.14\times0.5\times0.5 = 0.78\,m^2$$

Here the exponent n = 2

The fractional error

$$\frac{\Delta A}{A} = 2\frac{\Delta r}{r} = 2\times\frac{0.001}{0.5} = 0.004$$

The error in the area of the disc

$$\Delta A = 0.004\times0.78 = 0.003\,m^2$$

1.4.5 Precautions to avoid systematic and random error

We can reduce random errors by following methods

1. Taking repeated measurements
2. Using a large sample
3. Controlling extraneous variables

Systematic error can be reduced by following methods

1. Taking care in designing an experiment, data collection, and analysis procedures
2. Comparing results with standard values
3. Using different equipment or techniques

1.4.6 Engineering applications of error analysis

Error analysis and error propagation calculations are essential for ensuring the precision, dependability, and safety of engineering systems and products. These ideas are crucial to several branches of engineering, including as mechanical, civil, auto mobile, electrical, and chemical engineering and others. The importance of error analysis and error propagation in the engineering profession is as follows:

Accuracy and reliability in measurements:

Measurements and data collection are common tasks for engineers during production, testing, and experimentation procedures. Error analysis helps in quantifying measurement uncertainty, ensuring the reported results are correct and trustworthy.

Quality control and manufacturing:

Even small error in production procedures can result in flaws, waste, and safety risks. To ensure product quality and performance, manufacturing process are monitored and controlled through error analysis. The impact of changes in process parameters, equipment tolerances, and raw material variances on the finished product is assessed using error propagation. This supports engineers in their decision-making to reduce faults and enhance manufacturing methods.

1.4.7 Physical quantities:

Various physical quantities are used in engineering field and several of them is given in the **table 1.7**

Horsepower to watt conversion

Horsepower (HP) is the practical unit of power. The bore well motor brings water from the borewell and the capacity of bore well motor is still expressed in Horse power.

One horsepower refers to the power needed to move 550 pounds (249.47 kg) of mass to one foot in one second. Generally, the power is the measure of the rate of work.

$$1 \text{ HP} \approx 745.69987 \text{ W}$$

Calorie and Joule conversion

The calorie is practical unit of heat energy. One calorie is as the amount of heat required at a pressure of 1 standard atmosphere (1 atm) to raise the temperature of 1 gram of water by 1° Celsius.

$$1 \text{ Cal} = 4.184 \text{ J}$$

Table 1.7 Physical quantities and its dimensional formula

S. No	Physical quantity	Expression (Formula)	Unit	
			SI	Dimensional formula
1	Time	-	s	T
2	Length	-	m	L
3	Mass	-	kg	M
4	Velocity	displacement / time	ms^{-1}	LT^{-1}
5	Momentum	Mass x velocity	kg ms^{-1}	MLT^{-1}
6	Acceleration	velocity / time	ms^{-2}	LT^{-2}
7	Force	mass x acceleration	kg ms^{-2} (N)	MLT^{-2}
8	Impulse	force x time	N s	MLT^{-1}
9	Work (Energy)	Force x distance	N m (J)	ML^2T^{-2}
10	Power	Work / time	J s^{-1} (W)	ML^2T^{-3}

DO YOU KNOW?

Story 1: On September 23, 1999 NASA lost the $125 million Mars Climate Orbiter spacecraft after a 286-day journey to Mars. Miscalculations due to the use of English units instead of metric units apparently sent the craft slowly off course 60 miles in all. Thrusters used to help point the spacecraft had, over the course of months, been fired incorrectly because data used to control the wheels were calculated in incorrect units. Lockheed Martin, which was performing the calculations, was sending thruster data in British units (pounds) to NASA, while NASA's navigation team was expecting metric units (Newtons).

Story 2: On January 26, 2004 at Tokyo Disneyland's Space Mountain, an axle broke on a roller coaster train mid-ride, causing it to derail. The cause was a part being the wrong size due to a conversion of the master plans in 1995 from British units to Metric units. In 2002, new axles were mistakenly ordered using the pre-1995 British specifications instead of the current Metric specifications.

SUMMARY

- Physics is an experimental science in which measurements made must be expressed in appropriate units.
- All physical quantities have a magnitude (numerical value or size) and a unit.
- The SI unit of fundamental quantities namely length, mass, time, temperature, electric current, amount of substance and luminous intensity are meter, kilogram, second, kelvin, ampere, mole and candela respectively.
- Units of all mechanical, electrical, magnetic and thermal quantities are derived in terms of these base units.
- Screw gauge, Venire caliper methods are available for the measurement of length in the case of small distances of few microns.
- The uncertainty in a measurement is called error. The accuracy of a measurement is a measure of how close the measured value is to the true value of the quantity.
- When two or more quantities are added or subtracted, the result can be as precise as the least of the individual precisions.
- Dimensional formula is used to perform quick check on the validity of equations.

WORKED EXAMPLES

1. A vernier calipers has 1 mm marks on the main scale. It has 20 equal divisions on the Vernier scale which match with 16 main scale divisions. Find the least count (LC) of the scale.

   MSD = 1 mm and 20 VSD = 16 MSD

   $\Rightarrow$ VSD = 16/20 MSD

   = 0.8 MSD = 0.8 mm

   Least Count = MSD – VSD = 1 – 0.8

   Least Count = 0.2 mm

2. Thickness of Polyamide-imide insulator film coated copper winding wire is 105 micrometers. After removal of polymer coating by scratching, the thickens was measured as 94 micrometers. Find the thickness of polymer coating in mm range.

   105 – 94 = 11 micrometer

   or 94×10^{-6} m

   = 0.000095 m or 0.095×10^{-3} m

3. In a screw gauge; zero of the head scale lies 14 divisions above the pitch scale axis, then find the zero error and zero correction of the scale? Least count of the scale is 0.01 mm.

   HSC = +14 div

   Zero Error (ZE) = (HSC × LC)

   = (+14 × 0.01 mm)

   Zero Error (ZE) = + 0.14 mm

   Zero Correction (ZC) = –(ZE)

   Zero Correction (ZC) = – 0.14 mm

4. Derive the dimensional formula for Force.

   According to the Newton's second law, Force is the product of mass and acceleration.

   Force = mass × acceleration

   acceleration = velocity/ time or displacement/ time x time

   Applying dimensions, Mass, displacement and time

   Force = M x L/T^2 or MLT^{-2}

   Dimensional formula for force = [MLT $^{-2}$]

5. The temperatures of two bodies measured by a thermometer are $T_1 = (45 \pm 0.25)$°C, $T_2 = (50 \pm 0.20)$°C. Calculate the temperature difference and the error therein.

   Temperature of first body T_1 = 45 °C and uncertainty or error = 0.5 °C

   Temperature of first body T_2 = 50 °C and uncertainty or error = 0.5°C

   The difference in their Temperature = $T_2 - T_1$ = 5 °C

   The total error = 0.45°C

   Therefore, the difference in temperature is expressed as (5 ± 0.45) °C

EVALUATION

Part A (2 marks)

1. What is physical quantity?
2. How to express a physical quantity from a result of an experiment?
3. What are fundamental and derived physical quantity?
4. What are fundamental and derived units?
5. List out any physical quantity which does not have a unit?
6. Mention the significance of SI system.
7. In a screw gauge zero of the head scale lies below the pitch scale axis, the zero error is?
8. The possibilities of the propagation (combination) of errors in finding the volume of sphere using micro meter?
9. Newton's second law is , Find the dimensional formula for force?
10. Derive the dimensional formula for energy.
11. Show that a screw gauge of pitch 1 mm and 100 divisions is more precise than a vernier caliper with 1 MSR is 0.5 cm 50 divisions on the sliding scale (vernier scale).
12. Why dimensional methods are applicable only up to three quantities namely Length, Mass and Time?
13. What is absolute error?
14. What is relative or fractional error?
15. What is percentage error?

Part B (7 marks)

16. With a neat diagram explain the construction and working of a screw gauge.
17. With a neat diagram explain the construction and working of a vernier caliper.
18. List out engineering applications screw gauge and vernier caliper.
19. Explain in detail the various types of errors.
20. Explain the propagation of errors in addition and multiplication.
21. Discuss the precautions to avoid systematic and random errors.
22. List out significance of error in engineering field.

Problems

1. A student measures the thickness of a copper wire using standard instruments and reports it as 0.1 cm, 0.15 cm and 0.157 cm. What are name the instruments used to find these measurements?

   [**Ans:** Meter scale, vernier caliperand screw gauge.]

2. There are 25 divisions on the vernier scale which coincides with 24th division of the main scale. 1 cm on main scale is divided into 20 equal parts. Calculate the least count of the instrument.

   [**Ans:** LC= 0.002 cm]

3. The voltage across a wire is (100 ± 0.5) V and the current passing through it is (10 ± 0.2) A. Find the resistance of the wire.

   [**Ans:** R = 10 ± 0.25 ohm]

4. Find the dimensional formula for energy.

   [**Ans:** $M^1 L^2 T^{-2}$]

5. Radius of a sphere is 5.3± 0.1 cm. Calculate the percentage error in its volume.

   [**Ans:** 5.66%]

UNIT 2

STATICS

Objectives

The main objectives of this lesson are that the students will be able to

- Understand Lami's theorem relates the three concurrent forces acting on the body to keep it in equilibrium
- Describe the experimental verification of parallelogram law of forces and Lami's theorem.
- List out the engineering applications for both Parallelogram law of forces and Lami's theorem.
- Define the terms moment of force and couple.
- Understand the day-to-day life examples where the concepts on moment of force or couple plays an important role.
- Explain the principle of moments.
- Describe an experiment to determine the unknown mass of an object using principle of moments.

2.1 STATICS

Statics deals with the objects at rest or equilibrium under the action of multiple forces. It is applied in engineering fields extensively. It is the application of Newton's laws to design and analyze structures and systems. **Examples:**

1. A car resting on a bridge.
2. A portrait hanging on a wall.

Scalar Quantities

Physical quantities with only magnitude are known as scalar quantities. Quantities like mass, temperature, density can be specified completely by giving the magnitude (numerical value) alone.

Example: Mass, Speed, Work, etc.

Mass = 10 kg, Speed = 50 ms^{-1}.

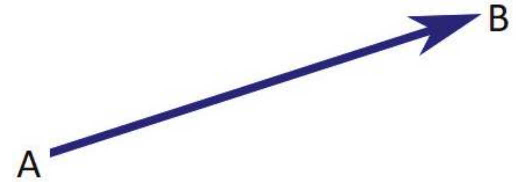
Vector quantities

Physical quantities with both magnitude and direction are known as vector quantities. Vectors are represented by an arrow with its length proportional to the magnitude. Physical quantities like force, velocity, etc need the direction also to be specified for complete information.

Examples : Velocity, Force, etc.

Velocity = 50 ms^{-1} towards North, Force = 10 N downwards.

A vector is a directed line segment which is shown below.



Magnitude of the $\overrightarrow{AB}$ = Length of the $\overrightarrow{AB}$

Direction of the $\overrightarrow{AB}$ = Direction of the line AB

2.1.1 Resolution of a vector into perpendicular components

In the Cartesian two-dimensional coordinate system any vector $\vec{R}$ can be resolved into two components along X and Y directions. This is shown in the **figure 2.1** below

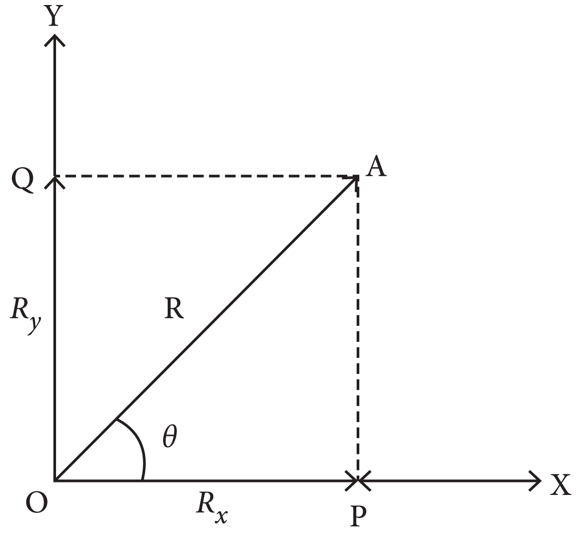


Figure 2.1 Resolution of a vector into perpendicular components

A vector $\vec{R}$ is represented by the line OA. $\vec{R}$ makes an angle θ with the X- axis. X and Y axes are perpendicular to each other.Dotted lines AP and AQ are drawn perpendicular to the axes X and Y respectively. R_x and R_y are the two perpendicular components of the vector .Here the length OA represents the magnitude of the vector $\vec{R}$.

In the rectangle $OPAQ$,

$$OP = QA = R_x$$
$$OQ = PA = R_y$$

In ΔOAP,

$$\sin\theta = \frac{opposite\ side}{hypotenuse}$$

$$\sin\theta = \frac{AP}{OA}$$

$$\sin\theta = \frac{R_y}{R}$$

$$R_y = R\sin\theta$$

The vertical component of $\vec{R}$ is $R\sin\theta$

Similarly,

$$\cos\theta = \frac{Adjacent\ side}{Hypotenuse}$$

$$\cos\theta = \frac{OP}{OA}$$

$$\cos\theta = \frac{R_x}{R}$$

$$R_x = R\cos\theta$$

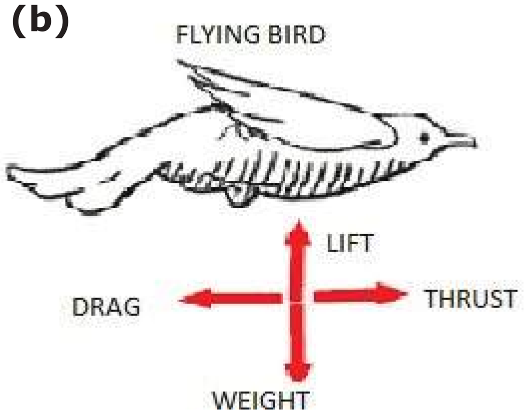
The horizontal component of $\vec{R}$ is $R\cos\theta$

2.1.2 Concurrent forces

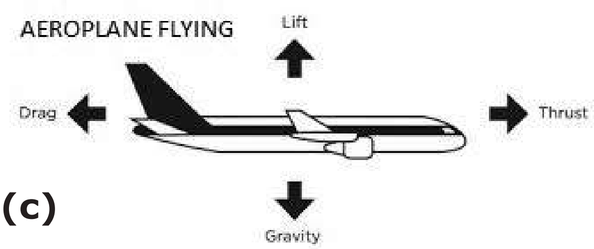
When two or more forces act at the same point and at the same time, they are called concurrent forces. A few examples are shown in **Figure 2.2 (a)** to **(d)**

(a)

(b)



(c)



(d)

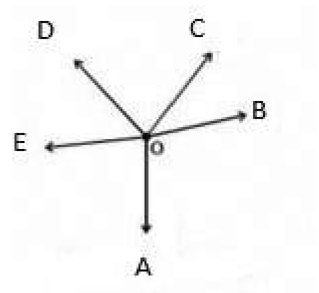


Figure 2.2 Concurrent forces

In the **Figure 2.2 (d)** shown above, A, B,C,D and E are concurrent forces. **Example:**

1. Forces at the hub of a ceiling fan.
2. Forces on the bob of a swinging pendulum.
3. Tension forces acting on a load through cables.
4. Forces acting on a flying bird.
5. Forces acting on a flying aero plane.

2.1.3 Coplanar forces

When two or more forces are acting in the same plane, they are called coplanar forces.

Figure 2.3(a) Coplanar forces

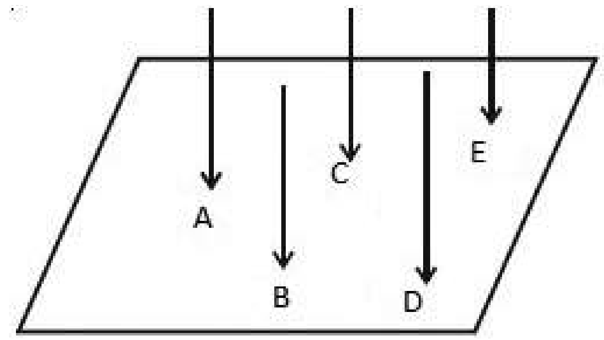


Figure 2.3(b) Coplanar forces

In the **figure 2.3(b)** shown above, A, B, C, D and E are coplanar forces. **Example:**

1. A rope that is attached to two or more points on a wall or a ceiling.
2. The steering wheel of vehicles subjected to coplanar forces.

2.1.4 Resultant

The resultant force is the vector sum of all the forces acting on an object and determines the motion of an object. For example, as shown in **Figure 2.4**, if you push a box with a force of 10 newton to the right, and your friend pushes the same box with a force of 7 newton to the left, the resultant force acting on the box would be 3 newton to the right (10 N – 7 N).

Figure 2.4 Resultant

2.1.5 Equilibrant

An equilibrant force is exactly equal and opposite to the resultant force. It causes the object to remain in a state of equilibrium by counteracting the other forces acting on the object.

For example, as shown in **Figure 2.5** below, when two group of people are playing tug-of-war and they both pull on the rope with equal force but in opposite directions, the rope remains in place because the forces are balanced.

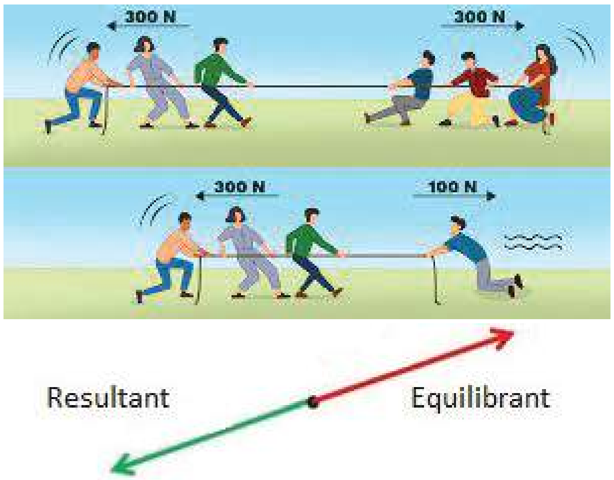


Figure 2.5 Equilibrant

2.2 TRIANGLE LAW FOR THE ADDITION OF TWO FORCES

The triangle law for addition states that if two forces are represented by two sides of a triangle taken in order, then their resultant vector is represented by the third side of the triangle taken in the reverse direction **(Figure 2.6)**.

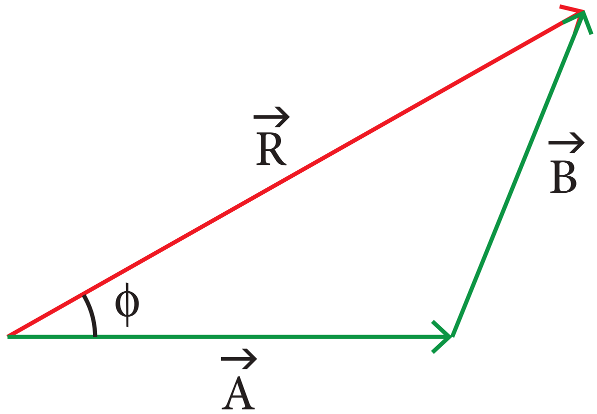


Figure 2.6 Triangle law for addition of forces

The two vectors $\vec{A}$ and $\vec{B}$ are taken in the anti-clockwise direction whereas the resultant vector $\vec{R}$ is in the clockwise direction.

Here,

Resultant $\vec{R} = \vec{A} + \vec{B}$

2.3 PARALLELOGRAM LAW FOR THE ADDITION OF TWO FORCES

Parallelogram law for addition states that if the two forces are represented by the two adjacent sides of a parallelogram, then their resultant force is represented by the diagonal of the parallelogram passing through point 'O'. **(Figure 2.7)**

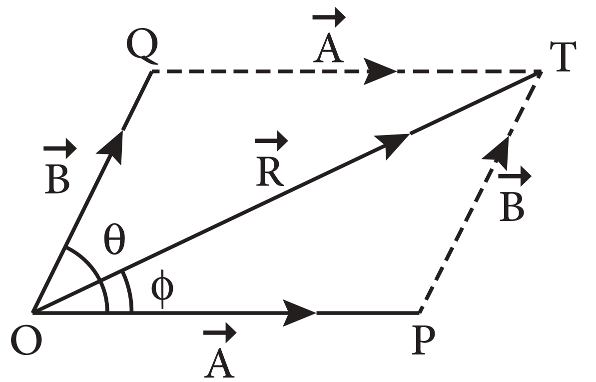


Figure 2.7 Parallelogram law for the addition of two forces

Here also,

Resultant $\vec{R} = \vec{A} + \vec{B}$

Hence the triangle and parallelogram law of addition of two forces are similar to each other. Let Θ be the angle between the two forces $\vec{A}$ and $\vec{B}$. Also, ϕ be the angle between the resultant $\vec{R}$ and the force $\vec{A}$. In both the cases,

The magnitude of the resultant force is given by,

$$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

The direction of the resultant force is given by,

$$\tan\phi = \frac{B\sin\theta}{A + B\cos\theta}$$

$$\phi = \tan^{-1}\left(\frac{B\sin\theta}{A + B\cos\theta}\right)$$

EXAMPLE 2.1

Two forces $\vec{A}$ and $\vec{B}$ of magnitude 4N and 3N respectively make an angle 90° with each other. Find the magnitude of the resultant vector and its direction with respect to the vector $\vec{A}$.

Given:

A = 4 N, B = 3 N, ϴ = 90°, R= ? ϕ = ?

Solution:

$$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$
$$= \sqrt{4^2 + 3^2 + 2 \times 4 \times 3 \times \cos 90}$$
$$= \sqrt{16 + 9 + 2 \times 4 \times 3 \times 0}$$
$$= \sqrt{25}$$
$$|\bar{R}| = 5\ N$$

$$\tan\phi = \frac{B\sin\theta}{A + B\cos\theta}$$
$$= \frac{3\sin 90}{4 + 3\cos 90}$$
$$= \frac{3 \times 1}{4 + 3 \times 0}$$
$$= \frac{3}{4}$$
$$= 0.75$$
$$\phi = \tan^{-1} 0.75$$
$$\phi = 36.87^o$$

2.4 LAMI'S THEOREM

In statics, Lami's theorem relates the magnitude of three concurrent forces in a given plane that keeps the body in static equilibrium. The theorem is named after Bernard Lamy.

Statement

Lami's theorem states that if a body is in equilibrium under the action of three concurrent forces in a given plane, then each of the force is directly proportional to the sine of the angle between other two forces.

Explanation

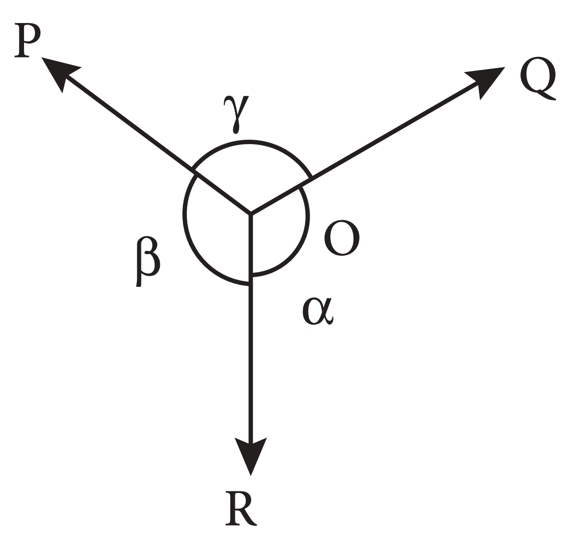


Figure 2.8 Lami's theorem

Let P, Q and R be three forces acting at a point O as shown in Fig. 2.8. Under the action of these three forces, the point O is at rest i.e., in equilibrium. Let α, β and γ be the angles opposite to the forces P, Q and R respectively, i.e., the angle between Q and R be α, between R and P be β and between P and Q be γ.

According to Lami's theorem,

$$P \propto \sin\alpha \Rightarrow P = K\sin\alpha \Rightarrow \frac{P}{\sin\alpha} = K$$

$$Q \propto \sin\beta \Rightarrow Q = K\sin\beta \Rightarrow \frac{Q}{\sin\beta} = K$$

$$R \propto \sin\gamma \Rightarrow R = K\sin\gamma \Rightarrow \frac{R}{\sin\gamma} = K$$

Therefore, $\frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma} = K$ (constant)

Limitations

Lami's theorem is not applicable for parallel or non-concurrent forces. Moreover, it is not applicable for more or less than three coplanar and concurrent force systems.

Applications

Lami's theorem is applied in static analysis of mechanical and structural systems.

2.4.1 Experimental verification of parallelogram law of forces

A drawing board is fixed vertically on the wall. Two frictionless pulleys are fixed at the top corners of the drawing board as shown in the **Figure 2.9**. A light and inextensible string is passed over these pulleys. Another short string is tied to the middle of the first string at O. Weight hangers P, Q and R are tied at the free ends of the strings as shown in the figure. Displace the slotted weight hangers from the position and note if they come to the original position to ensure that the pulley have minimum friction. The weights P, Q and R are adjusted suitably such that the system is at rest. The point O is in equilibrium under the action of these three coplanar and concurrent forces P, Q and R acting along the strings.

A white paper is held just behind the string without touching them. The point O and the directions of the strings along OA, OB and OC are marked on the paper. Then the paper is removed from the board. With suitable scale (50 g = 2 cm), the points A, B and C are marked. OA, OB and OC represent the forces P, Q and R respectively.

To determine the resultant of the two forces P and Q, the parallelogram OADB is drawn. Then the diagonal OD is drawn. The length of the diagonal OD gives the resultant

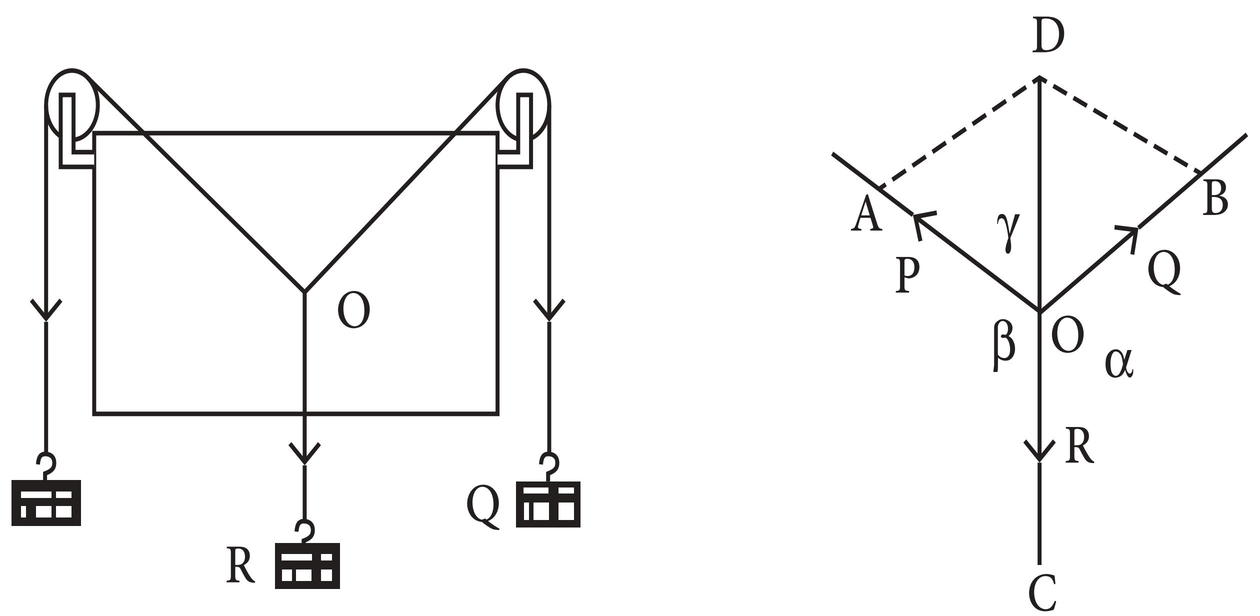


Figure 2.9 Experimental set up for verification of parallelogram law

Table 2.1 Parallelogram law

Sl. No.	P	Q	R	OA	OB	OC	OD	∠COD

and the angle ∠COD are measured and tabulated as shown in **Table 2.1**.

The experiment is repeated for different values of P, Q and R. It is found that OC = OD and

∠COD = 180°. Thus, the parallelogram law of forces is verified experimentally.

> **Note** A body is said to be in equilibrium when it is completely at rest. To obtain the equilibrium of the point O in the above experiment, choose the weights such that P + Q > R and P – Q < R.

2.4.2 Experimental verification of Lami's theorem

A drawing board is fixed vertically on the wall. Two smooth frictionless pulleys are fixed at the top corners of the drawing board as shown in the **figure 2.10**. A light and inextensible string is passed over these pulleys. Another short string is tied to the middle of the first string at O. Weight hangers P, Q and R are tied at the free ends of the strings as shown in the figure. Displace the slotted weight hangers from the position and note if they come to the original position to ensure that the pulley have minimum friction. The weights P, Q and R are adjusted suitably such that the system is at rest. The point O is in equilibrium under the action of these three coplanar and concurrent forces P, Q and R acting along the strings.

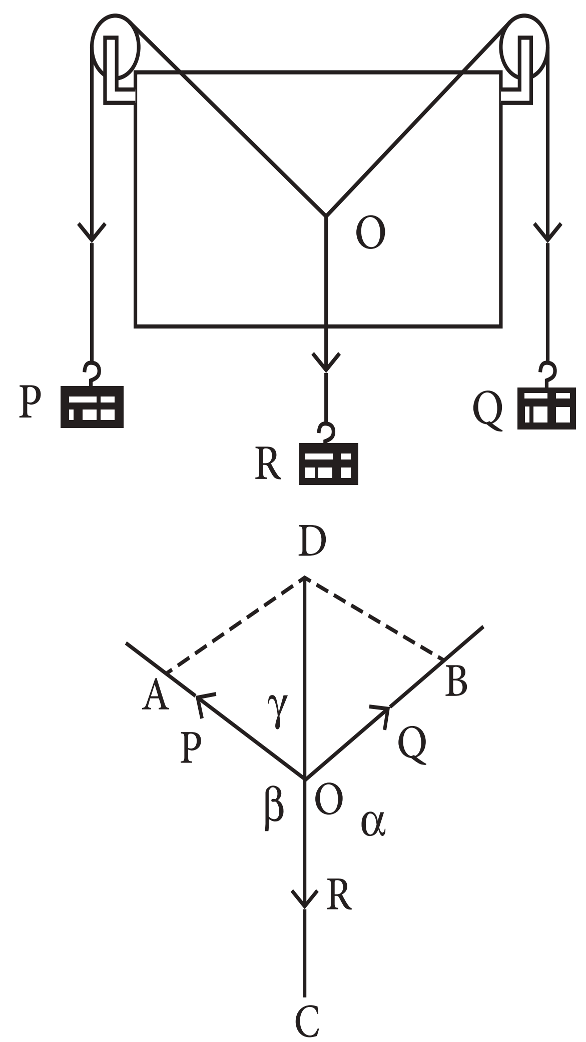


Figure 2.10 Experimental set up for verification of Lami's theorem

A white paper is held just behind the string without touching them. The point O and the directions of the strings along OA, OB and OC are marked on the paper. Then the paper is removed from the board. Let α, β and γ are the angles opposite to the forces

Table 2.2 Lami's theorem

Sl. No.	P	Q	R	α	β	γ	$\frac{P}{\sin \alpha}$	$\frac{Q}{\sin \beta}$	$\frac{R}{\sin \gamma}$

P, Q and R respectively. The angles ∠BOC = α, ∠COA = β, ∠AOB = γ are measured with the help of protractor and tabulated as shown in **Table 2.2**

The experiment is repeated for different values of P, Q and R. The ratios (P/ sin α), (Q / sin β) and (R / sin γ) are calculated. For each set of readings, the ratios are found to be equal. Thus, Lami's theorem is verified experimentally.

2.4.3 Engineering applications

Parallelogram law of forces and Lami's theorem are extensively used in the analysis of structures such as bridges, buildings, and towers.

1. By applying the law to the forces acting on the various members of the structure, engineers can determine the net forces acting on each member and ensure that the structure is capable of withstanding the external loads.
2. These laws are used in the design of machines such as cranes, hoists, presses and robotics.
3. In the design of aircraft and spacecraft, engineers can determine the net forces acting on each component by applying the parallelogram law and ensure that the vehicle is capable of flying or operating in space.

Figure 2.11 Engineering applications of Parallelogram law and Lami's theorem

2.5 MOMENT OF A FORCE

The effect of a force on a body at a point on the line of action of a force tends to move the body in the direction of force. However, if the point is not lying on the line of action of a force, the effect of the

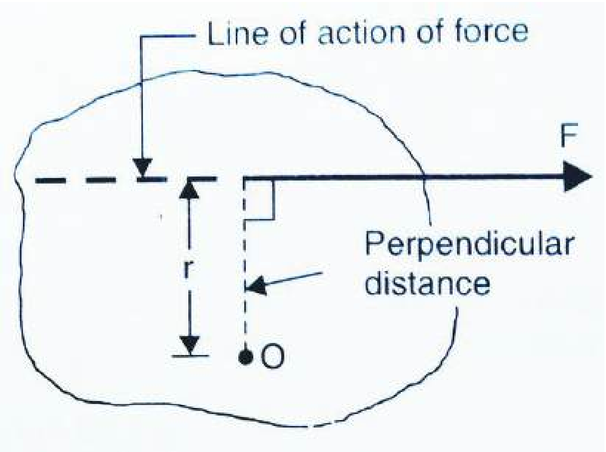


Figure 2.12 Moment of a force

force will tend to rotate the body. The turning effect produced by a force depends on the magnitude of the force and on the line of action of force. The moment of a force about a point or an axis is a measure of the turning effect, which it produces about that point or an axis. The moment of force is also known as torque.

Consider a body, which is fixed at a point O, about which it can rotate freely. Let a force F is acting on the body. The effect of the force is to rotate the body about the fixed point, unless the line of action of the force passes through that fixed point O. This rotating tendency or the turning effect of the force about that point is called moment of force i.e. the turning effect of the force acting on a body about an axis or point is called moment of force.

Example:

It is common experience that in opening or closing a door, the force we apply rotates the door about its hinges and a hammer is used to pull out the nail from the wall **(Figure 2.13)**.

Definition:

Moment of a force is equal to the product of the magnitude of the force and the perpendicular distance of the line of action of the force from the axis of rotation.

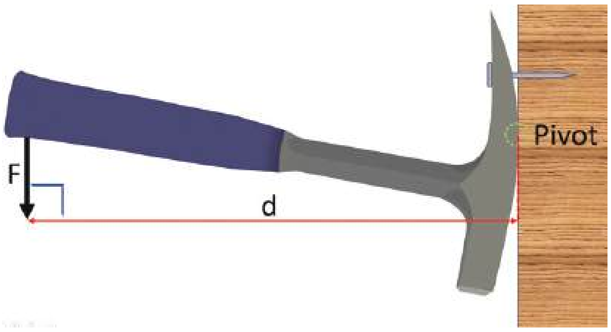


Figure 2.13 Example for moment of a force

Moment of force = Force × perpendicular distance of the force from the fixed point

The unit of moment of force is N m and the dimensional formula is ML^2T^{-2}.

Applications:

The concept of moment arm is used for the functioning of the lever, gear, pulley and other simple machines.

Clockwise and anti-clockwise moments

If the moment of a force turns or rotates the body in clockwise direction, then it is called as clockwise moment. If the moment of a force turns or rotates the body in anti-clockwise direction, then it is called anti-clockwise moment. The anti-clockwise moments are generally taken as positive and the clockwise moments as negative.

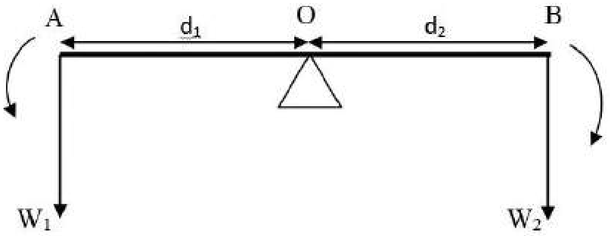


Figure 2.14 clockwise and anti-clockwise moments

$$\text{Clockwise moment} = W_2 \times d_2$$
$$\text{Anti-clockwise moment} = W_1 \times d_1$$

W_1 and W_2 are the loads acting at A and B, d_1 and d_2 are the respective distances from the center O.

2.5.1 Principle of moments

When a number of forces are acting on a body, the total turning effect of all the forces about any given point is equal to the algebraic sum of the moment of all the forces about the same point. If the body is in equilibrium, the resultant moment must be zero i.e., the clockwise moments must be equal to the anti-clockwise moments.

Statement

The principle of moment states that if a body is in equilibrium under the action of a number of parallel forces, the sum of the clockwise moments about any point must be equal to the sum of anti-clockwise moments about the same point.

Explanation

Four parallel forces m_1, m_2, m_3 and m_4 are acting on the body about the point O at distances d_1, d_2, d_3 and d_4 respectively. The forces m_1 and m_2 produce rotating effect in the anti-clockwise direction and m_3 and m_4 produce rotating effect in the clockwise direction.

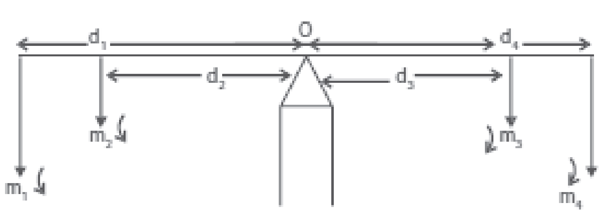


Figure 2.15 Principle of moments

When the body is in equilibrium, then according to the principle of moments,

Sum of anti-clockwise moments = Sum of clockwise moments

From the above figure,

$$m_1d_1 + m_2d_2 = m_3d_3 + m_4d_4$$
$$\text{or} \quad m_1d_1 + m_2d_2 - m_3d_3 - m_4d_4 = 0$$

i.e., the algebraic sum of all the moments is equal to zero.

Example:

See-saw works based on the principle of moments.

Figure 2.16 Sea-saw

Applications:

Principle of moments is used to determine the unknown mass of a given object.

2.5.2 Couple

Two equal and opposite parallel forces acting at different points in a body constitute a couple. A body acted upon by the couple will rotate the body in clockwise direction or anti-clockwise direction.

Example:

Steering wheel and pedals of bicycles are the examples for couple.

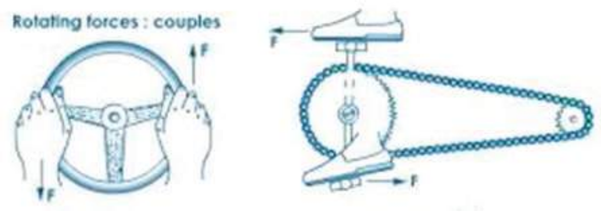


Figure 2.17 Example for couple

2.5.3 Torque due to couple (or) Moment of a couple

Torque is calculated by the product of either of forces forming the couple and the arm of the couple. Arm of the couple is the perpendicular distance between the two forces.

i.e., Torque due to couple = one of the force × arm of the couple.

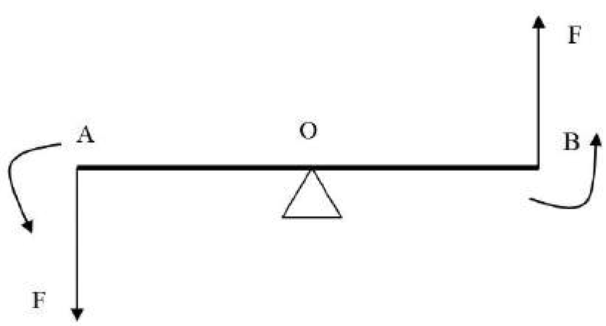


Figure 2.18 Moment of a couple

Consider two equal forces (F) acting on the arm AB as shown in the figure. Let O be the mid-point of the arm. The forces F and F are acting in opposite direction as shown in the figure, they constitute a couple. The distance AB is the arm of the couple. Then

Moment of couple or torque = F × AB

If the forces acting on the body have the same line of action, then the moment becomes zero. The torque is maximum when the forces are at right angles to the arm i.e., $\theta=90^o$.

2.5.4 Determination of mass of the given body using principle of moments.

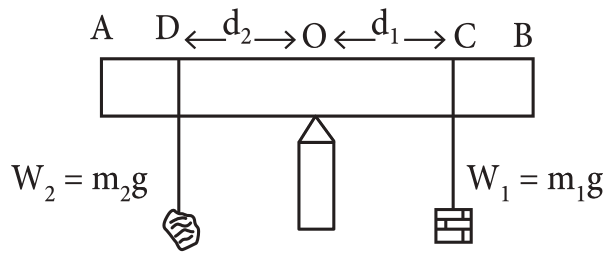


Figure 2.19 Experimental set up for determination of mass of the body

A meter scale AB is supported on a knife-edge at its center such that it remains in equilibrium state. Let O be the center of the scale AB. On the right side suspend the weight hanger of mass m_1 at a distance of d_1 and on the left side suspend the given body at a distance d_2 whose mass m_2 is to be calculated. Adjust the positions of m_1 and m_2 until the scale comes to the exact equilibrium position. Measure the distances d_1 (OC) and d_2 (OD) of m_1 andm_2.

According to the principle of moments,

Sum of anti-clockwise moments = Sum of clockwise moments

$$W_2 \times d_2 = W_1 \times d_1$$
$$m_2 g \times d_2 = m_1 g \times d_1$$
$$m_2 \times d_2 = m_1 \times d_1$$

The mass of the given body $m_2 = (m_1 \times d_1) / d_2$

By changing the values of m_1, the experiment is repeated and the readings are tabulated as in **Table 2.3**.

Table 2.3 Principle of moments

Sl. No.	m_1 kg	d_1 m	d_2 m	$m_2 = (m_1 \times d_1) / d_2$ kg

Average m_2=

The average value of the last column gives the mass of the given body.

SUMMARY

- Lami's theorem gives the condition for the body to be in equilibrium under the action of three concurrent forces acting on it.
- Parallelogram law of forces and Lami's theorem can be experimentally verified using a wooden board with slotted weights.
- There are numerous engineering applications for both Parallelogram law of forces and Lami's theorem.
- Moment of a force is turning effect of a force.
- Two equal, parallel and opposite forces constitute a couple.
- There are several examples in our day-to-day life on moment of force or couple.
- Principle of moments states that the sum of clockwise moments is equal to the sum of anti-clockwise moments, if the body is in equilibrium.
- The unknown mass of an object can be determined using principle of moments.

EVALUATION

Part A (2 marks)

1. Define scalar quantities. Give two examples.
2. Define vector quantities. Give two examples.
3. State parallelogram law of forces.
4. State triangle law of forces.
5. Define Concurrent forces.
6. Define Co-planar forces.
7. Define equilibrant.
8. Define resultant.
9. State Lami's theorem.
10. Define moment of a force.
11. Define clockwise and anti-clockwise moments.
12. State the principle of moments.
13. What is a couple?
14. Define moment of a couple.

Part B (7 marks)

15. Two forces $\vec{A}$ and $\vec{B}$ of magnitude 7 units and 9 units respectively make an angle 60° with each other . Find the magnitude of the resultant vector and its direction with respect to the vector $\vec{A}$.
16. Briefly explain how a vector is resolved into two perpendicular components.
17. Describe an experiment to verify the parallelogram law of forces.
18. Describe an experiment to verify Lami's theorem.
19. Describe an experiment to determine the unknown mass of a given body using principle of moments.

Problems

1. Find the magnitude and direction of the resultant of two forces of 5N and 3N at an angle of 60^o.

   [Ans: R =7N, $\alpha = 21^o47'$]

2. Two forces of magnitude 4N and 2.5N acting at a point inclined at an angle of 40^o to each other. Find their resultant.

   [Ans: R= 6.149N, $\alpha = 15^o8'$]

3. Find the resultant of two forces 3N and 4N acting on a particle in direction inclined at 30^o.

   [Ans: R= 6.767N, $\alpha = 17^o19'$}

4. If the resultant of two equal forces is 2 times the single force, find the angle between them.

   [Ans: $\theta = 90^o$]

5. If the resultant of two forces 6N and 8N is 12N, find the angle between them.

   [Ans: $62^o43'$]

UNIT 3

DYNAMICS

Objectives

- To understand Newton's three laws
- To understand and apply kinematic equations in day-to-day life
- To understand angular displacement and angular velocity present when particle in a circular motion.
- To understand centripetal acceleration and centrifugal acceleration.
- To understand centripetal and centrifugal forces and its applications.
- To understand Simple Harmonic Motion.
- To determine the value of acceleration due to gravity 'g' using Simple Pendulum.

3.1 NEWTON'S LAWS

Objects that we see in our day-to-day life are either at rest or in motion with respect to us. How an object is at rest or how an object is moving through the action of various forces is an important question in engineering field. Newton formulated three laws based on careful observation of motion of the objects and these three laws are the basis of mechanics. These three laws are called "Newton laws" or "Laws of motion". Especially in the engineering field, these laws play a fundamental role in understanding and predicting the behavior of objects under the action of various forces.

Newton's first law

An object at rest will remain at rest and object in motion will continue moving a straight line at constant velocity unless acted upon by an external force.

This law is also called "Law of inertia". Engineers apply this law to ensure stability, balance, and safety in various components and systems. This is of utmost importance in constructing buildings, bridges, and vehicles, wherein the acceleration, deceleration, or change in direction of structures and mechanisms must account for the inertia of the mass. Using Newton's first law, engineers can develop reliable and efficient structures which are capable of withstanding the dynamic forces they encounter.

Example: In the **Fig 3.1**, when the driver applied the brake, the truck comes to rest. But the big stone inside the container does not experience the breaking force, so according newton's first law, it continued to move and made huge damage.

Figure 3.1 Real life example of Newton's first law

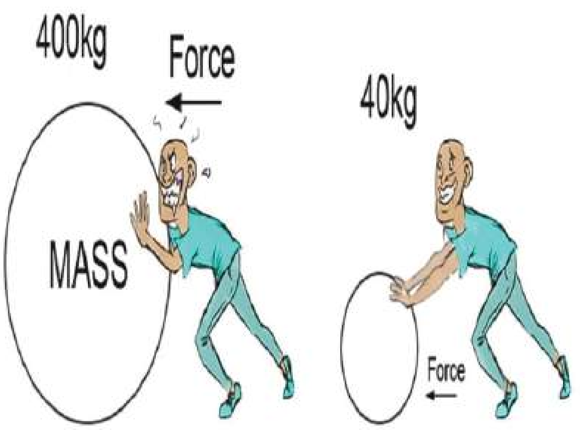


Figure 3.2 Newton's second law

Newton's second law

The acceleration experienced by the object is directly proportional to net external force acting on it and inversely proportional to its mass.

In equation form, $\vec{a} = \frac{\vec{F}_{net}}{m}$ and more commonly it is written as

$$\vec{F}_{net} = m\vec{a}$$

Here, $\vec{F}$ – net external forces acting on the object

$\vec{a}$ – acceleration of the object

m – mass of the object

From motion of cricket ball to motion of planets can be well explained by Newton's second law. This law is used by engineers in predicting how machines, machinery, and other mechanical systems would move when subjected to forces like gravity, friction, and applied loads. Engineers could improve the design as well as functionality of machines and machinery to make sure they can resist external forces and react correctly by using Newton's second law.

Example: In the **Figure 3.2** the force applied to two objects, bigger mass experience smaller acceleration and smaller mass experience larger acceleration.

Newton's third law

For every force(action), there is an equal and opposite force(reaction).

$$\vec{F}_{reaction} = -\vec{F}_{action}$$

According to this law, forces always occur in pairs and action and reaction forces acts on the two different object not on the same object. This law also called "Law of action - reaction".

Example

i) When you push the wall with some force, the wall will also give an equal force on your hands.

ii) During walking, our legs are applying force on the ground and ground exerts equal and opposite force on our legs which pushes us forward.

iii) An apple is falling due to force of gravity by earth. According to newton's third law, an apple also exerts equal and opposite force on the earth.

To maintain stability, balance, and safety, engineers must take the reactive forces that are present in the system into account while developing their designs. For instance, while constructing bridges, structures and dams, consideration of the pressures that

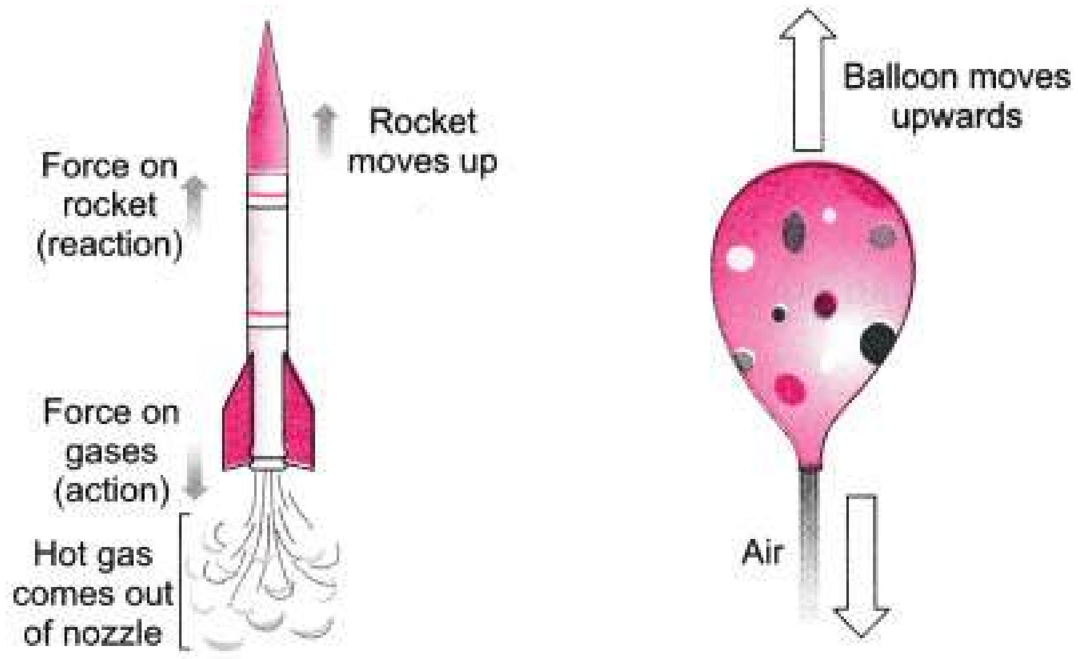


Figure 3.3 Newton's third law and real-life examples

the structures give on the earth is utmost important. Similar to this, in order to obtain the best performance and safety, engineers working in the automobile industry must balance the forces produced by various vehicle parts.

Example: In the **Figure 3.3** shows standard examples of Newton's third law. During the rocket launch, the engine produces hot exhaust gases which flow out of the back of the engine. In reaction, a thrusting force is produced in the opposite reaction. The air trapped inside the balloon is pushed out the open end of the balloon and the expelled air exerts an equal force in the opposite direction of the motion of the air, causing the balloon to move forward.

3.2 KINEMATIC EQUATIONS

When the object is moving with constant acceleration, Newton's second law is reduced to three simple equations which are called "Newton's kinematic equations". These equations are very important since the acceleration due to gravity near the surface of the earth is constant and motion of the objects in our day-to-day life, are mostly constant acceleration motion.

The three kinematic equations are given below

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Here, a – constant acceleration

s – displacement of the object in a time t,

v – final velocity,

u – initial velocity

3.2.1 Horizontal motion

When an object is moving with constant acceleration in the horizontal direction, Newton's kinematic equations can be used to understand the motion.

EXAMPLE 3.1:

A student who is initially at rest, started riding his bike with constant acceleration $a = 0.5\,m\,s^{-2}$ and he takes 2 minutes to reach his college. What is the distance of the college from his house?

Solution:

This is an example of horizontal motion.

In this case, $u = 0$ and $a = 0.5\,m\,s^{-2}$

By using $s = ut + \frac{1}{2}at^2$

Here $t = 2$ minutes = 120 s

The distance travelled by the student

$$s = \frac{1}{2}at^2$$

$$s = \frac{1}{2}\times 0.5\times 120\times 120 = 3600\,m = 3.6\text{ km}$$

3.2.2 Freely falling motion

When the object is falling towards the ground, it experiences constant acceleration due to gravity. If it starts to fall from rest, initial velocity $u = 0$ and acceleration is g.

The velocity of the object $v = gt$

The distance travelled at time t is given

$$s = \frac{1}{2}gt^2$$

The velocity of the object at a distance s is given by $v = \sqrt{2gs}$

EXAMPLE 3.2:

A mango is hanging in the tree. Suddenly it starts to fall and reaches the ground in $1\,s$. (i) How much distance it travelled? (ii) what is the speed of mango at $t = 0.5\,s$? (iii) what is the velocity of the mango when it touches the ground?

Solution:

Since mango was at rest before it starts to fall, so the initial velocity $u = 0$. While it is falling, it experiences only the acceleration due to gravity (g) and its value is $9.8\,m\,s^{-2}$ and it is constant.

(i) How much distance it travelled?

The distance travelled $s = ut + \frac{1}{2}at^2$

The initial velocity $u = 0$, here $a = g$

$$s = \frac{1}{2}gt^2$$

$$s = \frac{1}{2}\times 9.8\times 1 = 4.9\,m$$

(ii) what is the speed of mango at $t = 0.5\,s$?

$$v = u + at$$

Since $u = 0$, $v = at = gt$

$$v = 9.8\times 0.5 = 4.9\,ms^{-2}$$

(iii) what is the velocity of the mango when it touches the ground?

Since the mango travels 4.9 m when it touches the ground, then $s = 4.9\,m$ and $g = 9.8\,ms^{-2}$ and $u = 0$.

The equation $v^2 = u^2 + 2as$ becomes, $v^2 = 2gs$ and $v = \sqrt{2gs}$

$$v = \sqrt{2\times 9.8\times 4.9\,m} = 9.8\,ms^{-1}$$

3.2.3 For objects vertically thrown upwards

If an object is thrown vertically upwards with some initial velocity u, it experiences constant negative acceleration due to gravity. Here a = −g

The distance travelled by object at time t is given by $s = ut - \frac{1}{2}gt^2$

The velocity of the object at a time t is given by $v = u - gt$

The velocity of object at a distance s is related by the equation $v^2 = u^2 - 2gs$

EXAMPLE 3.3:

A person throwing a ball vertically upwards with an initial velocity $u = 5ms^{-1}$. What is the maximum height reached by this ball?

Solution:

In this case, when the ball is going up, it experiences constant deceleration $a = g = 9.8ms^{-2}$.

Since no time is given, the third equation $v^2 = u^2 + 2as$ must be used.

Initial velocity $u = 5\,m\,s^{-1}$

At the maximum height, the ball comes to rest momentarily, so the final velocity $v = 0$.

$0 = u^2 - 2gh$

The negative sign denotes deceleration and $s = h$ (maximum height)

$u^2 = 2gh$

$$h = \frac{u^2}{2g} = \frac{5 \times 5}{2 \times 9.8} = 1.27\,m$$

3.2 PROJECTILE MOTION

When an object is thrown with velocity u at an angle θ with respect to horizontal ground, then the object is said to be in "Projectile motion" and it executes parabolic path as shown in the **Figure 3.4**.

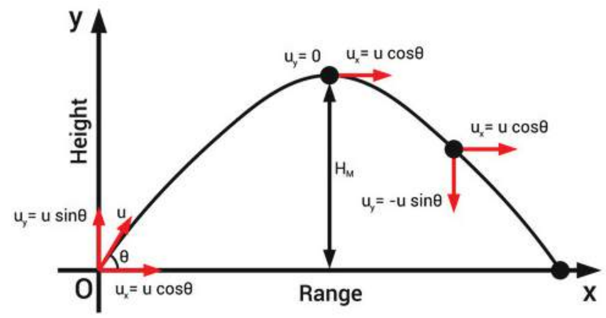


Figure 3.4 Projectile moion

The maximum height (H), time of flight (T) and horizontal distance (R) covered by the object are determined using the Newton's kinematic equations.

Maximum height $H = \frac{u^2 sin^2\theta}{2g}$

Time of flight $T = \frac{2u\,sin\theta}{g}$

Horizontal distance or range $R = \frac{u^2 \sin 2\theta}{g}$

If $\theta = 45°$ in the above equation, range is maximum $(R_{max}) = \frac{u^2 \sin 90°}{g} = \frac{u^2}{g}$

It implies, if an object is thrown at an angle of 45° with respect to ground, it reaches maximum horizontal distance for a given initial velocity u

3.4 CIRCULAR MOTION

Circular motion is defined as a motion described by a particle moving in a circular path. Here, the direction of particle is always changing but with constant speed or varying speed.

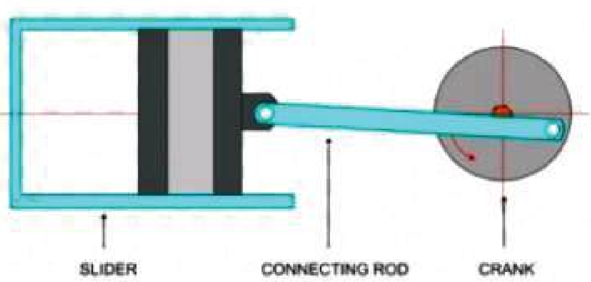


Figure 3.5 Examples for circular motion

Examples for circular motion:

1. The whirling of a stone tied to a string.
2. Artificial satellites revolving around the earth.
3. Motion of tip of blades of wind mill or fan.
5. Crank and slider used in combustion engines and robotics.

There are two types of circular motion,

1. Uniform circular motion
2. Non-uniform circular motion

Uniform circular motion

When a particle moves in a circular path with a constant speed, then such motion is called as uniform circular motion.

Non-uniform circular motion

If a particle moves in a circle with different speeds at different points, then this motion is called as non-uniform circular motion.

3.4.1 Angular Displacement (θ)

It is defined as the angle subtended by the radius vector drawn from the center of the circle to the revolving particle. It is represented by θ (theta). Angular Displacement is measured in units of radian (rad).

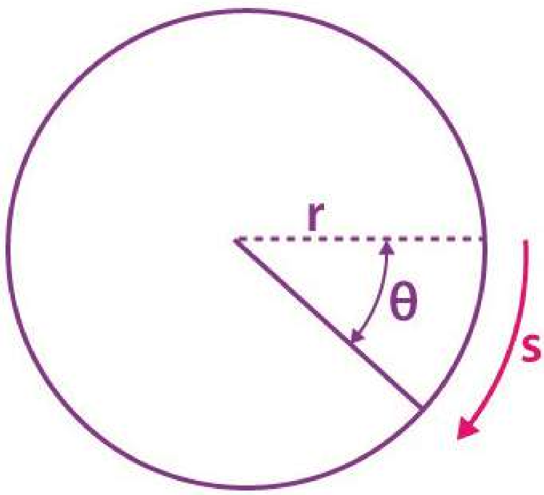


Figure 3.6 Angular displacement

Example: Motion of a needle in a clock.

$$\theta = \frac{Arc\,length}{Radius}$$

Arc length of AB, **S = r θ**

Note: $\mathbf{1^0 = 0.0175}$ **radian**

3.4.2 Angular Velocity ($\vec{\omega}$)

Angular velocity ($\vec{\omega}$) is defined as the time rate of change of angular displacement of a particle in a circular motion. (ω -Omega)

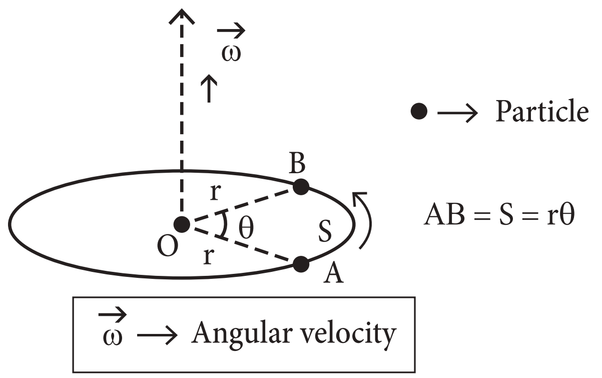


Figure 3.7 Angular velocity

$$\vec{\omega} = \frac{\theta}{t}$$

In differential form, $\vec{\omega} = \frac{d\theta}{dt}$

Angular velocity is a vector.

Direction of angular velocity is along the axis of rotation. Angular velocity is measured in rad s^{-1} (radian per second). Dimension is $M^0L^0T^{-1}$.

For a single revolution of a particle in a circle, change in angle = 2π

Time taken (or) Period = T

Then angular frequency, $\omega = \frac{2\pi}{T}$

Angular frequency (ω) is the magnitude of angular velocity vector ($\vec{\omega}$)

3.4.3 Relation between Linear velocity ($\vec{v}$) and Angular velocity ($\vec{\omega}$):

When a particle is in circular motion, there are two displacements, linear displacement (arc length) and angular displacement (angle). Both displacements are changing with time. Hence, there are linear velocity (→) and angular velocity ($\vec{\omega}$).

$$\theta = \frac{Arc\,length}{Radius}$$

AB = S (arc length)

Consider a particle moving from A to B in arc of length S of a circle with an angular displacement θ.

S = radius × angular displacement

Then, arc length $S = r\theta$ …….. (1)

(here, θ is in radian)

Divide equation (1) by 't',

$$\frac{S}{t} = r\frac{\theta}{t} \quad \text{……..} (2)$$

We know, linear velocity, $v = \frac{S}{t}$

Angular velocity, $\omega = \frac{\theta}{t}$

Hence, the equation (2) becomes, $\boldsymbol{v = r\omega}$

In vector notation, $\vec{v} = \vec{\omega} \times \vec{r}$

3.4.4 Angular acceleration (α)

The rate of change of angular velocity is called angular acceleration.

$$\alpha = \frac{\omega}{t}$$

The angular acceleration is also a vector quantity. Angular acceleration is measured in rad s^{-2}

3.4.5 Period of Revolution (Time Period)

Period of revolution is the time taken by a particle to complete one revolution in a circular path.

Period, T = 2πr / v

v → Speed of the particle

2πr → Circumference of the circle

Also T = 2π/ω.

3.4.6 Frequency of Revolution (f)

The number of revolutions when a particle completes in one second is called as frequency.

Frequency $f = \frac{1}{T}$

Unit of frequency is s^{-1} or hertz (Hz).

3.4.7 Centripetal Acceleration (or) Normal Acceleration:

When a particle moves in constant speed in a circular path, there is acceleration due to change in direction. **The acceleration of a particle directed radially towards the centre of the circle when a particle makes a circular motion is called centripetal acceleration.**

Centripetal acceleration is the product of linear velocity and angular velocity.

$a_c = v\omega$ ... (1)

We know, v = rω in eqn. (1)

$a_c = (r\omega) \times \omega = r\omega^2$ ... (2)

Also, put $\omega = \frac{v}{r}$ in eqn. (1)

$$a_c = v \times \frac{v}{r} = \frac{v^2}{r}$$

Hence, Centripetal Acceleration,

$$a_c = v\omega = r\omega^2 = \frac{v^2}{r}$$

Centripetal Force

Centripetal force is a force which acts on an object to keep it in circular motion.

We know, Centripetal acceleration equations are as

1. $a_c = v\omega$
2. $a_c = \frac{v^2}{r}$
3. $a_c = r\omega^2$

Centripetal Force = mass × centripetal acceleration

$F = mv\omega$

$F = \frac{mv^2}{r}$

$F = mr\omega^2$

Direction of centripetal force is towards the center along the radius.

Centrifugal Force

A force which tends to move objects away from the centre in a circular motion is known as centrifugal force.

Direction of centrifugal force is opposite to centripetal force along the radius.

3.4.8 Applications of centripetal and centrifugal forces

Knowledge of centripetal force and centrifugal forces can be applied to many everyday problems. Wherever centripetal force is there, centrifugal force is associated with in the opposite direction.

Centripetal Force

1. Planetary motion around the sun. Centripetal force is provided by gravitational force.
2. Electron motion around the nucleus.
3. Merry go round.

4. Artificial satellites orbiting the planets.
5. Roller coaster.
6. Cream separation from milk.
7. For car turning in a circular path, the centripetal force is provided by the frictional force between the ground and the wheel.
8. Designing of roads to prevent skidding.

Centrifugal Force

1. Centrifuge – a device used to separate particles of different mass (or) Blood products like RBC, WBC, Blood platelets.
2. Centrifugal pumps.
3. Water does not spill out of a bucket in a vertical spin, since centrifugal force is balanced by its weight.
4. Mud flying off the tyres of vehicles in motion, on a rainy day.
5. Pottery making.
6. Washing machine.
7. Centrifugal clutch.

3.4.9 CENTRIFUGE :

Figure 3.8 Centrifuge device

Principle : Centrifugal force and gravitational force are the principle of centrifuge.

Parts : Electrical Motor and Rotor.

Working : When the fluid present in the container is rotated by rotor, denser substances move outward, at the same time less denser move towards the centre. Thus particles are separated according to the size, shape, density and viscosity of the medium. The separation process depends on the rotor speed.

Uses : 1. To separate cream from milk, 2. To separate RBC, WBC platelet from blood, 3. To separate fluids like gases, liquid, 4. To separate virus, protein, Nucleic acid.

3.5 SIMPLE HARMONIC MOTION (SHM)

Simple Harmonic motion is defined as a motion in which the restoring force (F) is directly proportional to the displacement (x) of the particle from its mean position and the acceleration is always directed towards the mean position.

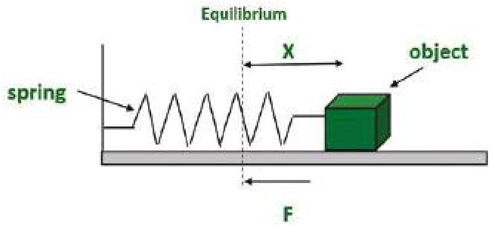


Figure 3.9 Simple Harmonic motion

$F \propto x$

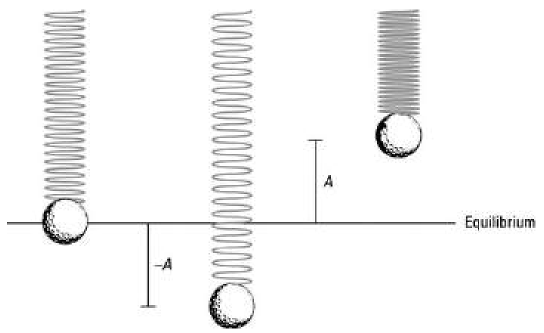
$F = -kx$, k = Force constant

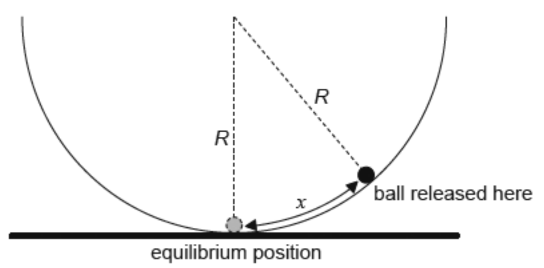
Negative sign is due to the restoring force opposite to displacement.

If displacement of the particle is in the right direction, restoring force will act towards the left.

Examples of SHM:

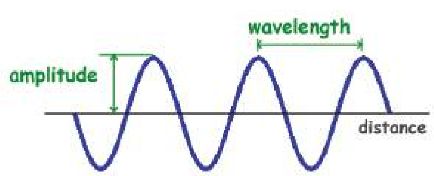
1. A child is playing in swing.
2. When a mass suspended to a spring is pulled down from its mean position
3. Initial position.
4. Oscillation of pendulum.
5. A steel ball in a curved bowl executes SHM.





Amplitude (A):

It is the maximum displacement of the particle from the mean position when a particle executes SHM.



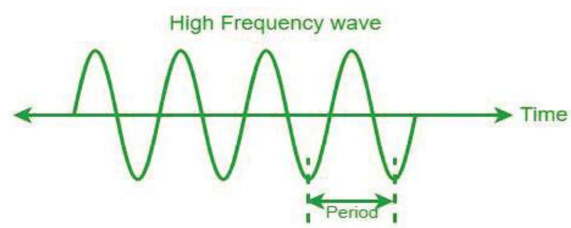
Period (T):

The period (T) of Simple Harmonic Motion is the time taken by a particle to complete one oscillation.

Frequency (f):

Number of oscillations per second is called as frequency. Unit is s^{-1} or hertz (Hz).

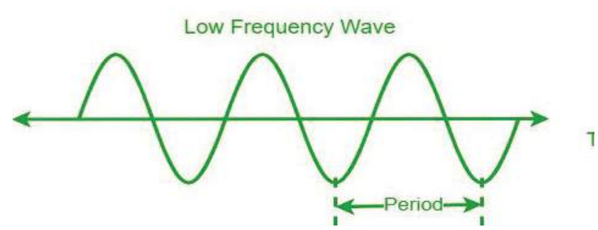
Frequency, $f = \frac{1}{T}$



Frequency measured in angles (radian) is called as angular frequency. A frequency in hertz can be converted in an angular frequency by multiplying it by 2π.

Angular frequency $\omega = 2\pi \times \frac{1}{T}$

$$\omega = 2\pi f$$



Unit of angular frequency is rad s^{-1}

3.6 SIMPLE PENDULUM

A simple pendulum consists of a small metal bob suspended from a fixed point using a long thread, so that the bob is free to swing back and forth under the influence of gravity and tension force.

In figure, A and C are extreme positions and B is the mean position.

Time period of simple pendulum,

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$l \rightarrow$ Length of the pendulum

g → Acceleration due to gravity
($g = 9.8\ ms^{-2}$)

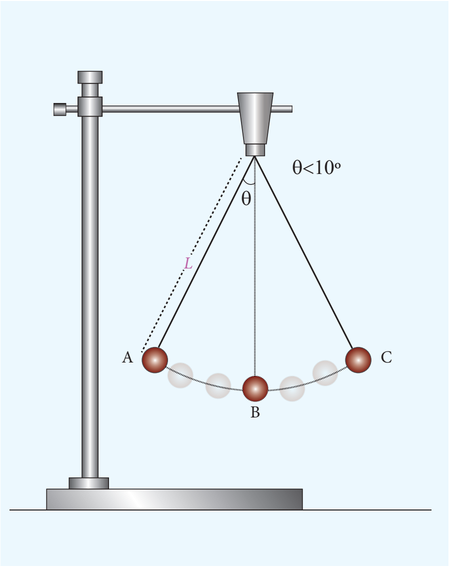


Figure 3.10 Simple pendulum

3.6.1 Acceleration Due to Gravity (*g*)

Acceleration due to gravity (g) is the acceleration (Rate of change of velocity) gained by an object due to gravitational force. SI unit is ms^{-2} and dimension is LT^{2}. The value of Acceleration due to gravity, $g = 9.8ms^{-2}$, on the surface of earth. Acceleration due to gravity is a vector, which has both magnitude and direction. Acceleration due to gravity on the moon is g/6.

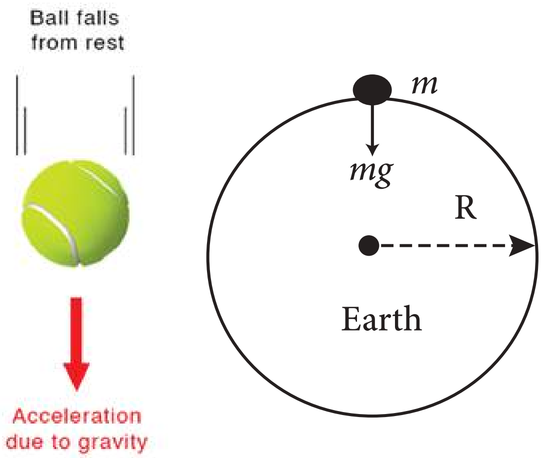


Figure 3.11 Acceleration due to gravity

Acceleration due to gravity on an object of mass (m) on the surface of earth is

$$g = \frac{GM}{R^2}$$

G = Gravitational constant
M = Mass of earth
R = Radius of earth

3.6.2 Determination of the value of acceleration due to gravity using Simple Pendulum

Acceleration due to gravity (g) can be determined with the help of Simple Pendulum. Simple Pendulum consists of a mass known as bob, which is suspended by means of a light inextensible string of length l from a fixed support. When the bob is pulled to one side from its mean position and then released, the pendulum is now set in to oscillation. The bob oscillates on either side of its mean position under the action of gravity.

The length of the pendulum is measured from the top of the string to the middle of the pendulum bob. Then pendulum is set in motion until it completes 10 oscillations (say) and the total time (t) of 10 oscillation is recorded using a stop watch. From this, the time period of one oscillation is determined.

$T = t / 10$

Expression for the time period of the pendulum is,

$$T = 2\pi\sqrt{\frac{l}{g}}$$

l = length of the pendulum

Squaring on both side, $T^2 = 4\pi^2 \frac{l}{g}$

T = Period of oscillation

$$g = 4\pi^2 \frac{l}{T^2}$$

g = Acceleration due to gravity

This experiment is repeated for different lengths of the pendulum. Finally, the mean value of (l/T^2) is determined. Acceleration due to gravity is determined from given formula by substituting the value of (l/T^2).

Length of the pendulum L (meter)	Time taken for 10 oscillations t (s)			Period of oscillation	T^2 (s^2)	$g = 4\pi^2\left(\frac{L}{T^2}\right)$ (ms^{-2})
	Trial 1	Trial 2	Average	$T = t/10$ (s)		
					Mean g =	

SUMMARY

- When there is no force acting on the objects, it moves at constant velocity or at rest.
- The force acting on the object is equal to product of mass and its acceleration.
- For every force, there will be an always an equivalent and opposite force.
- Three kinematic equations are valid only at constant acceleration.
- Circular motion is a motion described by a particle moving in a circular path.
- Uniform circular motion is related to a particle moves in circular path with constant speed.
- Angular velocity is the time rate of change of angular displacement.
- Relation between linear velocity and angular velocity is $v = r\omega$.
- Frequency is the number of revolutions per second.
- Centripetal acceleration and centripetal force are acting towards the centre.
- Equations for centripetal force are $F = mv\omega = \frac{mv^2}{r} = mr\omega^2$.
- In simple harmonic motion, the acceleration of a particle is proportional to its displacement.

WORKED EXAMPLES

1. If the angular velocity of a wheel is 40 rad s^{-1} and the wheel diameter is 60 cm, Calculate the linear velocity?

Solution:

Given Diameter = 60cm

$$Radius = \frac{Diameter}{2} = \frac{60}{2} cm = 30 \times 10^{-2} m$$

$$= 0.30 m$$

Angular velocity, $\omega = 40$ rad s^{-1}

Linear velocity, $v = r\omega = 40 \times 0.30$

$$= 12 \text{ m s}^{-1}$$

2. A wheel moves at a speed of 1 ms^{-1} and its angular velocity is 0.5 rad s^{-1}. Calculate the radius of the wheel.

Solution:

Linear velocity, v = 1 m s^{-1}

Angular velocity, $\omega = 0.5$ rad s^{-1}

Linear velocity, $v = r\omega$

$$r = \frac{v}{\omega} = \frac{1}{0.5} = 2m$$

3. A ball weighing 0.5 kg tied to end of a string of length 2m is whirled at a constant speed of 10ms^{-1} in a horizontal plane. Calculate the centripetal force on the ball.

Solution:

Given m = 0.5 kg, v = 10 m s^{-1}, r = 2 m

$$F = \frac{mv^2}{r} = \frac{0.5 \times 10 \times 10}{2} = 25 \text{ N}$$

4. A rope of length 1m can withstand a maximum weight of 10 kg wt. Now a stone of mass 200 g is tied to it and it is whirled round in a horizontal circle. Calculate the maximum permissible speed of the stone.

Solution:

Given: m = 200g = 0.2 kg, F = 10 kg wt = 10 × 9.8 = 98 N, r = 1 m

$$F = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{98 \times 1}{0.2}} = 22.14 ms^{-1}$$

5. An electric fan has blades of length 30 cm as measured from the axis of rotation. If the fan is rotating at 1200rpm, the acceleration of a point on the tip of the blade is about?

Solution:

Given Length of the blade = Radius = 30 cm = 30 × 10^{-2}m

Rotation per minute = 1200

Rotation per second = 1200 / 60

Acceleration of a point at the tip of the blade = Centripetal acceleration

$$= \omega^2 R = (2\pi f)^2 R$$

$$= \left(2 \times \frac{22}{7} \times \frac{1200}{60}\right)^2 \times \frac{30}{100}$$

$$= 4740 \text{ m s}^{-2}$$

6. If the length of the second hand in a stop clock is 3 cm. The angular velocity and linear velocity of the tip is?

Solution:

Given:

Here, r = 3 cm = 3 × 10^{-2}m, T = 60 s

$$\omega = \frac{2\pi}{T} = \frac{2 \times (22/7)}{60} = 0.1047 \text{ rad s}^{-1}$$

$$v = r\omega = (3 \times 10^{-2}) \times 0.1047$$

$$= 0.00314 \text{ m s}^{-1}$$

EVALUATION

Part A (2 marks)

1. State Newton's first law.
2. State Newton's second law.
3. State Newton's third law.
4. Write down the Newton's three kinematic equations.
5. Express the range equation in projectile motion. At what angle, the range will be maximum?
6. Define angular velocity.
7. Define period of revolution.
8. Define frequency of revolution.
9. Define amplitude.
10. Define period of simple harmonic motion.
11. Define centripetal acceleration.
12. Define centripetal force with equation.
13. What is centrifugal force and give its equation?
14. Why centrifugal force is not the reaction force of centripetal force?

Part B (7 marks)

15. Discuss in detail, three Newton's three laws and its applications.
16. Apply the kinematic equation to derive equation of motion for (a) Particle falling freely (b) Horizontal projection (c) Particle is thrown up vertically
17. Derive the relation between angular velocity and linear velocity.
18. Obtain expressions for the normal acceleration and centripetal force of a body executing uniform circular motion.
19. What are the applications of centripetal forces and centrifugal forces?
20. Describe the experiment of measuring acceleration due to gravity (g) using Simple Pendulum.

Problems

1. An apple of mass 200 g experiences a force 1.96N while falling towards earth. What is the acceleration experienced by the apple?

   [Ans: 9.8 ms^{-2}]

2. A stone of mass 50g which initially at rest, is thrown horizontally with a constant acceleration of 2 ms^{-2}. What is the distance travelled by the stone at time t=5s ?

   [Ans: 25m]

3. A body of mass 2 kg tied to a string of length 2m revolves in the horizontal circle. If it makes 5 revolutions per second, calculate the centripetal force acting on the body.

   [Ans : F_c = 3943.8 N]

4. An object of mass 20 kg is moving in a circular orbit of radius 20m at a velocity of 10ms^{-1}. Calculate the centripetal force required to maintain this orbit and the acceleration of this object.

   [Ans : F_c = 100 N, a_c = 5 ms^{-2}]

5. If a ball is travelling in a circle of diameter 10m with velocity 20ms^{-1}, find the angular velocity of the ball.

   [Ans : ω = 4 rad s^{-1}]

UNIT 4

ELASTIC PROPERTIES OF SOLIDS

Objectives

- To differentiate elastic and plastic material
- To understand the basic concepts and types of stress and strain
- To define Hooke's law
- To understand the types of modulus of elasticity
- To understand the stress-strain relationship
- To understand the types of beam
- To explain the experimental determination of Young's modulus-Uniform bending method
- To define Poisson's ratio
- To get a clear view of applications of elasticity in Industrial sectors.
- Ability to solve the problems on Young's modulus, bulk modulus, shear modulus and Poisson's ratio.

4.1 INTRODUCTION

Solids can be analyzed and understood based on its properties. The elastic property of materials plays an important role in structural design. Knowledge of elastic properties of materials like steel, concrete is essential for designing a building and bridges. In this unit, the elastic properties of solids are discussed in detail.

4.1.1 Elasticity and Plasticity

A solid has definite shape and size. When external forces are applied to a body, it undergoes a change in shape and size. Now the body is said to be deformed and the force applied is called deforming force. When the deforming forces are removed, some solids tend to regain its original size and shape (temporary deformation) and some times it may not regain its shape and size (permanent deformation).

The property by virtue of which a body tends to regain its original size and shape after removal of the deforming forces is known as elasticity. The property by virtue of which a body does not regain its original shape and size after removal of the deforming force is called plasticity.

Elastic Bodies

Bodies which completely regain their original shape and size after the removal of the deforming forces are called elastic bodies. **Examples:** Steel, Rubber.

Plastic bodies

Bodies which do not show any tendency to regain their original shape and size are called plastic bodies. Examples: Clay, Plastic.

4.1.2 Stress

When a body is subjected to deforming force it causes deformation (change in shape or in size or both). Due to elastic property of a material, a force is developed within the material, which is equal and opposite to the applied force, called 'restoring force'.

Stress is defined as the applied force per unit area.

Stress = Applied Force /area

Unit of stress is N m^{-2} or pascal (Pa)

There are three type of stress which causes deformation,

i) Linear or longitudinal stress
ii) Bulk or volume stress
iii) Shear or tangential stress

Linear or longitudinal stress

When a body is subjected to a force normal to its cross-sectional area, it tends to increase the length in the direction of the force, it is said to be tensile stress, if it decreases the length it is said to be compressive stress as shown in **Fig 4.1**.

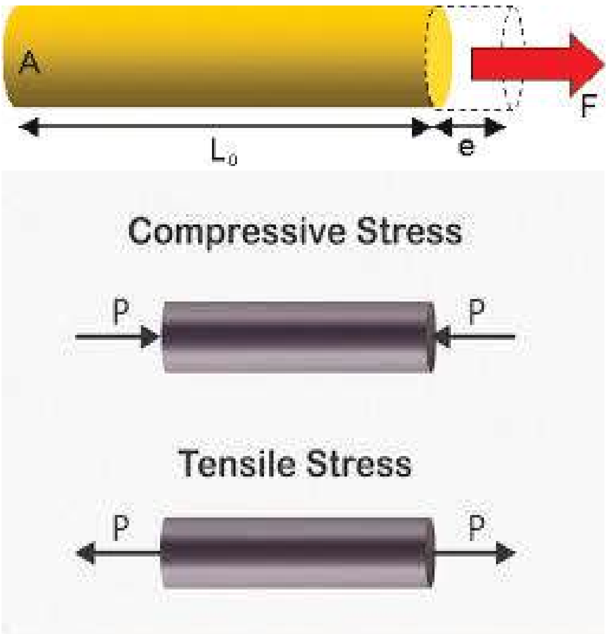


Figure 4.1 Linear stress

Tensile and compressive stress can also be termed as longitudinal stress. Example: Stretching of a rubber band.

Bulk or volume stress

When applied force acts on all dimensions resulting in the change in volume of the object then such stress is called Bulk stress or volume stress as shown in **Fig 4.2**. Example: Squeezing of smiley ball.

Figure 4.2 Bulk Stress

Shear or tangential stress

When the force is applied parallel to the cross-sectional area as shown in **Fig 4.3**, the stress experienced by the object is called shear stress or tangential stress. This results in the change in the shape of the body.

Figure 4.3 Shear Stress

Basic Physics - Unit 4.indd 46 29-07-2024 12:51:31

Example: Force applied parallel to the top surface of the book.

4.1.3 Strain

Strain is the measure of how much an object is deformed when a force is applied. Strain is the ratio of change in dimension to original dimension. As strain is the ratio between two physical quantities of the same dimensions, it has no unit.

$$\text{Strain} = \frac{\text{Change in dimension}}{\text{Original dimension}}$$

There are three type of strain,

i) Linear or longitudinal strain
ii) Bulk or volume strain
iii) Shear or tangential strain

Linear or longitudinal strain

When an object is subjected to linear stress, the body is elongated or compressed in the direction of the applied force. If the forces are tensile, the length is increased in the direction of the forces. If the forces are compressive, the length is shortened in the direction of the forces as shown in **Fig 4.4**. This is called the 'Linear or longitudinal strain'.

Linear or longitudinal strain is the ratio of change in length to original length of the object.

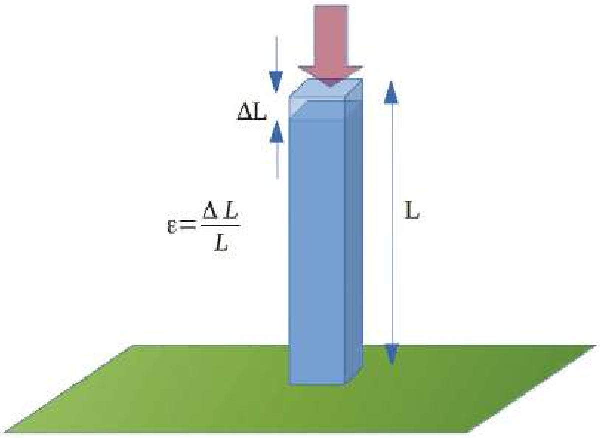


Figure 4.4 Linear strain

$$\text{Longitudinal Strain} = \frac{\text{Change in length}}{\text{Original length}}$$

$$\text{Longitudinal Strain} = \frac{\Delta L}{L}$$

Bulk strain or volume strain

A body subjected to a force which is compressed uniformly and normally on all directions of the body will result in the change in volume of the body, thus the resulting strain is called 'Bulk or volume strain' as shown in **Fig 4.5**.

Bulk strain or volume strain is the ratio of the change in volume to original volume.

$$\text{Bulk Strain} = \frac{\text{Change in volume}}{\text{Original volume}}$$

$$\text{Bulk Strain} = \frac{\Delta V}{V}$$

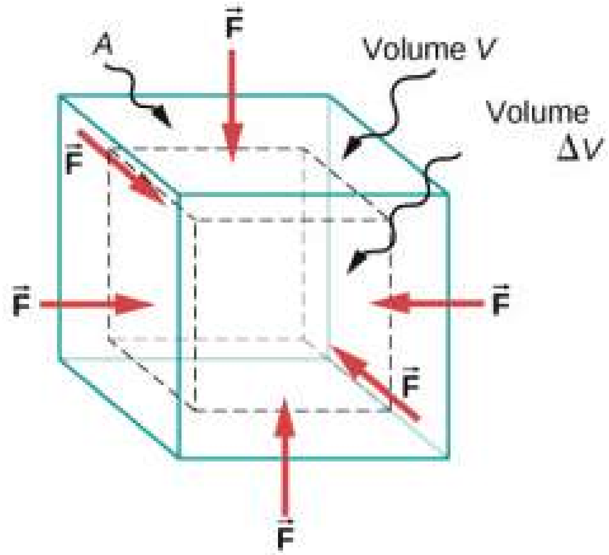


Figure 4.5 Bulk strain

Tangential or Shear strain

If a force is applied parallel to one face of a body as shown in **Fig 4.6**, then there is a relative displacement between the opposite faces of the cube. This leads to change in shape but not in size of the body, the strain so produced is called shear strain.

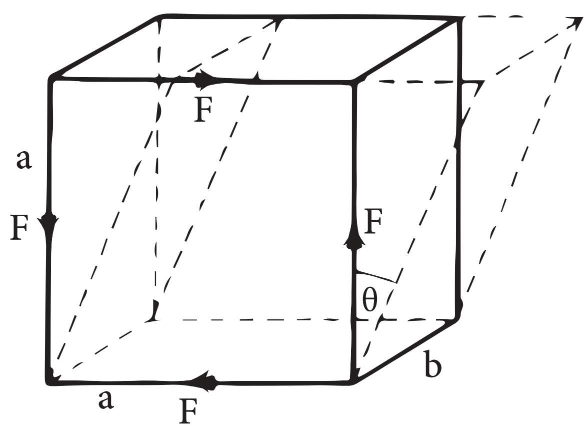


Figure 4.6 Shear strain

Shear strain is the angle through which a line originally normal to the tangential force is turned. It is measured by the angle of the shear 'θ' in radian.

4.2 HOOKE'S LAW

Hooke's law states that when an object is subjected to deformation then, within elastic limit the strain is directly proportional to stress.

i.e., stress α strain

$$\frac{stress}{strain} = constant$$

Here, 'constant' is called 'modulus of elasticity'. (Unit: N m^{-2} or Pa)

Hooke's law is also referred as law of elasticity. This law is found to be valid for most materials for definite stress range. However, there are some materials which do not exhibit this linear relationship. Hooke's law is used in design of spring systems such as shock absorbers. It is used as a fundamental principle behind the manometer, spring scale and balance wheel of the clock.

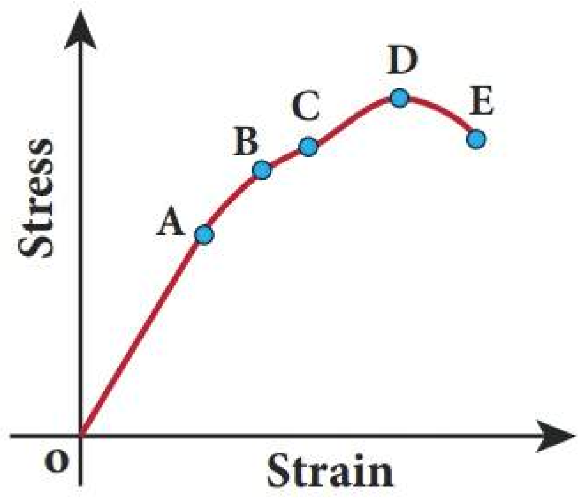
4.2.1 Stress-Strain curve

The relation between the stress and the strain for a given material under linear stress can be found experimentally. Let us consider a body which is subjected to a uniformly increasing stress. Due to the application of the stress, the change in length of the body takes place (i.e) the strain is developed. If we plot a graph between stress and strain, we get a curve as shown in **Fig 4.7** and is called as stress-strain diagram. The stress-strain curves vary from material to material. These curves help us to understand how a given material deforms with increasing loads.

a. **Portion OA:** In this region, the stress is proportional to strain, which means the plot is linear. In this region body behaves as an elastic body, where in body regains its original position when the force is removed. The region OA is called as elastic region. The point A is called limit of proportionality up to which Hooke's law is valid.

b. **Portion AB:** In this region from A to B, stress is not linearly proportional to the strain and in this region Hooke's law cannot be applied. However, the body will regain its original dimension when the load is removed. This behavior ends at point B and hence, the point B is known as yield point (elastic limit). The elastic behavior of the material in stress-strain curve is OAB in which the material exhibits elastic property.

c. **Portion BC:** If the body is subjected to further load beyond the point B (elastic limit), even for a small change in stress, the strain increases rapidly and at this point the body will not regain its original dimension even after the removal of load.



OA	:	Proportional limit
B	:	Elastic limit
C	:	Lower yield point
D	:	Ultimate stress point
E	:	Breaking or fracture point
OB	:	Elastic behaviour
BCDE	:	Plastic behaviour

Figure 4.7 Stress-Strain diagram

d. Portion CD: With further increase in load, the strain increases abruptly and reaches the point D. The point 'D' on the graph is the ultimate tensile strength of the material. Beyond this point, strain increases even under the reduced applied force and rupture (fracture) occurs at point E. The region BCDE represents the plastic behavior of the material.

4.3 THREE MODULUS OF ELASTICITY

Corresponding to three different types of strain, there are three kinds of moduli of elasticity. They are Young's modulus, Bulk modulus and Rigidity modulus.

4.3.1 Young's modulus (E)

If a metal bar of initial length 'L' and cross-sectional area 'A' is stretched by a force F at the end, the bar stretches from its original length to a new length as shown in **Fig 4.4**. ΔL is termed as change in length.

The ratio of the linear stress to the linear strain is called the Young's modulus and it is denoted by the symbol (Y)

The modulus of elasticity, in this case, is called Young's modulus and is given by

$$\text{Young's modulus (Y)} = \frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta L}{L}\right)} = \frac{FL}{A\Delta L}$$

Since strain is a dimensionless quantity, the unit of Young's modulus is the same as that of stress i.e., N m^{-2} or pascal (Pa).

4.3.2 Bulk Modulus (K)

The ratio of the volume stress to the volume strain is known as Bulk modulus denoted by letter 'K'. Let the body of volume V and surface area A be subjected to a force F applied normally and uniformly over the whole surface as shown in **Fig 4.5**.

Let ΔV be change in volume.

$$\text{Bulk modulus (K)} = \frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta V}{V}\right)} = \frac{FV}{A\Delta V}$$

Since strain is a dimensionless quantity, the unit of Bulk modulus is the same as that of stress i.e., N m^{-2} or pascal (Pa).

4.3.3 Rigidity or Shear modulus (n)

The ratio of the shear stress to the shear strain is known as rigidity or shear modulus and it is denoted by letter 'G'. If F is the force acting on an area A as shown in **Fig 4.6** then the shear stress is F/A and if the shear angle is θ.

$$\text{Shear modulus } (n) = \frac{\left(\frac{F}{A}\right)}{\theta} = \frac{F}{A\theta}$$

4.3.4 Relation between three modulii of elasticity

Young's modulus (Y), Bulk modulus (K) and Shear modulus (n) are called elastic constants.

The relation between three modulii of elasticity is as follows

$$\frac{9}{Y} = \frac{3}{G} + \frac{1}{K}$$

Y = Young's modulus

n = Shear modulus

K = Bulk modulus

Using the above equation, it is simple to calculate the value of required elastic constants from another material constant.

4.4 BENDING OF BEAMS

A beam is a structural material having uniform area of cross section used as a horizontal support to bridges and buildings which carries vertical loads. The length of the beam is to be very large compared to its thickness. When a beam is fixed at one end and loaded at the other end, it is called a cantilever (**Fig 4.8**).

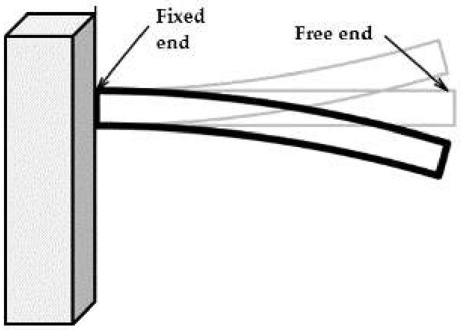


Figure 4.8 Cantilever

4.4.1 Uniform bending of beam

A beam is supported symmetrically on two knife edges at its end as shown in the **Fig 4.9**. If it is loaded symmetrically with two equal weights resulting in the elevation of the beam at the centre, then the bending is called uniform bending of beam.

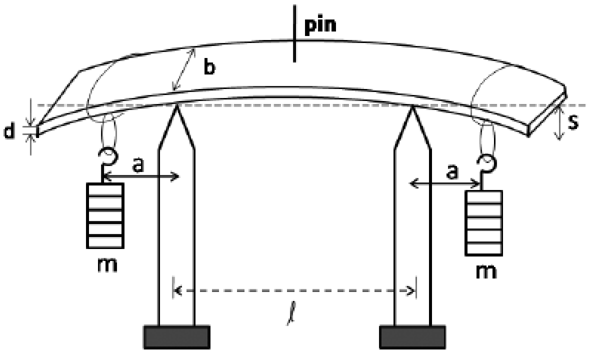


Figure 4.9 Uniform bending of beam

4.4.2 Non uniform bending of beam

In non uniform bending, a beam is supported symmetrically on two knife edges near its ends in a horizontal level and load is suspended exactly midway between two knife edges. This results in depression of beam at the centre as shown in **Fig 4.10**.

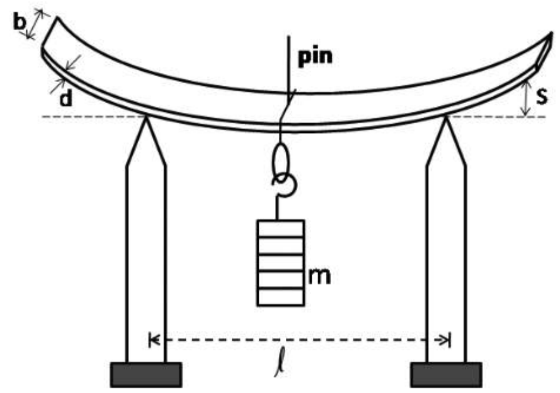


Figure 4.10 Non uniform bending of beam

4.4.3 Experimental determination of Young's modulus by uniform bending method

The Young's Modulus of a wooden bar can be determined by uniform bending method (**Fig 4.11**). The given beam is supported on two knife edges separated by a distance '*l*'. A pin is fixed vertically at the mid-point. Two weight hangers are suspended, one each on either side

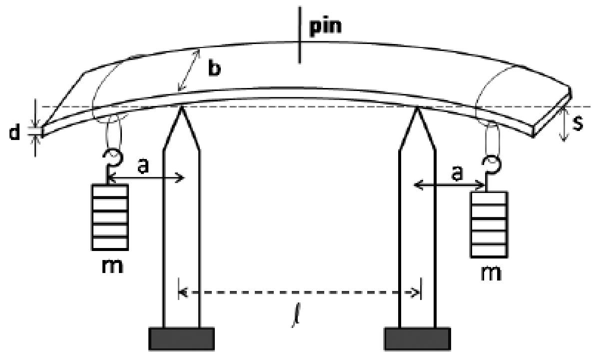


Figure 4.11 Experimental setup to determine Young's modulus- uniform bending method

of the knife edges so that their distances from the nearer knife edge are equal. With the load 'W', the pin is focused through microscope. The microscope is adjusted so that the horizontal crosswire coincides with the tip of the pin. The microscope reading is taken. The load is added in steps of 100 g and in each case the microscope reading is taken during loading. The readings are tabulated in Table 4.1. The elevation at the mid-point for 'm' kg is calculated.

The distance between the knife edges (*l*) is measured using metre scale. The breadth (b) and thickness (d) of the beam are found using Vernier calipers and screw gauge respectively.

The expression for Young's modulus of the material of the beam

$$Y = \frac{3mgal^2}{2sbd^3}\left(Nm^{-2}\right)$$

Where,

Y - Young's modulus of the material of the beam ($N\ m^{-2}$)

m - Load applied (Kg)

g - Acceleration due to gravity (ms^{-2})

a - distance between the load and nearest knife edge (m)

l - distance between the knife edges (m)

b - breadth of the beam (m)

d - thickness of the beam (m)

s - elevation produced for 'm' kg load (m)

Table 4.1

Load ($\times 10^{-3}$ kg)	Reading of the microscope			Elevation 's' for m kg ($\times 10^{-2}$ m)
	MSR ($\times 10^{-2}$ m)	VSC (divisions)	TR = MSR +(VSC $\times$ LC) ($\times 10^{-2}$ m)	
W				
W+100				
W+200				
W+300				

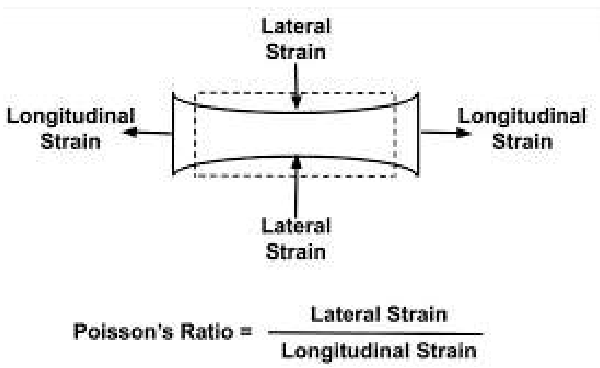


Figure 4.12 Poisson's ratio

4.4.4 Poisson'sratio

When a stretching force is applied to wire, deformation occurs in both the direction (Longitudinal and Lateral direction) as shown in **Fig 4.12**. It is observed as increase in length in longitudinal direction and decrease in diameter in lateral direction. To quantify these changes in longitudinal and lateral direction, French Physicist S.D. Poisson proposed a ratio, known as Poisson's ratio.

It is defined as the ratio of lateral strain to longitudinal strain. It is denoted by the symbol σ.

$$\text{Poisson's ratio}\,(\sigma) = \frac{\text{lateral strain}}{\text{longitudinal strain}}$$

4.4.5 Application of elasticity in field of engineering:

Civil and Mechanical engineering

Building based on cantilever design refers to a structure that extends horizontally from a vertical support without any additional support on the free end as shown in **Fig 4.13**. The cantilever design allows for overhanging portions, creating unique and visually striking architectural elements. It is commonly used in various types of buildings, bridges, and other structures (Fig 4.13).

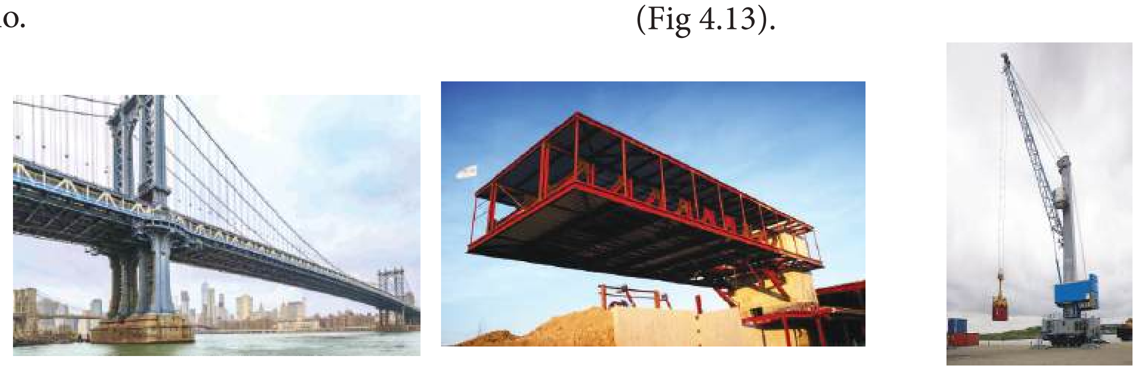


Figure 4.13 Application of elasticity- Civil and mechanical Engineering

Next, tall buildings and bridges are designed to withstand static as well as dynamic loads. So, they are usually built with pillars and beams. These beams and pillars are designed so that they do not bend excessively and break under the stress of the load on them and remain safe within the range of maximum load.

A thick metallic rope used in cranes (Fig 4.13) to lift heavy weight from one place to another. The material of the rope is decided based on the elastic limit.

Bio Engineering

Elasticity is widely used in Bio engineering fields (**Fig 4.14**). In certain commercials, eyeglass companies demonstrate eyeglass frames that can be bent back and forth, and retain their shape. These frames are made such that it can demonstrate super-elasticity. In Dental wires for braces, the alloys used should retain their original shape after stress has been applied and removed.

Figure 4.14 Application of elasticity- Bio Engineering

Automobile engineering:

Numerous applications of elasticity are found in automobile sectors (Fig 4.15). Leaf spring in car is a simple form of spring commonly used for suspension in wheeled vehicles. Steel coil spring is a type of secondary suspension for railway vehicles, typically having steel coil springs between the bogie trucks and chassis/frame of a passenger coach and locomotive. Aircraft Strut is a hydraulic device used as a shock absorber in the landing gear of aircraft. One of the most common landing strut systems on general aviation aircraft is the spring steel strut.

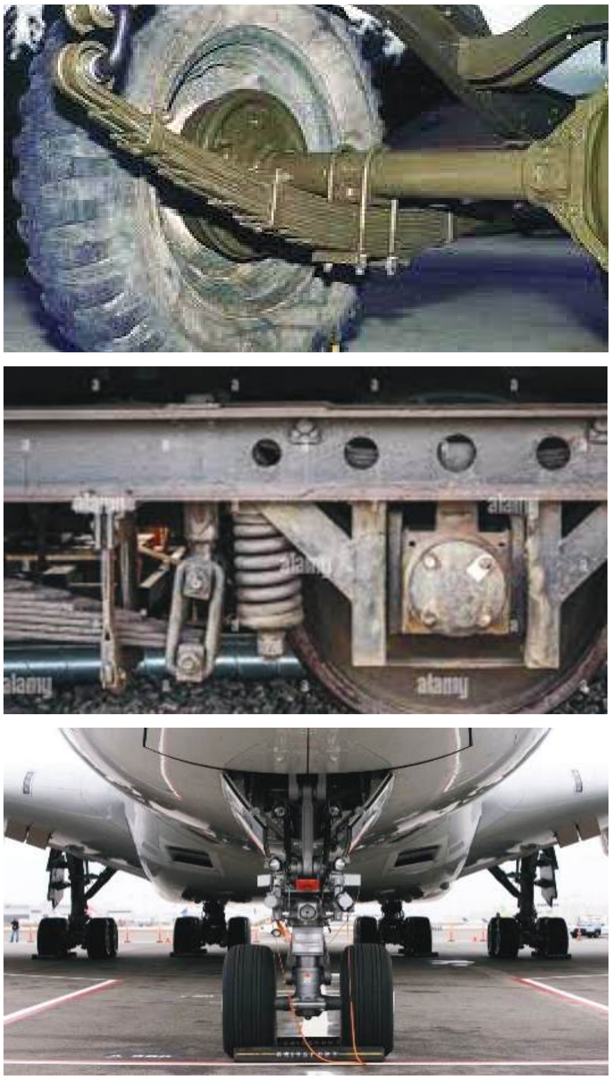


Figure 4.15 Shock absorbers in Automobiles

SUMMARY

- Bodies which completely regain their original shape and size after the removal of the deforming forces are called elastic bodies.
- Bodies which do not show any tendency to regain their original shape and size are called plastic bodies.
- The force per unit area is known as stress. If F is the applied force and A is the area of cross section of the body then the magnitude of stress is equal to F/A.
- Tensile or compression stress can be expressed using a single term called linear or longitudinal stress. The ratio of change in length to the original length is ΔL/L, which is known as linear or longitudinal strain.
- When applied force acts on all dimensions resulting in the change in volume of the object then such stress is called bulk or volume stress. The ratio of change in volume to original volume is known as bulk or volume strain.
- When the force is applied parallel to the cross-sectional area, the stress experienced by the object is called shear or tangential stress. This leads to change in shape but not in size of the body, the strain so produced is called shear or tangential strain.
- Hooke's law states, within elastic limit the strain is directly proportional to stress
- Within the elastic limit, the ratio of linear stress to the linear strain is called the Young's modulus of the material of the wire.
- Within the elastic limit, the ratio of bulk stress to the bulk strain is called the bulk modulus.
- Within the elastic limit, the ratio of shear stress to the shear strain is called the rigidity modulus.
- Poisson's ratio = lateral strain/longitudinal strain.

WORKED EXAMPLES

1. A wire 5m long and 4 mm diameter supports a load of 784 N. If the wire stretches by 2.6 mm. Find the value of the Young's modulus for the material of the wire.

Given data:

$L = 5$ m; $d = 4$ mm $= 4 \times 10^{-3}$ m; $F = 784$ N;
$\Delta L = 2.6$ mm $= 2.6 \times 10^{-3}$ m ; Y=?

Young's modulus, $Y = \dfrac{E}{A\Delta L}$

$$A = \pi r^2$$

$$r = \frac{d}{2} = \frac{4\times10^{-3}}{2} = 2\times10^{-3}\,\text{m}$$

$$A = 3.14 \times (2 \times 10^{-3})^2$$

$$= 1.256 \times 10^{-5}\ \text{m}^2$$

$$Y = \frac{784\times5}{1.256\times10^{-5}\times2.6\times10^{-3}}$$

$$Y = \frac{3920}{3.2656\times10^{-8}}$$

$$Y = 1.20 \times 10^{11}\ \text{Pa}$$

2. A copper wire of 3 m length and 1mm diameter is subjected to a tension of 49

N. Calculate the elongation produced in the wire, if Young's modulus of elasticity of copper is 120 GPa.

Given data:

L = 3m; F = 49 N; d = 1 mm;

r = d/2 = 0.5 mm = 0.5×10^{-3} m

Y = 120 GPa = 120×10^{9} Pa

ΔL = ?

Young's modulus, $Y = \dfrac{E}{A\Delta L}$

$$\Delta L = \frac{FL}{AY}$$

$$\Delta L = \frac{49\times3}{3.14\times\left(0.5\times10^{-3}\right)^2\times120\times10^9}$$

$\Delta L = 1.562 \times 10^{-3}$ m

3. A metallic cube of side 100 cm is subjected to a uniform force acting normal to the whole surface of the cube. The pressure is 10^6 Pa. If the volume changes by 1.5×10^{-5} m^3, calculate the bulk modulus of the material.

Given data:

P = 10^6 Pa; a = 100 cm = 1 m

ΔV= 1.5×10^{-5} m^3 ; K = ?

$$\text{Bulk modulus (K)} = \frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta V}{V}\right)} = P\frac{\Delta V}{V}$$

Volume of the cube, V = a^3= $(1)^3$ = 1 m^3

$$K = 10^6\times\frac{1.5\times10^{-5}}{1}$$

$$K = 6.67\times10^{10}\,Pa$$

4. A metal cube of side 0.20 m is subjected to a shear force of 4000 N. The top surface is displaced through 0.50 cm with respect to the bottom. Calculate the shear modulus of elasticity of the metal?

Given data:

l = 0.20 m; F = 4000 N;

x = 0.50 cm = 0.005 m

n= ?

Area = l^2 = $(0.20)^2$= 0.04 m^2

$$n = \frac{F\times l}{A\times x} = \frac{4000\times0.20}{0.04\times0.005}$$

$$n = \frac{800}{2\times10^4}$$

$$n = 4\times10^6\,Pa$$

5. A uniform rectangular bar 1m long, 2cm broad and 0.5 cm thick is supported on its flat face symmetrically on two knife edges 70 cm apart. If loads of 200 g are hung from the two ends, find the elevation of the centre of the bar.

Young's modulus of the material of the bar is 18×10^{10} Pa.

Given data:

b = 2 cm = 2×10^{-2} m

d = 0.5 cm = 0.5×10^{-2} m

M = 200 g = 200×10^{-3} kg

Y = 18×10^{10} Pa = 70 cm = 70×10^{-2} m

a = 15×10^{-2} m; s =?

$$Y = \frac{3mgal^2}{2sbd^3}$$

$$s = \frac{3mgal^2}{2bd^3Y}$$

$$s = \frac{3\times200\times10^{-3}\times9.8\times15\times10^{-2}\times\left(70\times10^{-2}\right)^2}{2\times\left(2\times10^{-2}\right)\times\left(0.5\times10^{-2}\right)^3\times18\times10^{10}}$$

$$s = \frac{0.43218}{900}$$

$$s = 4.802\times10^{-4}\,m$$

$$s = 48.02\ mm$$

EVALUATION

Part A (2 marks)

1. Define stress.
2. Define strain.
3. Define linear strain
4. Define bulk strain
5. Define shear strain.
6. State Hooke's law.
7. Define Modulus of elasticity
8. Name the three modulii of elasticity.
9. What is uniform bending of a beam?
10. What is non uniform bending of a beam?
11. Define Poisson's ratio.
12. Mention three applications of elasticity.

Part B (7 marks)

13. Explain the stress-strain curve with neat diagram.
14. Discuss the three modulii of elasticity with neat diagram.
15. Describe an experiment to determine the Young's modulus of the material of a bar by bending it uniformly.
16. Discuss the applications of elasticity in industries.

Problems

1. A wire of 3.9 m long and 0.3 mm diameter elongates 2 mm when stretched by the force of 6.6 N. Find the Young's modulus of the wire?

   (1.8221×10^{11} Pa).

2. A uniform wire of length 10 m and diameter 1 mm is required to be stretched by 5 mm. Calculate the force in N if the Young's modulus of the wire is 187 GPa. (73.4 N).

3. A spherical ball contracts in certain volume with bulk strain 1×10^{-4} when subjected to a normal uniform pressure of $10 \text{ x } 10^6$ Pa. Calculate the bulk modulus of the material. (1×10^{11} pa)

4. A steel beam is under 0.004 shear strain. What is the shear stress exerted on the beam, if shear modulus is 11.5×10^6 Pa? (46,000 Pa)

5. A uniform metal bar, one meter long, is placed symmetrically on two knife-edges separated by a distance of 64.2 cm. When two equal weights of 0.5 kg each are suspended from points 5cm from the two ends respectively, the mid-point of the bar is elevated by 0.76 mm. Calculate the Young's modulus of the material of the bar if the width of the bar is 2.2 cm and its thickness 0.62 cm.

   (9.81×10^{10} Pa)

UNIT 5

HEAT & THERMODYNAMICS

Objectives

- To learn different types of temperature scales and their interconversion
- To understand the different types of heat transfer methods
- To understand and apply the specific heat capacity
- To explain laws of thermodynamics and its relevance to engineering field
- To introduce good and bad thermal conductors
- To understand different types of thermodynamic processes
- To introduce ideal gas law and Boyle's law

5.1 CONCEPT OF HEAT AND TEMPERATURE

Heat is a form of energy which is always transferred from hot objects to cold objects. The degree of hotness or coldness of an object is quantitatively expressed by a physical quantity called temperature. Hotter object has high temperature while colder object has low temperature. Hotter objects give up heat while colder objects take up heat. When the temperature of two objects are the same, no heat is transferred between them.

So, heat is the energy that is transferred, while temperature is a measure of how hot or cold something is with respect to surroundings.

To define temperature scales, the boiling point and freezing point of water are taken as upper and lower reference limits respectively. Many scales are used to measure temperature. However, mainly the following three scales are widely used.

5.1.1 Centigrade scale

It is denoted by the symbol °C. In this scale, the freezing point of water is taken as 0°C and the boiling point of water is taken as 100°C. This scale is based on dividing the temperature range between the freezing point and boiling point of water into 100 equal parts, called degree Celsius. The Celsius scale is commonly used in weather forecasts, temperature measurements, and general temperature references.

Fahrenheit scale

This scale is denoted by the symbol °F. In this scale, the freezing point of water is taken as 32 °F and the boiling point of water is taken as 212 °F. This scale is based on dividing the temperature range between the freezing point and boiling point of water into 180 equal parts, called degrees Fahrenheit.

Absolute scale or Kelvin scale

This scale is denoted by the symbol "K". This is the SI unit of temperature.

Usually, the temperatures are measured in centigrade scale. To convert the temperature from centigrade scale to Kelvin scale, we have to add 273, because 0 K corresponds to -273.15°C. On the Kelvin scale, the size of each unit is the same as the Celsius scale (one degree Celsius is equal to one Kelvin), but the Kelvin scale has no negative values. The Kelvin scale is an absolute temperature scale commonly used in scientific and technical contexts.

5.1.2 Relation between Centigrade, Fahrenheit and Kelvin scales

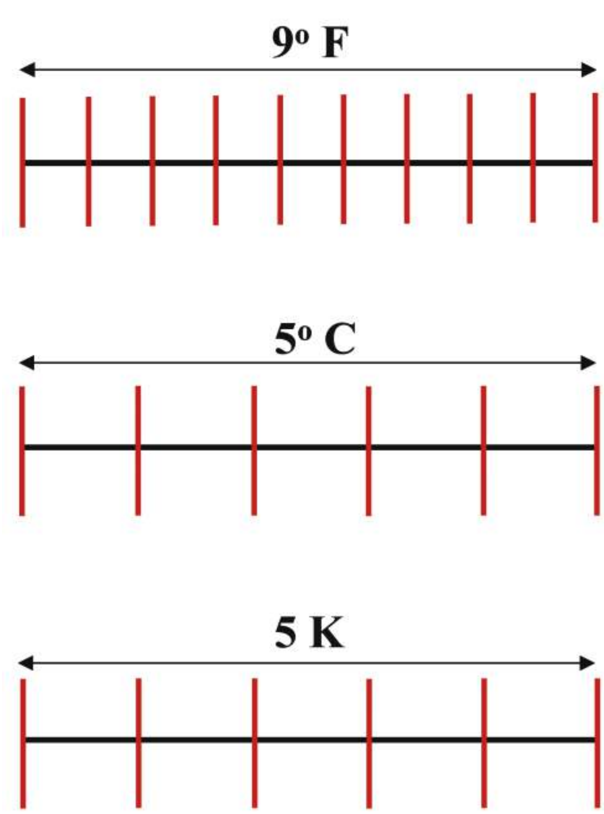


Figure 5.1 Different temperature scales

The relation between Celsius (C), Kelvin (K) and Fahrenheit (F) is given by

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$$

5.2 HEAT TRANSFER

Heat is transferred within a body or between bodies through three modes. They are Conduction, Convection and Radiation.

5.2.1 Conduction

Conduction is defined as the transfer of heat from one point to another without the displacement of the particles. When an iron rod is heated at one end, the iron atoms at the hot end vibrate about their mean position and transfer the heat energy to the neighbouring iron atoms. As a result, the heat energy reaches the other end of the rod. In conduction, only the energy is transferred and not the particles. In solids, conduction is the primary mode of heat transfer.

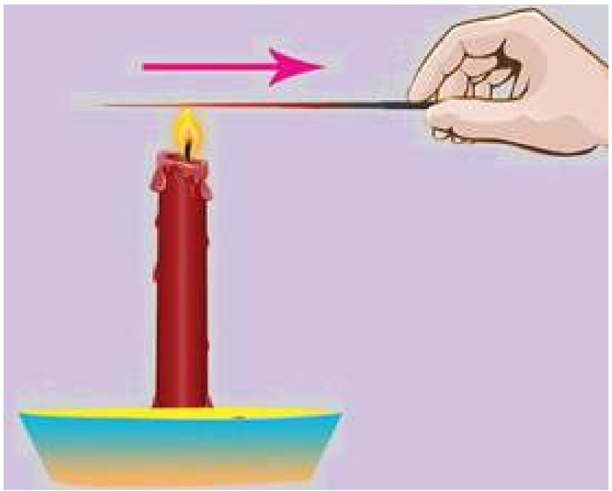


Figure 5.2 Heat Conduction

Applications of Conduction

1) **Cooking:** Heat conduction is used in cooking when heat is transferred from a heat source (like a stove) to the cooking utensils and then to the food, allowing it to cook evenly.

2) **Thermal management in electronics:** Heat conduction helps dissipate heat from electronic devices to heat sinks or other cooling components, preventing overheating and ensuring proper functioning.
3) **Ventilating and Air conditioning:** Heat conduction is involved in transferring heat from heating elements (e.g., radiators) to the surrounding air or building structures, maintaining desired indoor temperatures.
4) **Industrial processes:** Heat conduction is crucial in industrial processes like metalworking and welding, where heat is transferred through materials to shape or join them.
5) **Everyday heat transfer:** Heat conduction occurs in everyday scenarios when objects at different temperatures come into contact, like holding a hot cup of coffee or touching a cold surface.

5.2.2 Convection

Convection is defined as the transfer of heat from one point to another by the displacement of particles. The portions of the fluid that get warmed up by contact with the heat source, expand and so move up through the body of the fluid due to the decrease in density. There is an inflow of cooler molecules to take the place of heated mass of the fluid which has moved up. This circulatory motion of the fluid mass by which heat is transferred from place to place is called Convection. In convection, both energy and particles are transferred. Convection takes place only in liquids and gases. It cannot take place in solids as the particles are rigidly bonded.

Figure 5.3 Heat Convection

Applications of Convection

1) **Cooling systems:** Convective heat transfer is used in air conditioning units and refrigeration systems to cool indoor spaces or refrigerated areas.
2) **Electronics cooling:** It helps cool electronic devices like computers and smartphones to prevent overheating and ensure proper functioning.
3) **Automotive cooling:** Convective heat transfer is involved in keeping car engines cool through systems like radiators.
4) **Natural ventilation:** Convective currents promote air circulation in buildings, maintaining comfortable indoor temperatures.
5) **Industrial processes:** It finds application in various industrial processes, such as drying, distillation, and chemical reactions, to control temperatures and improve efficiency.

5.2.3 Radiation

Radiative heat transfer is defined as the transfer of heat from one point to another even without any material medium. No matter is involved in radiative heat transfer. The heat from the Sun is received by earth only by radiation. Heat radiation is an electromagnetic wave which lies in the 'infra-red' region of the electro-magnetic spectrum. Like conduction, only energy is transferred during radiative heat transfer.

1) **Solar energy:** Radiative heat transfer from the Sun is used to generate electricity and heat water in solar panels and solar thermal systems.
2) **Heating and lighting:** Radiative heat transfer is used in heaters and light bulbs to provide warmth and illumination.
3) **Manufacturing and materials processing:** Radiative heat transfer is used to heat and process materials in industries like printing, ceramics, and metalworking.
4) **Thermal insulation:** Radiative heat transfer is considered in designing insulation materials that help maintain desired temperatures in buildings and vehicles.
5) **Food processing:** Radiative heat transfer is used in cooking processes like baking and roasting to cook food and achieve desired textures and flavours.

In practice, heat transfer is an interplay of conduction convection and radiation. One such example is the case of engine fins. Engine fins employ a combination of conduction, convection, and radiation to manage and dissipate the excess heat generated during engine operation, helping to maintain safe and efficient engine performance.

Conduction involves the heat moving through the fins' solid material, like how a spoon heats up when placed in hot soup. Convection happens as air flows around the fins, carrying heat away, similar to how a fan cools you on a hot day. Additionally, radiation occurs when the fins release heat in the form of invisible waves. These combined processes ensure efficient cooling and help the engine perform optimally.

5.2.4 Properties of thermal radiation

The nature of thermal radiation is similar to that of light. Following are some of the properties of thermal radiation.

1. Thermal radiation is an electromagnetic wave, travels with the speed of light
2. Thermal radiation undergoes reflection, refraction etc., as light.

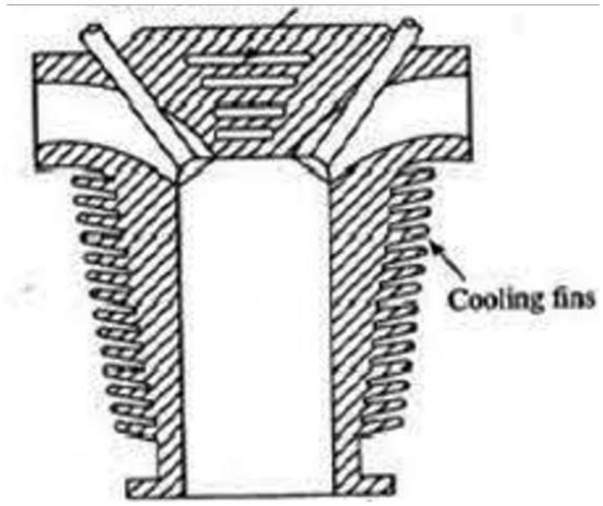


Figure 5.4 Heat Transfer in Engine Fins

3. Thermal radiation travels through vacuum.
4. It travels in straight lines in homogenous medium
5. It has longer wavelengths (lower frequencies) when compared to light
6. It heats the media when absorbed by them
7. The intensity of thermal radiation decreases upon increasing distance.
8. It is absorbed by dark rough surfaces and reflected by light smooth surfaces.

5.3 GOOD AND BAD THERMAL CONDUCTORS

Based on the ability of heat conduction, materials are classified into good and bad thermal conductors. Good thermal conductors are materials that allow the efficient transfer of heat (through conduction). They have high thermal conductivity, which is a measure of how well a material conducts heat. It is expressed in W m^{-1} K^{-1}. When heat is applied to a good thermal conductor, the kinetic energy of the atoms or molecules increases, and they transfer this energy to neighbouring particles through collisions resulting in the rapid propagation of heat through the material. Generally, all metals are good thermal conductors of heat. Interestingly, diamond, a non-metal, has the highest value of thermal conductivity

Bad thermal conductors, also known as thermal insulators, are materials that have low thermal conductivity. These materials resist the flow of heat and are used to minimize heat transfer. They are commonly employed in applications where heat insulation is desired.

Some important materials and their values of coefficient of thermal conductivity at 20^0C are listed in the **table 5.1**.

Table 5.1 Thermal Conductivity of a few materials

Material	Thermal Conductivity ($Wm^{-1}K^{-1}$)
Air	0.0257
Paper	0.05
Rubber	0.13
Wood	0.15
Polyethylene	0.33
Water	0.606
Glass (borosilicate)	1.2
Stainless Steel	16.3
Iron	80.2
Brass	109
Aluminium	205
Gold	315
Copper	398
Diamond	1000

5.4 SPECIFIC HEAT CAPACITY (*S*)

When you go to the seashore at noon, the sand is so hot but the seawater is cool even though both of them are heated by the same intensity of sunlight. This is because the same heat energy does not increase the same amount of temperature in substances. The quantity which is used to explain this behavior is called specific heat capacity denoted by *S*.

The amount of heat energy (Q) absorbed by the substance is directly proportional to

i) the mass of the substance (m) and

ii) increase in temperature of the substance ($T_2 - T_1$)

where T_1 initial temperature of the substance and T_2 final temperature of the substance.

$$Q \propto m (T_2 - T_1)$$
$$Q = m S (T_2 - T_1)$$

Where the proportionality constant S is called as the specific heat capacity of the substance

Table 5.2 Specific heat Capacity values of certain substances

Material	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
Silver	236
Copper	390
Steel	450
Silicon	710
Sand	780
Glass	840
Brick	841
Clay	878
Aluminum	900
Air	1005
Rubber	2005
Human body	3470
Water	4186

The specific heat capacity (S) of a substance may be defined as the amount of heat energy required to raise the temperature of 1 kg of a substance by 1 K. Its unit is $J\ kg^{-1}\ K^{-1}$. Some important materials and their values of specific heat capacity at 20^0C are listed below in **table 5.2**.

5.5 THERMODYNAMICS

Thermodynamics is the branch of physics that deals with the relationship between heat, work, and energy in various systems. It helps us to understand and predict how energy flows and transforms in different systems, from the smaller to larger systems. The laws of thermodynamics are formulated over three centuries of experimental works of Boyle, Charles, Bernoulli, Joule, Clausius, Kelvin, Carnot and Helmholtz. In our day-to-day life, the functioning of everything around us and even our body is governed by the laws of thermodynamics. There are four laws of thermodynamics namely, zeroth law, first law, second law and third law. However, here we focus only on first law and second law.

5.5.1 First law of thermodynamics

Heat and work are two distinct forms of energy transfer that play fundamental roles in thermodynamics. They are both ways in which energy can be transferred into or out of a system, and they can cause changes in the system's internal energy. The internal energy change is linked with the change of temperature.

The first law of thermodynamics is a statement of the law of conservation of energy. The first law of thermodynamics states that the quantity of the heat absorbed by a system (ΔQ), is equal to the sum of the increase in internal energy of the system (ΔU) due to a rise in temperature and the external work done by the system (ΔW).

$$\Delta Q = \Delta U + \Delta W$$

5.5.2 Second law of thermodynamics

In our modern technological world, the role of automobile engines plays a vital role in for transportation. In motor bikes and cars there are engines which take in petrol or diesel as input, and do work by rotating wheels. Most of these automobile engines have efficiency not greater than 40%. The second law of thermodynamics puts a fundamental restriction on efficiency of engines. The second law of thermodynamics has many statements. The statement that is related to heat engines is known as the Kelvin's statement of second law of thermodynamics. It is one of the formulations of the second law and is named after the renowned physicist William Thomson, also known as Lord Kelvin.

In simpler terms, Kelvin's statement of second law of thermodynamics highlights that no heat engine (a device that converts heat energy into mechanical work) can be 100% efficient in converting all the heat it receives into useful work without any losses. Some amount of heat will always be wasted or transferred to a colder reservoir during the process.

In essence, Kelvin's statement of the second law of thermodynamics emphasizes the inevitability of energy losses and the notion that achieving complete conversion of heat into work is not achievable in practice. This concept is a fundamental principle that underlies many real-world applications and engineering considerations, such as the design and efficiency of heat engines and power plants.

5.5.3 Thermodynamic system

A thermodynamic system refers to a specific portion of the universe that is under consideration for analysis. It could be anything from a simple gas-filled container to a complex power plant. The system is chosen based on the problem one wants to study. It generally characterized by thermodynamic variables like temperature, pressure, volume, etc. The state of the system is changed by changing the thermodynamic variables.

5.6 THERMODYNAMIC PROCESSES

Thermodynamic processes refer to the different ways in which a system changes its state and properties. These processes describe the interactions and transformations of system. Here are a few common types of thermodynamic processes:

5.6.1 Isothermal Process

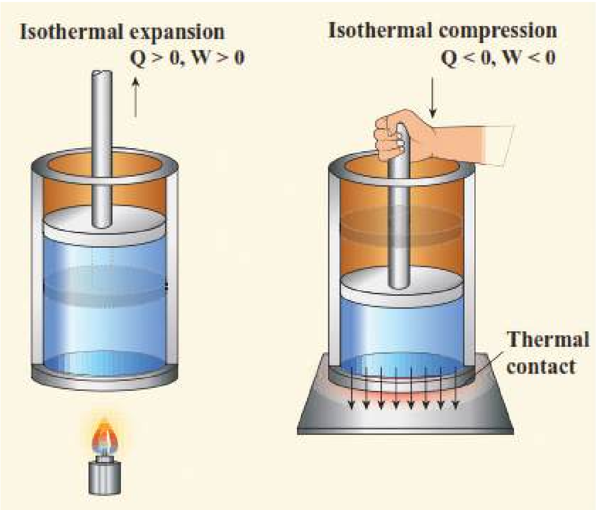


Figure 5.5 Isothermal compression and expansion process

An isothermal process is a thermodynamic process where the volume and pressure of the system may change keeping the temperature constant throughout the process. During an isothermal process, heat is exchanged between the system and its surroundings to maintain a constant temperature. The heat transfer occurs in such a way that the system's internal energy remains constant.

Examples

1. Slow gas expansion or compression in thermal contact.
2. Cooling or heating a gas at constant temperature.
3. Chemical reactions at controlled temperature.
4. Heat conduction in a material at steady temperature.

5.6.2 Adiabatic Process

An adiabatic process is a process in which there is no heat exchange between a system and its surroundings. During this process, there is no heat transfer, meaning that the system is insulated or isolated from its surroundings. When work is done by the system or on the system, there can be a change in temperature, pressure, and volume of the system with no heat transfer.

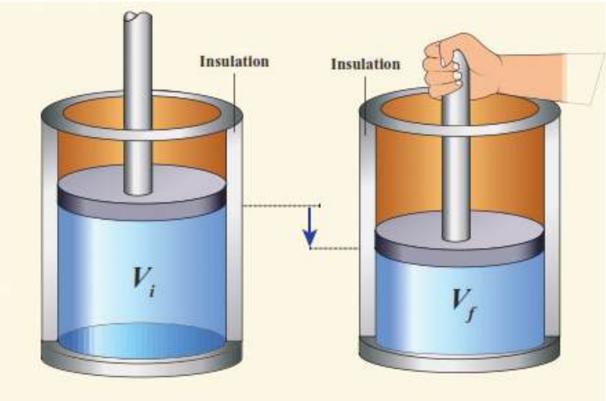


Figure 5.6 Adiabatic process

Examples

1. Rapid expansion of gas in an insulated container.
2. Compressing air in a bicycle pump quickly.
3. Rising and sinking air in the atmosphere.
4. Propagation of sound in a medium.

5.6.3 Isobaric Process

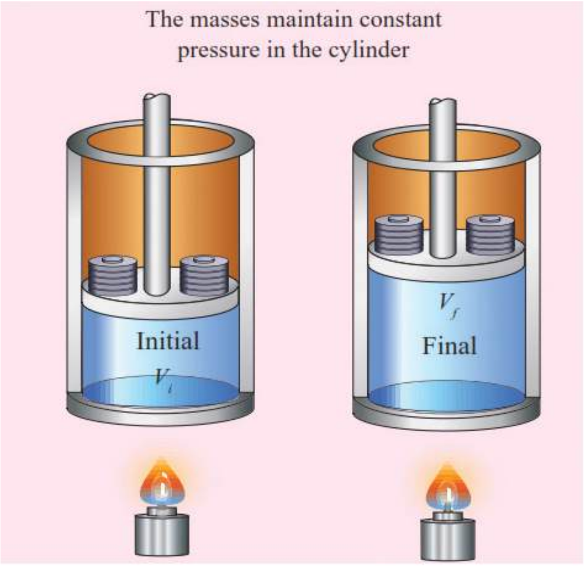


Figure 5.7 Isobaric process

An isobaric process is a thermodynamic process in which the pressure of a system remains constant while other variables, such as volume and temperature, may change. During an isobaric process, the system is in contact with a constant-pressure environment. This means that any change in the system's internal energy occurs solely due to work done on or by the system, as well as heat transfer.

Examples

1. Boiling water at atmospheric pressure.
2. Gas expanding in a cylinder against constant pressure.
3. Heating a gas at a constant pressure.

4. Melting solid material at constant pressure.

5.6.4 Isochoric Process

An isochoric process, also known as an isovolumetric process or constant-volume process, is a thermodynamic process in which the volume of a system remains constant while other variables, such as pressure and temperature, may change.

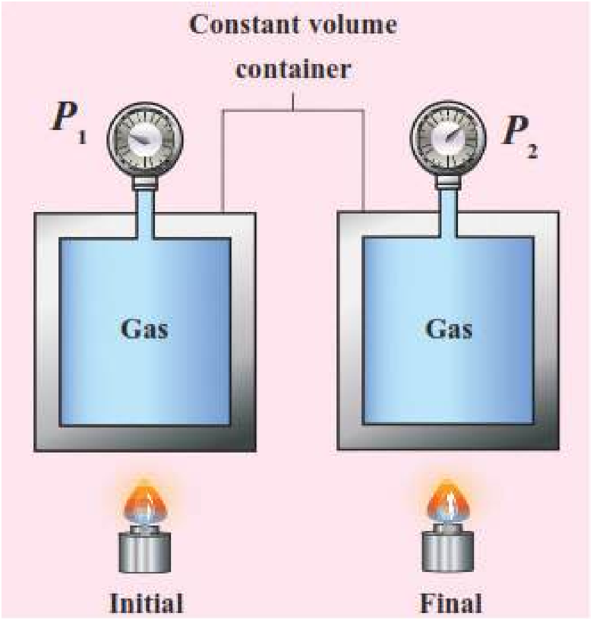


Figure 5.8 Isochoric process

During an isochoric process, no work is done by or on the system because there is no change in volume. The energy transferred to or from the system is solely in the form of heat.

Examples

1. Heating gas in a sealed container.
2. Chemical reactions in a closed volume.
3. Melting or solidification at constant volume.
4. Cooling liquid in a fixed-volume container.

5.7 IDEAL GAS

The simplest model to study the thermodynamic system is the ideal gas. This thermodynamic model gas is a theoretical concept used to describe the behavior of real gases under certain conditions. Ideal gases are hypothetical gases that strictly adhere to the following assumptions:

1) Gas particles are considered to be point masses, having negligible volume.
2) Gas particles have no intermolecular forces; they do not attract or repel each other.
3) Collisions between gas particles are perfectly elastic.
4) The kinetic energy of the gas particles is directly proportional to the temperature of the gas.

With these assumptions, the ideal gas law is stated as

$$PV = nRT$$

Where:

P is the pressure of the gas,
V is the volume of the gas,
n is the number of moles of gas,
R is the universal gas constant ($R = 8.314\ J\ mol^{-1}\ K^{-1}$)
T is the temperature of the gas in Kelvin.

This equation represents the relationship between the pressure, volume, temperature, and amount of gas in a closed system. The ideal gas law is widely applicable to a wide range of gases under relatively low pressures and high temperatures. The ideal gas law also forms the basis for various thermodynamic equations and processes involving ideal gases, such as isothermal, isobaric, isochoric, and adiabatic processes.

5.7.1 Boyle's law

Boyle's law states that at constant temperature, the volume of a given amount of an ideal gas is inversely proportional to its pressure. In simpler terms, when you decrease the pressure on a gas, its volume will increase, and vice versa, as long as the temperature remains constant. The law describes the relationship between the pressure and volume of a gas when temperature remains constant.

Using ideal gas equation, Boyle's law can be expressed as:

$$P_1 \times V_1 = P_2 \times V_2$$

Where:

P_1 is the initial pressure of the gas,

V_1 is the initial volume of the gas,

P_2 is the final pressure of the gas after a change,

V_2 is the final volume of the gas after a change.

This equation shows that the product of the initial pressure and volume of a gas is equal to the product of its final pressure and volume. It is essential to note that Boyle's law holds true for ideal gases and real gases under certain conditions. Boyle's law is an essential principle in various applications, such as scuba diving, where changes in pressure affect the volume of the air in a diver's tank.

SUMMARY

- Heat is a form of energy and it exists only when energy transfer from high temperature object to lower temperature object
- Temperature is a measure of degree of hotness in the object
- Three different temperature scales: Celsius, Fahrenheit and Kelvin
- Three types of heat transfer modes: Conduction, Convection and Radiation
- The specific heat capacity (*S*) of a substance may be defined as the amount of heat energy required to raise the temperature of 1 kg of a substance by 1 K. Its unit is J kg^{-1} K^{-1}.
- The first law of thermodynamics states that the quantity of the heat absorbed by a system (ΔQ), is equal to the sum of the increase in internal energy of the system (ΔU) due to a rise in temperature and the external work done by the system (ΔW).
- no heat engine (a device that converts heat energy into mechanical work) can be 100% efficient in converting all the heat it receives into useful work without any losses. Some amount of heat will always be wasted or transferred to a colder reservoir during the process.
- Thermodynamic processes: Isothermal, Adiabatic, Isochoric and Adiabatic
- Ideal gas law: PV = nRT
- Boyle's law: $P_1 \times V_1 = P_2 \times V_2$

WORKED EXAMPLES

1. A saucepan containing 2 kg of water initially at a temperature of 25°C is heated over a gas burner for 3 min. The final temperature of the water is 30°C. What is the energy gained by the water? (Specific heat capacity of water = 4186 J)

Solution:

Given:

Mass of the water, m = 2 kg

Specific heat capacity of water, S = 4186 J kg^{-1} K^{-1}

$T_1 - T_2$ = 30°C – 25°C = 5°C

Energy gained, $Q = m \times S \times (T_1 - T_2)$

$Q = 2 \times 4186 \times 5$

$Q = 41860$ J

2. A closed hall of volume 125 m^3 experiencing a pressure of 10^5 Pa due to 0.05 moles of air. Calculate the temperature of the hall. (Gas constant R=8.314 J $mol^{-1}K^{-1}$)

Solution:

Given:

Volume of the hall, V = 125 m^3

Pressure, P = 10^5 Pa

Number of moles, n = 0.05

Ideal gas equation, PV = nRT

T = (P × V)/(n×R)

T = (10^5 × 125)/(0.05 × 8.314)

∴ Temperature of the hall, T = 300 K

3. Human body temperature is given by 37°C. Express it in Fahrenheit and Kelvin

Solution:

Given:

C = 37°C, K= ?, F= ?

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$$

$$\frac{C}{100} = \frac{F-32}{180}$$

$$F = \left(\frac{C}{100} \times 180\right) + 32$$

$$F = \left(\frac{37}{100} \times 180\right) + 32$$

$$F = 98.6^o F$$

$$\frac{C}{100} = \frac{K-273}{100}$$

$$C = K - 273$$

$$K = C + 273$$

$$K = 37 + 273$$

$$K = 310K$$

4. An ideal gas occupying a 2 L flask at 10^5 Pa is allowed to expand to a volume of 4 L at constant temperature. Calculate the final pressure.

Solution:

Given

Initial volume of the flask, V_1 = 2 L

Initial Pressure, $P_1 = 10^5$ Pa

Final volume, V_2 = 4 L

Using Boyle's and ideal gas equation, $P_1 \times V_1 = P_2 \times V_2$

$P_2 = (P_1 \times V_1) / V_2$

$P_2 = (10^5 \times 2)/(4)$

$P_2 = 0.5 \times 10^5$

∴ Final pressure of the flask,

P_2 = 0.5×10^5 Pa

5. What is the volume occupied by one mole of carbon dioxide gas at a temperature of 27 °C and pressure of 10^5 Pa?

Solution:

Given

Pressure, $P = 10^5$ Pa

Temperature, T= 27 °C = 27 + 273 = 300 K

Number of moles, n = 1

Ideal gas equation, $PV = nRT$

$V = (n \times R \times T)/P$

$V = (1 \times 8.314 \times 300)/(10^5)$

$V = 0.0249$

∴ Volume of the carbon di-oxide gas, $V = 2.49 \times 10^{-3}\ m^3$

EVALUATION

Part A (2 marks)

1. What is centigrade scale?
2. What is Fahrenheit scale?
3. What is Kelvin scale?
4. Give the relation between centigrade, Fahrenheit and Kelvin scale.
5. What are the different modes of heat transfer?
6. Mention two applications of conduction.
7. Mention two applications of convection.
8. Mention two application of radiation.
9. Define specific heat capacity.
10. Write down first and second laws of thermodynamics
11. Define thermodynamic system.
12. Write down the various thermodynamic processes
13. Write down the ideal gas law and Boyle's law equation.
14. What are good and bad conductors? Give two examples of each.

Part B (7 marks)

15. Explain in detail the different types of thermodynamics scale and their conversion to each other
16. Discuss the different types of heat transfer methods and its few applications.
17. Describe in detail (a) isothermal process (b) adiabatic process (c) isobaric process.

Problems

1. What is the typical room temperature of 25 °C on the Fahrenheit scale and on the Kelvin scale?
   [**Ans**: 77 °F & 298 K]
2. One mole of air is contained in a vessel of volume $7 \times 10^{-3}\ m^3$ at a temperature of 30 °C. Assume that the gas behaves as an ideal gas. What is the pressure inside the vessel?
   [**Ans**: 3.6×10^5 Pa]
3. Calculate the amount of heat energy required to raise the temperature of 1 kg of water and 1 kg of sand from 30°C to 70°C. [**Ans**: 1,67,440 J & 31,200 J]
4. Express the auto-ignition temperature (the temperature at which a material spontaneously ignites without an external source of ignition) of Diesel, 410 °F in Celsius and Kelvin scales
   [**Ans**: 210 °C & 483 K]
5. What is the volume occupied by one mole of nitrogen gas at a temperature of 227 °C and pressure of 5×10^5 Pa?
   [**Ans**: $0.831 \times 10^{-3}\ m^3$]

DIPLOMA COURSE IN ENGINEERING & TECHNOLOGY

BASIC PHYSICS

FIRST SEMESTER

PRACTICAL

LIST OF EXPERIMENTS

1. (A) Determination of thickness and volume of given gauge wires using screw gauge.

   (B) Determination of volume of the glass plate by measuring its thickness and area using screw gauge.

2. (A) Determination of volume of the given solid cylinder by measuring the length and diameter using vernier caliper.

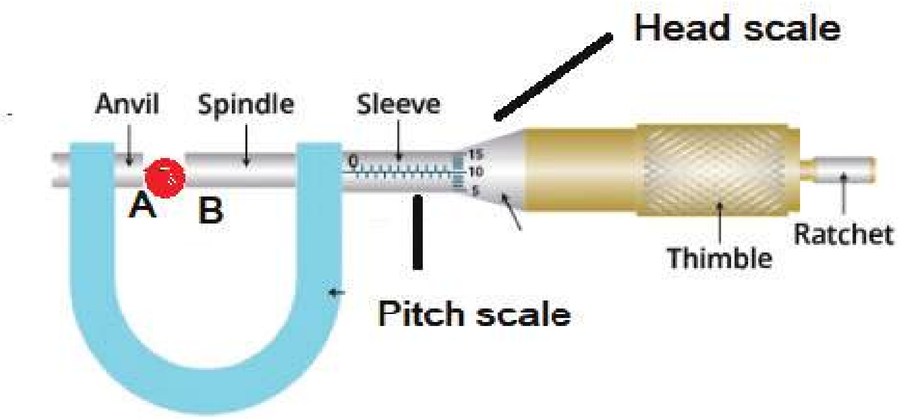
   (B) Determination of volume of the hollow cylinder by measuring the length and diameter using vernier caliper.

   (C) Determination of volume of the rectagular solid block by measuring its length, breadth and thickness using vernier caliper.

3. Verification of (i) Parallelogram law of forces (ii) Lami's theorem.
4. Determination of mass of a given object using the principle of moments.
5. Measurement of acceleration due to gravity using simple pendulum.
6. Determination of force constant of a helical spring.
7. Determination of Young's modulus of a wooden bar – Uniform bending method.
8. Verification of Boyle's law using quill tube.

1. (A) DETERMINATION OF THICKNESS AND VOLUME OF GIVEN GAUGE WIRES USING SCREW GAUGE

AIM Using Screw Gauge find the volume of given gauge wires (5,6,7,8,9) by measuring its length and diameter and error estimation.



Screw gauge

APPARATUS REQUIRED Screw gauge and gauge wire

FORMULA Volume of the given gauge wire = = $\pi r^2 l$ m^3

where, r → radius of the gauge wire (thickness /2) in mm

l → length of the gauge wire in mm

Thickness or diameter of the wire (d) = Observed Reading + Zero Correction

= {PSR+ (HSC × LC)} + ZC

where, PSR = Pitch scale reading

HSC = Head scale coincidence

LC = Least Count

ZC = Zero Correction

Head Scale Reading (HSR) = Head Scale coincidence × Least Count

Observed Reading (OR) = Pitch Scale Reading + Head Scale Reading

Correct Reading (CR) = Observed Reading ± zero Correction

PROCEDURE

(i) To find the least count (LC):

Least count is the minimum measurement that can be made with the given instrument.

$$LC = \frac{\text{distance moved in pitch scale for one complete rotation of head scale (mm)}}{\text{Number of divisions in head scale (division)}}$$

$$LC = \frac{1\text{ mm}}{100} = 0.01\text{ mm}$$

(ii) To find Zero Error (ZE) and Zero Correction (ZC):

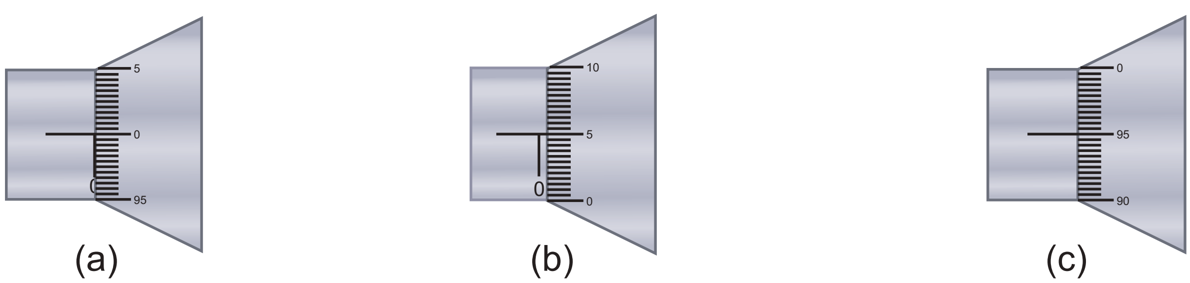
The Screw gauge is checked to find whether there is any zero (initial) error in the instrument. If there's any initial error, suitable correction is to be made.

When the studs A and B touch each other, if the zero of the head scale lies on the same line as that of the pitch scale index line (I.L), the instrument has no error.

If the zero of the head scale is above the index line, it has negative error. So, the zero correction is positive. If the zero of the head scale is below the index line, it has positive error. So, the zero correction is negative.

The type of error (ZE) and the suitable zero correction (ZC) for the given micrometer is determinedwith the help of figures and formulae given (Fig.1.1).

Zero Correction (ZC) = – (ZE × L.C)



(a) No zero error (b) Positive zero error (c) Negative zero error

ZE =0 ZC = – (ZE × L.C) ZC = 0	ZE = + 5 div ZC = - (ZE×L.C) = - (5×0.01 mm) ZC = – 0.05 mm	ZE = – 5 div ZC = – (ZE×L.C) = – (–5 × 0.01 mm) ZC = + 0.05 mm

(iii) To find thickness (diameter) of the gauge wire:

The given gauge wire is placed gently in between the two studs A and B and the ratchet is rotated till the wire is firmly but gently gripped. Note the number of completed divisions in mm on the pitch scale as Pitch scale reading (PSR) and the divisions on the head scale, which coincides with the index line as head scale coincidence (HSC). The PSR and HSC are entered in the tabular column. Then the head scale reading (HSR), observed reading (OR) and correct reading (CR) are calculated.

The procedure is repeated for different positions of the wire and the average thickness of the wire is calculated.

Similarly, the readings for length of the gauge wire are taken by placing the wire suitably placed in between the studs of the Screw Gauge and the readings are noted in the tabular column I.

Table 1 Thickness (diameter) and length of the gauge wire

LC =___ mm ZE =___ div ZC =___ mm

Dimension	S. No	PSR mm	HSC div	HSR = HSC × LC mm	OR =PSR + HSR mm	CR = OR ± ZC mm	The average mm
Diameter or Thickness (d)	1						**(d)**
	2						
	3						
	4						
Length (l)	1						**(l)**
	2						
	3						
	4						

OBSERVATION

The thickness (diameter) of the given gauge wire (d) = mm

The radius of the given gauge wire (r) = mm

Length of the gauge wire (l) = mm

CALCULATION

Volume of the gauge wire (V) $= \pi r^2 l$ m^3

=

= m^3

RESULT

The volume of the gauge wire (V) = m^3

1. (B) DETERMINATION OF VOLUME OF THE GLASS PLATE BY MEASURING ITS THICKNESS AND AREA USING SCREW GAUGE

AIM Using Screw Gauge Find the volume of the glass plate by measuring its thickness and area.

APPARATUS REQUIRED Screw gauge given glass plate and graph sheet .

FORMULA Volume of the glass plate = $t \times A$ m^3

where, $t \rightarrow$ Thickness of the glass plate in mm

$A \rightarrow$ Area of the glass plate in mm^2

Thickness of the glass plate = Observed Reading + Zero Correction

= {PSR + (HSC × LC)} + ZC

where, PSR = Pitch scale readingWhere

HSC = Head scale coincidence

LC = Least Count

ZC = Zero Correction

Head Scale Reading (HSR) = Head Scale coincidence × Least Count

Observed Reading (OR) = Pitch Scale Reading + Head Scale Reading

Correct Reading (CR) = Observed Reading ± Zero Correction

(i) To find thickness of the glass plate:

The given glass plate is placed gently in between the two studs A and B and the ratchet is rotated till the glass plate is firmly but gently gripped. Note the number of completed divisions in mm on the pitch scale as Pitch scale reading (PSR) and the divisions on the head scale, which coincides with the index line as head scale coincidence (HSC). The PSR and HSC are entered in the tabular column 1. Then the head scale reading (HSR), observed reading (OR) and correct reading (CR) are calculated. The procedure is repeated for different positions of the glass plate and the average thickness is calculated.

(iI) To measure the area of the glass plate:

The given irregular glass plate is placed on a graph sheet. The trace of the glass plate is drawn on the graph sheet. The number of squares inside the trace in mm^2 is counted. This gives the area of the glass plate in mm^2.

By multiplying the thickness of the glass plate and the area of the glass plate, the volume of the glass plate is determined.

Table 1.1 Thickness glass plate

LC =___ mm   ZE =___ div   ZC =___ mm

S. No	PSR mm	HSC div	HSR = HSC × LC mm	OR =PSR + HSR mm	CR = OR ± ZC mm
1					
2					
3					
4					
1					
2					
3					
4					

The average thickens =   mm

OBSERVATION

The thickness of the given glass plate (t) =   mm

Area of the glass plate (A) = mm^2

CALCULATION

Volume of the glass plate (V) = t × A mm^3

=

= m^3

RESULT

The volume of the glass plate (V) = m^3

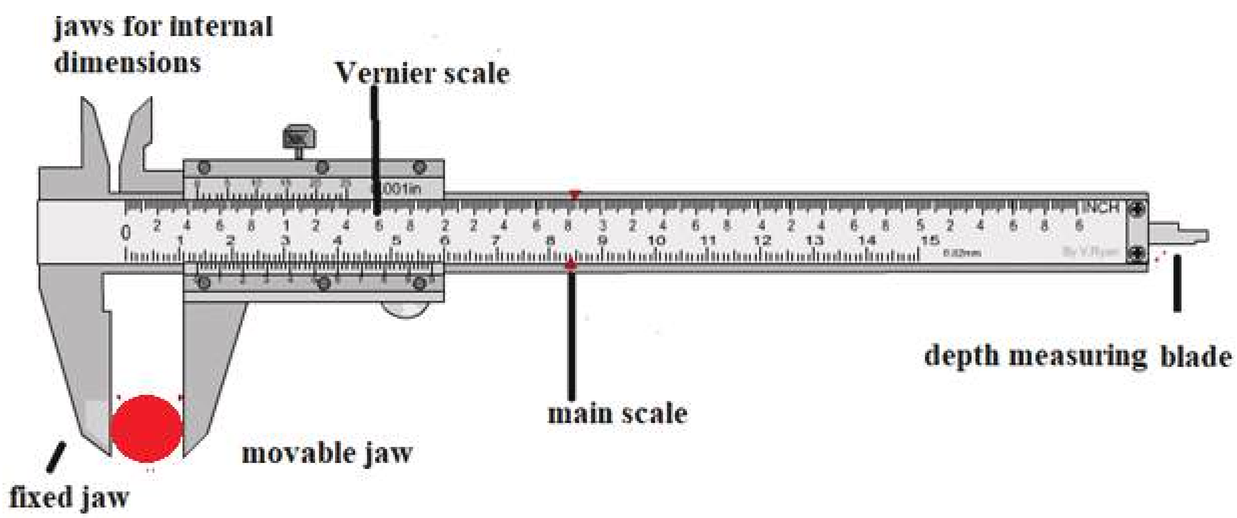
2. (A) DETERMINATION OF VOLUME OF THE GIVEN SOLID CYLINDER BY MEASURING THE LENGTH AND DIAMETER USING VERNIER CALIPER

(B) DETERMINATION OF VOLUME OF THE HOLLOW CYLINDER BY MEASURING THE LENGTH AND DIAMETER USING VERNIER CALIPER

(C) DETERMINATION OF VOLUME OF THE RECTAGULAR SOLID BLOCK BY MEASURING ITS LENGTH, BREADTH AND THICKNESS USING VERNIER CALIPER

AIM

(a) To measure the length and diameter of the given solid cylinder using vernier caliper and to calculate the volume of the solid cylinder.



Vernier caliper

APPARATUS REQUIRED Vernier calipers, solid cylinder and hollow cylinder, rectagular block

FORMULA Volume of the solid cylinder = $\pi r^2 l$ m^3

where, $l \to$ length of the cylinder

$r \to$ radius of the cylinder

To find the least count (LC):

Least count is the minimum measurement that can be made with the given instrument

The value of 1 main scale division (MSD) and number of divisions (n) on the vernier scale are determined. The least count of the instrument is calculated using the formula

$$LC = \frac{1MSD}{n}$$

$$LC = \frac{0.1cm}{10} = 0.01\ cm$$

(a) To find the length and diameter of the solid cylinder:

The given cylinder is gently placed in between the two lower jaws of the vernier calipers such that the length of the cylinder is parallel to the scale.

The completed main scale reading (MSR) is taken by noting the position of zero of the vernier scale. The vernier scale coincidence (VSC) is then noted. VSC is that particular division which coincides with any one of the main scale divisions, making a straight line.

The MSR and VSC are noted in the tabular column I for different settings of the cylinder. Then the Vernier Scale Reading (VSR), Observed Reading (OR) and Correct Reading (CR) are calculated using the formula given. The average value of CR is determined, which gives the length of the given cylinder.

Similarly, the readings for diameter of the solid cylinder are taken by placing the cylinder suitably in between the lower jaws and the readings are noted in the tabular column I.

Tabular column I: To find the length and diameter of the solid cylinder

LC =0.01 cm

Dimension	S.No	MSR cm	VSC div	VSR=VSC × LC cm	TR =MSR+VSR cm	The average diameter cm
Length (l)	1					(l)
	2					
	3					
	4					
Diameter (d)	1					(d)
	2					
	3					
	4					

OBSERVATION

The average radius of the solid cylinder ‘r’ = $\times 10^{-2}$ m

The average length of the solid cylinder ‘l’ = $\times 10^{-2}$ m

CALCULATION

Volume of the solid cylinder (V) = $\pi r^2 l$ m^3

= m^3

RESULT

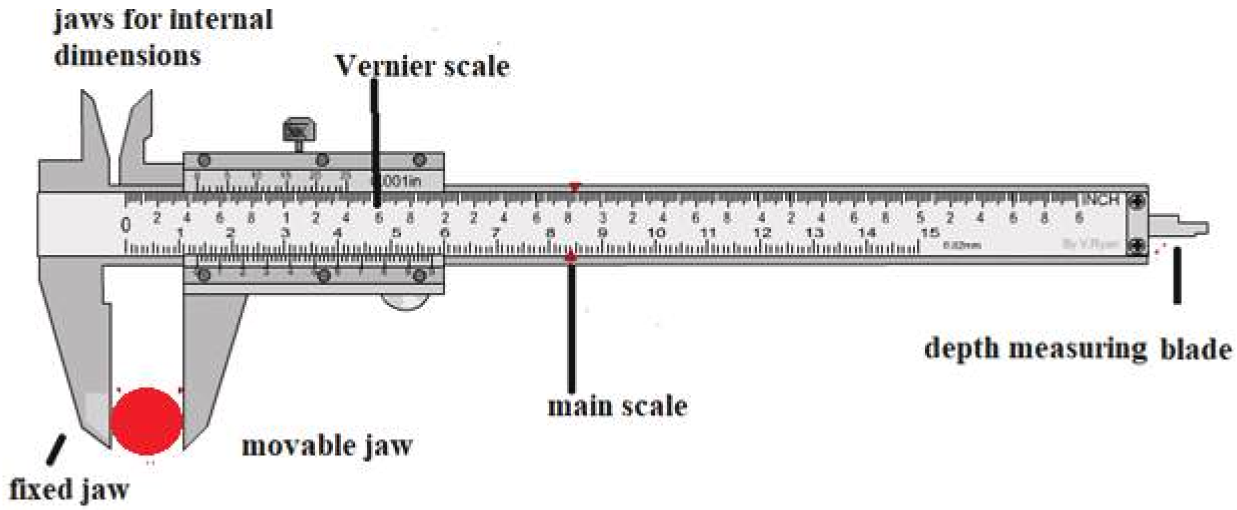
The average radius of the solid cylinder 'r' = $\times 10^{-2}$ m

The average length of the solid cylinder 'l' = $\times 10^{-2}$ m

Volume of the solid cylinder 'V' = m^3

(b) To find the volume of the hollow cylinder:

AIM (b) To measure the length and diameter of the given hollow cylinder using vernier caliper and to calculate the volume of the solid cylinder.



Vernier caliper

APPARATUS REQUIRED Vernier calipers, solid cylinder and hollow cylinder, rectagular block

FORMULA Volume of the hollow cylinder = $\pi (r_2^2 - r_1^2) l$ m^3

where, $l \rightarrow$ length of the hollow cylinder

r_2 = outer radius of the hollow cylinder

r_1 = inner radius of the hollow cylinder

Length / diameters of the hollow or solid cylinder = Observed reading ± Zero Correction

$$= \{MSR + (VSC \times LC)\} \pm ZC$$

where, MSR = Main Scale Reading

VSC = Vernier Scale Coincidence

LC = Least Count

ZC = Zero Correction

To find the least count (LC):

Least count is the minimum measurement that can be made with the given instrument

The value of 1 main scale division (MSD) and number of divisions (n) on the vernier scale are determined. The least count of the instrument is calculated using the formula

$$LC = \frac{1MSD}{n}$$

$$LC = \frac{0.1cm}{10} = 0.01\ cm$$

To find the length and diameter of the hollow cylinder:

The given hollow cylinder is gently placed in between the two lower jaws of the vernier calipers such that the length of the cylinder is parallel to the scale.

The completed main scale reading (MSR) is taken by noting the position of zero of the vernier scale. The vernier scale coincidence (VSC) is then noted. VSC is that particular division which coincides with any one of the main scale divisions, making a straight line.

The MSR and VSC are noted in the tabular column I for different settings of the cylinder. Then the Vernier Scale Reading (VSR), Observed Reading (OR) and Correct Reading (CR) are calculated using the formula given. The average value of CR is determined, which gives the length of the given cylinder.

Similarly, the readings for inner and outer diameters of the hollow cylinder are taken by placing the cylinder suitably in between the upper jaws and the readings are noted in the tabular column II.

Tabular column II: To find the length and inner and outer diameter of the hollow cylinder

LC =0.01 cm

Dimension	S.No	MSR cm	VSC div	VSR = VSC × LC cm	TR = MSR + VSR cm	The average diameter cm
Length (l)	1					(l)
	2					
	3					
	4					
Inner diameter (d_1)	1					(d_1)
	2					
	3					
	4					
Outer diameter (d_2)	1					(d_2)
	2					
	3					
	4					

OBSERVATION

The outer diameter radius of the hollow cylinder 'd_2' = $\times 10^{-2}$ m

The outer radius of the hollow cylinder 'r_2' = $\times 10^{-2}$ m

The inner diameter radius of the hollow cylinder 'd_1' = $\times 10^{-2}$ m

The inner radius of the hollow cylinder 'r_1' = $\times 10^{-2}$ m

The average length of the solid cylinder 'l' = $\times 10^{-2}$ m

CALCULATION

Volume of the hollow cylinder (V) = $\pi (r_2^2 - r_1^2) l$ m^3

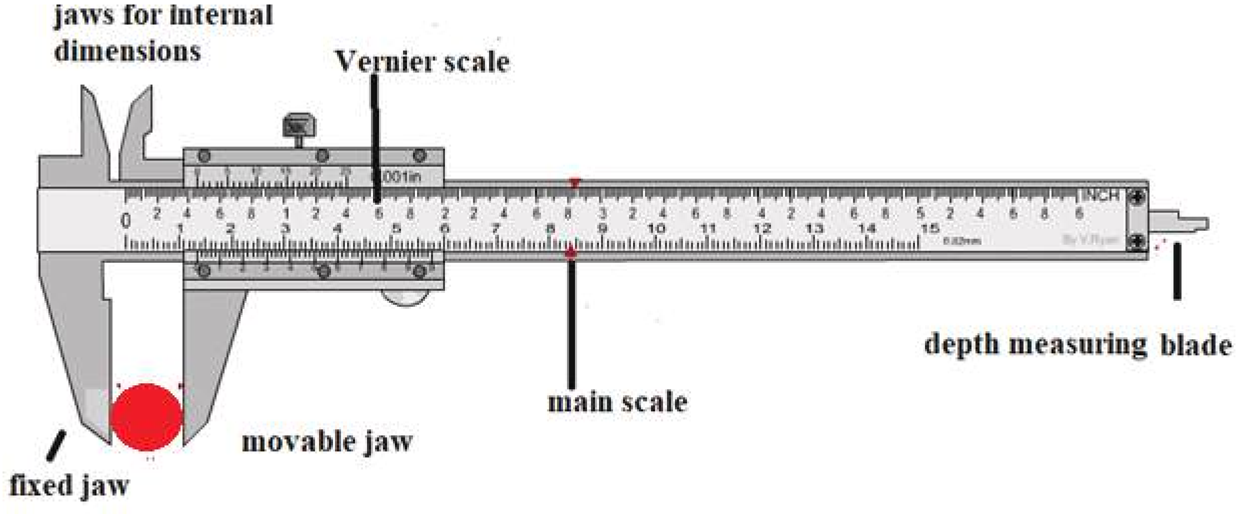
= m^3

RESULT

Volume of the hollow cylinder 'V' = m^3

(c) To find the volume of rectangular block

AIM (c) To Measure the length, breadth and thickness of rectangular block using vernier caliper and to calculate the volume of rectangular solid slab



Vernier caliper

APPARATUS REQUIRED Vernier calipers, solid cylinder and hollow cylinder, rectagular block

FORMULA Volume of the rectangular solid block $V = L \times B \times H$ m^3

where, L = length of the the rectangular solid block

B = Breadth of the the rectangular solid block

H = Height of the the rectangular solid block

Vernier Scale Reading (VSR) = Vernier Scale Coincidence (VSC) × Least Count (LC)

Observed Reading (OR) = Main Scale Reading (MSR) + Vernier Scale Reading (VSR)

Correct Reading (CR) = Observed Reading (OR) ± Zero Correction (ZC)

To find the least count (LC):

Least count is the minimum measurement that can be made with the given instrument

The value of 1 main scale division (MSD) and number of divisions (n) on the vernier scale are determined. The least count of the instrument is calculated using the formula

$$LC = \frac{1\,MSD}{n}$$

$$LC = \frac{0.1\,cm}{10} = 0.01\,cm$$

To find the length, breadth and height rectangular solid slab:

The given slab is gently placed in between the two lower jaws of the vernier calipers such that the length of the slab is parallel to the scale.

The completed main scale reading (MSR) is taken by noting the position of zero of the vernier scale. The vernier scale coincidence (VSC) is then noted. VSC is that particular division which coincides with any one of the main scale divisions, making a straight line.

The MSR and VSC are noted in the tabular column I for different settings of the cylinder. Then the Vernier Scale Reading (VSR), Observed Reading (OR) and Correct Reading (CR) are calculated using the formula given. The average value of CR is determined, which gives the length of the given slab.

Similarly, the readings of breadth and height for rectangular slab are taken by placing the slab suitably in between the lower jaws and the readings are noted in the tabular column III.

Tabular column III: To find the length, breadth and height rectangular solid slab

LC =0.01 cm

Dimension	S.No	MSR cm	VSC div	VSR = VSC × LC cm	TR =MSR+VSR Cm	The average reading cm
Length (L)	1					(L)
	2					
	3					
	4					
Breadth (B)	1					(B)
	2					
	3					
	4					
Height (H)	1					(H)
	2					
	3					
	4					

OBSERVATION

The average length of rectangular slab 'L' = $\times 10^{-2}$ m

The average breadth of rectangular slab 'B' = $\times 10^{-2}$ m

The average height of rectangular slab 'H' = $\times 10^{-2}$ m

CALCULATION

Volume of the rectangular slab (V) = L × B × H m^3

= m^3

RESULT

Volume of the rectangular slab (V) = m^3

3. VERIFICATION OF (i) PARALLELOGRAM LAW OF FORCES (ii) LAMI'S THEOREM

AIM To verify the (i) Parallelogram law of forces and (ii) Lami's theorem.

APPARATUS REQUIRED Vertical drawing board, two pulleys with clamps, three sets of slotted weights, thread, white paper, scale, protractor, compass and pencil.

FORMULA **(i)** To verify the parallelogram law of forces, it is to be shown that Resultant = Equilibrant and they are opposite in directions.

i.e. OD = OC and $\angle COD = 180^{o}$

where, OD and OC are lines drawn representing the resultant and equilibrant of P and Q.

FORMULA **(ii)** To verify Lami's theorem, it is to be shown that

$$\frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma} = \text{constant}$$

where, P, Q and R are the forces α, β and γ are the angles opposite to P, Q and R respectively.

DESCRIPTION:

A drawing board is fixed vertically on the wall. Two frictionless pulleys are fixed at the top corners of the drawing board as shown in the figure. A light and inextensible string is passed over these pulleys. Another short string is tied to the middle of the first string at O. Weight hangers P, Q and R are tied at the free ends of the strings.

PROCEDURE:

- Displace the slotted weight hangers from the position and note if they come to the original position to ensure that the pulley have minimum friction. The weights P, Q and R are adjusted suitably such that the system is at rest. The point O is in equilibrium under the action of these three coplanar and concurrent forces P, Q and R acting along the strings as shown in the figure.
- A drawing paper is fixed on the board, behind the strings. The trace of the three strings is taken on the sheet of paper, using an adjustable lamp arrangement in front of the threads. The trace sheet is removed and the lines are joined to get the image of the threads. These lines meet at a point O.

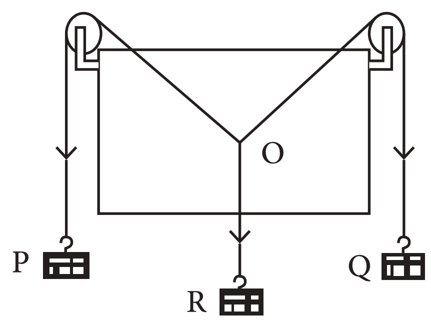
Note: A body is said to be in equilibrium when it is completely at rest. To obtain the equilibrium of the point O in this experiment, choose the weights such that $P + Q > R$ and $P - Q < R$.

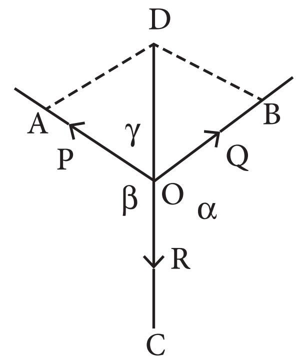
i) To verify parallelogram law of forces:

Taking a suitable scale (0.050 kg = 1 cm) OA, OB and OC are marked to represent the forces P, Q and R respectively both in magnitude and in direction. With OA and OB as adjacent sides, a parallelogram OADB is completed. The length of the diagonal OD is measured and entered in the tabular column. In addition, the ∠COD is measured and entered in the tabular column I. According to parallelogram law, the diagonal OD gives the resultant of P and Q, where OC is the equilibrant of P and Q. The procedure is repeated thrice with different combinations of P, Q and R.

ii) To verify Lami's theorem:

In all the three figures drawn in the trace sheet, the angles between the forces are marked. The angle between the forces Q and R is marked as α. The angle between the forces R and P is marked as β. The angle between the forces P and Q is marked as γ as shown in the figure. The angles are measured and entered in the corresponding tabular column II. To check the accuracy of angle measurement, for each case, the sum of the three angles measured should be equal to 360°. i.e. $(\alpha + \beta + \gamma) = 360°$. Then the calculations are done using the given formula and the values are entered in the tabular column.





Tabular Column I : To verify parallelogram law of forces.

Scale: 0.05 kg wt = 1 cm

Sl. No.	P kg wt.	Q kg wt.	R kg wt.	OA cm	OB cm	OC cm	OD cm	∠COD degree
1								
2								
3								

Tabular Column II : To verify Lami's Theorem.

Sl. No.	P kg wt.	Q kg wt.	R kg wt.	α degree	β degree	γ degree	$\frac{P}{\sin\alpha}$ kg wt.	$\frac{Q}{\sin\beta}$ kg wt.	$\frac{R}{\sin\gamma}$ kg wt.
1									
2									
3									

CALCULATION

1. P = kg wt, Q = kg wt, R = kg wt

   α = β = γ =

   $\frac{P}{\sin\alpha}$ =

   $\frac{Q}{\sin\beta}$ =

   $\frac{R}{\sin\gamma}$ =

2. P = kg wt, Q = kg wt, R = kg wt

   α = β = γ =

   $\frac{P}{\sin\alpha}$ =

   $\frac{Q}{\sin\beta}$ =

   $\frac{R}{\sin\gamma}$ =

3. P = kg wt, Q = kg wt, R = kg wt

   α = β = γ =

   $\frac{P}{\sin\alpha}$ =

   $\frac{Q}{\sin\beta}$ =

   $\frac{R}{\sin\gamma}$ =

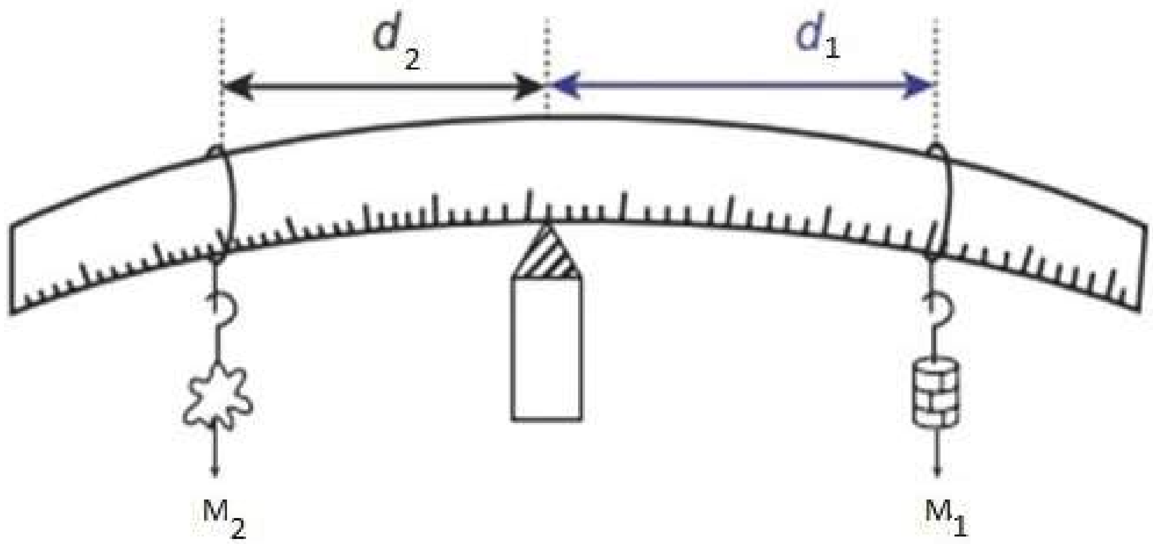
RESULT

1. In the tabular column I, in all cases, it is seen that Resultant = Equilibrant i.e. OD = OC and ∠COD = 180°, which verifies parallelogram law of forces.
2. In the tabular column II, in all cases, it is seen that the values in the last three columns are found to be equal, which verifies Lami's theorem i.e., $\frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma}$ = constant

4. DETERMINATION OF MASS OF A GIVEN OBJECT USING THE PRINCIPLE OF MOMENTS

AIM To determine the mass of a given object using the principle of moments.

DIAGRAM



APPARATUS REQUIRED A metre scale, a knife edge or a vertical stand with a clamp, slotted weights, thread, unknown mass.

FORMULA

$M_2 = (M_1 \times d_1) / d_2$ (kg)

where, M_2 – Unknown Mass (kg)

M_1 – Known Mass (kg)

d_1 – Distance of known mass from equilibrium position. (metre)

d_2 – Distance of unknown mass from equilibrium position. (metre)

PROCEDURE:

- A metre scale is supported at its centre of gravity by a knife edge or suspended by using a thread tied to its centre so that the scale is in the horizontal position. Ensure that the scale is in equilibrium position.
- A known mass M_1 and an unknown mass M_2 are suspended from either side of the scale using the weight hangers.
- Fix the position of one weight hanger and adjust the position of the second weight hanger such that the scale is in equilibrium.
- Measure the distance d_1 and d_2 of the two weight hangers from the centre of the scale accurately.
- The experiment is repeated for different known masses M_1 and the distances d_1 and d_2 are tabulated.

Tabular Column I : Mass of a given object.

S.No	Known Mass M_1 (Kg)	Distance of known mass d_1 (m)	Distance of unknown mass d_2 (m)	$M_2 = (M_1 \times d_1) / d_2$ (Kg)
1				
2				
3				
4				
5				
			Mean value	

OBSERVATION

Known Mass 'M_1' = Kg

Distance of known mass from equilibrium position 'd_1' = m

Distance of unknown mass from equilibrium position 'd_2' = m

CALCULATION

Unknown Mass $M_2 = (M_1 \times d_1) / d_2$ **kg**

= kg

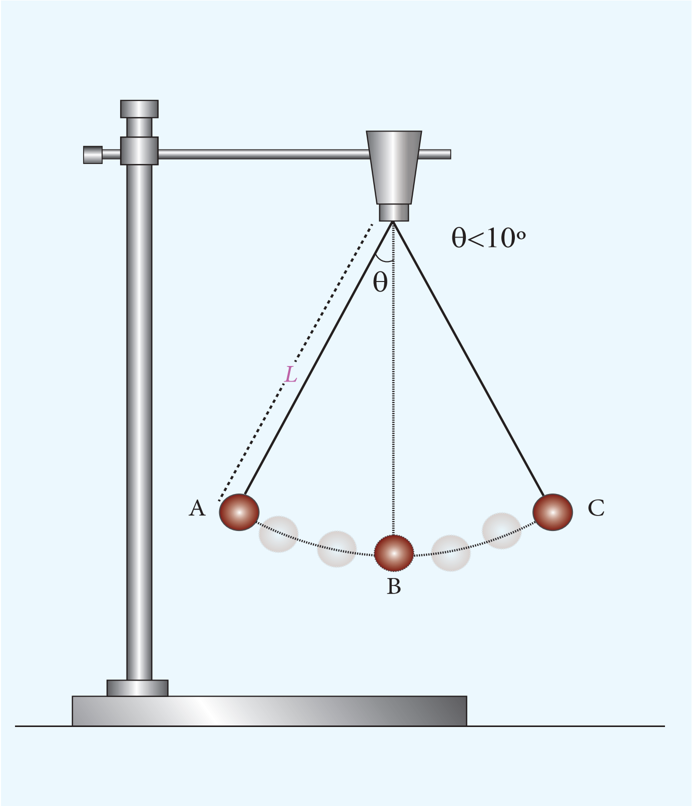
RESULT

Using the principle of moments, the mass of the unknown body M_2 = kg.

5. MEASUREMENT OF ACCELERATION DUE TO GRAVITY USING SIMPLE PENDULUM

AIM To determine acceleration due to gravity using a simple pendulum.

DIAGRAM



APPARATUS REQUIRED Pendulum bob, Thread, Retort stand, Meter scale, Stop watch.

FORMULA

$$g = 4\pi^2 \left(\frac{L}{T^2}\right) \text{ms}^{-2}$$

where, T = Time period of simple pendulum (second)

g = Acceleration due to gravity (meter sec^{-2})

L = Length of the pendulum (meter)

PROCEDURE

- Attach a small brass bob to the thread.
- Fix this thread on to the stand.
- Measure the length of the pendulum from top to the middle of the bob of the pendulum. Record the length of the pendulum in the table below.
- Note the time (t) for 10 oscillations using stop watch.
- The period of oscillation T = t / 10
- Repeat the experiment for different lengths of the pendulum 'L'. Find acceleration due to gravity 'g' using the given formula.

OBSERVATIONS:

To find the acceleration due to gravity 'g'.

Length of the pendulum L (meter)	Time taken for 10 oscillations t (s)			Period of oscillation T = (s)	T^2 (s^2)	$\left(\frac{L}{T^2}\right)$ (ms^{-2})
	Trial 1	Trial 2	Average			
					Mean $\left(\frac{L}{T^2}\right)$ =	

CALCULATION

$g = 4\pi^2\left(\frac{L}{T^2}\right)$ (ms^{-2}), substitute the value of $\pi = 3.14$

g = ms^{-2}

RESULT

The acceleration due to gravity 'g' determined using simple pendulum is = $m\ s^{-2}$

6. DETERMINATION OF FORCE CONSTANT OF A HELICAL SPRING

AIM To determine the force constant of a helical spring by elongation and oscillation method.

APPARATUS REQUIRED Stand, spring, slotted weights, scale and stopwatch.

FORMULA

Force constant (k) = F/l (gf/cm) (1)

Force constant (k) = $4\pi^2 m/T^2$ (Nm^{-1}) $= 0.04\ m/T^2$ (gf/cm) (2)

where, F – Force (gf)

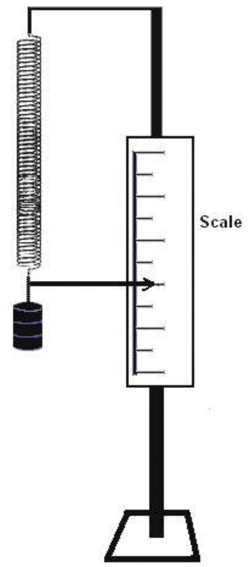
l – Elongation (cm)

m – mass (g)

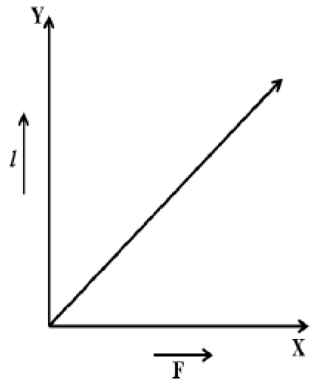
T – Time period (s)

PROCEDURE

- **I Method:** The given spring is hung from the clamp of a stand. A pointer, attached to the bottom end of the spring moves over a vertical scale. Weights are added in the weight hangers in steps of 100 gf and the corresponding readings on the scale are noted down. The elongation produced for 100, 200, 300, 400 and 500 gf are found and the force constant is calculated using formula (1). Force versus elongation graph is drawn.
- **II Method:** To calculate the force constant using the second method a known mass (say 300 g) is hung at the end of the spring and it is made to oscillate. Time taken for 20 oscillations is noted and time period is calculated. By substituting in formula (2) force constant can be calculated.



Spring-mass arrangement



Model graph

Tabular column (Method I):

To determine the Force constant using Elongation method:

S.No	Force (F) gf	Scale reading cm	F gf	Elongation (l) cm	Force constant k = F/ l gf/cm
1					
2					
3					
4					
5					
6					

Mean k =

Tabular column (Method II):

To determine the Force constant using Oscillation method:

S.No	Mass (m) g	Time for 20 oscillations s			Time period (T) s	T^2 s^2	Force constant $K = 0.04\ m/T^2$ gf/cm
		Trial 1	Trial 2	Mean			

Mean k =

CALCULATION

Elongation method

Force constant (k) = F/ l (gf/cm)

Oscillation method

Force constant (k) = $4\pi^2 m/T^2$ (Nm^{-1}) $=0.04\ m/T^2$ (gf/cm)

RESULT

The force constant of the spring'k'(Elongation method) = ___________

The force constant of the spring 'k'(Oscillation method) = ___________

From the graph, it is found that the elongation is directly proportional to the force.

7. DETERMINATION OF YOUNG'S MODULUS OF A WOODEN BAR – UNIFORM BENDING METHOD

AIM To find the Young's Modulus of a wooden bar by Uniform bending method.

APPARATUS REQUIRED Wooden bar, Weight hangers with slotted weights, Knife edges, Travelling microscope, Vernier caliper, Screw gauge, Metre scale.

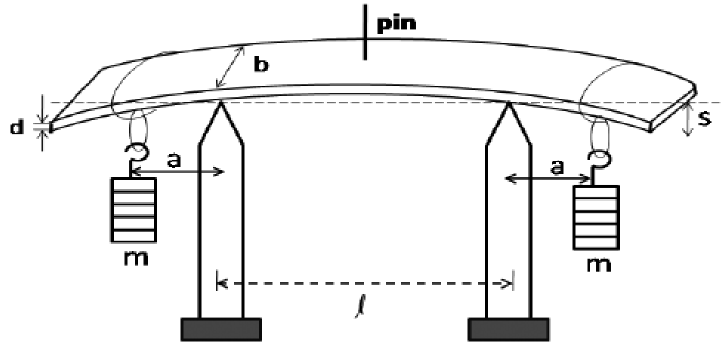
FORMULA Young's modulus of the material of the wooden bar

$$Y = \frac{3mgal^2}{2sbd^3} \ (\text{N m}^{-2})$$

where, Y – Young's modulus of the material of the wooden bar (N m^{-2})
m – mass for the elevation (kg)
g – Acceleration due to gravity (ms^{-2})
a – distance between the load and nearest knife edge (m)
l – distance between the knife edges (m)
b – breadth of the beam (m)
d – thickness of the beam (m)
s – elevation produced for mass (m)

PROCEDURE

- The given beam is supported on two knife edges separated by a distance 'l'. A pin is fixed vertically at the mid-point. Two weight hangers are suspended, one each on either side of the knife edges so that their distances from the nearer knife edge are equal. With the load 'm', the pin is focused through microscope. The microscope is adjusted so that the horizontal crosswire coincides with the tip of the pin.
- The microscope reading is taken. The load is added in steps of 50 g and in each case the microscope reading is taken during loading. The readings are tabulated. The elevation at the mid-point for 'm' kg is calculated.
- The distance between the knife edges (l) is measured using metre scale. The breadth (b) and thickness (d) of the beam are found using vernier calipers and screw gauge respectively.



Young's modulus-Uniform bending method

OBSERVATIONS:

Least Count Calculation:

Value of 1 MSD =

Number of divisions in the Vernier scale (N) =

$$\text{Least count} = \frac{\text{value of 1 MSD}}{N} =$$

Tabular column I:

To determine the breadth 'b' of the beam using Vernier caliper:

LC:

S.No	Main Scale Reading (MSR) cm	Vernier Scale Coincidence (VSC)	TR = MSR + (VSC × LC) cm

Mean (b) = $\times 10^{-2}$ m

Tabular column II:

To determine the thickness 'd' of the beam using screw gauge:

LC:

S.No	Pitch Scale reading (PSR) mm	Head Scale Coincidence (HSC) (div)	TR = PSR + (HSC × LC) mm

Mean (d) = $\times 10^{-3}$ m

Tabular column III:

To determine the elevation (s):

Total reading (TR) = MSR + (VSC × LC) **LC:**

Load g	Reading of the microscope			Elevation 's' for M g cm
	MSR cm	VSC	TR cm	

Mean (s): **X 10^{-2} m**

OBSERVATIONS:

Mass for the elevation m = $\times 10^{-3}$ kg

Distance between two knife edges l = $\times 10^{-2}$ m

Acceleration due to gravity g = ms^{-2}

Breadth of the beam b = $\times 10^{-2}$ m

Thickness of the beam d = $\times 10^{-3}$ m

Elevation produced for 'm' kg load s = $\times 10^{-2}$ m

Distance between one of the knife edges and the adjacent weight hanger a = $\times 10^{-2}$ m

CALCULATION

Young's modulus

$$Y = \frac{3mgal^2}{2sbd^3} \text{ (N m}^{-2}\text{)}$$

$Y =$ (N m^{-2})

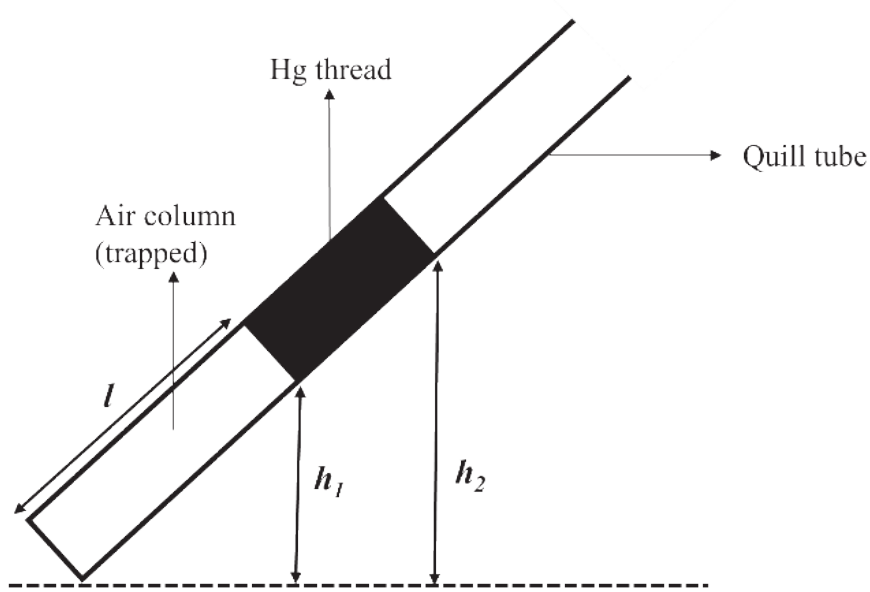
RESULT

The Young's Modulus of a wooden bar by Uniform bending method = (N m^{-2})

8. VERIFICATION OF BOYLE'S LAW USING QUILL TUBE

AIM To verify Boyle's law using quill tube.

DIAGRAM



APPARATUS REQUIRED Quill tube, Stand, Meter scale.

FORMULA

$$P \times l = \text{constant},$$

Where, P = Pressure of the trapped air column in the quill tube (cm of Hg)

l = Length of the trapped air column in the quill tube (cm)

PROCEDURE

- Arrange the quill tube horizontally on a stand.
- The length of the trapped air column is measured using a metre scale.
- Vertical heights at the two ends of mercury thread from the table are also measured using a metre scale.
- The difference between them gives the vertical height h of the mercury thread. Here h =0. So, pressure inside the tube is also H, which is the atmospheric pressure.ie; 76 cm of Hg
- The quill tube is then placed in a slanting position with the open end upwards.
- The length of the air column is measured and the vertical height, h of mercury is noted. Now the pressure inside the tube, P = H + h.
- Quill tube is then placed in different positions, such as: vertical position with open end upwards and with open end downwards, slanting position with open end downwards and measure its corresponding length of the air column l and vertical height h as noted above.
- Now P×l is calculated in each case.

Tabular column:

Verification of Boyle's law:

S.No	Position of the tube	Height of Hg thread from table to		Vertical height, $h = h_2 - h_1$ cm	Pressure $P = H \pm h$ cm	Length of air column, l cm	$P \times l$ cm^2
		lower end, h_1 cm	upper end, h_2 cm				
1	Vertical (open end up)						
2	Slanting (open end up)						
3	Horizontal						
4	Slanting (open end down)						
5	Vertical (open end down)						

CALCULATION

$P \times l$ = constant

RESULT

The pressure of the trapped air column is inversely proportional to its length and hence Boyle's law is verified.

NOTE

NOTE

NOTE

NOTE

NOTE