ENGINEERING PHYSICS

DIPLOMA COURSE IN ENGINEERING

FIRST & SECOND SEMESTER

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DIRECTORATE OF TECHNICAL EDUCATION
GOVERNMENT OF TAMIL NADU

Government of Tamilnadu
First Edition – 2011

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This book has been prepared by the Directorate of Technical Education

This book has been printed on 60 G.S.M Paper

Through the Tamil Nadu Text Book Corporation

FOREWORD

With the concept of Global Village after liberalisation and globalisation , our country India has become one of the most sought after destinations by many Multi National Companies for investment. The rapid growth in various fields of Engineering and Technology like Information technology, Automobile engineering, Infrastructure development, etc., demands much needed Human Resources.

The growth of various Industries demand qualified Technicians at different categories. The Diploma level education of Engineering and Technology offered by the various Polytechnic Colleges cater these Technician needs of the Industries.

Every Polytechnic college is offering diploma programmes in many fields of Engineering like Mechanical, Electrical, Civil, Electronics, Information Technology, etc.,

For all branches of study, the first year curriculum is common. The syllabus provides the necessary bridge between the school education and engineering education which the students pursue from their second year of study. For successful completion of engineering diploma with flying colours, a thorough knowledge of basics is very much essential.

The Content of this Engineering physics I and II provides necessary basic ideas and concepts in a lucid manner. Real life applications and practical examples are included in this text, wherever required. The experiments to be performed by the student in I and II semester Engineering Physics Practical are also included in this text for the benefit of students.

The students should give due importance in understanding the various basic concepts with which only they can shine in their career, rather than reading them by heart.

ENGINEERING PHYSICS-I

FIRST SEMESTER

UNIT – I

SI UNITS AND STATICS

1.1 UNITS AND MEASUREMENT 5 Hrs

Unit-Definition-Fundamental Quantities-Definition-Seven fundamental quantities; their SI units and symbol for the units-Dimensional formula for length, mass and time -Supplementary quantities-plane angle and solid angle; their SI units and symbol for the units.

Derived physical quantities-Definition-SI units, symbol for the units and derivation of dimensional formula for area, volume, density, velocity, momentum, acceleration, force, impulse, work or energy and power.

Conventions followed in SI-Multiples & sub-multiples and prefixes of units.

1.2 STATICS 11 Hrs

Scalar and vector quantities – Definitions and examples – Concurrent forces and coplanar forces – Definition - Resolution of a vector into two perpendicular components- Resultant and equilibrant – Definitions- Parallelogram law of forces- statement- Expressions for magnitude and direction of the resultant of two forces acting at a point with an acute angle between them - Lami's theorem- Statement and explanation- Experimental verification of parallelogram law of forces and Lami's theorem.

Simple problems based on expressions for magnitude and direction of resultant.

Moment of a force- Clockwise and anti-clockwise moments - Principle of moments- Couple – Torque acting due to a couple – Experimental determination of mass of the given body using principle of moments.

UNIT-II

PROPERTIES OF MATTER

2.1 ELASTICITY 6 Hrs

Elastic and plastic bodies – Definition - stress, strain - Definitions – Hooke's law –statement - three types of strain– Elastic and plastic limit – Elastic behaviour of a material, stress- strain curve, elastic range, elastic limit, yield point, plastic limit and breaking point - Young's modulus, Bulk modulus, Rigidity modulus and Poisson's ratio – Definitions - Uniform and non uniform bending of beams- Explanation - Experimental determination of the Young's modulus of the material of a beam by uniform bending method.

Simple problems based on stress, strain and Young's modulus.

2.2 VISCOSITY 6 Hrs

Viscosity – Definition - Coefficient of viscosity- Definition, SI unit and dimensional formula - Stream line flow, turbulent flow-Explanation - Critical velocity –Definition- Reynolds number - Derivation of Poiseuille's formula by dimensional method- Experimental determination of coefficient of viscosity of a low viscous liquid by capillary flow method using graduated burette (Variable pressure head method)– Terminal velocity – Definition – Experimental determination of coefficient of viscosity of a high viscous liquid by Stokes' method – Practical applications of viscosity.

2.3 SURFACE TENSION 4 Hrs

Surface tension & angle of contact- Definitions - Explanation for capillary rise and dip - Expression for surface tension of a liquid by capillary rise method - Experimental determination of surface tension of water by capillary rise method – Practical applications of capillarity.

Simple problems based on expression for surface tension.

UNIT III

DYNAMICS - I

3.1 PROJECTILE MOTION 5Hrs

Projectile motion, angle of projection, trajectory, maximum height, time of flight and horizontal range – Definitions - Expressions for maximum height, time of flight and horizontal range – Condition for getting the maximum range of the projectile- Derivation of the equation to show that the trajectory of the projectile is a parabola.

Simple problems based on expressions for maximum height, time of flight and horizontal range.

3.2 CIRCULAR MOTION 5Hrs

Circular motion, angular velocity, period and frequency of revolutions– Definitions – Relation between linear velocity and angular velocity – Relation between angular velocity, period and frequency – Normal acceleration, centripetal force and centrifugal force – Definitions – Expressions for normal acceleration and centripetal force.

Simple problems based on expression for centripetal force.

3.3 APPLICATION OF CIRCULAR MOTION 3Hrs

Banking of curved paths – Angle of banking – Definition – Expression for the angle of banking of a curved path. $\{\tan\theta = v^2/(rg)\}$

Simple problems based on expression for angle of banking.

3.4 SIMPLE HARMONIC MOTION 3Hrs

Simple harmonic motion, amplitude, frequency, period and phase - Definitions – Simple harmonic motion as a projection of a uniform circular motion on any diameter.

UNIT - IV

DYNAMICS - II

4.1 ROTATIONAL MOTION OF RIGID BODIES 7Hrs

Rigid body – Definition - Moment of inertia of a particle about an axis, moment of inertia of a rigid body about an axis – expressions – Radius of gyration – Definition – Expression for the kinetic energy of a rotating rigid body about an axis – Angular momentum – Definition – Expression for the angular momentum of a rotating rigid body about an axis – Law of conservation of angular momentum – Examples.

4.2 GRAVITATION 4Hrs

Newton's laws of gravitation – Acceleration due to gravity on the surface of earth –Difference between mass and weight of a body – Expression for variation of acceleration due to gravity with altitude – Concept of weightlessness.

4.3 SATELLITES 5Hrs

Satellites – Natural and artificial – Escape velocity and orbital velocity – Definitions – Expression for escape velocity – Expressions for orbital velocity and period of revolution of a satellite around earth – Geo-stationary and polar satellites – Uses of artificial satellites.

Simple problems based on expressions for escape velocity, orbital velocity and period of revolution

UNIT V

SOUND AND MAGNETISM

5.1 SOUND 10 Hrs

Wave motion – Introduction and definition – Progressive waves, longitudinal and transverse waves – Examples and comparison –Amplitude, wave length, period and frequency of a wave – Definitions - Relation between wavelength, frequency and velocity of a wave - Stationary or standing waves.

Vibrations - Free & forced vibrations and resonance – definitions and examples –Laws of transverse vibrations of a stretched string – Sonometer – Experimental determination of frequency of a tuning fork.

Ultrasonic – Introduction – Production of ultrasonic waves by piezo-electric method – Properties and applications.

Acoustics of buildings – Reverberation, reverberation time, Sabine's formula for reverberation time (no derivation) – Coefficient of absorption of sound energy – Noise pollution – Noise control in machines.

Simple problems based on expression for frequency of vibration.

5.2 MAGNETISM 6 Hrs

Coulomb's laws of magnetism – Pole strength and unit pole – Definitions – Magnetic moment, intensity of magnetisation, magnetising field intensity, magnetic induction, permeability, hysteresis, saturation, retentivity and coercivity – Definitions - Method of drawing hysteresis loop of a specimen using a solenoid – Uses of Hysteresis loop.

SECOND SEMESTER

UNIT I

HEAT

1.1 TRANSFER OF HEAT 3 Hrs

Concept of Heat and Temperature – Centigrade, Fahrenheit and Kelvin scales of temperature measurement – Conduction, convection and radiation – Definitions and explanations – Coefficient of thermal conductivity – Definition and SI unit – Selection of good and poor thermal conductors – Properties of thermal radiation.

1.2 KINETIC THEORY OF GASES 5 Hrs

Postulates – Mean square velocity and Root Mean Square (RMS) velocity of molecules – Definitions and expressions – Expression for the pressure of a gas on the basis of postulates of kinetic theory of gases- Relation between pressure, kinetic energy and absolute temperature of the gas – Mean kinetic energy per molecule of the gas.

Simple problems based on the expression for the pressure of a gas.

1.3 SPECIFIC HEAT CAPACITY 4 Hrs

Specific heat capacity of a substance (solids and liquids) – Definition – Specific heat capacity of a gas at constant volume – Specific heat capacity of a gas at constant pressure – Ratio of specific heat capacities – Explanation for C_p greater than C_v – Derivation of Meyer's relation – calculation of Universal gas constant R from the gas equation PV = RT.

Simple problems based on Meyer's relation.

UNIT - II

THERMODYNAMICS, LIQUEFACTION OF GASES & NON- CONVENTIONAL ENERGY.

2.1 THERMODYNAMICS 5 Hrs

Zeroth law and first law of thermodynamics – Explanation - Isothermal and Adiabatic changes - Explanation – Equations for isothermal and adiabatic changes (No derivation)

Simple problems based on equations $P_1V_1 = P_2V_2$ and $P_1V_1^{\gamma} = P_2V_2^{\gamma}$

Second law of thermodynamics – Clausius statement and Kelvin's statement – Concept of Carnot's reversible engine and efficiency.

2.2 LIQUEFACTION OF GASES 3Hrs

Liquefaction, critical temperature, critical pressure and critical volume – Definitions – Principle used in cascade process – Cascade process of liquefaction of oxygen –Disadvantages of cascade process - Joule Thomson effect – Temperature of inversion – Liquefaction of air by Linde's process.

2.3 NON – CONVENTIONAL ENERGY 5Hrs

Introduction – Non-renewable and Renewable (Alternate) energy sources – Examples – Solar energy, wind energy, tidal energy, geothermal energy, Hot Dry Rocks (HDR) and bio-mass – Advantages and disadvantages of renewable energy.

UNIT III

LIGHT AND REMOTE SENSING

3.1 OPTICAL FIBRE CABLE 3 Hrs

Refraction – Laws of refraction – Refractive index of a medium / material – Definition – Fibre optics – Introduction – Phenomenon of total internal reflection – Application of total internal reflection in Optical Fibre Cable (OFC) as a wave guide – Advantages of O.F.C.

3.2 LASER 3 Hrs

LASER – Characteristics of LASER – principle of LASER – Spontaneous emission – Stimulated emission – population inversion – Production of LASER using semiconductor (GaAs) diode source – Uses of LASER.

3.3 PHOTO ELECTRIC EFFECT 3 Hrs

Photo electric effect – Introduction – Hallwachs experimental arrangement – Einstein's photoelectric equation – Laws of photoelectric emission – Photo emissive cell –Photo conductive cell - Photo voltaic cell – Applications of photo cells.

3.4 REMOTE SENSING 4 Hrs

Remote sensing – Introduction – Active and passive remote sensing – Explanation and examples – Components of remote sensing – Data acquisition, data analysis and reference data – Components of electromagnetic spectrum used in remote sensing – Microwave remote sensing – RADAR – principle and working with block diagram .

UNIT IV

ELECTRICITY

4.1 ELECTRICAL CIRCUITS 3 Hrs

Ohm's law – Laws of resistances – Resistivity and Conductivity – Definitions – Kirchoff's current and voltage laws – Condition for balancing the Wheatstone's network .

Simple problems based on expression for resistivity.

4.2 HEATING AND CHEMICAL EFFECTS OF CURRENT 3 Hrs

Joule's law of heating – Experimental determination of specific heat capacity of a liquid using Joule's calorimeter – Faraday's laws of electrolysis – Electro chemical equivalent (e.c.e) of an element – Definition – Experimental determination of e.c.e. of copper.

Simple problems based on expression for e.c.e.

4.3 MEASURING INSTRUMENTS 5 Hrs

Motion of a charged particle inside a uniform magnetic field – Expression for the force acting on a current carrying straight conductor placed in a uniform magnetic field – Fleming's Left Hand rule – Expression for the torque experienced by a rectangular current carrying coil placed inside a uniform magnetic field – Working of a moving coil galvanometer and its merits – Conversion of galvanometer into an Ammeter and Voltmeter .

Simple problems based on conversion of galvanometer into ammeter and voltmeter.

4.4 ELECTRO MAGNETIC INDUCTION 2 Hrs

Faraday's laws of electro magnetic induction – Lenz's law – Fleming's Right Hand Rule – Self induction and mutual induction.

UNIT-V

BASICS OF ELECTRONICS

5.1 CAPACITORS 3 Hrs

Capacitance of a capacitor – Definition – ' farad '– Definition – Energy stored in a capacitor – Expressions for effective capacitance when capacitors are connected in series and parallel – Applications of capacitors.

Simple problems based on expressions for effective capacitance for series and parallel connections of capacitors.

5.2 SEMI CONDUCTORS 3 Hrs

Semi conductors – Energy bands in solids – Energy band diagram of good conductors, insulators and semi conductors – Fermi Level – Intrinsic semiconductors - Concept of positive holes - Doping – Extrinsic semiconductors – P type and N type semiconductors.

5.3 DIODES AND TRANSISTORS 4 Hrs

P-N junction diode – Forward bias and reverse bias – Rectification action of diode – Working of full wave rectifier using P N junction diodes in bridge type configuration.

PNP and NPN transistors – Three different configurations – Advantages of common emitter configuration – working of NPN / PNP transistor as an amplifier in common emitter configuration.

5.4 DIGITAL ELECTRONICS 3 Hrs

Digital electronics – Introduction – Logic levels – Basic logic gates: OR, AND and NOT gates – Universal logic gates: NAND and NOR gates – Special logic gates: XOR and XNOR gates – Symbolic representation, Boolean expression and Truth table for all above logic gates – Integrated circuits – Levels of integration – SSI, MSI, LSI and VLSI.

FIRST SEMESTER

Contents

		Page No.
UNIT - 1:	**SI UNITS AND STATICS**	**1**
1.1	Units and Measurement	1
UNIT - 2:	**PROPERTIES OF MATTER**	**21**
2.1	Elasticity	21
2.2	Viscosity	29
2.3	Surface Tension	38
UNIT - 3:	**DYNAMICS – I**	**47**
3.1	Projectile Motion	47
3.2	Circular Motion	56
3.3	Application of Circular Motion	65
3.4	Simple Harmonic Motion	68
UNIT - 4:	**DYNAMICS – II**	**73**
4.1	Rotational Motion of Rigid Bodies	73
4.2	Gravitation	80
4.3	Satellites	83
UNIT - 5:	**SOUND AND MAGNETISM**	**92**
5.1	Sound	92
5.2	Magnetism	107
	MODEL QUESTION PAPERS	**118**
	PRACTICAL	**122**

SECOND SEMESTER

Contents

Page No.

UNIT - 1: HEAT 151

1.1 Transfer of Heat 151

1.2 Kinetic Theory of Gases 156

1.3 Specific Heat Capacity 162

UNIT - 2: THERMODYNAMICS, LIQUEFACTION OF GASES & NON- CONVENTIONAL ENERGY 171

2.1 Thermodynamics 171

2.2 Liquefaction of Gases 177

2.3 Non – Conventional Energy 181

UNIT - 3: LIGHT AND REMOTE SENSING 193

3.1 Optical Fibre Cable 193

3.2 Laser 198

3.3 Photo Electric Effect 203

3.4 Remote Sensing 208

UNIT - 4: ELECTRICITY 217

4.1 Electrical Circuits 217

4.2 Heating and Chemical Effects of Current 225

4.3 Measuring Instruments 232

4.4 Electro Magnetic Induction 241

UNIT - 5: BASICS OF ELECTRONICS 248

5.1 Capacitors 248

5.2 Semi Conductors 257

5.3 Diodes and Transistors 264

5.4 Digital Electronics 274

MODEL QUESTION PAPERS 292

PRACTICAL 296

SEMESTER I

UNIT – I

SI UNITS AND STATICS

1.1 UNITS AND MEASUREMENT

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 all walks of 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 the development of engineering and technology.

Measurement consists of the comparison of an unknown quantity with a known fixed quantity. The quantity used as the standard of measurement is called ‘unit’. For example, a vegetable vendor weighs the vegetables in terms of units like kilogram.

Fundamental physical quantities

Fundamental quantities are the quantities which cannot be expressed in terms of any other physical quantity.

(eg) length, mass and time.

Derived quantities

Quantities that can be expressed in terms of fundamental quantities are called derived quantities.

(eg) area, volume, density.

Unit

Unit of a physical quantity is defined as the accepted standard used for comparison of given physical quantity.

The unit in which the fundamental quantities are measured are called fundamental unit and the units used to measure derived quantities are called derived units.

SI Units

SI unit is the abbreviation for **Systeme International d' units** and is the modern form of metric system finally agreed upon at the eleventh International conference of weights and measures, 1960. This system of units is now being adopted throughout the world and will remain the primary system of units of measurement. SI system possesses features that make it logically superior to any other system.

There are seven fundamental units (base units) and two supplementary units.

SI system of units

Physical quantity	Unit	Symbol
Fundamental quantities		
1.Length	metre	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		
1. Plane angle	radian	rad
2. Solid angle	steradian	sr

Derived quantities and their units

Sl.No	Physical quantity	Formula	Unit	Symbol
1	Area of the square	side × side	metre^2 or square metre	m^2
2	Volume of the cube	side × side × side	metre^3 or cubic metre	m^3
3	Density	Mass / volume	kilogram metre^{-3}	kgm^{-3}
4	Velocity	Displacement / time	metre second^{-1}	ms^{-1}
5	Acceleration	velocity/ time	metre second^{-2}	ms^{-2}
6	Momentum	mass × velocity	Kilogram metre second^{-1}	$kgms^{-1}$

Sl.No	Physical quantity	Formula	Unit	Symbol
7	Force	mass × acceleration	newton	N
8	Impulse	force × time	newton second	Ns
9	Work (or) Energy	force × displacement	newton metre or joule	J
10	Power	Work / time	joule second^{-1} or watt	W

Dimensions

The fundamental physical quantities namely length, mass and time are symbolically represented by the capital letters L, M and T respectively.

Dimensional formula is the formula in which the given physical quantity is expressed in terms of the fundamental quantities raised to suitable powers.

Dimensional formula for derived physical quantities.

1. Area of the square = side × side

   Applying dimensions

   Area of the square = $L \times L = L^2$

   Dimensional formula for Area $= L^2$

2. Volume of the cube = side× side × side

   Applying dimensions

   Volume of the cube = $L \times L \times L = L^3$

   Dimensional formula for Volume = L^3

3. Density is the mass per unit Volume.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Applying dimensions

$$\text{Density} = \frac{M}{L^3} = ML^{-3}$$

Dimensional formula for Density = ML^{-3}

4. Velocity is the rate of change of displacement

$$\text{Velocity} = \frac{\text{displacement}}{\text{time}}$$

Applying dimensions,

$$\text{velocity} = \frac{L}{T} = LT^{-1}$$

Dimensional formula for Velocity = LT^{-1}

5. Acceleration is the rate of change of velocity

$$\text{Acceleration} = \frac{\text{velocity}}{\text{time}}$$

$$= \frac{\text{displacement}}{\text{time}} \times \frac{1}{\text{time}}$$

Applying dimensions

$$= \frac{L}{T \times T} = \frac{L}{T^2} = LT^{-2}$$

Dimensional formula for Acceleration= LT^{-2}

6. Momentum is the product of mass and velocity.

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

$$= \text{mass} \times \frac{\text{displacement}}{\text{time}}$$

Applying dimensions

$$\text{Momentum} = M \times \frac{L}{T} = MLT^{-1}$$

Dimensional formula for Momentum= MLT^{-1}

7. Force is the product of mass and acceleration.

$$\text{Force} = \text{mass} \times \text{acceleration}$$

$$= \text{mass} \times \frac{\text{velocity}}{\text{time}}$$

$$= \frac{\text{mass}}{\text{time}} \times \frac{\text{displacement}}{\text{time}}$$

Applying dimensions,

$$\text{Force} = \frac{M}{T} \times \frac{L}{T} = MLT^{-2}$$

Dimensional formula for force = MLT^{-2}

8. Impulse is the product of force and time

Impulse = force $\times$ time

= mass $\times$ acceleration $\times$ time

$$= \text{mass} \times \frac{\text{velocity}}{\text{time}} \times \text{time}$$

= mass $\times$ velocity

= mass $\times$ (Displacement/time)

Applying dimensions,

$$\text{Impulse} = \frac{M \times L}{T} = MLT^{-1}$$

Dimensional formula for Impulse= MLT^{-1}

9. Work (or) Energy is the product of force and displacement

Work or Energy = force $\times$ displacement

= mass $\times$ acceleration $\times$ displacement

$$= \text{mass} \times \frac{\text{velocity}}{\text{time}} \times \text{displacement}$$

$$= \frac{\text{mass}}{\text{time}} \times \frac{\text{displacement}}{\text{time}} \times \text{displacement}$$

Applying dimensions

$$\text{Work or energy} = M \times \frac{L}{T} \times \frac{L}{T} = ML^2T^{-2}$$

Dimensional formula for Work or Energy = ML^2T^{-2}

10. Power is the rate of doing work.

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

$$= \frac{\text{force x displacement}}{\text{time}}$$

Applying dimensions,

$$\text{Power} = MLT^{-2} \times \frac{L}{T} = ML^2T^{-3}$$

Dimensional formula for Power = ML^2T^{-3}

CONVENTIONS TO BE FOLLWED IN SI UNITS

1. When we write a unit in full, the first letter should not be in capital letter.
   (eg) metre and not as Metre
   kilogram and not as Kilogram
2. The symbols of unit in the name of scientist should be in upper case (capital) letter
   (eg) N for newton, J for joule.
3. Only the singular form of the unit is to be used.
   (eg) km and not as kms
   Kg and not as kgs
4. There should be no full stop at the end of the abbreviations.
   (eg) mm and not as mm.
   kg and not as kg.
5. When temperature is expressed in Kelvin, the degree sign is omitted.
   (eg) 273K not as 273^0K
6. Only accepted symbols should be used.
   (eg) ampere is represented as 'A' and not 'amp'
   second is represented as 's' and not 'sec'
7. Use of the solidus or slash is to be avoided, but when used, not more than one solidus be employed.
   (eg) J/k.mol or $Jk.mol^{-1}$ but not J/k/mol
   $J\ kg^{-1}K^{-1}$ but not J/kg/K
8. One letter space is always to be left between the number and the symbol of the unit.
   (eg) 2.3 m and not as 2.3m
   $Kg\ m\ s^{-2}$ and not $kg\ ms^{-2}$
9. The numerical value of any physical quantity should be expressed as $p = a \times 10^m$. Here 'a' is a number between 1 and 10 and 'm' is the appropriate power of 10.
   (eg) velocity of light $c = 2.997 \times 10^8\ m\ s^{-1}$.

Multiples and Submultiples of units

In SI, some units are not of convenient size to measure certain quantities. Hence multiples and submultiples of the base units are used in measurements.

Multiplication factor	Prefix	Symbol
1 000 000 000 000 = 10^{12}	Tera	T
1 000 000 000=10^{9}	Giga	G
1 000 000=10^{6}	Mega	M
1 000=10^{3}	Kilo	k
100=10^{2}	hecto*	h
10=10^{1}	deca*	da
0.1=10^{-1}	deci	d
0.01=10^{-2}	centi*	c
0.001=10^{-3}	milli	m
0.000 001=10^{-6}	micro	μ
0.000 000 001=10^{-9}	nano	n
0.000 000 000 001=10^{-12}	pico	p
0.000 000 000 000 001=10^{-15}	femto	f
0.000 000 000 000 000 001=10^{-18}	atto	a

*These are not preferred ones. They are used where the other prefixes are inconvenient

1.2 STATICS

Statics is the part of mechanics which deals with forces acting on bodies at rest. The weight of the body, the tension of a string, the load and the reaction are the different names of forces that are used in statics.

Any force can be represented in magnitude and direction by a straight line with an arrow head. The beginning of the line represents the point of application of the force. The arrow head represents the direction of the force. The magnitude of the force is given by the length of the line drawn to scale.

Scalar and Vector quantities

Physical quantities which have magnitude only are called scalar quantities.

(e.g) Mass, Volume, Speed

Physical quantities which have both magnitude and direction are called vector quantities.

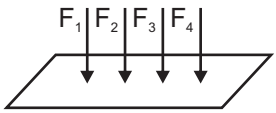
(e.g) Velocity, Momentum, Force

Concurrent forces

Two or more than two forces acting at a point are called concurrent forces.

Coplanar forces

Two or more than two forces lie on same plane are called coplanar forces.



Resultant

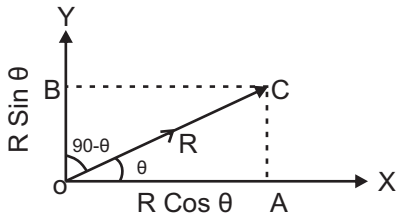
Resultant is that single force which produces the same effect as that produced by two or more forces acting on the body.

Equilibrant

Equilibrant is the single force which acting along with the other forces keeps the body in equilibrium.

Resolution of a vector into two perpendicular components

The process of splitting up a vector (force) into two perpendicular component parts is known as resolution of a vector. As the two component forces are mutually perpendicular, they are called rectangular components.



Let a force R act at a point O at an angle θ with x- axis. This force can be resolved into two rectangular components along x and y axis. Two lines CA and CB are drawn perpendicular to x and y axis as shown in the figure.

In the right angled triangle OAC,

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

$$OA = OC\cos\theta$$

$$= R\cos\theta$$

Therefore the horizontal component of the force R is R cosθ.

In the right angled triangle OBC,

$$\cos(90 - \theta) = \frac{OB}{OC}$$

$$\sin\theta = \frac{OB}{OC}$$

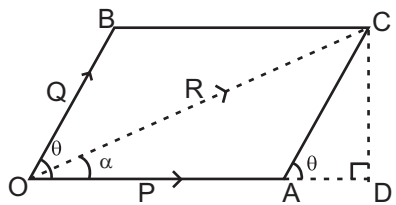
$$OB = OC\sin\theta = R\sin\theta$$

The vertical component of the force R is R sinθ.

Parallelogram law of forces

If two forces acting at a point are represented in magnitude and direction by the two adjacent sides of a parallelogram drawn from that point, their resultant is given in magnitude and direction by the diagonal of the parallelogram drawn through that point.

Expressions for the magnitude and direction of the resultant of two forces acting at a point, with an acute angle between them.



Consider two forces P and Q acting at a point O with an angle θ between them as shown in the figure. The forces P and Q are represented in magnitude and direction by the sides OA and OB of a parallelogram

OACB. The diagonal OC gives the resultant of two forces P and Q in magnitude and direction. From C draw a perpendicular to meet OA extended at D.

In the right angled triangle OCD

$$OC^2 = OD^2 + CD^2$$

$$= (OA + AD)^2 + CD^2$$

$$OC^2 = OA^2 + AD^2 + 2OA.AD + CD^2 \quad ...(1)$$

In the right angled triangle ACD

$$\cos\theta = \frac{AD}{AC} = \frac{AD}{Q}$$

$$AD = Q\cos\theta$$

$$\sin\theta = \frac{CD}{AC} = \frac{CD}{Q}$$

$$CD = Q\sin\theta.$$

Substituting AD and CD values in eqn.(1)

$$R^2 = P^2 + Q^2\cos^2\theta + 2PQ\cos\theta + Q^2\sin^2\theta$$

$$R^2 = P^2 + Q^2(\cos^2\theta + \sin^2\theta) + 2PQ\cos\theta$$

$$R^2 = P^2 + Q^2 + 2PQ\cos\theta \quad \text{where } \cos^2\theta + \sin^2\theta = 1$$

$$\text{Resultant, } R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

This is the expression for the magnitude of the resultant.

Let α be the angle between the resultant R and the force P.

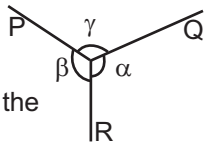
$$\tan\alpha = \frac{CD}{OD} = \frac{CD}{OA + AD} = \frac{Q\sin\theta}{P + Q\cos\theta}$$

$$\text{Direction, } \alpha = \tan^{-1}\left[\frac{(Q\ \sin\theta)}{(P + Q\cos\theta)}\right]$$

In the right angled triangle COD,

This is the expression for the direction of the resultant.

Lami's theorem



If three forces acting at a point are in equilibrium, then each force is directly of proportional to the sine of the angle between the other two forces.

Let P, Q and R be three forces acting at a point O. Under the action of three forces, the point is at rest. Let α, β and γ be the angles opposite to the forces P, Q and R respectively.

By Lami's theorem

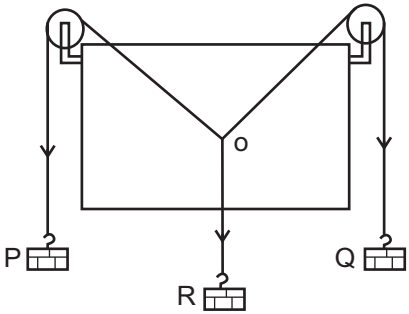
$$P \propto \sin\alpha \Rightarrow P = K\sin\alpha \Rightarrow \frac{P}{\sin\alpha} = K$$

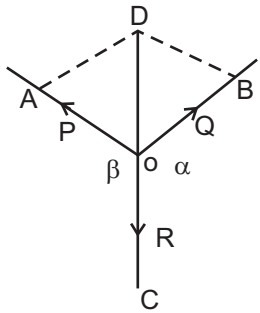
$$Q \propto \sin\beta \Rightarrow Q = K\sin\beta \Rightarrow \frac{Q}{\sin\beta} = K$$

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

$$\therefore \frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma} = \text{constant}$$

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. A light and inextensible string is passed over these pulleys. Another short string is tied to the first string at O. Weight hangers P, Q and R are tied at the ends of the strings as shown in the figure. The weights P, Q and R are adjusted suitably such that the point O is at rest.

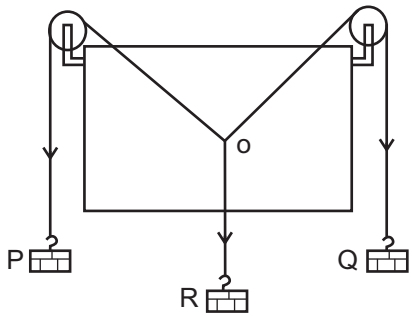
A white paper is held just behind the string without touching them. The point O and the directions of the strings are marked on the paper. Then the paper is removed from the board. With suitable scale the points A, B and C are marked. OA, OB and OC represent the forces P, Q and R respectively.

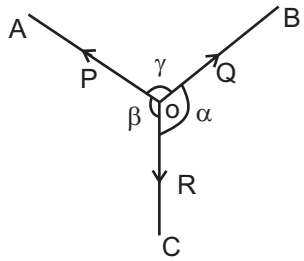
The parallelogram OADB is drawn. Then the diagonal OD is drawn. The length of the diagonal OD and ∠COD are measured and tabulated.

Sl. No	P	Q	R	OA	OB	OC	OD	∠COD

The experiment is repeated for different values of P, Q and R. It is found that OC = OD and ∠COD = 180º. Thus the parallelogram law of forces is verified experimentally.

Experimental verification of Lami's theorem





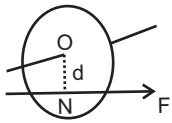
A drawing board is fixed vertically on the wall. Two frictionless pulleys are fixed at the top corners of the drawing board. A light and inextensible string is passed over these pulleys. Another short string is tied to the first string at O. Weight hangers P, Q and R are tied at the ends of the strings as shown in the figure. The weights P, Q and R are adjusted suitably such that the point O is at rest.

A white paper is held just behind the string without touching them. The point O and the directions of the forces P, Q and R 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 P, Q and R respectively. The angles are measured with the help of protractor and tabulated.

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

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.

Moment of a force



Consider a body which is fixed at a point, 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.

It is common experience that in opening or closing a door, the force we apply rotates the door about its hinges. This rotating effect is known as the moment of force.

Moment of force is also 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.

Moment of force about the point O = Force × perpendicular distance of the force from the point O

$= F \times ON$

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

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.

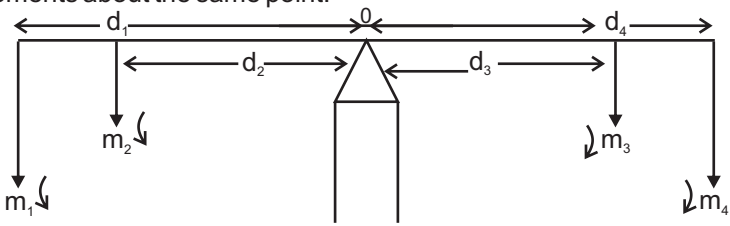
If the moment of a force turns or rotates the body in anti-clockwise direction, then it is called anti-clockwise moment.

Clockwise moment= $m_2 \times d_2$

Anti-clockwise moment = $m_1 \times d_1$

Principle of moments

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.



According to the principle of moments,

Sum of anti-clockwise moments = sum of clockwise moments

From figure,

$m_1d_1 + m_2d_2 = m_3d_3 + m_4d_4$.

Couple:

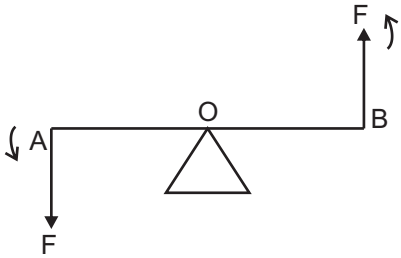
Two equal and opposite parallel forces acting at different points in a body constitute a couple. A body acted upon by the couple will rotate the body in clockwise direction or anti-clockwise direction.

Steering wheel and pedals of bicycles are the examples for couple, where the two forces are equal but acting in opposite direction.

Torque acting due to couple (or) Moment of couple

Torque is calculated by the product of either of forces forming the couple and the arm of the couple.

i.e.) Torque = one of the force × perpendicular distance between the forces.

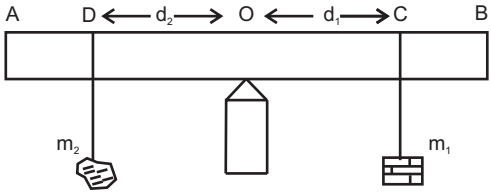


Consider two equal forces F and F acting on the arm AB. Let O be the mid point of the arm .The forces F and F are acting in opposite direction as shown in the figure, they constitute a couple. Then

Moment of couple or torque = $F \times AB$.

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.) $\theta=90^o$.

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



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

According to the principle of moments

$m_2 \times d_2 = m_1 \times d_1$

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.

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

Mean=

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

WORKED EXAMPLES

1. Find the magnitude and direction of the two forces 20N and 25N acting at an angle 60º to each other.

Given

$P = 20N$

$Q = 25N$

$\theta = 60^o$

$$\text{Resultant } R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

$$= \sqrt{20^2 + 25^2 + 2x20x25\cos 60}$$

$$= \sqrt{1525}$$

$R = 39.05N$

$$\text{Direction } \alpha = \tan^{-1}\left[\frac{Q\sin\theta}{P + Q\cos\theta}\right]$$

$$\alpha = \tan^{-1}\left[\frac{25 \text{ x } \sin 60^\circ}{20 + 25\cos 60^\circ}\right]$$

$\alpha = \tan^{-1}(0.6661)$

$\alpha = 33^o40'$

2. Find the magnitude and direction of the resultant of two forces 30N and 40N acting at right angles to each other.

Given

$P = 30N$

$Q = 40N \qquad \theta = 90^\circ$

$$\text{Resultant } R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

$$= \sqrt{30^2 + 40^2 + 2 \times 30 \times 40 \times \cos 90}$$

$$= \sqrt{2500}$$

$R = 50N$

$$\text{Direction } \alpha = \tan^{-1}\left[\frac{(40 \times \sin 90)}{(30 + 40\cos 90)}\right]$$

$= \tan^{-1}(1.333)$

$\alpha = 53^o7'$

3. If the resultant of two equal force is $\sqrt{3}$ times a single force, find the angle between the forces.

Given

Two forces are equal

$$P = Q = P$$

$$R = \sqrt{3}\ P$$

$$R^2 = P^2 + Q^2 + 2PQ\cos\theta$$

$$(3P)^2 = P^2 + P^2 + 2.P.P.\cos\theta$$

$$3P^2 - 2P^2 = 2P^2\cos\theta$$

$$P^2 = 2P^2\cos\theta$$

$$\cos\theta = ½$$

$$\therefore\ \theta = 60^o$$

Angle between the forces is 60°

4. If the resultant of two equal forces inclined to each other at 60° is $8\sqrt{3}$ N, find the component forces.

Given

Two forces are equal.

$$P = Q = P$$

$$R = 8\sqrt{3}\ N$$

$$\theta = 60^o$$

$$R^2 = P^2 + Q^2 + 2PQ\cos\theta$$

$$(8\sqrt{3})^2 = P^2 + P^2 + 2.P.P\cos 60^o$$

$$192 = 2P^2 + 2P^2.½$$

$$192 = 3P^2$$

$$64 = P^2$$

$$P = 8N$$

Component force is 8N

5. The sum of two forces is 8N and the magnitude of the resultant is at right angles to the smaller force 4N. Find the forces and the inclination between them.

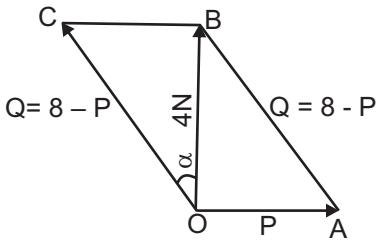
Given

Sum of the two forces = 8 N

Resultant of 2 forces = 4 N

Let the smaller force be P

Larger force Q = (8–P)



In the right angled triangle OAB,

$$AB^2 = OA^2 + OB^2$$

$$(8 - P)^2 = P^2 + 4^2$$

$$64 - 16P + P^2 = P^2 + 16$$

$$16P = 48$$

$$P = 3N$$

Therefore the larger force Q = 8–3

$$Q = 5N$$

In triangle OCB,

$$\tan\alpha = \frac{BC}{OB} = \frac{P}{4} = \frac{3}{4} = 0.75$$

$$\alpha = \tan\text{-}1(0.75)$$

$$\alpha = 36^o52'$$

Angle between the forces P and Q

$$90 + \alpha = 90 + 36^o52'$$

$$= 126^o52'$$

QUESTIONS

Part A

1. Define unit of a physical quantity.
2. What are the fundamental quantities?
3. Give two examples for fundamental quantities.
4. What are the derived quantities?
5. Give two examples for derived quantities.
6. Expand SI .
7. What are the supplementary quantities and their SI units?
8. Write the SI units for plane and solid angles.
9. What are the units for momentum and force?
10. What are the units for impulse and work?
11. What are the units for energy and power?
12. Derive the dimensional formula for impulse.
13. Derive the dimensional formula for work or energy.
14. Derive the dimensional formula for power.
15. Derive the dimensional formula for force.
16. Define scalar quantity.
17. Define vector quantity.
18. Give two examples for scalar quantities.
19. Give two examples for vector quantities.
20. What is resultant?
21. What is equilibrant?
22. Write the parallelogram law of forces.
23. Write the Lami's theorem.
24. Write any two conventions followed in SI.
25. Define concurrent forces.
26. Define coplanar forces.
27. Define moment of a force.
28. Write the principle of moments.
29. Define couple.
30. Define moment of a couple.
31. Define clockwise moment.
32. Define anticlockwise moment.

Part- B

1. Derive dimensional formula for impulse, work and power.
2. Give the rules and conventions followed while writing SI units.
3. Explain how a vector can be resolved into two rectangular components.
4. Derive expressions for the magnitude and direction of the resultant of two forces acting at a point with an acute angle between them.
5. Describe an experiment to verify the parallelogram law of forces.
6. Describe an experiment to verify Lami's theorem.
7. Describe an experiment to determine the mass of the given body using principle of moments.

Exercise Problems

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

   (Ans: R =7N, α = 21º47')

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

   (Ans: R= 6.149N, α =15º8')

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

   (Ans: R= 6.767N, α =17º19')

4 Two forces of magnitude 4N and 3N respectively, act on a particle at right angles to each other. Find the magnitude and direction of the resultant of two forces.

   (Ans: R= 5N, α =36º52')

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

   (Ans: θ=90º)

6. If the resultant of two equal forces inclined to each other at 60º is 8.660 N, find the component force.

   (Ans:5N)

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

   (Ans: 62º43')

8. The sum of two forces inclined to each other at an angle is 18N and their resultant which is perpendicular to the smaller force is 12N. Find the forces and angle between them.

   (Ans: P= 5N,Q=13N,θ =112º36')

UNIT - II

PROPERTIES OF MATTER

2.1 ELASTICITY

Introduction

When an external force is applied on a body, which is not free to move, the shape and size of the body change. The force applied is called deforming force. When the deforming forces are removed, the body tends to regain its original shape and size due to a force developed within the body. The force developed within the body, which is equal and opposite to deforming force is called restoring force.

Bodies, which completely regain their original size and shape after the removal of the deforming force, are called elastic bodies. Bodies which change the shape and size on the application of force and which do not regain their original condition on removal of the deforming forces are said to be plastic bodies. Bodies which do not change their shape and size on application of force are called rigid bodies.

The property by virtue of which a body tends to regain its original shape and size after removal of the deforming force is known as elasticity.

Stress :

When an external force is acting on an elastic body, it causes deformation (change in shape or in size or both). At the same time, due to elastic property, a force is developed within the material, which is equal and opposite to the applied force, to bring the body to its original shape and size. This force is 'restoring force'.

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

The stress is defined as the restoring force acting on unit area.

Since the applied force and the restoring force are equal in magnitude, the 'stress' is measured as the applied force acting per unit area.

The unit for stress is newton metre^{-2} with symbol N m^{-2} or 'pascal' with symbol 'Pa'.

When the applied force tends to compress the body, the stress is compressive. When it tends to increase the length in the direction of the force, it is tensile and when it acts parallel to the surface of a body, the stress is tangential stress.

Hooke's law:

Within the elastic limits, the strain produced in a body is directly proportional to the stress which causes it.

i.e., strain $\propto$ stress

or stress $\propto$ strain

stress = (constant) strain

This constant is called 'modulus of elasticity'.

Types of strains:

$$\therefore \frac{\text{stress}}{\text{strain}} = \text{a constant}$$

(1) Linear Strain:

When a wire or bar is subjected to two equal and opposite forces, namely pulls, at its ends, there is an increase in the length. If the forces are tensile, the body is elongated. If the forces are compressive, the length is shortened in the direction of the forces. This is called the 'linear strain'.

The linear strain is defined as the ratio of change in length to the original length. If the change (increase or decrease) in length is ' l ' in a wire or bar of original length L,

As the linear strain is ratio of lengths, it has no unit.

$$\text{linear strain} = \frac{\text{Change in length}}{\text{orignal length}} = \frac{l}{L}$$

(2) Bulk (or) Volume Strain:

When a force is applied uniformly and normally to the entire surface of the body, there is a change in volume of the body, without any change in its shape. This strain is called 'bulk or volume strain'.

Volume strain is defined as the ratio of change in volume to the original volume. It has also no unit. If 'v' is the change in volume produced in a body of original volume ‘V’,

$$\text{bulk or volume strain} = \frac{\text{Change in volume}}{\text{orignal volume}} = \frac{v}{V}$$

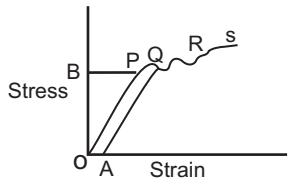
(3) Shearing (or) Rigidity strain:

When a force is applied parallel to one face of a body, the opposite side being fixed, there is a change in shape but not in size of the body. This strain is called the shearing strain.

Solids alone can have a shearing strain. It is measured by the angle of the shear 'θ' in radian.

Elastic behaviour of a material-stress strain curve:

Let a wire be suspended from a rigid support. At the free end, a weight hanger is provided on which weights could be added to study the behaviour of the wire under different load conditions. The extension of the wire is measured for various load and stress – strain graph is drawn as shown in the diagram below.



The region OP is linear. Within a normal stress, strain is proportional to the applied stress. This is Hooke's law. Up to P when the load is removed the wire regains its original length along PO. The point P represents the elastic limit, PO represents the elastic range of the material and OB is the elastic strength.

Beyond P, the graph is not linear. In the region PQ the material is partly elastic and partly plastic. From Q, if we start decreasing the load, the graph does not come to O via P, but traces a straight line QA. Thus a permanent strain OA is caused in the wire. This is called permanent set.

Beyond Q addition of even a very small load causes enormous strain. This point Q is called the yield point. The region QR is the plastic range.

Beyond R, the wire loses its shape and becomes thinner and thinner in diameter and ultimately breaks, say at S. Therefore S is the breaking point. The stress corresponding to S is called breaking stress.

Three modulii of elasticity

There are three types of modulii depending upon the three kinds of strain.

(a) *Young's modulus (E):*

It is defined as the ratio of linear stress to linear strain.

Let a wire of initial length L and cross-sectional area ' A', undergo an extension *l*, when a stretching force 'F', is applied in the direction of its length.

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

$$\text{i.e., Young's modulus (E)} = \frac{\text{Linear stress}}{\text{Linear strain}}$$

$$\text{Then, longitudinal or linear stress} = \frac{F}{A}$$

$$\text{and longitudinal strain} = \frac{l}{L}$$

$$E = \frac{\text{Linear stress}}{\text{Linear strain}} = \frac{F/A}{l/L} = \frac{F.L}{A.l}$$

The unit for Young's modulus is newton metre^{-2} with symbol N m^{-2}. The single term unit which is widely used for Young's modulus is 'pascal' with symbol 'Pa'.

(b) *Bulk (or) Volume modulus (k):*

It is defined as the ratio of bulk stress to bulk strain.

When a body is subjected to a uniform compressive force, its volume decreases and the strain produced is a bulk or volume strain.

If 'v' is the change in volume and V is the original volume, then

If F is the total compressive force acting on a total area A, then bulk stress = F/A = P

$$\text{Bulk modulus (k)} = \frac{\text{Bulk stress}}{\text{Bulk strain}}$$

If P is the stress applied i.e. (force/unit area) then,

$$\text{bulk strain} = \frac{v}{V}$$

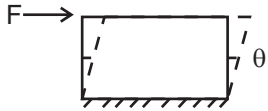
$$\text{bulk modulus } k = \frac{P}{v/V} = \frac{P.V}{v}$$

The unit for bulk modulus is 'newton metre^{-2}' with symbol N m^{-2}. The single term unit which is widely used for bulk modulus is 'pascal' with symbol 'Pa'.

(c) *Shearing (or) Rigidity modulus 'n':*

The ratio of the shearing stress applied to the body to the shearing strain produced is called the rigidity modulus and denoted by the letter 'n'.

If T is the tangential force/unit area and if θ is the angle of shear measured in radian, then



$$\text{rigidity modulus } n = \frac{T}{\theta} = \frac{F}{A\theta}$$

The unit for rigidity modulus is 'newton metre^{-2} radian^{-1}' with symbol N m^{-2} rad^{-1}. The other unit which is widely used for rigidity modulus is 'pascal radian $^{-1}$' with symbol 'Pa rad^{-1}'.

Poisson's ratio: σ

When a tensile stress is applied to a wire, the wire undergoes not only an extension of length in the direction of the force but also a contraction in its thickness. The ratio of decrease in thickness to the original thickness in lateral direction is known as lateral contraction.

The ratio of lateral contraction to linear elongation is called Poisson's ratio.

$$\text{Poisson's ratio } \sigma = \frac{\text{Lateral contraction}}{\text{Linear elongation}}$$

Bending of beams:

A beam is a body having uniform cross section, the length of which is very large compared to its thickness. When such a beam is fixed at one end and loaded at the other end, it is called a cantilever.

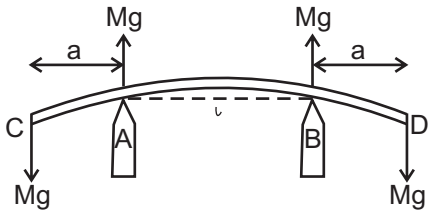
A beam is supported symmetrically on two knife edges A and B at the same level. It is loaded symmetrically with two equal weights W, W, beyond the knife edges, at C and D, so that AC=BD=a. Now the beam is

elevated at the centre. This type of bending is called uniform bending of beam.

A beam is supported symmetrically on two knife edges A and B near its ends in a horizontal level. A weight hanger W is suspended by means of a loop of thread from a point which is exactly midway between the two knife edges. Now the beam is depressed at the centre. This type of bending is called non-uniform bending of beam.

Experiment to determine the Young's modulus of the material of a beam by uniform bending method:

The given bar is supported symmetrically on two knife edges in a horizontal level, so that a quarter of the bar projects beyond each knife edge. Two weight hangers are suspended from two loops of string tightly attached at distances about 5 cm from each end so that their distances from the knife edges are equal. A pin is fixed vertically at the midpoint of the bar. A traveling microscope is focused on the pin such that the horizontal crosswire coincides with the tip of the pin. The reading in the



vertical scale of the microscope is noted. Weights are added in steps of M kg and the corresponding readings of the image of the pin in the microscope are noted. Similarly readings are taken while unloading and tabulated.

The mean elevation y is found for a load of M kg. The distance 'l' between the knife edges is measured. The distance 'a' between the point of suspension of the weight and the nearest knife edge is also measured. The breadth 'b' of the bar found accurately with the vernier calipers and its thickness d is found with a screw gauge. Young's modulus is calculated using the formula.

$$E = \frac{3Mgal^2}{2bd^3y} \qquad Nm^{-2}$$

Load in Kg	Microscope reading			Elevation y For M kg
	Load increasing	Load decreasing	Mean	
x				
x + M				
x+2M				
x+3M				

Worked examples

1. A load of 5 kg is attached to the free end of a wire of length 2 m and diameter 0.6 mm. If the extension of the wire is 0.2 mm, calculate the Young's modulus of the material of the wire. ($g = 9.8\ ms^{-2}$)

   Length of the wire L = 2 m

   Extension of the wire l = 0.2 mm = 0.2×10^{-3} m

   Force acting of the wire F = 5kgf = 5 x 9.8 N

   Diameter of the wire d = 0. 6 mm = 0.6×10^{-3} m

   Radius of the wire =0.3×10^{-3} m

   Area of cross section of the wire $a = \pi r^2 = \pi (3 \times 10^{-4})^2\ m^2$

   Young's modulus = Linear stress/Linear strain

$$\text{Linear stress} \frac{F}{A} = \frac{5 \times 9.8}{\pi(3 \times 10^{-4})^2} = 1.734 \times 10^8\ Nm^{-2}$$

$$\text{Linear strain} \frac{l}{L} = \frac{2 \times 10^{-4}}{2} = 1 \times 10^{-4}$$

$$= \frac{1.734 \times 10^8}{1 \times 10^{-4}} = 1.734 \times 10^{12} Nm^{-2}$$

2. A copper wire of 3 m length and 1 mm diameter is subjected to a tension of 5 kg wt. Calculate the elongation produced in the wire, if Young's modulus of elasticity of copper is 120 G Pa.

$$\text{Young's modulus } E = \frac{F/A}{l/L}$$

$$E = \frac{FL}{Al}$$

$$\text{Elongation produced } l = \frac{FL}{AE}$$

$$= \frac{MgL}{\pi r^2 \times E} = \frac{5x9.8x3}{3.14(0.5x10^{-3})^2 x120x10^9}$$

$$1.562 \text{ x } 10^{-3} \text{m}$$

3. What is the force required to a steel wire to double its length when its area of cross-section is one sq. cm and Young's modulus is 200 G Pa. As the length of the wire is doubled, the change in length is equal to its original length.

$$\text{The young's modulus } E = \frac{FL}{Al}$$

$$F = \frac{EAl}{L}$$

$$= \frac{EAL}{L}$$

If L is the original length, then l= L

$$F = EA$$

$$= 200 \text{ x } 10^9 \text{ x } 10^{-4}$$

$$= 2 \text{ x } 10^7 \text{ N}$$

2.2 VISCOSITY

Let us consider a liquid flowing over a horizontal surface. The layer in contact with the surface is at rest. The top most layer have the maximum velocity. The intermediate layers have intermediate velocity. To maintain this relative motion of the layers, an external force must be acting on the liquid. Otherwise the liquid will come to rest due to internal frictional forces acting between the layers of the liquid. These internal frictional forces that bring the liquid to rest are known as viscous force and this property is known as viscosity.

The property by virtue of which the relative motion between the layers of a liquid is maintained is called viscosity. We can also say viscosity is the resistance to flow.

Coefficient of viscosity of a liquid

Let F be the viscous force acting between two layers of a liquid separated by a distance dx. Let dv be the difference in velocity between the two layers. Let A be the area of the layers. The velocity gradient dv/dx acts perpendicular to direction of flow of the liquid.

The viscous force F is found to be directly proportional to

i. the area of the layers 'A'

ii. the velocity gradient $\frac{dv}{dx}$

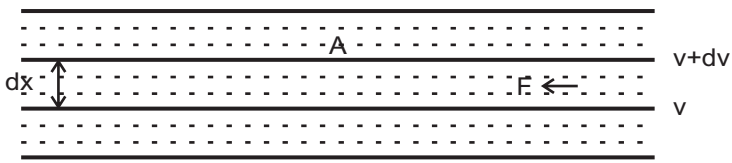
$$F \alpha \frac{Adv}{dx}$$

$$F = \frac{\eta Adv}{dx}$$

If $A = 1$ and $\frac{dv}{dx} = 1$, then $F = \eta$

Where η is constant, called Coefficient of viscosity of the liquid

Coefficient of viscosity of a liquid is defined as the viscous force acting between two layers of a liquid having unit area of layers and unit velocity gradient normal to the direction of flow of the liquid.



SI unit of η:

$\eta = \frac{F}{A\ dv/dx}$ Substituting the respective units of the quantities on the R.H.S,

The unit of coefficient of viscosity $\eta = \frac{N}{m^2.ms^{-1}/m}$

$= Nsm^{-2}$

Dimensional formula of η:

$$\eta = \frac{F}{A\ dv/dx}$$ Substituting the respective dimentional formula of the quantities on the R.H.S,

The dimensional formula of coefficient of viscosity $\eta = \frac{MLT^{-2}}{L^2.LT^{-1}/L}$

$= ML^{-1}T^{-1}$

Stream line flow (laminar flow) and turbulent flow:

To maintain the flow of a liquid through a tube, some pressure should be given at one end of the tube to overcome the viscous drag. For a given external pressure, the velocity of flow depends on the coefficient of viscosity. At low pressure the velocity is less than a certain velocity called the critical velocity and the liquid flows in an orderly manner and the flow is called steady flow or streamline flow.

In stream line flow,

1. The liquid particles flow in an orderly manner. i.e., the liquid particles flow along straight lines, each line is called the line of flow.
2. The lines of flow are parallel to the axis of the tube.
3. The velocity of all particles in a line of flow is a constant.
4. The velocity of flow is always less than the critical velocity.
5. Stream line flow will happen only when the driving pressure is small.
6. The flow of water through a capillary tube at the rate of 5 to 6 drops per minute is an example for stream line flow.

When the external pressure causing the flow of the liquid is high, the flow of the liquid is said to be turbulent.

In turbulent flow,

1. There is no orderliness in the flow of liquid.
2. The liquid particles will not flow along straight lines, but will flow in curved paths in a zig-zag manner.
3. The different particles of the liquid will flow in different directions with different velocities.
4. The velocity of flow is always greater than the critical velocity.

5. Turbulent flow will happen when the driving pressure is high.
6. The flow of water from a tap is an example for turbulent flow.

Distinction between streamline motion and turbulent motion

Critical velocity:

When the external pressure driving the flow of liquid increases slowly, the velocity of flow of liquid will also increase gradually. At a particular velocity the flow of liquid will change from laminar flow to turbulent flow. This velocity is called critical velocity.

Sl. No.	Stream line motion	Turbulent motion
1	Flow of liquid is orderly.	Flow of liquid is zigzag and random.
2	At any point along a straight line parallel to the axis of the tube, velocity is constant	Velocity varies along the straight line parallel to the axis of the tube.
3	Velocity is proportional to the pressure	Velocity is proportional to the square root of pressure
4	Velocity will always be less than critical velocity	Velocity will always be greater than critical velocity

The critical velocity is defined as the velocity at which the streamline flow ceases out and the turbulent flow sets in.

Reynolds number:

Reynolds number is a pure number, which determines the type of flow of a liquid, whether a streamline flow or a turbulent flow through a cylindrical pipe. It has no units and dimensions. It is given by the expression

$$R = \frac{V \rho D}{\eta}$$

where V is velocity of the liquid, ρ is the density of the liquid, η is the coefficient of viscosity of the liquid and D is the diameter of the pipe. This equation is applicable only for liquids flowing through cylindrical pipe.

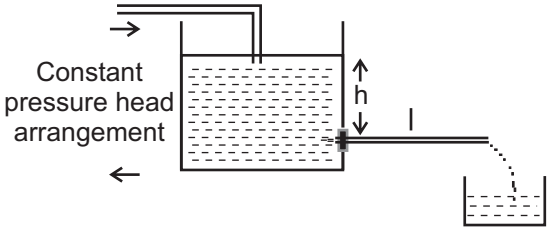
Experiments show that the flow of a viscous liquid is laminar or streamlined, if Reynolds number is less than 2000. The flow of a viscous

liquid is turbulent if Reynolds number is more than 2800. Between 2000 and 2800 there is a transition region in which the flow may change from streamline to turbulent.

Narrow tubes and highly viscous liquids tend to promote streamline motion, while wider tubes and liquids of low viscosity leads to turbulence.

Poiseuille's formula:

Consider a capillary tube of length 'l' and radius 'r' fixed horizontally



to a side of a vessel. Let a liquid be filled in the vessel. The level of the liquid is maintained constant by constant pressure head arrangement. Let 'h' be the height of the liquid and P be the pressure at the capillary tube. Let 'η' be the coefficient of viscosity of the liquid and 'ρ' be the density of the liquid.

When the liquid is in streamline flow, it is found that, the volume of liquid flowing per second 'v'

Is proportional to

i) some power of pressure gradient $(P/l)^x$

ii) some power of radius of the capillary tube $(r)^y$

iii) some power of coefficient of viscosity of the liquid $(\eta)^z$

i.e $v \propto (P/l)^x (r)^y (\eta)^z$

$$v = K(P/l)^x (r)^y (\eta)^z \qquad ...(1)$$

Where K is a constant.

Substituting the respective dimensional formula of the quantities in the equation 1

$$L^3T^{-1} = [ML^{-1}T^{-2}/L]^x L^y [ML^{-1}T^{-1}]^z$$

$$L^3T^{-1} = M^{x+z} L^{-2x+y-z} T^{-2x-z}$$

Equating the powers of like terms, we get

x+z=0

-2x+y-z=3

-2x-z=-1

Solving the above equations,

x=1, y=4, z=-1

Substituting these values in equation (1)

$v=KPr^4 / (l\ \eta)$

The value of K is found to be π/8 by experiments,

$$v = \frac{\pi P r^4}{8 l \eta} \quad \text{(or)} \quad \eta = \frac{\pi P r^4}{8 l v} = \frac{\pi h \rho g r^4}{8 l v}$$

Experiment to determine coefficient of viscosity of a low viscous liquid- Capillary flow method.

Aim:

To determine the coefficient of viscosity of water by capillary flow method, using graduated burette without stopper.

Formula:

The coefficient of viscosity of the water

$$\eta = \frac{\pi \rho g r^4 Ht}{8 / v}$$

where

ρ = density of water

g = acceleration due to gravity

r = radius of the capillary tube

l = length of the capillary tube

v = volume of water comes out of the capillary flow (5 cc)

t = time taken for 5 cc flow of water

H = the average pressure head height of the liquid levels from the capillary tube.

$$= \frac{h_1 + h_2}{2} - h_3$$

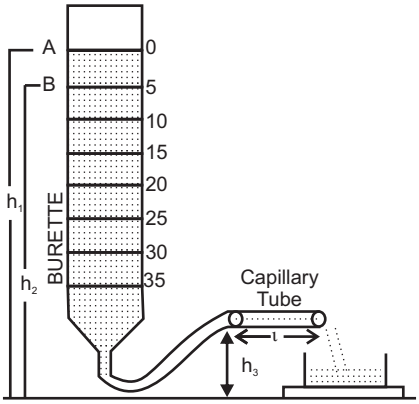
h1 = height of initial level from the experimental table

h2 = height of final level from the experimental table

h3 = height of the axis of capillary tube from the table

Description:

The graduated burette without stopper is mounted vertically in the stand. A rubber tube is connected to the bottom of the burette. To the other end of the tube, a capillary tube is inserted and placed in a perfectly horizontal position.



Procedure:

The pure water is poured into the burette using a funnel. The height of the liquid level in the burette is adjusted such that there is a streamline flow of water through the capillary tube i.e. 5 to 8 drops per minute. This can be achieved by raising or lowering the capillary tube. When the water level in the burette comes to zero mark a stop watch is started and the time for the water level to reach 5 cc, 10 cc, 15 cc, 20 cc and 25 cc mark is noted and entered in the tabular column.

From the above readings, the time of flow of water (t) 5 cc, at various ranges like 0 cc to 5 cc, 5 cc to 10 cc, 10 cc to 15 cc, 15 cc to 20 cc and 20 cc to 25 cc are tabulated. In each case the heights of the respective initial levels and final levels from the experimental table are noted. The average pressure head height is calculated and entered in the tabular column. Substituting the average value of Ht values in the formula given, the coefficient of viscosity of water is calculated.

Tabular column:

Height of the axis of cap. tube from the table h_3 = m

Sl. No	Initial water level	Final Water level	Height of Initial level h_1	Height of final Level h_2	Ave. Pr. Head height $H = \frac{h_1 + h_2}{2} - h_3$	Time Of Flow t	H.t
	cc	cc	m	m	m	s	ms

Mean

Terminal velocity

When a small metallic sphere is gently placed on the surface of a highly viscous liquid it descends down with an acceleration. As its velocity increases, the viscous force opposing the motion of the sphere also increases.

At some stage the apparent weight of the sphere becomes equal to the force due to viscous drag. So the resultant force on the sphere is zero. Therefore the sphere moves down with a constant velocity known as terminal velocity.

Terminal velocity is that velocity at which the apparent weight of the sphere is equal to the viscous force acting on the sphere moving in a high viscous liquid.

Experimental determination of the coefficient of viscosity of a high viscous liquid by Stokes' method:

Aim:

To determine the coefficient of viscosity of highly viscous liquid (Castor oil) by Stokes' method.

Formula:

The coefficient of viscosity of the highly viscous liquid

$$\eta = \frac{2}{9}\frac{(\rho-\sigma)g\left(r^2 t\right)}{h}$$

where

ρ = the density of the material of the solid sphere (glass beads)

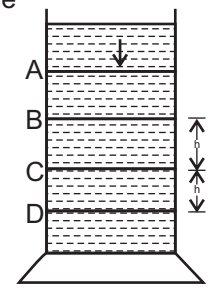
σ = the density of the liquid (castor oil)

g = the acceleration due to gravity

r = the radius of the glass beads

t = the time taken by the solid sphere to travel the marked distance h, inside the high viscous liquid.

h = the distance between the marks B and C



Description:

The pure, transparent, highly viscous liquid (castor oil) is taken in the tall glass jar. On the outer surface of the jar, two markings B and C or C and D are made at a distance of say 50 cm. The marking B should be well below the free surface of the liquid. Then only the sphere can attain terminal velocity when travelling from B to C or C to D.

Procedure:

First the least count, zero error and zero correction of screw gauge are determined. Then using the screw gauge, the diameters of the given glass beads are measured. The radii of the beads are calculated. Values of ρ and σ are taken from standard tables.

The sphere is placed gently on the surface of the highly viscous liquid and dropped. When it crosses the marking B, a stop clock is started and when it crosses the marking C, the clock is stopped. The time taken (t) to travel by the sphere from B to C is recorded in the tabular column. The distance between B and C is noted as 'h'. The same procedure is repeated for all the given spheres. Then the coefficient of viscosity of highly viscous liquid (castor oil) is calculated, using the formula.

Tabular column:

To find r^2t

Glass beads	Radius (r)	Radius^2 (r^2)	Time taken (t)	r^2t
Unit	mm	mm^2	s	mm^2s
Bead 1				
Bead 2				
Bead 3				

The average of r^2t = mm^2s

= $\times 10^{-6}\ m^2s$

Applications of viscosity

To reduce friction between the two moving surfaces which are in contact, a drop or two of some oil is introduced between the two contact surfaces. The oil enters into the depressions in the contact surfaces and form a thin layer so that direct contact between the surfaces is prevented. Now, the viscous force of the oil in between the surfaces (lubricant) reduces the friction between the two moving surfaces because the fluid friction is always less than the friction between the solid surfaces. However a good viscous lubricant can only reduce friction, but cannot completely eliminate the friction.

Generally, for high speeds and low pressures, highly viscous oils such as Mobil oil, grease, etc. are used. For low speeds, oils of lower viscosity are used. It may be interesting to note that air also acts as a sort of lubricant in reducing friction. The friction between two metallic surfaces in vacuum is found to be greater than that in air.

2.3 SURFACE TENSION

Introduction

The free surface of a liquid at rest behaves like a stretched elastic membrane with a tendency to contract in area. The following simple experiments will illustrate this property.

1. When a camel hairbrush is dipped into water, the hairs remain spread out. When the brush is taken out, the hairs cling together on account of the films of water between them contracting.

2. A film of the soap solution is formed in a wire ring. If a wetted loop of thread is gently placed on the film, the film is unaffected and the thread remains in any form in which it is placed on the film. But if the film is pricked inside the loop, the film outside contracts on all sides and hence the circular loop is formed. The area of the film is reduced to a minimum.

The above examples show that a force acts on the surface of liquid to reduce the surface area to a minimum. This force is known as surface tension.

A water drop takes the spherical shape because for a given volume, sphere has the minimum surface area. This is due to surface tension.

Surface tension

Surface tension is the force acting on unit length of an imaginary line drawn on the free surface of a liquid, the force acting normal to the line and parallel to the surface. The unit of surface tension is Nm^{-1} and its dimension is MT^{-2}

Angle of contact

The angle of contact is the angle by which the tangent drawn to the liquid surface at the point of contact with the solid, makes with the surface of the solid, the angle being measured within the liquid.

For liquids like water and kerosene which spread on glass, the angle of contact $\theta = 0°$. In the case of mercury and clean glass, the angle of contact $\theta = 137°$. For ordinary water and glass, the angle of contact $\theta = 8°$.

When a glass rod is dipped vertically in water, which wets the glass, the water is drawn up around the glass rod at all points of contact. Here, the angle of contact is acute. When a glass rod is dipped vertically in mercury, which does not wet the glass, the liquid is depressed around the glass rod at all points of contact. Here, the angle of contact is obtuse.

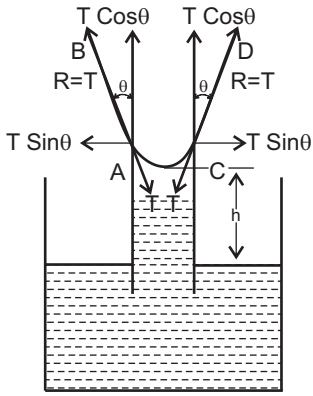
Explanation for capillary rise and capillary dip

When a capillary tube is dipped vertically into a liquid, it is found that the liquid rises or falls in the tube. This phenomenon is known as capillarity and it is due to the surface tension of the liquid.

When a capillary tube is dipped vertically into a liquid like water. the liquid rises through a height in the capillary tube. This is called capillary rise.

When a capillary tube is dipped vertically in mercury, taken in a beaker, the level of mercury inside is found to be lower than the level of mercury outside the capillary tube, in the beaker. This is called 'capillary dip'.

Expression for the surface tension by capillary rise:



Let a capillary tube of uniform radius (r) be dipped vertically into a liquid of density ρ taken in a beaker. Let the liquid rises through a height (h) in the capillary tube. Let θ be the angle of contact with glass and T be the surface tension of the liquid. The surface tension is acting tangential to the liquid surface. The reaction R=T, offered by the walls of tube acts at an angle θ to the verticals. This reaction T along AB can be resolved vertically as Tcosθ and horizontally as Tsinθ. Similarly the reaction T along CD can also be resolved along the horizontal and vertical directions. The horizontal components along the circumference are equal and opposite in direction. So they get cancelled. So the total force due to surface tension is only due to vertical components.

The total upward force acting through the length of the meniscus $2\pi r$

$$= 2\pi r . T\cos\theta$$

This force balances the weight of the liquid column of height h and radius r.

The weight of the liquid column = $\pi r^2 h \rho g$

$$2\pi r T\cos\theta = \pi r^2 h\rho g$$

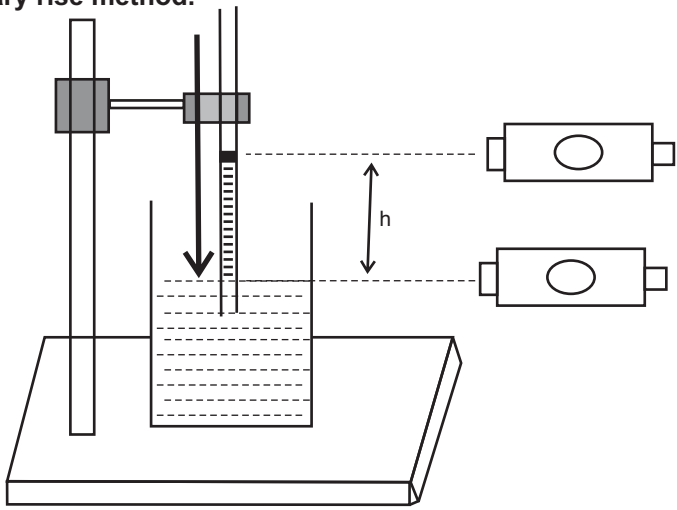
$$T = \frac{hr\rho g}{2\cos\theta}$$

In the case of water $\theta = 0^\circ$ and hence $\cos\theta = 1$

Hence for water, Surface tension

$$T = \frac{hr\rho g}{2}$$

Experimental determination of the surface tension of water by capillary rise method.



A capillary tube of uniform cross sectional area is first cleaned with dilute acid and washed with distilled water and dried. It is then clamped vertically with one end inside the water taken in a beaker. Due to surface tension, water rises to a definite height in the tube. A pointer is attached to the capillary tube such that it just touches the surface of the water in the beaker.

Using a travelling microscope the reading in the vertical scale corresponding to the lower meniscus of the water in the tube is taken. The beaker is removed and the microscope is brought down and the reading corresponding to the tip of the pointer is taken. The difference between the two readings gives the height of the capillary rise of water 'h' in the

capillary tube. The diameter and hence the radius 'r' of the capillary tube is also determined with the help of microscope. If ρ is the density of water and g, the acceleration due to gravity, then surface tension of water,

$$T = \frac{hr\rho g}{2}$$

Applications of capillarity:

1. Lubricating oil spread easily on all parts because of their low surface tension.
2. Cotton dresses are preferred in summer because cotton dresses have fine pores which act as capillaries for sweat.
3. Dirt get removed when detergents are added while washing clothes because surface tension of water is reduced.
4. The absorption of ink by a blotting paper is due to capillary action, as the blotting paper is porous. When it is placed over the ink, the ink raises into the pores. Also rise of oil in the wick of a lamp is due to capillary action.
5. If one end of a towel is dipped into a bucket of water and the other end hangs over the bucket, the entire towel soon becomes wet due to capillary action.
6. The supply of water to the leaves at the top of even a tall tree is through capillary rise.
7 A fabric can be waterproof, by adding suitable waterproofing materials to the fabric. This addition increases the angle of contact, thereby making the fabric waterproof.

Worked examples

1. A capillary tube of diameter 0.5 mm is dipped into a liquid vertically and the liquid rises to a height of 6 cm. If the density of the liquid is 1000 kgm^{-3}, calculate the value of surface tension of the liquid. ($g = 9.81 ms^{-2}$)

   Diameter of the capillary tube 2r = 0.5 mm

   Radius of the capillary tube $r = 0.25 \times 10^{-3} m$

   Rise of liquid in the tube $h = 6 cm = 6 \times 10^{-2} m$

   Density of the liquid $\rho = 1000 kg\ m^{-3}$

   Liquid being water, angle of contact $\theta = 0°$

Surface tension of the liquid $T = \frac{h \rho g r}{2\cos\theta}$

$$\frac{6 \times 10^{-2} \times 1000 \times 9.81 \times 0.25 \times 10^{-3}}{2\cos 0}$$

$$T = 72.5 \times 10^{-3}\ Nm^{-1}$$

2. Calculate the diameter of a capillary tube in which a liquid rises 2.34×10^{-2} m. Surface tension of the liquid is 25×10^{-3} Nm^{-1}. Relative density of the liquid is 0.79. Angle of contact = 11°12'. ($g = 9.81 ms^{-2}$)

   Relative density of the liquid = 0.79

   Density of the liquid $\rho = 0.79 \times 10^{3}$ kgm^{-3}

Diameter of the tube = $2r = 5.41 \times 10^{-4}$m

We know $T = \frac{h \rho g r}{2\cos\theta}$

$$r = \frac{2T\cos\theta}{h\rho g}$$

$$= \frac{2 \times 25 \times 10^{-3}\ \ Cos 11^{\circ}12'}{2.34 \times 10^{-2} \times 0.79 \times 10^{3} \times 9.81} = 2.705 \times 10^{-4}m$$

3. A liquid of density 1000 kgm^{-3} is taken in a beaker. A capillary tube of diameter 1.0 mm is dipped vertically in it. Calculate the rise of liquid in the tube. Surface tension of the liquid is $72 \times 10^{-3} Nm^{-1}$.

   For water, angle of contact $\theta = 0°$

   Surface tension $T = 72 \times 10^{-3}$ Nm^{-1}

   Diameter of the capillary tube 2r = 1 mm

   Radius of the capillary tube $r = 0.5 \times 10^{-3}$ m

   $h = 2.939 \times 10^{-2}$ m

   Rise of liquid in the tube $h = \frac{2T\cos\theta}{r\rho g}$

$$h = \frac{2 \times 72 \times 10^{-3}\ \ Cos 0^{\circ}}{0.5 \times 10^{-3} \times 1000 \times 9.8} = 2.939 \times 10^{-2}m$$

4. A capillary tube of internal diameter 0.5 mm is dipped into a liquid of density 1140 kgm^{-3}. The liquid rises to a height of 2.6 cm in the capillary tube. If the angle of contact of liquid with glass is 55°, calculate the surface tension of the liquid.

Diameter of the capillary tube = 0.6 mm
Radius of the capillary tube $r = 0.3 \times 10^{-3}$ m
Density of the liquid, $\rho = 1140$ kg m^{-3}
Height through which liquid rises $h = 2.6 \times 10^{-2}$ m
Angle of contact, $\theta = 55°$

Surface tension of the liquid $T = \dfrac{h \rho g r}{2\cos\theta}$

$$T = \frac{2.6 \times 10^{-2} \times 0.3 \times 10^{-3} \times 1140 \times 9.8}{2 \cos 55^{\circ}}$$

$$T = 75.96 \times 10^{-3} \text{ Nm}^{-1}$$

Questions

Part – A

1. Define stress.
2. Define strain.
3. Which is more elastic, rubber or steel and why?
4. What is elastic limit and plastic limit?
5. Define elastic body and plastic body.
6. What are the three modulii of elasticity?
7. Define (i) linear strain (ii) bulk strain and (iii) shearing strain.
8. Write the statement of Hooke's law.
9. Define Modulus of elasticity
10. Define (i) Young's modulus (ii) Bulk modulus and (iii) Rigidity modulus.
11. Define Poisson's ratio.
12. What is uniform bending of a beam?
13. What is non uniform bending of a beam?
14. Define coefficient of viscosity.
15. Derive the dimensional formula and the SI unit for the coefficient of viscosity.
16. What is stream line motion?
17. What is turbulent motion?
18. What is Reynolds number?

19. What is critical velocity?
20. What is terminal velocity?
21. Write the application of viscosity.
22. Derive the S.I. unit and the dimensional formula of surface tension.
23. What is the effect of surface tension on the surface area of liquids?
24. The droplet of rain is spherical. Why?
25. How do insects run on the surface of water?
26. Define surface tension of a liquid.
27. Define angle of contact.
28. Define capillarity.
29. Write any two applications of capillarity.

Part - B

1. Explain the elastic behavior of a material with the help of stress-strain curve.
2. Explain uniform and non-uniform bending of beams.
3. Describe an experiment to determine the Young's modulus of the material of a bar by bending it uniformly.
4. Distinguish between stream line and turbulent motion.
5. Derive the Poiseuille's formula for the coefficient of viscosity of a liquid by dimensional method.
6. Describe as experiment to determine the coefficient of viscosity of a low viscous liquid by capillary flow method.
7. Describe Stokes' method of determining the coefficient of viscosity of a transparent, high viscous liquid.
8. Explain the phenomenon of surface tension, capillary rise and capillary dip.
9. Derive an expression for the surface tension of a liquid in the case of the capillary rise.
10. Describe an experiment to determine the surface tension of water by capillary rise method.
11. List the various applications of capillarity.

Exercise Problems

1. The length of a wire increases from 1.25 m to 1.2508 m when a load of 12 kg is suspended. The radius of the wire is 0.5 mm. Find the stress, strain and young's modulus of material of the wire. (149.7×10^{6} Nm^{-2}, 6.4×10^{-4}, 23.4×10^{10} Nm^{-2})
2. What load in kilogram must be applied to a steel wire of length 1m and diameter 0.05 cm to produce an extension of 1 cm. The Young's modulus of steel = 2×10^{11}. Pa. (40 kg)
3. A wire 10m long of area of cross section 1.22cm^2 elongates by 1.5 cm when 4.5 kg is suspended from it. Find the (i) stress (ii) strain and (iii) young's modulus of the wire. (g = 9.8m s^{-2}) [(i) $3.528 \times 10^{5} Nm^{-2}$ (ii) 0.0015 (iii) 2.352×10^{8} Nm^{-2}]
4. A body of mass 5kg is suspended by means of a steel wire of length 1 m and diameter 1mm. The Young's modulus of steel is 21×10^{10} Nm^{-2}.calculate the elongation of the wire. (l=2.97×10^{-4}m)
5. A uniform metal bar, one metre 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. (Ans: 9.81×10^{10} Nm^{-2})
6. Calculate the surface tension of water if it rises to a height of 4.2cm in a capillary tube dipped vertically in it. Radius of the capillary tube is 3.5×10^{-4}m. ($72.03 \times 10^{-3} Nm^{-1}$)
7. A capillary tube of diameter 0.5 m is dipped into a liquid vertically and the liquid rises to a height of 4.4 cm. If the density of the liquid is 1000 kg m^{-3}, calculate the value of the surface tension of the liquid.
8. A capillary tube of bore 0.84 mm in dipped into a liquid of density 840 kgm^{-3} and surface tension 0.049 Nm^{-1}. Find the rise of the liquid in the tube.

Brain teasers

1. A wire of diameter 2.5 mm is stretched by force of 980 N. If the Young's modulus of the material of the wire is 12.5×10^{10} Nm^{-2}.Find the percentage increase in the length of the wire.
2. Two wires are made of same material. The length of the first wire is half of the second wire and its diameter is double that of the second wire. If equal loads are applied on both the wires find the ratio of increase in their lengths.
3. The diameter of a brass rod is 4 mm. Calculate the stress and strain when it is stretched by 0.25% of its length. Find the force exerted ($E=9.2 \times 10^{10}$ Nm^{-2} for brass)

UNIT - III

DYNAMICS - I

Introduction

Dynamics is a branch of mechanics which deals with the motion of the bodies under the action of forces.

A body is said to be at rest if it does not change its place or position with respect to its surroundings. No body in this earth is at absolute rest. Because, they are sharing the motion of the earth. A body can be at rest with respect to another body.

A body is said to be in motion if it changes its place or position with respect to its surroundings. For example, a person in the moving train feels the motion, seeing the passing objects through the windows. Hence rest and motion are relative terms.

The motion of the body is characterised by two quantities, Force and Momentum. If a body is in motion with acceleration, then the body is acted upon by a force (F=ma). If a body is in motion with uniform velocity, there is no acceleration, then the motion of the body is only under momentum (mv).

Newton's Laws of motion: These laws are very important in dynamics.

I Law: Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by an external force.

II Law: The rate of change of momentum of a body is directly proportional to the force acting on it and it takes place in the direction of the force.

III Law: For every action, there is always an equal and opposite reaction.

In this unit we shall study about the Projectile motion, Circular motion, its application and Simple Harmonic Motion.

3.1 PROJECTILE MOTION

In this chapter we shall consider the motion of the objects projected in any direction from the earth making the following assumptions.

1) The air resistance is negligible
2) The acceleration due to gravity remains constant.

When an object is projected vertically up from the earth, we regard the upward direction as the positive direction. The force of gravity produces acceleration downwards on the object. Acceleration is therefore taken as negative.

Equations of motion: Let u = initial velocity, v = final velocity, a = acceleration, t = time and s = displacement.

(I) For Objects in motion

(1) $v = u + at$

(2) $s = ut + 1/2\, at^2$

(3) $v^2 = u^2 + 2as$

(ii) For objects falling freely

Here initial velocity u = 0 and a =+g

(1) $v = gt$

(2) $S = \frac{1}{2}gt^2$

(3) $v^2 = 2gs$

(iii) For objects thrown vertically upwards

Here a = -g

(1) $v = u - gt$

(2) $s = ut - \frac{1}{2}gt^2$

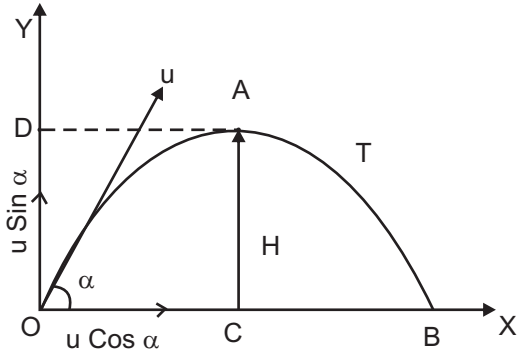
(3) $v^2 = u^2 - 2gs$

Projectile

Projectile is any object thrown obliquely into the space. The object which is given an initial velocity and afterwards follows a path determined by the gravitational force acting on it is called projectile. Its motion is called projectile motion.

A stone projected at an angle, a bomb released from an aeroplane, a shot fired from a gun, a shotput or javelin thrown by the athlete are the various examples for the projectile.

Consider a body projected from a point 'O' with velocity 'u'. The point 'o' is called point of projection and 'u' is called velocity of projection.



Velocity of Projection (u): The velocity with which the body projected is called velocity of projection.

Angle of Projection (α): The angle between the direction of projection and the horizontal plane passing through the point of projection is called angle of projection.

Trajectory (OAB): The path described by the projectile from the point of projection to the point where the projectile reaches the horizontal plane passing through the point of projection is called trajectory. The trajectory of the projectile is a parabola.

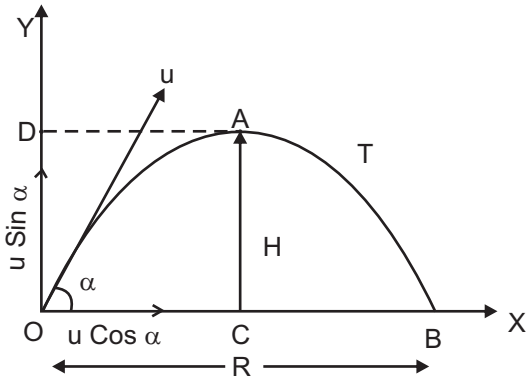
Maximum height (H): The maximum vertical displacement of the projectile from the horizontal plane passing through the point of projection is called maximum height.

Time of flight (T): The time taken by the projectile to travel from the instant of projection to the instant when it reaches the horizontal plane passing through the point of projection is called time of flight (or) The time taken by the projectile to describe the trajectory.

Range (R): The distance between the point of projection and the point where the projectile reaches the horizontal plane passing through the point of projection is called the range of the projectile.

Note: The horizontal component of velocity $u\cos\alpha$ is constant throughout the motion and the vertical component of velocity $u\sin\alpha$ goes on decreasing and becomes zero at the highest point A, because of the constant retardation '-g' acting on the projectile.

Expressions for maximum height, time of flight and horizontal range of a projectile.



Consider a body be projected upwards from the point of projection O with the velocity u. Let α be the angle of projection. The velocity u can be resolved into two components. Let u sin α and u cos α are the vertical and horizontal components of the velocity.

Maximum height reached by the projectile:

Let H be the maximum height reached by the projectile. At the highest point the vertical component of velocity becomes zero.

Considering the vertical motion of the projectile,

Taking the equation of motion

$v^2 = u^2 + 2as$ ...(1)

Final velocity at A, v = 0

Initial velocity at O, along vertical direction $u = u\sin\alpha$

Acceleration a = -g

Vertical displacement AC, s= H

Substituting these values in equation (1)

$0 = u^2\sin^2\alpha + 2(-g)H$

$0 = u^2\sin^2\alpha - 2gH$

$2gH = u^2\sin^2\alpha$

$\therefore$ Maximum height, $H = \dfrac{u^2 \sin^2 \alpha}{2g}$

Time of Flight of the Projectile:

The time taken by the projectile to describe the path is called time of flight. i.e., It is the time taken by the projectile to travel from 'O' to 'B', via A.

Let T be the time of flight. Here, the vertical displacement at B is zero.

Considering the vertical motion, Taking the equation of motion

$$S = ut + \frac{1}{2}at^2 \qquad (2)$$

Vertical displacement $S = 0$

Initial velocity at O, along vertical direction $u = u \sin \alpha$

Acceleration $a = -g$; Time $t = T$; Substituting these values in equation (2)

$$0 = u \sin\alpha\ T + \frac{1}{2}(-g)T^2$$

$$0 = u \sin\alpha\ T - \frac{1}{2} g\ T^2$$

$$\frac{1}{2}gT^2 = u \sin\alpha\ T$$

$\therefore$ Time of flight, $T = \dfrac{2u\sin\alpha}{g}$

Horizontal Range of the Projectile:

The horizontal distance between the point of projection and the point where the projectile meets the horizontal plane passing through the point of projection is called range of the projectile.

Let R be the range of the projectile.

Range R = Horizontal component of velocity x Time of flight

$$R = u\cos\alpha \times \frac{2u\sin\alpha}{g}$$

$$= \frac{u^2 2\sin\alpha\cos\alpha}{g} \qquad \therefore \sin 2a = 2\sin a\cos a$$

$$\therefore \text{Range, } R = \frac{u^2 \sin 2\alpha}{g}$$

Condition for maximum range (R_{max}):

The expression for Horizontal Range, $R = \frac{u^2 \sin 2\alpha}{g}$

For a given velocity of projection, range will be maximum only when $\sin 2\alpha$ is maximum. The maximum value for sine function is 1.

i.e $\sin 2\alpha = 1$ but, $\sin 90^0 = 1$

$\therefore \sin 2\alpha = \sin 90° \therefore 2\alpha = 90° \qquad \therefore \alpha = 45°$

For getting maximum range, the condition is the angle of projection should be 45°.

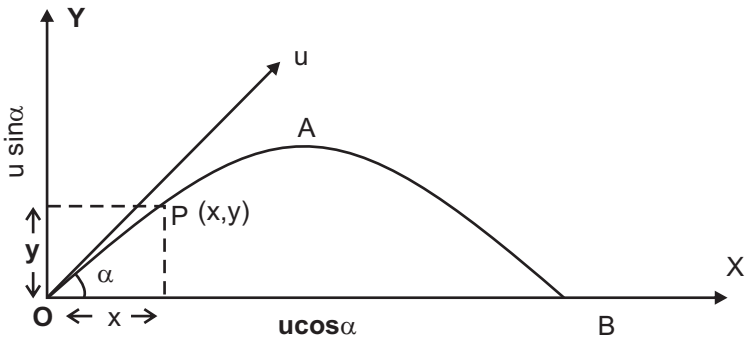
$$\therefore \text{Maximum range, } R_{max} = \frac{u^2 \sin(2x45^\circ)}{g}$$

$$R_{max} = \frac{u^2 \sin 90^\circ}{g} = \frac{u^2}{g} \qquad (\because \sin 90^\circ = 1)$$

$$\therefore R_{max} = \frac{u^2}{g}$$

This is the expression for the maximum range of the projectile.

Path of the projectile (the trajectory) is a Parabola:



Consider a body be projected from the point of projection O with the velocity u as shown in the figure. Let α be the angle of projection of the body. The velocity u can be resolved into two components. $u\sin\alpha$ and $u\cos\alpha$ are the vertical and horizontal components of velocity u. Let P (x,y)

Horizontal displacement in t second, $x = u \cos \alpha \times t$

$$t = \frac{x}{u\cos\alpha}$$

Taking the equation of motion $S = ut + \frac{1}{2}at^2 \text{ ------>} (1)$

be the position of the body after 't' second.

Vertical displacement in t second, S = y

Time taken to reach P, $t = \frac{x}{u\cos\alpha}$

Initial velocity at O along vertical direction, $u = u\sin\alpha$

Acceleration a = -g

$$y = u\sin\alpha \ \frac{x}{u\cos\alpha} + \frac{1}{2}(-g)\frac{x^2}{u^2\cos^2\alpha}$$

$$y = x\tan\alpha - \frac{g}{2u^2\cos^2\alpha}x^2$$

$$y = x\tan\alpha - \frac{gx^2}{2u^2\cos^2\alpha}$$

Substituting these values in equation (1)

The above equation is similar to the equation of the parabola $y = bx - cx^2$. Hence the path of the projectile is a parabola.

SOLVED PROBLEMS:

1. A body is thrown with a velocity of projection 49 ms^{-1} at an angle of projection 45°. Find (i) Maximum height (ii) Time of flight (iii) Range ($g = 9.8\ ms^{-2}$).

Given

$$u = 49ms^{-1}$$

$$\alpha = 45^{\circ}$$

Maximum height, $H = \dfrac{u^2 \sin^2 \alpha}{2g}$

$$= \frac{49x49x\sin 45^{\circ} x \sin 45^{\circ}}{2x9.8}$$

$$= 61.25 \text{ m}$$

Time of flight, $T = \dfrac{2u\sin\alpha}{g}$

$$= \frac{2 \times 49 \times \sin 45}{9.8}$$

$$= 7.07\,s$$

Range, $R = \dfrac{u^2 \sin 2\alpha}{g}$

$$= \frac{49 \times 49 \times \sin(2 \times 45)}{9.8}$$

$$= \frac{49 \times 49 \times \sin 90}{9.8}$$

$$= 245\,m$$

2. A bullet fired from a gun with a velocity of 80 ms^{-1} strikes the ground at the same level as the gun at a distance of 460 m. Find the angle of inclination with the horizontal at which the gun was fired.

Given

$u = 80\ ms^{-1}$, $R = 460$ m, $g = 9.8\ ms^{-2}$

Range $R = \dfrac{u^2 \sin 2\alpha}{g}$

$$\text{Sin } 2\alpha = \frac{g.R}{u^2} = \frac{9.8x460}{(80)^2} = 0.7044$$

$2\alpha = \text{Sin}^{-1}(0.7044) = 44^{\circ}\,46'$ $\therefore \alpha = 22^{\circ}\,23'$

3. The range of a projectile is equal to double the maximum height attained. Find the angle of projection.

Given

Horizontal range = 2 X maximum height

ie., R = 2H

$$\frac{u^2 \sin 2\alpha}{g} = 2\frac{u^2 \sin^2 \alpha}{2g}$$

$\sin 2\alpha = \sin^2 \alpha$

$2 \sin \alpha \cos \alpha = \sin \alpha \sin \alpha$

$2 \cos \alpha = \sin \alpha$

$\therefore \tan \alpha = 2$

$\therefore \alpha = \tan^{-1}(2) = 63^\circ 26'$

4. A projectile is thrown at an angle θ and another is thrown at $(90-\theta)$ from the same point both with the velocities $78.4 ms^{-1}$. The second reaches 36.4m higher than the first. Find the individual heights.

Given

Angle of projection of first projectile = θ

Angle of projection of second projectile = $(90 - \theta)$

Velocity of projection u = $78.4\ ms^{-1}$

and $H_2 = H_1 + 36.4m$

$H_2 - H_1 = 36.4m$

Where H_1 is the maximum height of first one and H_2 is the maximum height of second one.

$$H_1 = \frac{u^2 \sin^2 \theta}{2g} \quad \text{and } H_2 = \frac{u^2 \sin^2 (90-\theta)}{2g} = \frac{u^2 \cos^2 \theta}{2g}$$

Adding, $$H_2 + H_1 = \frac{u^2 \cos^2 \theta}{2g} + \frac{u^2 \sin^2 \theta}{2g}$$

$$= \frac{u^2}{2g} = \frac{78.4 \times 78.4}{2 \times 9.8} = 313.6$$

$2H_2 = 36.4 + 313.6 = 350$

$H_2 = 175\ m$

Also, $H_1 = H_2 - 36.4 = 175 - 36.4$

$H_1 = 138.6\ m$

5. If the range of a projectile is and $256\sqrt{3}$ m the maximum height reached is 64m. Calculate the angle of projection.

Given H = 64m R = $256\sqrt{3}$ m

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

$$64 = \frac{u^2 \sin^2 \alpha}{2g} \quad (1)$$

Range, $R = \frac{u^2\ 2\sin\alpha\cos\alpha}{g}$

$$256\sqrt{3} = \frac{u^2\ 2\sin\alpha\cos\alpha}{g} \quad (2)$$

Dividing eqn. (1) by (2)

$$\frac{64}{256\sqrt{3}} = \frac{u^2 \sin^2 \alpha}{2g} \times \frac{g}{u^2 2\sin\alpha\cos\alpha} = \frac{\tan\alpha}{4}$$

$$\tan\alpha = \frac{1}{\sqrt{3}} \qquad \alpha = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right)$$

$$\alpha = 30^\circ$$

3.2 CIRCULAR MOTION

Introduction

In this chapter we study the motion of the bodies moving in a circular path. The motion of the body in a circular path is called circular motion. The motion of the body in the circular path with uniform velocity is called uniform circular motion. When it is in uniform velocity, the direction of motion at any point is along the tangent to the circle at that point. If the body is set free, it would move in the direction of the tangent at that point.

Angular velocity

Consider a body (or particle) moving along a circular path. If θ is the angle turned by the radius vector in t second, then

$$\text{Angular velocity} \quad \omega = \frac{\theta}{t}$$

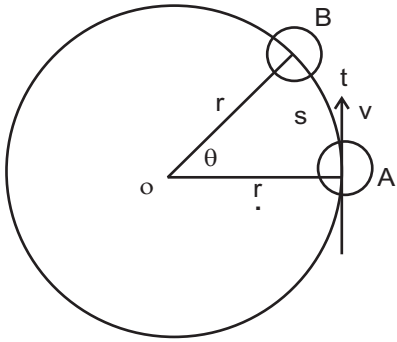
The angle covered or swept or turned by the radius vector in one second is known as angular velocity.

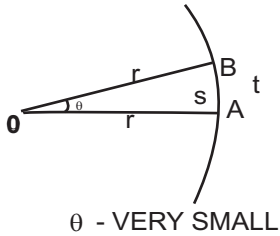
SI Unit of angular velocity is radian / second (rad s^{-1})

Radian is the angle made at the centre of the circle by an arc whose length is equal to the radius of the circle.

Relation between angular velocity and linear velocity

Consider a particle moving along a circular path of radius r. Initially the particle is at a point A. After t second the particle reaches the point B. Let θ be the angle swept by the radius vector in t-second.





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

If θ is very small, the distance AB will be considered as a straight line. Let v be the linear velocity of the particle.

$$\text{Linear velocity, } v = \frac{s}{t}$$

$$\text{In } \Delta \text{ OAB, } \sin\theta = \frac{s}{r}$$

If θ is very small, $\sin\theta = \theta$ in radian

$$\therefore \theta = \frac{s}{r} \text{(or) } s = r\theta$$

$$\text{Linear velocity, } v = \frac{r\theta}{t} = r\omega \qquad \left(\because \omega = \frac{\theta}{t}\right)$$

$$\therefore v = r\omega$$

Linear velocity = Radius of the circle x Angular velocity

Note:

If $\theta = 1°$, $1° = 0.0175$ radian; Also $\sin 1° = 0.0175$

Then $\sin 0.0175$ (radian) $= 0.0175$ (natural value)

$\theta = 2° = 0.0349$ radian; Also $\sin 2° = 0.0349$

Then $\sin 0.0349$ (radian) $= 0.0349$ (natural value)

Hence $\sin\theta = \theta$ for very small values of θ.

It is practically valid up to $= 4° = 0.0698$ radian.

Period and frequency of revolution

Period (T): Period of revolution of a particle is the time taken by the particle to complete one revolution.

Frequency (n): Frequency of revolution of a particle is the number of revolutions made in one second.

Relation between period T **and angular velocity** ω:

For one complete revolution (in T second),

Angle turned by the radius vector in T second $= 2\pi$

$\therefore$ Angle turned by the radius vector in one second $= \frac{2\pi}{T}$

i.e., Angular velocity, $\omega = \frac{2\pi}{T}$ or $T = \frac{2\pi}{\omega}$

Relation between period T and frequency n:

Let the particle completes n rotations in one second.

This is called frequency. So, the time taken complete one rotation which gives period = 1/n. Therefore, T = 1/n.

Relation between frequency n and angular velocity ω**:**

No. of revolutions in 1 second = n

Angle turned by the radius vector for one revolution $= 2\pi$

$\therefore$ Angle covered by the radius vector for n revolutions in 1 second $= 2\pi n$

i.e., Angular velocity, $\omega = 2\pi n$

Normal acceleration:

For a particle in uniform circular motion, the direction of its velocity changes continuously but the magnitude remains constant. For this, a force must act along the radius, towards the centre of the circle, to maintain the circular path. Hence, there is acceleration acting on the body towards the centre of the circle.

Thus, for a particle executing uniform circular motion, there must always be acceleration directed towards the centre of the circular path along the radius. This acceleration is called normal acceleration and the force responsible for this acceleration is known as centripetal force.

When a particle is moving along a circular path, the particle is accelerated towards the centre of the circular path in a direction normal to the direction of its motion. This acceleration of the particle is known as normal acceleration.

Centripetal force and Centrifugal force:

When a particle is moving along a circular path, it is accelerated towards the centre of the circular path. Due to this acceleration there must be force acting on the particle towards the centre and this force is known as centripetal force.

Centripetal force is defined as the force which acts towards the centre along the radius of the circular path on which the particle is moving with uniform velocity.

Let a stone be tied to one end of a string and whirled in a horizontal plane with constant speed. The stone is subjected to a force directed towards the centre of the circle. This force acting towards the centre of the circle is called centripetal force.

The expression for centripetal force is given by

$$\frac{mv^2}{r} \text{ or } mr\omega^2$$

By Newton's third law, there must be a reaction to this force. This reactive force which is directed away from the centre is called centrifugal force.

The centrifugal force is defined as the force acting along the radius of the circle, away from the centre, to balance the centripetal force.

The centripetal force and centrifugal force are equal in magnitude but opposite in direction. As centrifugal force is a reaction force, it ceases once the centripetal force stops.

Examples for centripetal force:

The centripetal force is responsible for circular motion. Without this force the body cannot move along a circular path. This force can be produced in different ways.

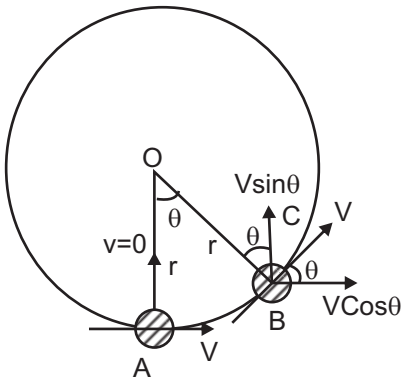
1. A body tied to one end of a string is being rotated in a circle; the centripetal force is supplied by the tension of the string.
2. The moon revolving around the earth, the centripetal force is the gravitational pull of the earth on the moon.
3. A person riding a cycle along a circular path, the necessary centripetal force is supplied by a sidewise pressure exerted by the road on the tyres.

Examples for centrifugal force:

1. A stone tied to one end of a string is being rotated in a circle, the stone itself exerts an equal and opposite force on the hand. It is due to the centrifugal force.
2. A centrifugal pump is used to pump well water on the basis of centrifugal force.

Expressions for Normal acceleration and Centripetal force

Consider a particle of mass 'm' moving along a circular path of radius r. Let v be the velocity of the particle. Initially the particle is at a point A. After t second the particle reaches the point B. Let θ be the angle covered by the radius vector. Let B be very close to A, so that the angle covered θ is small.



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

Initially,

The velocity component in AO direction = zero

After t second

The velocity component in BC direction = $v\sin\theta$

Since θ is very small, the direction BC is very close to AO direction.

$\therefore$ The change in velocity towards the center of the circle in

't' second $= v\sin\theta - 0$

$= v\sin\theta$

As θ is very small, $\sin\theta = \theta$ (in radian)

$$\text{The change in velocity in one second} = \frac{v\sin\theta}{t}$$

$$\text{ie., Normal acceleration, } a = \frac{v\sin\theta}{t}$$

$$\therefore \text{Normal acceleration, } a = \frac{v\theta}{t}$$

$$\text{Since } \omega = \frac{\theta}{t}, \quad a = v\omega$$

$$\text{since } v = r\omega, \quad a = r\omega.\omega = r\omega^2$$

$$\text{since } \omega = \frac{v}{r}, \quad a = v.\frac{v}{r} = \frac{v^2}{r}$$

$$\text{Normal acceleration, } a = \frac{v^2}{r} \text{ or } a = r\omega^2$$

Centripetal force

According to Newton's II Law of motion, F = ma. As 'm' is the mass of the particle moving along a circular path of radius r,
Centripetal force = mass X normal acceleration.

$$\text{Normal acceleration, } a = \frac{v^2}{r} \quad \text{or} \quad a = r\omega^2$$

$$\text{Centripetal force, } F = \frac{mv^2}{r} \quad \text{or} \quad F = mr\omega^2$$

SOLVED PROBLEMS

(1) A ball weighing 0.5 kg is tied to one end of a string and is whirled at a constant speed of $10ms^{-1}$ in a horizontal plane. If the length of the string is 1m, calculate the normal acceleration and the tension in the string.

Given m = 0.5 kg, $v = 10ms^{-1}$ $\ell = r = 1m$ a = ? F = ?

$$\text{Normal acceleration } a = \frac{v^2}{r} = \frac{(10)^2}{1} = 100 \text{ ms}^{-2}$$

Tension in the string (Cntripetal force)

$$F = \frac{mv^2}{r} = 0.5 \times (10)^2 = 50\text{N}$$

(2) A body of mass 1 kg is tied to a string of length 1m revolves in a horizontal circle. If the angular velocity is 3 rad s^{-1}, calculate the centripetal force acting on the body.

Given, m = 1 kg, $\ell = r = 1$ m, $\omega = 3$ rad s^{-1}

Centripetal force $F = mr\omega^2 = 1 \times 1 \times (3)^2 = 9$ N

(3) Find the centripetal force on a body of mass 500 g when it revolves in a circle of radius 1.5m. The body makes 120 R.P.M.

Given m = 500 g = 0.5 kg, r=1.5m

No. of revolutions = 120 per minute

$$\text{i.e., } n = \frac{120}{60} = 2 \text{ revolutions per second}$$

Centripetal force $F = m\,r\,\omega^2$

$= mr\,(2\pi n)^2$ (since $\omega = 2\pi n$) $= 4\pi^2 mrn^2$

$= 4 \times 3.14 \times 3.14 \times 0.5 \times 1.5 \times 2^2$ $F = 118.4$N

(4). A mass of 5kg is moving in a circle of radius 1m. If the centripetal force acting on the mass is 20N, find the linear velocity and angular velocity .

Given : F = 20N, r=1m, m = 5 kg

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

$$v^2 = \frac{Fr}{m} = \frac{20 \times 1}{5} = 4$$

$$v = 2 \text{ ms}^{-1}$$

$$\text{Angular velocity, } \omega = \frac{v}{r} = \frac{2}{1} = 2 \text{ rad s}^{-1}$$

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

Given : r = 1m, m = 200g = 0.2kg and F = 10 x 9.8 N

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

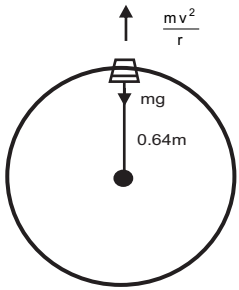
$$v^2 = \frac{Fr}{m} \therefore v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{10x9.8x1}{0.2}}$$

$$v = 7.07\ ms^{-1}$$

(6) One end of a string of length 0.64 m is attached to a bucket containing water and the bucket is rotated about the other end in a vertical circle. Find the minimum speed with which it can be rotated without spilling the water at the highest point. How many revolutions per minute it is making?

Given: Length of the string (or) radius of the circle $r = 0.64$ m

For without spilling the water at highest point



$$mg = \frac{mv^2}{r} (\text{or})\ g = \frac{v^2}{r}$$

$$\therefore v^2 = rg = 0.64 \times 9.8 = 6.272$$

$$\therefore \text{The minimum speed } v = \sqrt{6.272} = 2.504\ ms^{-1}$$

Let n' be the no. of revolutions per second.

$$n = \frac{\omega}{2\pi} = \frac{v}{r.2\pi} = \frac{2.504}{0.64x2\pi} = 0.6231$$

No of revolutions per minute = 0.6231 x 60

= 37.4 revolutions

3.3 APPLICATION OF CIRCULAR MOTION

Banking of curved paths:

Curved track is to be considered as a part of the circular path. Consider a motor car moving along a curved road. Now two forces are acting on the car, one is the weight of the car acting downward and second is the normal reaction acting upward. In addition to these two forces, a horizontal centripetal force should act on the car for safe negotiation of curved motion. This force is supplied by the pressure exerted by the road on the tyres of the car towards inner side.

According to Newton's third law of motion, the tyres exert an equal and opposite pressure on the road towards the outer side. Hence there must be a frictional force between the road and the tyres. This frictional force tries to balance the centifugal force. If the road is in horizontal level, the friction may not be sufficient to balance the centrifugal force. Then the car may skid. To avoid this the outer edge of the road is raised a little above the level of the inner edge. This formation is called as banking of curved paths.

In the case of train moving along a curved track, the necessary centrifugal force is supplied by the pressure exerted by the rails on the flanges of the wheels. Also the flanges of the wheels exert an equal and opposite pressure on the rails. Hence there must be a large amount of friction and it leads to damage the rails also to derailment of the train.

To avoid this damage and derailment, the outer rail is suitably raised over the inner rail to eliminate the flange pressure on the rails. This formation is called as banking of curved railway tracks.

The raising of outer edge of a curved path than the inner edge for providing the necessary centripetal force is known as banking of curved path.

Angle of Banking

It is the angle between the normal horizontal path and the curved banked path.

The angle of banking of a curved path is defined as the angle through which the outer edge of the road is raised over the inner edge.

The angle of banking of curved railway tracks is defined as the angle through which the outer rail is raised over the inner rail.

Expression for Angle of banking of Railway tracks

Consider a train moving along a curved path of radius r. In figure, ABCD shows the vertical cross section of a railway carriage. If the outer rail is raised over the inner rail by an angle θ, the carriage is inclined to the horizontal by the same angle . This angle is called angle of banking of the railway tracks.

Let R_1 and R_2 be the reactions of the inner and outer rails.

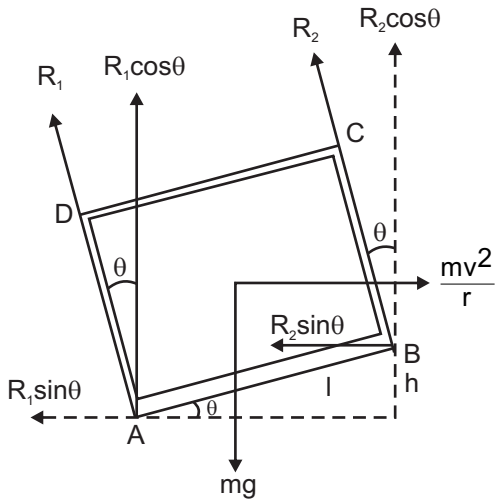
The total vertical component of R, and R_2 $= R_1 \cos\theta + R_2 \cos\theta$

$= (R_1 + R_2) \cos\theta$

The total horizontal component of R_1 and R_2 $= R_1 \sin\theta + R_2 \sin\theta$

$= (R_1 + R_2) \sin\theta$

The vertical component balances the downward weight of the carriage. The horizontal component supplies the necessary centripetal force and it balances the centrifugal force. Let m be the mass of the carriage and v be the speed of the train.



$$\text{The downward weight} = mg$$

$$\text{The centrifugal force} = \frac{mv^2}{r}$$

$$\text{Equating the forces } (R_1 + R_2)\cos\theta = mg \qquad (1)$$

$$(R_1 + R_2)\sin\theta = \frac{mv^2}{r} \qquad (2)$$

$$\frac{(2)}{(1)} \quad \frac{(R_1 + R_2)\sin\theta}{(R_1 + R_2)\cos\theta} = \frac{mv^2}{r\,m\,g}$$

$$\text{ie., } \tan\theta = \frac{v^2}{rg}$$

$\therefore$ The angle of banking of railway track,

$$\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$$

Let 'l' be distance (AB) between the rails.

If 'θ' small, $\sin\theta = \tan\theta$

$$\therefore \frac{h}{l} = \frac{v^2}{rg} \qquad h = \frac{v^2 l}{rg}$$

While constructing curved railway tracks, the value of h is obtained for fixed values of v, l and r.

Therefore, on a curved rail track, every train has to move with a particular speed specified for the track.

SOLVED PROBLEMS

(1) A cyclist is riding at a speed of $22 ms^{-1}$ takes a turn on a curved circular road of radius 44m. What is his inclination to the vertical?

Given, $V = 22\ ms^{-1}$, $r = 44m$, $g = 9.8\ ms^{-2}$

$$\tan\theta = \frac{v^2}{rg}$$

$$= \frac{(22)^2}{44 \times 9.8} = \frac{484}{431.2}$$

$$\tan\theta = 1.122$$

$$\theta = \tan^{-1}(1.122) = 48°18'$$

(2) An electric train has to travel on a railway track with a curve of radius 120 m with a speed of 36 kmph. Calculate the angle of banking of the rails.

$$\text{Given } v = 36 \text{ kmph} = 36 \times \frac{1000}{3600} = 10 ms^{-1}$$

$$r = 120 \text{ m} \qquad g = 9.8 \text{ ms}^{-2}$$

$$\tan\theta = \frac{v^2}{rg} = \frac{(10)^2}{120 \times 9.8}$$

$$\tan\theta = 0.0850$$

$$\theta = \tan^{-1}(0.085) = 4^\circ 51'$$

(3) A bend in level road has a radius of 18m. Find the maximum speed with which a car negotiates the bend without skidding. The elevation of the road is 7°.

$$\text{Given, } R = 18\text{m}, \qquad \theta = 7^\circ \quad \text{and} \quad g = 9.8 ms^{-2}$$

$$\tan\theta = \frac{v^2}{rg}$$

$$v^2 = rg \times \tan\theta = 18 \times 9.8 \times \tan 7^o$$

$$= 18 \times 9.8 \times 0.1222 = 21.65$$

$$v = 4.65 ms^{-1}$$

3.4 SIMPLE HARMONIC MOTION

Any motion in nature is classified into two types, viz., periodic and non-periodic motion. Periodic motion is that motion which repeats itself after equal intervals of time. The examples of periodic motion are the motion of planets around the sun, motion of hands of a clock, motion of the balance wheel of a watch.

It a body moves back and forth repeatedly about a mean position, it is said to possess oscillatory motion. Vibrations of guitar strings, motion of a pendulum bob, vibrations of a tuning fork, oscillations of mass suspended in a spring, vibrations of diaphragm in telephones are few

examples of oscillatory motion. In all the cases of vibrations of bodies, the path of vibration is always directed towards the mean or equilibrium position.

The oscillations can be expressed in terms of simple harmonic functions like sine or cosine function. A harmonic oscillation of constant amplitude and single frequency is called simple harmonic motion (SHM).

A particle is said to execute simple harmonic motion if its acceleration is directly proportional to the displacement from a fixed point and is always directed towards that point.

Important definitions of SHM

Displacement

The distance travelled by the oscillating particle from its mean position at any instant is called displacement.

Amplitude

The maximum displacement of the oscillating particle from its mean position is called amplitude.

Oscillation

One complete to and fro motion is called one oscillation.

Period

Time taken by the oscillating particle to complete one oscillation is called period.

Frequency

The number of oscillations or vibrations made by the vibrating particle in one second is called frequency.

Phase

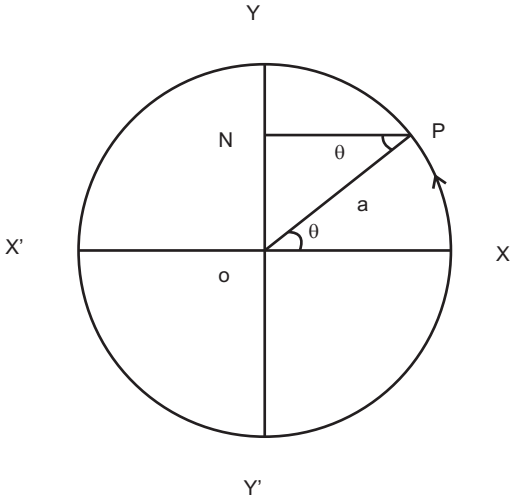
Phase of a particle vibrating in SHM at any instant is the state of vibrating particle regarding its position and direction of vibration at that particular instant.

The Projection of uniform circular motion on a diameter is SHM

Consider a particle moving along the circumference of a circle of radius 'a' and centre O, with uniform speed 'v', in anticlockwise direction as shown in the figure. Let XX' and YY' be the two perpendicular diameters.

Suppose the particle is at P after a time t second. If ω is the angular velocity. then the angular displacement in time t is given by $\theta = \omega t$. From P draw PN perpendicular to YY'. As the particle moves from X to Y, foot of the perpendicular N moves from O to Y. As it moves further from Y to X', then from X' to Y' and back again to X, the point N moves from Y to O, from O to Y' and back again to O. When particle completes one revolution along the circumference, the foot of the perpendicular point N completes one to and fro about the mean position O. This motion of the point N along the diameter YY' is simple harmonic.

Hence, the projection of a uniform circular motion on a diameter of a circle is simple harmonic motion.



QUESTIONS

PART – A

1. What is a projectile?
2. Define velocity of projection.
3. Define angle of projection.
4. Define trajectory of a projectile.
5. Define maximum height of a projectile.
6. Define time of flight of a projectile.
7. Define range of a projectile.

8. Give the condition for maximum range of a projectile.
9. What is a circular motion?
10. Define radian.
11. Define angular velocity.
12. Define normal acceleration.
13. Define centripetal force.
14. What is centrifugal force?
15. Define angle of banking.
16. Why does the outer rail is raised over the inner rail along a curved railway track?
17. Define Simple Harmonic Motion
18. Define amplitude
19. Define frequency
20. Define period
21. Define phase

PART B

1. Derive an expression for the maximum height reached by the projectile.
2. Derive an expression for the time of flight of the projectile.
3. Derive an expression for the horizontal range of the projectile.
4. Derive the condition for the maximum range the projectile (OR) Show that the range is maximum when the angle of projection is 45° for a given velocity of projection.
5. Prove that the path of a projectile is a parabola.
6. Derive the relation between angular velocity and linear velocity.
7. Derive the relations between angular velocity, period and frequency.
8. Obtain expressions for the normal acceleration and centripetal force of a body executing uniform circular motion.
9. Explain the banking of curved tracks.
10. Derive an expression for the angle of banking.
11. Show that the projection of uniform circular motion on the diameter of a circle is SHM.

Exercise problems

1. A particle is thrown at an angle of 30° with a velocity of 36 kmph Calculate its (1) time of flight and (2) horizontal range.

[**Ans:** (i) 1.02s, (ii) 8.84m]

2. The range of a projectile is equal to 3 times the maximum height attained. Find the angle of projection.

[**Ans**: $53^\circ 7'$]

3. The maximum height of a projectile is 2 times its horizontal range reached. Find the angle of projection.

[**Ans**: $79^\circ 58'$]

4. A bomber flying horizontally with a constant velocity of 600 kmph at a height 480m wants to hit a target on the ground. Find at what horizontal distance from the target should a bomb be dropped in order to hit the target.

[**Ans**: R = 1648 m]

5. A body of mass 2 kg tied to a string of length 2m revolves in a horizontal circle. If the angular velocity of the body is 5 rad s^{-1}, calculate the centripetal force acting on the body.

[**Ans**: F = 100N]

6. In a circus, a man is riding a motor cycle in the form of vertical circle inside the hollow spherical cave of diameter 6m. Find the minimum speed of the rider with which he can be riding without falling at the highest point.

[**Ans**: v = 7.668ms^{-1} or 27.6 kmph]

7. A string of length 1.5 m can withstand a maximum weight of 5kg.wt. A body of mass 2kg is tied to it and whirled round in a horizontal plane. Calculate the possible maximum number of revolutions per minute

[**Ans** : RPM = 38.6]

8. A scooter rider negotiates a curve of 100m radius on a level road with a speed of 72 kmph. Calculate the angle of inclination to the vertical he should make to avoid falling.

[**Ans**: $\theta = 22^\circ 12'$]

9. An electric train has to travel a curved railway line of radius 50m with maximum speed of 36 kmph. Calculate the angle through which the outer rail should be raised so that there is no lateral thrust on the rails.

[**Ans**: = 11°31']

10. An aeroplane with a speed of 120 ms^{-1} negotiates a curve of radius 1200m. Calculate its angle of banking.

[**Ans**: = 50°45']

11. The expected average speed of the traffic on a high way around the curve is 20 kmph. Calculate the angle of banking of the high way if its radius of curvature be 12m.

[**Ans**: = 14°42']

Brain teaser

1. An electric train has to travel on a railway track with a bend of radius 120m with a speed of 45 kmph. Calculate the height through which the outer rail should be raised for safe running of the train, if the distance between the two rails is 1.6m.

UNIT-IV

DYNAMICS - II

4.1 ROTATIONAL MOTION OF RIGID BODIES

Introduction

According to Newton's first law of motion, "Every body continues to be in a state of rest or in a state of uniform motion along a straight line, unless it is compelled to change that state by some external force".

This law consists of two parts i.e., (1) A body at rest will not move on its own unless an external force acts on it and (2) A body which is in uniform linear motion will not change either its speed or direction of motion on its own, without the help of an external force.

The inability of a body to change its state on its own, without the help of external force is termed as inertia. Inertia is a fundamental property of the matter. The more is the mass of the body, the more will be inertia. Thus in translatory (linear) motion the mass of the body is a measure of coefficient of inertia.

Rigid body

If the distance between any two points in a body is not altered by applying a force, however large the force may be, the body is said to be a rigid body.

A rigid body may be defined as that body which does not undergo any change in its shape or size due to the application of force.

Actually, no body is a perfect rigid body. When the changes in the body are negligible, it can be considered as a rigid body.

Rotational motion

Each body is made of large number of tiny particles. In the case of linear motion, all the particles present in the body will have same linear velocity.

When the body rotates about a fixed line (axis of rotation), its motion is known as rotatory motion.

The axis of rotation may lie within the body or outside the body. If all the particles of a body move in a circular path about the axis of rotation, the rigid body is said to have pure rotational motion.

When a body is in rotational motion about an axis, all the particles present in the body will have same angular velocity, but different linear velocities. The values of the linear velocities of these particles depend on the distance of the particles from the axis of rotation, since $v = r\omega$

In rotational motion also, a rigid body which is free to rotate about an axis, opposes the change to θ be produced in its state. The measure of opposition not only depends on the mass of the body but also on the distances of the particles of the body from the axis of rotation.

Suppose a particle of mass 'm' is at a distance r from an axis, the product mr^2 is called the moment of inertia of the particle about that axis.

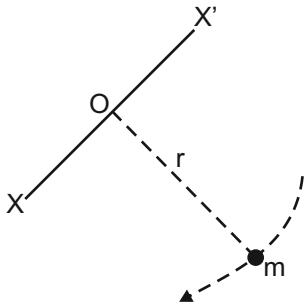
Thus in rotational motion the moment of inertia of the body about the given axis of rotation is a measure of coefficient of inertia.

Hence, the moment of inertia plays the same role in rotational motion as that of mass in translatory motion.

Moment of Inertia of a particle

The moment of inertia of a particle about an axis is equal to the product of the mass of the particle and square of its distance from the axis.

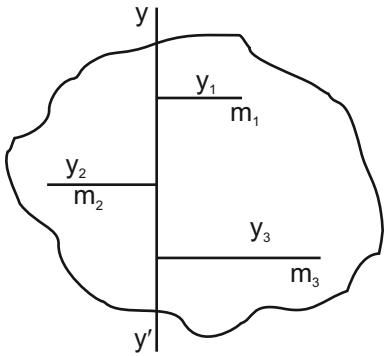
Consider a particle of mass 'm' is placed at a distance 'r' from the fixed axis. Then, the moment of inertia of the particle about the axis = mr^2
The S.I. unit for moment of inertia is kg m^2.



Moment of Inertia of a rigid body

Inertia of a body is its inability to change by itself its state of rest or of uniform motion in a straight line.

Similarly Moment of inertia of a body is its inability to change by itself its state of rest or of uniform rotatory motion about an axis.



An external torque (rotating effect of force) is necessary to change its state.

Let us consider the rotation of a rigid body about an axis. It consists of a large number of particles of masses m_1, m_2, m_3 etc., situated at distances r_1, r_2, r_3 etc., from the axis yy'. Then $m_1 r_1^2$ is known as the moment of inertia of the particle of mass m_1 about that fixed axis.

Then, the moment of inertia of the rigid body = Sum of moments of inertia of all the particles present in the body.

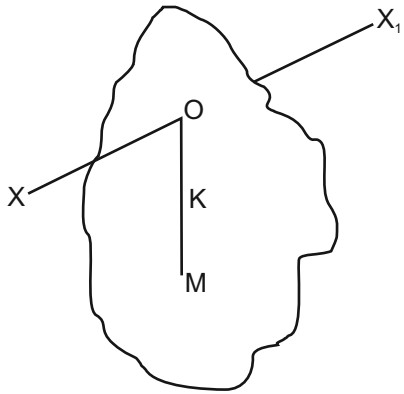
$$I = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 + \ldots\ldots\ldots\ldots\ldots\ldots$$

$$I = \sum mr^2$$

Hence the moment of inertia of a rigid body about a fixed axis is the sum of the moment of inertia of all the particles of the rigid body.

Radius of gyration

Radius of gyration is the distance between the given axis and the centre of mass of the body. The centre of mass of a body is point where the entire mass of the body is supposed to be concentrated.



It is denoted by ‘ K ’.

If M is mass of the body, then moment of inertia $I = MK^2$.

Hence, $mr^2 = MK^2$

Expression for Kinetic Energy of a Rigid body rotating about an axis:

Consider a rigid body rotating about a fixed axis XOX’. The rigid body consists of a large number of particles. Let m_1, m_2, m_3,….. ... etc., be the masses of the particles situated at distances. r_1, r_2, r_3, ... etc., from the fixed axis. All the particles rotate with the same angular velocity ω. But the linear velocities of the particles are different.

$$\text{Kinetic Energy} = \frac{1}{2} mv^2$$

$$= \frac{1}{2} m (r\omega)^2 \qquad (\because v = r\omega)$$

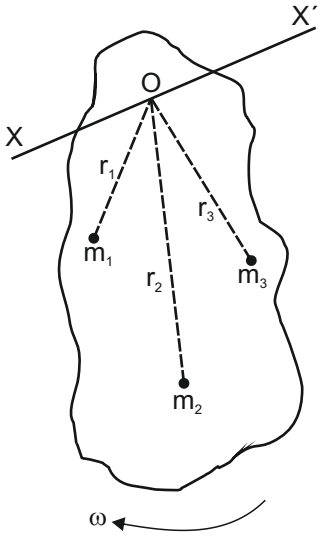
$$= \frac{1}{2} m r^2 \omega^2$$

The kinetic energy of the first particle $= \frac{1}{2} m_1 r_1^2 \omega^2$

The kinetic energy of the second particle $= \frac{1}{2} m_2 r_2^2 \omega^2$

The kinetic energy of the third particle $= \frac{1}{2} m_3 r_3^2 \omega^2$

and so on.



The kinetic energy of the whole body is equal to the sum of the kinetic energy of all the particles present in the body.

$$\text{The kinetic energy of the rigid body} = \frac{1}{2} m_1 r_1^2 \omega^2 + \frac{1}{2} m_2 r_2^2 \omega^2 + \frac{1}{2} m_3 r_3^2 \omega^2 + ...$$

$$= \left(\frac{1}{2} m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 + ... \right) \omega^2$$

$$= \frac{1}{2} \Sigma m r^2 \omega^2$$

But, Σmr^2 = Moment of inertia of the rigid body about the fixed axis = I

$$\text{Therefore, The kinetic energy of the rigid body} = \frac{1}{2} I \omega^2$$

Angular momentum

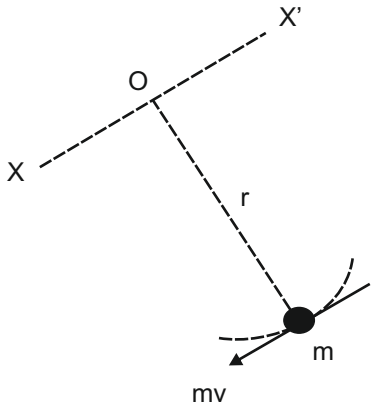
The moment of linear momentum is known as angular momentum.

Consider a particle of mass m is at a distance r from the axis of rotation. When a particle is in rotational motion about an axis, it has both linear velocity 'v' and angular velocity 'ω'.

Then, Angular momentum of the particle = linear momentum x perpendicular distance between the particle and the axis of rotation

$= m v \times r$

$= m r \omega \times r \quad (\because v = r\omega)$

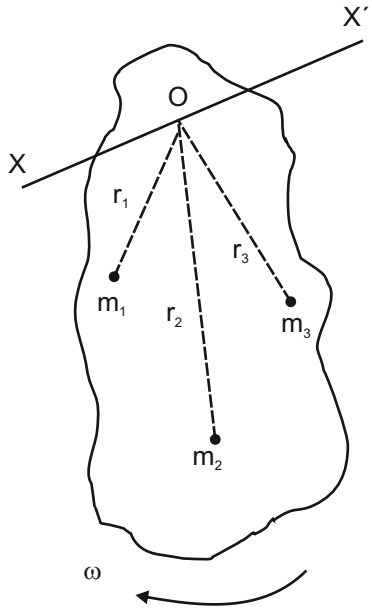


$\therefore$ Angular momentum = $mr^2\omega$

Where ω is the angular velocity of the particle.

The SI unit for angular momentum is kg m^2s^{-1}

Expression for Angular momentum of a Rigid body rotating about an axis:



Consider a rigid body rotating about a fixed axis XOX'. The rigid body consists of a large number of particles. Let m_1, m_2, $m_{3...}$ etc., be the masses of the particles situated at distances r_1, r_2, r_3, ... etc., from the fixed axis. All the particles rotate with the same angular velocity, but with different linear velocities depending on the values of 'r'.

Angular momentum = moment of linear momentum

= linear momentum x distance

$= mv \times r = mr\omega \times r \quad (\therefore v = r\omega)$

$= mr^2\omega$

$\therefore$ The angular momentum of the first particle $= m_1r_1\omega^2$

The angular momentum of the second particle $= m_1r_2\omega^2$

The angular momentum of the third particle $= m_3r_3\omega^2$

...and so on.

The angular momentum of the whole body is equal to the sum of the angular momenta of all the particles present in the body.

$$\left.\begin{array}{l}\text{The angular momentum}\\ \text{of the rigid body}\end{array}\right\} L = m_1r_1^2\omega^2 + m_2r_2^2\omega^2 + m_3r_3^2\omega^2 + \ldots$$

$$= \left(m_1r_1^2 + m_2r_2^2 + m_3r_3^3 + ..\right)\omega$$

$$= \sum mr^2\omega$$

But, Σmr^2 = moment of inertia of the rigid body = I

$\therefore$ The angular momentum of the rigid body = $I\omega$

Law of conservation of angular momentum

When there is no external torque acting on a rotating body, the angular momentum of that body remains a constant. This is the statement of law of conservation of angular momentum.

i.e., if I_1 and ω_1 are the initial moment of inertia and angular velocity of a rotating body and if I_2 and ω_2 are new moment of inertia and angular velocity of the body, without the help of any external torque, then according to this law,

$$I_1\,\omega_1 = I_2\,\omega_2$$

Examples

a) Consider a person standing on a turn-table with arms extended and a pair of weights, one in each hand. The table is made to rotate by a motor and then the motor is switched off. Now, if that person pulls his arms inwards, we can see a considerable increase in the speed of rotation. This is because, in the new position, his moment of inertia I about the axis of rotation decrease, due to the decrease in the value of r. Since the angular momentum is conserved, a decrease in the value I results in an increase in the value of angular velocity ω. Therefore the person is found to rotate faster.

b) A circus acrobat, a diver or skater, all take advantage of this principle. consider a diver has just left a diving board with his arms and legs extended, with a particular angular momentum. If he now pulls his arms and legs in, his moment of inertia I decreases, leading to increase in angular velocity ω. By increasing ω, the diver can perform more number of somersaults, before entering the swimming pool.

4.2 GRAVITATION

Newton's laws of Gravitation

Law 1 : Any two particles of matter attract each other with a force

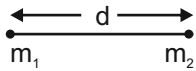
Law 2 : The force of attraction between any two objects is

i. directly proportional to the product of the masses

ii. inversely proportional to the square of the distance between them.

If m_1, m_2 are masses of two particles, separated by a distance 'd' then the force of attraction between the particles,

$$F \alpha \frac{m_1 m_2}{d^2}$$



$$F = G \frac{m_1 m_2}{d^2}$$

where G is known as "universal gravitational constant" and the value of $G = 6.6733 \times 10^{-11}$ N $m^2 kg^{-2}$

Acceleration due to gravity

Galileo was the first to make a systematic study of the motion of a body under the gravity of Earth. He dropped various objects from the leaning tower of Pisa and made analysis of their motion under gravity. He came to the conclusion that "in the absence of air, all bodies will fall at the same rate". It is the air resistance that slows down a piece of paper or a parachute falling under gravity. If a heavy stone and a parachute are dropped where there is no air, both will fall together at the same rate.

Experiments showed that the velocity of a freely falling body under gravity increases at a constant rate. i.e., with a constant acceleration. The acceleration produced in a body on account of the force of gravity is called acceleration due to gravity. It is denoted by 'g'. At a given place, the value of 'g' is the same for all bodies irrespective of their masses. It differs from place to place on the surface of the Earth. It also varies with altitude and depth.

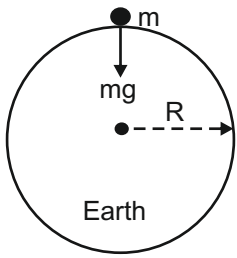
The value of g at sea-level and at a latitude of 45° is taken as the standard (i.e) $g = 9.81\ m\,s^{-2}$.

Acceleration due to gravity at the surface of the Earth

Consider a body of mass m on the surface of the Earth as shown in the Figure. Its distance from the centre of the Earth is R (radius of the Earth).

The gravitational force experienced by the body, $F = \frac{GMm}{R^2}$

where M is the mass of the Earth.



From Newton's second law of motion,

Force $F = mg$.

Equating the above two forces, $\frac{GMm}{R^2} = mg$

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

This equation shows that g is independent of the mass of the body m. But, it varies with the distance from the centre of the Earth. If the Earth is assumed to be a sphere of radius R, the value of g on the surface of the Earth is given by

Mass and Weight $g = \frac{GM}{R^2}$

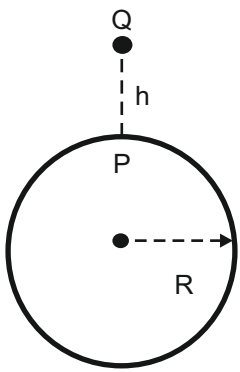
The mass of a body is defined as the quantity of matter contained in it. The mass of a body is always constant. It is measured in kilogram.

The weight of the body is usually defined as the force with which the earth attracts the body. Since the value of g varies slightly from place to place, the weight of a body is not a constant but varies slightly from place to place. However, at any particular place the weight of a body is proportional to its mass. Thus if w_1 and w_2 are the weights of two masses m_1 and m_2 at any place, then .

$$\frac{w_1}{w_2} = \frac{m_1}{m_2}$$

Variation of acceleration due to gravity with altitude (height):

Let P be a point on the surface of the Earth and Q be a point at an altitude h. Let the mass of the Earth be M and radius of the Earth be R. Consider the Earth as a spherical shaped body.



The acceleration due to gravity at P on the surface is

$$g = \frac{GM}{R^2} \quad ------> (1)$$

Let the body be placed at Q at a height h from the surface of the Earth. The acceleration due to gravity at Q is

$$g_h = \frac{GM}{(R+h)^2} \quad -------> (2)$$

dividing (2) by (1) $\quad \frac{g_h}{g} = \frac{R^2}{(R+h)^2}$

By simplifying and expanding using binomial theorem, $g_h = g\left(1 - \frac{2h}{R}\right)$

The value of acceleration due to gravity decreases with increase in height above the surface of the Earth.

Weightlessness

Television pictures and photographs show astronauts and objects floating in satellites orbiting the Earth. This apparent weightlessness is sometimes explained wrongly as zero-gravity condition. Then, what should be the reason?

Consider the astronaut standing on the ground. He exerts a force (his weight) on the ground. At the same time, the ground exerts an equal and opposite force of reaction on the astronaut. Due to this force of action, he has a feeling of weight.

When the astronaut is in an orbiting satellite, both the satellite and astronaut have the same acceleration towards the centre of the earth. Hence, the astronaut does not exert any force on the floor of the satellite. So, the floor of the satellite also does not exert any force of action on the astronaut. As there is no reaction, the astronaut has a feeling of weightlessness.

4.3 SATELLITES

A body moving in an orbit around another bigger body is called a satellite. A body that moves around a planet is called a satellite.

The objects that are moving in orbit by nature itself around a planet are called natural satellites. For example, moon is the natural satellite for the earth. The earth is a satellite for the sun. Man also has placed artificially some satellites to move in orbit around the desired planets. These satellites are called artificial satellite.

The artificial satellites are carried by rockets to the predetermined height, a few hundred kilometers above the surface of the earth. At this height the air is in a rarefied state and hence air friction is negligible.

After reaching the predetermined height, the satellite is given very high horizontal velocity so that it remains moving in a nearly circular orbit.

The artificial satellites are broadly classified as earth resources satellites, meteorological satellites and satellites carrying microwave sensors.

Escape velocity and Orbital velocity

Escape velocity (V_e): When a body is thrown vertically upwards, it will return to the earth's surface after attaining certain height. If the velocity of projection is increased, the height attained by the body becomes greater and then the body returns to the earth. This is due to the gravitational force of attraction of the earth. If the body is to be projected with a particular greater velocity, the body escapes from the gravitational pull so that it never returns to the earth. This velocity of projection is called escape velocity, it is different for different planets.

The minimum velocity required to project a body in upward direction from the surface of the earth so that it escapes from the earth's gravitational pull is called escape velocity.

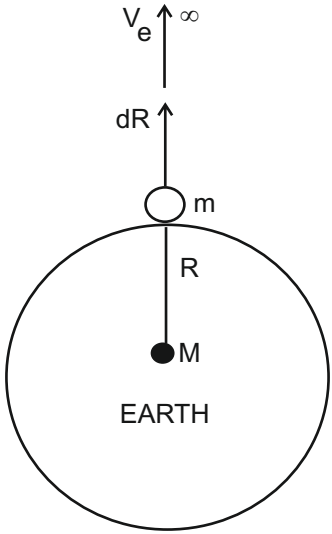
Orbital velocity (V_o)

In order to put a satellite into the orbit around the earth, the satellite must be projected to the particular height and then it must be turned in a direction perpendicular to the line from the centre of the earth so that it moves in an orbit around the earth.

The velocity of the satellite along its orbit around the earth is called orbital velocity.

Expression for Escape Velocity (V_e) :

Consider a body of mass m which is to be projected with escape velocity V_e from the surface of the earth. If the body is placed on the surface of the earth, then



The weight of the body = mg ...(1)

Let M be the mass of the earth and R its radius. According to Newton's law of gravitation,

The gravitational force, $F = \frac{GMm}{R^2}$ ...(2)

where G is a constant known as gravitational constant. The gravitational force on a body in the earth's atmosphere is also equal to the weight of the body. Equating the eqns. (1) and (2)

$$\frac{GMm}{R^2} = mg$$

$$GM = gR^2$$

Since V_e is the escape velocity given to the body.

The given kinetic energy $= \frac{1}{2} mV_e^2$ .....(3)

This kinetic energy is converted into workdone to escape the body from gravitational pull.

If the body moves a distance dR in vertical direction against the force F, then, Work = Force X distance

$\therefore$ Work done by the body = F dR

$$= \frac{GMm}{R^2} \times dR$$

In order to escape the body from the gravitational pull, the work done by the body to move from the distance R to infinity (the boundary of the gravitational field) is given by

$$W = \int_R^{\infty} \frac{G\ M\ m}{R^2}\ dR \qquad (4)$$

$$W = \frac{GMm}{R}$$

$$\frac{1}{2} m V_e^2 = \frac{GMm}{R}$$

Equating the eqns. (3) and (4).

$$V_e = \sqrt{\frac{2GM}{R}}$$

$$\text{Here, } GM = gR^2$$

$$\therefore V_e = \sqrt{\frac{2gR^2}{R}}$$

$\therefore$ The Escape velocity $V_e = \sqrt{2gR}$

Expression for orbital velocity of a satellite :

Consider a satellite of mass m is placed on the surface of the earth.

The weight of the satellite = mg ...(1)

Let M be the mass of the earth, and R its radius. According to Newton's law of gravitation,

$$\text{The gravitational force } F = \frac{GMm}{R^2} \qquad (2)$$

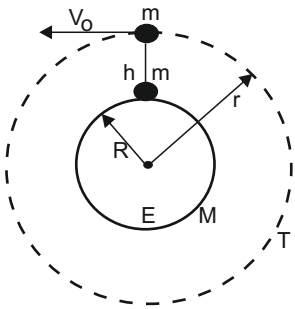
where G is a constant known as gravitational constant.

The gravitational force on the satellite is equal to its weight. Equating the eqns. (1) and (2).

$$\frac{GMm}{R^2} = mg \qquad \therefore GM = gR^2$$

The satellite is to be projected vertically upto a particular height h, after it must be turned in a perpendicular direction, then the satellite revolves around the earth in a circular orbit of radius r, with an orbital velocity of V_0.

The centripetal force, $F = \frac{mV_0^2}{r}$ ...(3)



The necessary centripetal force for circular motion of the satellite is given by the gravitational force. Hence, equating the equations (3) and (2)

$$\frac{mV_0^2}{r} = \frac{GMm}{r^2}$$

$$\therefore V_o = \sqrt{\frac{GM}{r}} = \sqrt{\frac{gR^2}{r}} \qquad (\because GM = gR^2)$$

The orbital velocity of the satellite, $V_o = \sqrt{\frac{gR^2}{R+h}}$ $(\because r = R + h)$

Note: When the satellite is launched in near earth orbit which is 200 km to 300 km , h is small when compared to R so that, R + h = R. Then

$$V_0 = \sqrt{gR}$$

Expression for period of Revolution

Time taken by the satellite to complete one revolution round the earth is called period of revolution.

$$\text{Period} \quad T = \frac{\text{Circumference of the orbit}}{\text{Orbital Velocity}}$$

$$= 2\pi\,(R + h)\sqrt{\frac{(R + h)}{gR^2}}$$

$$T = 2\pi\sqrt{\frac{(R + h)^3}{gR^2}}$$

$$T = \frac{2\pi r}{v_o} \quad \text{here r = radius of the orbit} = R + h$$

$$= \frac{2\pi\,(R + h)}{\sqrt{\frac{gR^2}{(R + h)}}} \qquad \left(\because V_0 = \sqrt{\frac{gR^2}{R + h}}\right)$$

If h is very small when compared to R,

$$R + h = R, \text{ then period } T = 2\pi\sqrt{\frac{R^3}{gR^2}}, \qquad \therefore T = 2\pi\sqrt{\frac{R}{g}}$$

Geo – Stationary Satellite

A geo-stationary satellite is a particular type used in television and telephone communications. A number of communication satellites, which appear to remain in fixed position at a height of 36,000 km above the equator, are called synchronous satellites or geostationary satellites. Some television programmes or events occurring in other countries are often transmitted live with the help of these satellites.

The orbit at a height of 36,000 km above the equator, on which satellites are revolving, is called geosynchronous orbit. In this orbit, the satellite takes 24 hours for revolving round the earth once.

For a satellite to appear fixed at a position above a certain place on the Earth, its orbital period around the earth must be exactly equal to the rotational period of the earth about its axis. As the relative angular velocity of the earth and that of satellite, which is revolving from west to east over the equator, are identical, the satellite appears stationary to an observer on the earth.

The ground-based transmitting antenna, which is directed towards the satellite, can operate effectively without need for expensive equipment to track the satellite's motion. This implies enormous savings. TV waves originating from the ground-based station are re-transmitted from the satellite and are received at the destination. As the geostationary satellite can 'see' only one-third of the earth's surface, atleast three such satellites are required to cover the entire globe.

Polar Satellites

The polar satellites revolve around the earth in a north-south orbit passing over the poles as the earth spins about its north-south axis.

The Polar satellites positioned nearly 500 to 800 km above the earth travels from pole to pole in 102 minutes. The polar orbit remains fixed in space as the earth rotates inside the orbit. As a result, most of the earth's surface crosses the satellite in a polar orbit. Excellent coverage of the earth is possible with this polar orbit. The polar satellites are used for mapping and surveying.

Uses of Artificial Satellites

The artificial satellites are launched for many purposes by different countries. The important uses of artificial satellite are

i. Collection of scientific data
ii. Weather monitoring
iii. Military Spying
iv. Remote sensing
v. Communication purpose – the satellite receives microwaves and TV signals from the earth and amplifies them and transmits them back to various stations on the earth.

Worked Problems

1. If the radius of the earth is 6400km and the acceleration due to gravity is $9.8 ms^{-2}$. Calculate the escape velocity

   Given R = 6400 km and g = $9.8\ ms^{-2}$

   Escape velocity $V_e = \sqrt{2gR} = \sqrt{2x9.8\ x\ 6400 x\ 10^3}$

   $V_e = 11.2$ km per second

2. A satellite is revolving round the earth at a distance of 182 km from the surface of the earth. The radius of the earth is 6371 km and g is 9.81 ms^{-2}. Calculate the orbital velocity of the satellite.

   Given; $g = 9.81\ ms^{-2}$, $R = 6371 \times 10^3$ m, $h = 182 \times 10^3$ m

   $(R+h) = (6371 + 182)\ 10^3 = 6553 \times 10^3$ m

   $$V_o = \frac{gR^2}{(R+h)} = \sqrt{\frac{9.81\ x\ (6371 \times 10^3)^2}{6553\ x\ 10^3}}$$

   $V_o = 7795\ ms^{-1}$ (or) $7.795\ kms^{-1}$

3. An artificial satellite revolves around the earth at a distance of 3400 km. Calculate the period of revolution. Radius of the earth R = 6400 km, $g = 9.8\ ms^{-2}$

Given

$$R = 6400 \times 10^3\ m$$

$$h = 3400 \times 10^3\ m$$

$$g = 9.8\ ms^{-2}$$

$$T = 2\pi \sqrt{\frac{(R+h)^3}{gR^2}}$$

$$T = 2\pi \sqrt{\frac{(6400 \times 10^3 + 3400 \times 10^3)^3}{9.8 \times (6400 \times 10^3)^2}}$$

$$= 2\pi \sqrt{\frac{(9800 \times 10^3)^3}{9.8 \times (6400 \times 10^3)^2}}$$

$$= 2\pi \sqrt{\frac{9.41192 \times 10^{20}}{4.01408 \times 10^{14}}}$$

$$= 2\pi \sqrt{2.3447 \times 10^6}$$

$$= 2 \times 3.14 \times 1.53125 \times 10^3$$

$$= 9.616 \times 10^3\ \text{second}$$

QUESTIONS

Part – A

1. Define inertia
2. Define rigid body
3. Define moment of inertia of a particle
4. Define moment of inertia of a rigid body
5. Define radius of gyration
6. Define angular momentum
7. State the law of conservation of angular momentum
8. State Newton's I law of gravitation
9. State Newton's II Law of gravitation
10. Define mass of a body
11. Define weight of a body

12. What is a satellite?
13. Define escape velocity
14. Define orbital velocity
15. Define period of revolution of a satellite
16. Give any two uses of artificial satellites.

Part – B

1. Derive an expression for the moment of inertia of a rigid body about an axis.
2. Derive an expression for the kinetic energy of a rigid body rotating about an axis.
3. Derive an expression for the angular momentum of a rigid body rotating about an axis.
4. Obtain an expression for the acceleration due to gravity on the surface of the earth.
5. Obtain an expression for the variation of acceleration due to gravity with altitude.
6. Explain the concept of weightlessness.
7. Derive an expression for the escape velocity from the surface of the earth
8. Derive an expression for the orbital velocity of a satellite.
9. Derive an expression for the period of revolution of a satellite
10. Write notes on Geo-stationary and Polar satellites.

Exercise Problems

1. Find the escape velocity at the surface of the moon, given that the radius of moon is 2×10^6 m and acceleration due to gravity on the surface of moon is $1.69\ ms^{-2}$.
2. A satellite is revolving in circular orbit at a height of 800 km from the surface of the earth. Calculate the orbital velocity. The radius of the earth is 6400 km and $g = 9.8\ ms^{-2}$
3. A satellite is revolving in circular orbit at a height of 1200 km from the surface of the earth calculate the period of revolution. Radius of the Earth is 6400 km and $g = 9.8\ ms^{-2}$

Brain teaser

1. The escape velocity from the surface of the earth is 11.2 kms^{-1}. Find the escape velocity from the surface of another planet where mass and diameter are twice that of earth.
2. What is the acceleration due to gravity at a distance from the centre of the Earth, which is equal to diameter of the Earth ?.

UNIT - V

SOUND AND MAGNETISM

5.1 SOUND

Introduction

Sound is produced due to the vibrations of the body. These vibrations are transferred to the air medium and propagated in all directions in the form of waves. When the vibrational sound waves reach our ear, the diaphragm of the ear vibrates with equal vibrations produced by the body. Hence we are able to hear the sound by the sensation perceived by the nerves of the ear.

The number of vibrations made in one second is known as frequency of the sound. It is expressed in hertz (Hz). The range of the frequency between 20 Hz and 20,000 Hz is the audible range, Human ears cannot respond to the sound below and above this range. In this sense, all vibrating bodies cannot produce audible sound. The vibrations of frequency below 20 Hz are called infrasonic and above 20,000 Hz are called ultrasonic.

Sound is a mechanical wave and hence it requires a medium to propagate. So we can't hear the sound in vacuum. It travels with the velocity of 330 ms^{-1} in air. Sound waves are reflected and refracted like light waves.

Wave motion:

When a stone is thrown on a pond of water, ripples spread out in all directions on the surface of water. The stone disturbs the water medium at one place but the disturbance is transferred in all directions continuously. This continuous movement of the disturbance is called a wave.

If a wave passes in a medium, the particles of the medium vibrate about their mean position. The particles do not move along with the wave, only the vibrations are transferred from one particle to adjacent particle of the medium in the form of energy.

There are two types of wave motion. They are

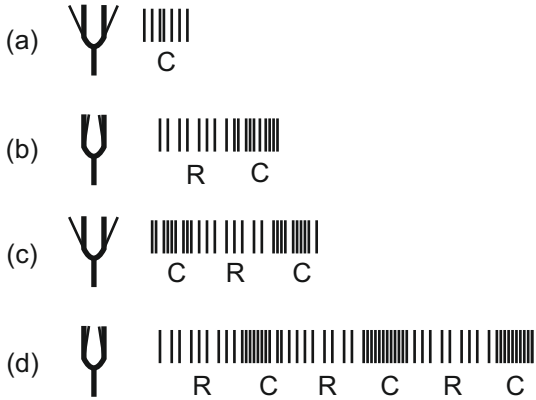
1) Longitudinal wave motion and
2) Transverse wave motion

1) Longitudinal wave motion:

If the particles of the medium vibrate parallel to the direction of propagation of the wave, the wave is known as longitudinal wave.

Examples:

1. The propagation of sound in air
2. The propagation of sound in gas
3. The propagation of sound inside the liquid



The longitudinal waves travel in a medium in the form of compressions and rarefactions. The place where the particles of the medium crowded together are called compressions and the places where the particles spread out are called rarefactions.

The compressions and rarefactions produced by a vibrating tuning fork are as shown in the figure. When the prong (arm) of the fork moves to the right, it compresses the medium in front of it to form compression. Meanwhile the prong returns to the left, a temporarily vacuum is created there. To fill it, the particles of the medium spread out in that place to form a rarefaction.

Thus as the prong of the fork vibrates to and fro, alternate compressions and rarefactions are transmitted in the medium. As a

result, the particles of the medium simply move back and forth about their mean position parallel to the direction of the propagation of the wave.

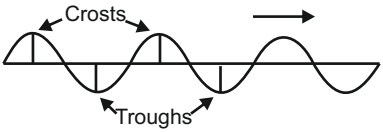
2) Transverse wave motion:

If the particles of the medium vibrate perpendicular to the direction of propagation of the wave, the wave is known as transverse wave.

Examples :

1. Ripples travelling on the water surfaces.
2. Waves travelling along a rope.
3. Other waves like light waves,heat radiations, radio waves etc.

The transverse waves travel in a medium in the form of crests and troughs. The points where the particles of the medium displaced maximum in the upward direction are called crests. The points where the particles displaced maximum in the downward direction are called. troughs



The crests and troughs produced by the transverse wave motion are as shown in the figure. In transverse wave, alternate crests and troughs are transmitted in the medium. As a result, the particles of the medium move up and down about their mean position perpendicular to the direction of propagation of the wave.

Distinction between Transverse and Longitudinal Waves

Transverse Wave	Longitudinal Wave
1. It is a wave motion in which the particles of the medium are vibrating perpendicular to the direction of propagation	It is a wave motion in which the particles of the medium are vibrating parallel to the direction of propagation.
2. Alternate crests and troughs are formed	Alternate compressions and rarefactions are formed.

Transverse Wave	Longitudinal Wave
3.Transverse waves can travel through solids and on liquid surfaces.	Longitudinal waves can travel through any medium whether solid, liquid or gas.
4.Transverse waves can be reflected, diffracted and polarized.	Longitudinal waves cannot be polarized.

Progressive Waves:

If a wave travels continuously in a medium without any disturbance, then the wave is said to be progressive wave. Longitudinal waves and Transverse waves are two types of progressive waves and they can travel continuously in any medium if there is no obstruction.

Amplitude:

When sound wave propagates in a medium, the maximum displacement of the vibrating particles of the medium from their mean position is called amplitude.

Wavelength (λ) :

The wavelength is the distance between two consecutive particles of the medium which are in the same state of vibration.

It is also defined as the distance travelled by the wave during the time the vibrating particle completes one vibration.

In longitudinal waves, the wavelength is the distance between two successive compressions or rarefactions. In transverse waves, the wavelength is the distance between two successive crests or troughs.

Period (T):

The time taken by the vibrating particle to make one vibration is called period.

Frequency (n):

The frequency is the number of vibrations made by the vibrating particle in one second.

Velocity (v):

The distance travelled by the sound wave in one second is known as velocity of sound.

Relation between Wavelength, Frequency and Velocity of a Wave :

Let n be the number of vibrations made by the vibrating particle in one second. It is also known as its frequency.

Time taken for one vibration = period (T) = 1/n.

Let λ be the wavelength of the wave produced

Velocity of the wave is the distance through which the wave advances in the medium in one second

$$\therefore \text{Velocity of wave motion,.} V = \frac{\text{distance travelled}}{\text{time taken}}$$

$$V = \lambda/T = \lambda/(1/n) = \lambda n$$

$$\therefore V = n\lambda$$

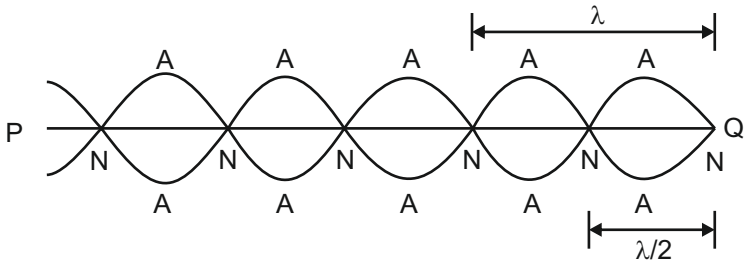
Stationary Waves:

If a progressive wave travelling in a medium meets the surface of an obstacle, it is reflected. The reflected wave is superimposed on the incident wave to form a new type of wave called stationary wave.

Also, when two identical waves having equal wavelength and amplitude travel in opposite directions they superimpose on each other forming stationary wave.

A stationary wave formed by a vibrating string is as shown in the figure. Consider a string P Q fixed at the end Q and it vibrates up and down at the free end P. Then a transverse wave is setup and it proceeds towards the fixed point Q and gets reflected back to the end P. Now the stationary wave is formed in the string.

At certain points of the medium, the displacement due to the two waves cancel each other and those points remain at rest. Such points are called nodes (N). At certain other points there is maximum displacement. Such points are called antinodes (A). The distance between two successive nodes or antinodes is $\lambda / 2$.



The distance between a node and the next antinode is $\lambda / 4$

The longitudinal waves also produce the stationary waves.

VIBRATIONS

Free Vibrations :

The vibrations of any body with its natural frequency are called free vibrations.

When a body is set in vibration and left free, it executes vibrations. The frequency depends upon the dimensions and elastic constants of the body. Such vibrations are called free vibrations and the frequency of vibration is known as the natural frequency.

If a tuning fork is set in vibration, it vibrates with its own frequency. Such vibrations are called free vibrations or natural frequency.

Forced Vibrations :

The vibrations of a body with a frequency induces vibrations on another vibrating agent are called forced vibrations.

Suppose a vibrating tuning fork is placed with its stem on a table, the vibrations of the fork are impressed on the table and the table is forced to vibrate. The vibrations set up on the table are called forced vibrations.

Resonance :

When the forced vibrations given on the body is equal to its natural frequency of vibrations, the body vibrates with maximum amplitude. This phenomenon is called resonance.

When a vibrating tuning fork is kept on a table, the table is forced to vibrate with the frequency of the tuning fork. If the natural frequency of the table is equal to the frequency of the tuning fork, the table vibrates with its natural frequency and hence resonance occurs.

Laws of vibration in stretched strings:

I Law : The frequency of vibrating string is inversely proportional to its length, when the tension and linear density of the string are kept constant.

$$n \propto \frac{1}{l}$$

II Law : The frequency of vibration is directly proportional to the square root of the tension, when the length and linear density of the string are kept constant.

$$n \propto \sqrt{T}$$

III Law : The frequency of vibration is inversely proportional to the square root of the linear density of the string, when the tension and length of the string are kept constant.

$$n \propto \frac{1}{\sqrt{m}}$$

According to above laws,

$$n \propto \frac{1}{l} \cdot \sqrt{\frac{T}{m}} \qquad \text{(or)} \qquad n = k\frac{1}{l} \cdot \sqrt{\frac{T}{m}}$$

Where k – is a constant and its value is equal to ½.

$$\therefore n \propto \frac{1}{2l}\sqrt{\frac{T}{m}}$$

$$\text{If } T = Mg, n = \frac{1}{2l}\sqrt{\frac{Mg}{m}}$$

$$n = \frac{1}{2}\sqrt{\left(\frac{M}{l^2}\right)\frac{g}{m}}$$

Note: The linear density,

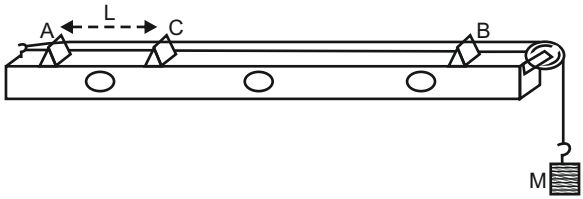
$$m = \frac{\text{mass}}{\text{length}} = \frac{\text{Volume} \times \text{density}}{\text{length}} = \frac{\pi r^2 l \rho}{l} = \pi r^2 \rho$$

Sonometer :

The phenomenon of resonance is used in sonometer. In sonometer, the frequency of a tuning fork is equal to the frequency of the vibrating string. Here resonance takes place and the string vibrates with maximum amplitude.

Experimental determination of frequency of a tuning fork using sonometer:

The sonometer consists of a hollow wooden box. A nail is fixed at one end and a smooth pulley is fixed at the other end of the box. One end of a sonometer string is tied to the nail and other end of the string passes over the smooth pulley. The free end is attached to the weight hanger. A, B and C are three knife edges placed on the box under the string. A, B are fixed and C is movable.



A suitable tension (T = Mg) is applied to the string. A small paper rider is placed on the string in between A and C. The tuning fork of frequency 'n' is excited with a rubber hammer and its stem is kept on the sonometer box. Now the string is made to vibrate. The movable knife-edge C is adjusted such that the string vibrates with the same frequency of the fork. At that time, the paper rider placed on the string between A and C, is violently thrown off from the string. Now the vibrating length of the string AC= l is measured.

Let r be the radius of the string measured by using screw gauge and 'ρ' be the density of the material of the wire, then

The linear density, $m = \pi r^2 \rho$

The experiment is repeated by changing the value of tension (load). The readings are tabulated.

Sl.No.	Load (M)	Vibrating length AC = l	l^2	$\frac{M}{l^2}$

Mean :

The frequency of the tuning fork, $n = \frac{1}{2}\sqrt{\left(\frac{M}{l^2}\right)\frac{g}{m}}$

The mean value of $\frac{M}{l^2}$ is substituted in the above formula and the frequency of the tuning fork 'n' is calculated

ULTRASONIC:

The sound waves above the frequency of 20000 Hz (20 KHz) are known as ultrasonic waves. Ultrasonic waves are inaudible to humans, because. their high frequencies are unable to vibrate the human ear

drum. The ultrasonic waves are high frequency sound waves smaller wave length. Its wave length at room temperature is 0.0175 m. Since they are sound waves, they require a material medium to travel and have most of the properties of sound waves. In addition to this, the ultrasonic waves are having high energy and it helps in large number of applications in engineering and medical fields.

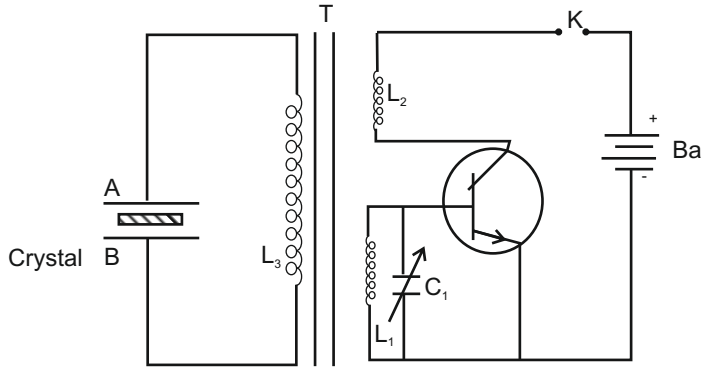
The ultrasonic waves are usually generated by the application of magnetostriction effect or piezo electric effect. The piezo electric generator is more efficient than the magnetostriction generator.

Production of ultrasonic waves – Piezo electric method:

In this method, the ultrasonic waves are produced by using the principle of piezo electric effect. According to this effect, if a mechanical pressure is applied to one pair of opposite faces of certain crystals like quartz, cut with their faces perpendicular to its optic axis, the other pair of opposite faces develop equal and opposite electrical charges. The inverse of piezo electric effect is also true. According to this, if an AC-voltage is applied to one pair of opposite faces of the crystal, alternative mechanical elongations and contractions are produced in the other pair of opposite faces of the crystal. Inverse piezo electric effect is used in this method to vibrate the crystals and to produce ultrasonic waves.

The experimental arrangement of piezo electric oscillator is shown in the figure. It consists of a common emitter transistor circuit, a transformer (T) and two metal plates A and B. In transformer, three inductive coils are used, L_1, L_2 are the primary coils and L_3 is the secondary coil. The coil L_1 is connected to the variable capacitor C_1 to form a tank circuit in which frequency is generated. The coil L_2 is connected to the collector of the transistor. The base of the transistor is coupled to the tank circuit. The coil L_3 is connected to the parallel plates A and B. A quartz crystal is placed in between them.

When the circuit is switched on, current starts to flow in the tank circuit and setting up oscillations. These oscillations are mutually inducted in the secondary coil L_3. The crystal is now under high frequency alternating voltage and it starts vibrating under inverse piezo electric



effect. This causes a back emf to be formed across L_2. This emf is amplified by the transformer and fed back into the tank circuit, where the oscillations get sustained. The capacitor C_1 is varied till the frequency of oscillations reaches with the natural frequency of the crystal. Due to resonance the crystal vibrates with large amplitude. The vibrations of the crystal produce high power ultrasonic waves in the surrounding air.

Properties of Ultrasonic waves:

1. The ultrasonic waves are high frequency sound waves.
2. They are having smaller wavelength.
3. They produce heating effect when passes through the medium.
4. They get reflected, refracted and absorbed by the medium similar to the ordinary sound waves.
5. They act as catalytic agents to accelerate chemical reactions.
6. They produce stationary wave pattern in the liquid while passing through it.

Applications of ultrasonic waves:

Ultrasonic waves have a large number of practical applications. Some important applications are given below.

1. The ultrasonic waves are used to find the depth of the sea, distance and direction of submarine and depth of the rocks in the sea.
2. They are used in non-destructive testing to detect cracks in the materials, welding, castings etc.

3. They are used in the ultrasonic microscope to detect concealed objects.
4. They are used to heat the substance.
5. They are used to bore holes in steel and other hard metals.
6. They are used to accelerate chemical reactions.
7. They are used to solder the aluminium. In ordinary soldering method aluminium cannot be soldered.
8. They are used in the mixing of alloys of different compositions.
9. They are broadly used in medical field such as to detect tumours, abnormal growth, cancer, broken teeth, relieving neuralgic pains, head ache, body massage action and also used in bloodless surgery.
10. They are used in the sterilization of water and milk.

ACOUSTICS OF BUILDINGS:

Echo : The first reflected sound is known as echo. The sound produced by a source is propagated continuously in a medium if there is no disturbance. But if it meets the hard surface of an obstacle, it is reflected. The clear echo depends upon the following factors.

1. Good reflector of sound
2. Maximum surface area of the reflector and
3. The distance of the reflector from the source of sound.

Reverberation : The sound produced in a hall suffers multiple reflections before it becomes inaudible. As a result of these reflections, the listener continues to receive sound, even if the source of sound is cut off. This prolonged reflection of sound in a room even after the sound source has been stopped is called reverberation. It is the persistence of sound due to multiple reflections from the walls, floor and ceiling of a hall. The reverberation is also called multiple echoes. In a room, the walls, floor and other flat surfaces reflect sound with a small loss of energy.

Reverberation time: If a building is to be acoustically correct, its reverberation time must be in optimum level. It should not be too long or too short. if it is too short, then the room becomes dead in sound aspect. If it is too long, then the reverberation will be there inside the building for long duration. The reverberation produces continuous sound with decreasing intensity upto a particular time after that it disappears. This time is known as reverberation time.

The reverberation time is defined as the time taken by the sound to fall from its original intensity to one millionth of its original intensity.

Sabine formula : Sabine derived an equation for the reverberation time.

Where V is the volume of the hall, α is the coefficient of absorption of each reflecting surface present in the hall and A is the area of the each

$$T = \frac{0.16V}{\alpha A} \quad \text{second}$$

sound absorbing surface present in the hall.

Coefficient of absorption of sound energy:

The co-efficient of absorption of sound energy of any surface is defined as the ratio of the sound energy absorbed by the surface to the total sound energy incident on the surface.

Let α be the coefficient of absorption of sound energy of a surface, then

$$\alpha = \frac{\text{The sound energy absorbed by the surface}}{\text{The total sound energy incident on the surface}}$$

Acoustics of Buildings (Architectural acoustics):

The term 'Acoustics of building' describe the production, transmission and reception of sound inside the building. The following points should be taken into consideration for the acoustic design of the buildings, auditorium, cinema theatres etc.

1. The sound heard by the audience should be sufficiently loud in any part of the hall.
2. The quality of the speech and music should not be changed any where inside the hall.
3. There should not be focusing of sound due to walls and ceiling, in any part of the hall.
4. There should not be any vibrations due to resonance.
5. There should not be any other noise from other sources, both from outside the hall and from with in the hall.

Two more important factors should also be considered for good acoustic design of the buildings.

1. Echo and 2. Reverberation

1. Echo : The direct sound from the source and the reflected sound (echo) from the walls produce confusion in certain buildings. A hall with large number of open windows is free from the defect. Echoes can be eliminated by making the walls rough. But in the case of musical hall, however echoes are desirable, to a certain extent.

2. Reverberation : The Reverberation is the prolonged reflections of sound from the walls, floor and ceiling of a hall. The sound produced in the hall undergoes multiple reflections before it becomes inaudible. As a result the clarity of the successive speech is affected. Due to this reason, the reverberation time should be optimum to hear the clear sound in the hall.

To minimize this defect, Sabine derived an equation for the reverberation time,

Where V is the volume of the hall, α is the coefficient of absorption of

$$T = \frac{0.16V}{\alpha A} \text{ second}$$

each reflecting surface present in the hall and A is the area of the each sound absorbing surface present in the hall.

In the above Sabine's equation, T will be minimized by increasing the value of α. So the reverberation is minimized by covering the inner surfaces of the hall using absorption materials like carpets, wall screen, porous tiles etc.

The reverberation time value depends on the use for which the building is designed. The acceptable limit for reverberation time is

For speech, 0.5 s

For music, between 1.0 and 2.0 s

For small theatres, between 1.0 and 1.5 s

For larger theatres, up to 2.3 s

Noise Pollution:

The unwanted sounds which are dumped into the atmosphere, thus producing a nuisance and adverse effect on the health of human beings, are known as noise pollution. Noise pollution leads to severe health

problems by creating either physical or mental problems. As a result, it affects the working efficiency, personal comfort, and in some cases it may lead to industrial accidents. There are varieties of noises such as domestic noise, traffic noise, aircraft noise, etc. Even though the sources of noise are numerous, the types of sources of noise are generally classified into two types.

(i) Industrial noises and (ii) Non- industrial noises

The noises which are produced due to the movements of car, motor truck, motor cycle, aircraft, machines, explosions, etc. are known as industrial noises. The noises which are produced due to the loudspeaker, construction work, radio, etc. are known as non-industrial noises. The industrial and non-industrial noises are generally measured by using the sound pressure level in decibel (dB).

Some important sound pressure level for domestic and industrial noise is listed below.

Source of noise.	Sound pressure level (dB)
Garden	20
Library	30
Ringing alarm clock	80
Heavy traffic	90
Electric generator	76
Concrete mixer	85
Power saw	90
Noisy factory	100
Threshold of pain	140

Noise control in Machines:

In industry, the noise pollution produced by the machines is to be acceptable to the working environment for the employees. When the noise level (dB) is above the acceptable level, it will affect the workers efficiency, comfort, and sometimes may lead to industrial accidents. Therefore, one has to take necessary care for the design of machine and work place for quieter operations. The following are the some of the general principles to be followed in controlling the noise pollutions in machines:

1. The impacting parts of the machines must be enclosed within enclosures.
2. All the enclosures should have high sound absorbing materials.
3. Care must be taken to select the sound absorbing materials to suit the environmental conditions.

4. The vibrating machines must be dynamically balanced.
5. The rotating or impacting machines must be fixed using a fixed bed.
6. The connections such as electricity, gas, air etc. should be provided within the vibration decouplers around the machine.
7. The water connections should be provided through pressure release chambers.
8. Engines like internal combustion should be properly silenced.
9. All the machines should be kept in a large work area which includes good sound absorbing materials as an enclosure.
10. The machine should be isolated from the offices, show rooms etc. Therefore, the noise pollution due to the machines will not have any influence on office/show rooms.

The other source of noise pollution in machines is the vibration of the machines. The impact noise produced by the machine under operating conditions will be transferred into the building in the form of vibration. These vibrations passes throughout the building and hence, the problem will be extended to the remote parts of the building. This can be reduced to a greater extent by providing discontinuities in the construction of the building.

Worked Problems:

1. A wire 50 cm long and of mass 6.5×10^{-3}kg is stretched so that it makes 80 vibrations per second. Find the stretching tension.

$$m = \frac{\text{mass}}{\text{length}} = \frac{6.5 \times 10^{-3}}{0.5} = 13 \times 10^{-3}\ \text{kgm}^{-1}$$

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} \text{ or } n^2 = \frac{1}{4l^2}\frac{T}{m}$$

$\therefore$ Tension $T = 4l^2m^2n = 2 \times 0.5 \times 0.5 \times 13 \times 10^{-3} \times 80 \times 80$

$= 83.2$ N

2. The density of a sonometer wire of radius 0.3mm is 7800 kgm^{-3}. Find its linear density.

Linear density $m = \pi r^2 \rho$

$m = 3.14 \times (0.3 \times 10^{-3})^2 \times 7800$

$= 2204.28 \times 10^{-6}$

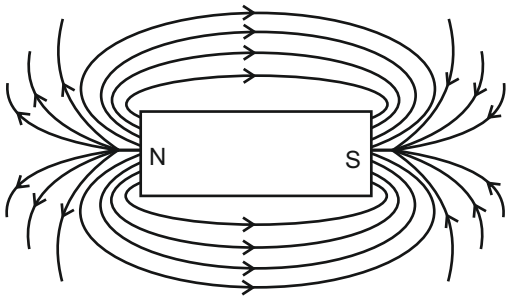
$= 2.204 \times 10^{-3}$ kg m^{-1}

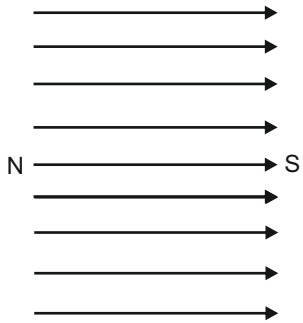
5.2 MAGNETISM

The word 'magnetism' is derived from the name of a dark brown coloured ore called magnetite found in Magnesia. The ore possesses the property of attracting small pieces of iron. The ore magnetite available in nature is called as natural magnet. Artificial magnets also can be prepared from iron or steel materials. Iron materials are mostly used to prepare electromagnets and temporary magnets whereas the steel materials are used to prepare permanent magnets.

Magnetic field:

The space around the magnet in which the magnetic lines of force act is called the magnetic field. The direction of magnetic field at a point is given by the direction of the force acting on the north pole of a magnetic needle placed at the point. If the magnetic lines of force formed are parallel, the field is called uniform magnetic field and have equal strength at all the points.





Coulomb's Inverse Square Law:

The force of attraction or repulsion between two poles is

I) directly proportional to the product of the two poles,

ii) Inversely proportional to the square of the distance between the poles.

Let the two poles of strength P_1 and P_2 are placed in air (or) vacuum at a distance d. The force of attraction or repulsion between the poles

$$F \propto \frac{P_1P_2}{d^2} \text{ (or) } F = k\frac{P_1P_2}{d^2}$$

where k is a constant and $k = \frac{1}{4\pi\mu_o}$

μ_0 is permeability of the free space

$$\therefore F = \frac{1}{4\pi\mu_O}\ \frac{P_1P_2}{d^2}$$

$$\mu_o = 4\pi \times 10^{-7} \text{ henry / metre}$$

$$F = \frac{1}{4\pi \times 4\pi \times 10^{-7}} \times \frac{P_1P_2}{d^2}$$

$$F = \frac{10^7}{16\pi^2}\ \frac{P_1P_2}{d^2}$$

If $P_1 = P_2 = 1$ and $d = 1m$

Then, $F = \frac{10^7}{16\pi^2}$ newton

Unit Pole :

Unit pole is defined as that pole which is placed at a distance of 1m in air (or) vacuum from an equal and similar pole repels it with a force of $\frac{10^7}{16\pi^2}$ newton

Pole Strength (P) :

The pole strength of a magnet is defined as the force acting on the pole when it is placed in a uniform magnetic field of unit intensity.

Let P be the pole strength placed in a uniform magnetic field of intensity H, Force acting on the pole, F = HP. If H = 1, then F = P

The unit of pole strength is ampere metre (Am.)

Magnetic Induction (B) :

The magnetic induction or magnetic flux density is defined as the total number of magnetic lines of force passing normally, through unit area of cross section.

The unit of magnetic induction is weber/metre².

Intensity of magnetic field (H) :

The intensity of the magnetic field at a point in a magnetic field is defined as the force experienced by a unit north pole placed at that point.

The unit of Intensity of magnetic field is ampere/metre (Am^{-1})

Magnetic permeability (μ) :

The magnetic permeability of the medium (material) is the ratio of the magnetic induction in the medium to the intensity of magnetic field

$$\text{Magnetic permeability} = \frac{\text{Magnetic induction}}{\text{Intensity of magnetic field}} \text{ i.e. } \mu = \frac{B}{H}$$

producing that induction.

The unit of magnetic permeability is weber/ampere-metre ($WbA^{-1}m^{-1}$)or henry/metre.

Magnetic moment (m) :

Magnetic moment of a magnet is defined as the moment of the couple acting on a magnet when it is placed perpendicular to a uniform magnetic field of unit intensity.

Consider a magnet of length 2l placed perpendicular to the uniform magnetic field of intensity H. If P is the pole strength of the magnet,
Force experienced by the poles

$F = HP$

If $H = 1$, unit intensity of magnetic field, Force $F = P$

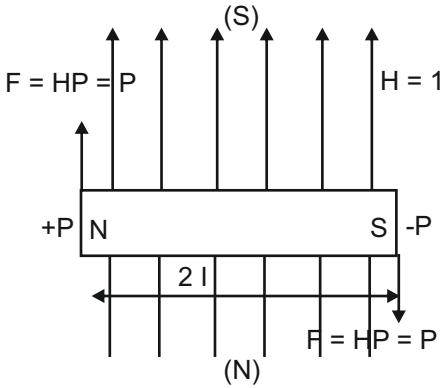
Two equal forces P and P acting on the magnet in opposite directions to form a couple.

$\therefore$ Moment of the couple $= P \times 2l$

i.e. Magnetic moment $M = 2\,l\,P$

Hence, the magnetic moment of a magnet can also be defined as the product of pole strength and the distance between the poles. But, the distance between the poles is approximately equal to the length of the magnet. So, the moment can be taken as the product of pole strength and length of the magnet.

The unit of magnetic moment is ampere metre² (Am^2)



Intensity of Magnetisation (M) :

Intensity of magnetisation of a magnet is defined as the magnetic moment per unit volume of the magnet.

Let m be the magnetic moment of the magnet having volume v, then

$$\text{Intensity of magnetisation} = \frac{\text{Magnetic moment}}{\text{Volume of the magnet}}$$

$$\text{i.e. } M = \frac{m}{v}$$

The unit of intensity of magnetisation is ampere/metre (Am^{-1})

Hysteresis :

In electrical method, a magnetic material can be magnetised by keeping it inside an insulated coil (solenoid) through which a current is passed. Before passing the current, the magnetising field around the coil is zero. Then there is no magnetism induced in the material. If the magnetising field H is gradually increased by increasing the current **'I'** the intensity of magnetisation induced in the material also increases upto a particular value. After that the intensity of magnetisation is not increased even though the magnetising field is increased. Now the material is said to be saturated.

If the magnetising field is gradually decreased to zero value, the intensity of magnetisation in the material also decreases but not to zero value. There is a tendency in the material to retain some amount of magnetism. Then, if the field is increased in the reverse direction from zero value, for a particular value the retained magnetism in the material is removed completely. Further increasing the field, the material attained the saturated value of magnetism in the reverse direction and so on.

Definition : The lagging in intensity of magnetisation behind the magnetising field is known as hysteresis.

A graphical curve which represents the variation in the intensity of magnetisation (M) with magnetic field intensity (H) is known as hysteresis loop (M-H curve).

Retentivity, Coercivity and magnetic saturation :

1. Retentivity or residual magnetism :

Retentivity or residual magnetism is the amount of intensity of magnetisation retained in the material after removing the magnetising field.

2. Coercivity or coercive force :

Coercivity or coercive force is the amount of magnetising field applied in the reverse direction to remove the residual magnetism completely from the material.

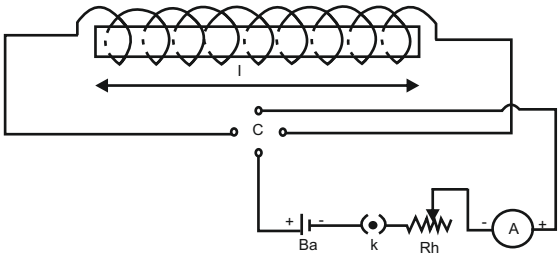
3. Magnetic saturation :

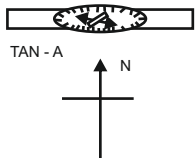
When the magnetising field is increased, the intensity of magnetisation induced in the material also increases up to a particular value. After that the intensity of magnetisation is not increased even though the magnetising field is increased. Now the material attains the saturation value of intensity of magnetisation.

Experiment to draw the Hysteresis loop:

The experimental arrangement is shown in the figure. A long solenoid is connected in a circuit. The direction of the current can be reversed by using a commutator C. The given specimen in the form of a rod is placed inside the solenoid. A deflection magnetometer is placed in Tan-A position at a short distance along the axis of the rod. The deflection magnetometer is adjusted zero position.

The intensity of magnetic field H can be calculated by using the formula H = (N L) / L, where N is the number of turns in the solenoid, 'I' the strength of the current passing through the solenoid and L, the length of the solenoid. The value of I can be measured by using ammeter. The intensity of magnetisation M induced in the specimen can be calculated by using the formula $M = k \tan \theta / V$ where k is constant, θ is the deflection in the magnetometer and V is the volume of the magnet.





The strength of the current I is gradually increased in steps of 0.2A up to a required value. Every time the deflection in the magnetometer is noted. Then the values of H and the corresponding values of M are calculated. The current is decreased in steps up to zero value and again the corresponding values of H and M are calculated. The experiment is also repeated by passing the current in the reverse direction.

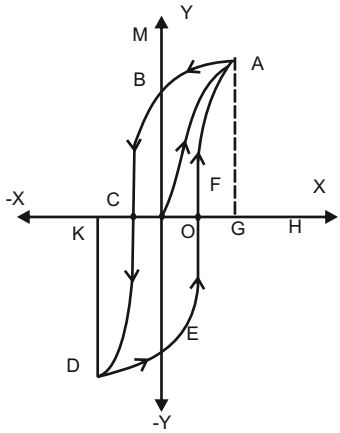
A graph is drawn by taking the values H along X-axis and M along Y-axis. A loop OABCDEFA is obtained as shown in the figure.

In the figure, when H is increased from zero to G, the value of M is increased from zero to A represented by OA. At the point A, the specimen reached the saturated value.

If H is decreased from G to zero, the value of M decreases from A to B, but not to zero. Now the specimen retains some amount of magnetism known as retentivity (OB).

When H is increased in the reverse direction from zero to C, the value M reaches zero value at a point C. The amount of H applied in the reverse direction to remove the residual magnetism is known as coercive force or coercivity (OC). Further repeating the process the remaining portion CDEFA is obtained. The closed loop ABCDEFA is called one cycle of hysteresis loop or M-H curve.

When the material is taken through a cycle of magnetisation, there is some expenditure of energy. This loss of energy dissipates in the form of heat in the specimen. The loss of energy is directly proportional to the area of the hysteresis loop.

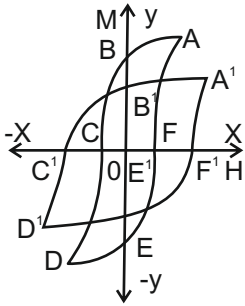


Selection of magnetic materials for permanent and temporary magnets (Uses of Hysteresis loops):

The hysteresis loops are very useful in the selection of magnetic materials for permanent and temporary magnets and other industrial purposes. The hysteresis loops for different materials are compared to one another and then the materials are selected for suitable purposes.

For example, let ABCDEFA be the hysteresis loop for soft iron and A' B' C' D' E' F' A' the hysteresis loop for steel. Here the area of the hysteresis loop for steel is more than that of soft iron. Therefore the loss of energy is more in steel than that in soft iron. Hence the quantity of heat emitted by steel is more than that by soft iron. For this reason soft iron is selected as a core materials for transformers, chokes, AC motors, dynamos, etc.

The retentivity of soft iron (OB) is more than that for steel (OB'). So, soft iron retains more magnetism than steel. But the coercivity for soft iron (OC) is less than the coercivity for steel (OC'). So the strength of the magnetic field needed to remove the residual magnetism in soft iron is less than in steel. That means it is easy to remove the residual magnetism in soft iron than steel. Hence steel retains the magnetism during long period. For the above reasons steel is used for permanent magnets and soft iron is used for temporary magnets and electromagnets.



QUESTIONS

Part - A

1. Define wave motion.
2. Define transverse wave motion.
3. Define longitudinal wave motion.
4. Define progressive wave.
5. Define amplitude of a wave.
6. Define wavelength of a wave.
7. Define period of wave motion.
8. Define frequency of a wave.
9. Define velocity of sound wave.
10. Define stationary wave.
11. Define free vibrations.
12. Define forced vibrations.
13. Define Resonance.
14. State any one of the laws of transverse vibrations in stretched strings.
15. What is the use of a sonometer?
16. What is ultrasonic?
17. Write any two properties of ultrasonic.
18. Write any two applications of ultrasonic.
19. What is an echo?

20. What is reverberation?
21. What is reverberation time?
22. Write sabine's formula.
23. Define co-efficient of absorption of sound energy.
24. State coulomb's Inverse Square Law.
25. Define Pole Strength.
26. Define Unit Pole.
27. Define magnetic induction.
28. Define intensity of magnetic field.
29. Define permeability.
30. Define magnetic moment of a magnet.
31. Define intensity of magnetisation.
32. Define Hysteresis.
33. Define Retentivity
34. Define coercivity
35. Define magnetic saturation.

Part – B

1. Explain transverse wave motion and longitudinal wave motion.
2. Distinguish between transverse and longitudinal wave motion.
3. Write short notes on stationary waves.
4. Explain the laws of transverse vibrations in a stretched string and obtain the expression for the frequency of vibration.
5. Describe how the frequency of a tuning fork is determined using a sonometer.
6. Explain the production of ultrasonic by piezo-electric method.
7. Explain the properties and applications of ultrasonic.
8. Write a note on acoustics of buildings.
9. Explain noise pollution and the methods of controlling industrial noise.

10. Describe the method of drawing hysteresis loop of a specimen using a solenoid.

11. Explain the uses of hysteresis loop.

Exercise Problems

1. A sonometer wire of 0.5 m long gives vibrations of 256 Hz when stretched with a load of 5 kg. Find the linear density of the material of the wire.

2. Find the frequency of sound produced by a string 25 cm long stretched by load of 5 kg. The linear density of the wire is 4.9×10^{-3} kgm^{-1}

3. A string 75 cm long and weighing 15 g produces a note of frequency 100 cycles per second on plucking. What is the tension in the string?

(Ans: 450 N)

4. A wire of 50 cm long and of mass 6×10^{-3} kg is stretched so that it makes 60 vibrations per second. Find the tension in the wire.

(Ans: 43.20 N)

5. The vibrating length of 0.75 m of a sonometer wire is unison with a tuning fork when stretched by weight of 5 kg. The linear density of the wire is 0.5×10^{-3} kg m^{-1}. Calculate the frequency of the tuning fork.

(Ans: 209 Hz)

6. A wire 50 cm long and of mass 0.6×10^{-3} kg is stretched by a tension of 4 kg.wt. When sounded, it is found to vibrate in 2 loops. Calculate the frequency of the note emitted by the wire.

(Ans: 361.Hz)

7. A wire 0.5 m long vibrates 100 times a second. If the length of the wire is shortened to 0.4 m and the stretching force is increased to 4 times its original value, what will be the new frequency?

(Ans : 250 Hz)

Brain Teaser

1. Thunder was heard 6 second after a flash of lighting was seen. If the velocity of sound is $345ms^{-1}$, calculate the distance at which flash occurred.
2. Two magnetic poles, one of which is twice stronger than the other repel one another with a force of $2x\ 10^{-5}$ N when kept separated at a distance of 20 cm in air. Calculate the strength of each pole.

FIRST SEMESTER

1004 ENGINEERING PHYSICS – I

MODEL QUESTION PAPER - 1

Time : 3 Hrs Max Marks : 75

PART- A

Marks 15 x 1 = 15

Note : Answer any 15 Questions.

1. Define unit.
2. Define derived quantities.
3. Write Parallelogram Law of forces.
4. Define moment of a force.
5. Write Hooke's Law.
6. Define Co-efficient of viscosity.
7. Define Terminal velocity.
8. Write any two practical applications of capillarity.
9. Define trajectory.
10. Define angular velocity.
11. Define angle of banking.
12. Define frequency.
13. Define rigid body.
14. Write law of conservation of angular momentum.
15. Define escape velocity.
16. Write any two uses of artificial satellites.
17. Define resonance.
18. What is ultrasonic?
19. Define intensity of magnetisation.
20. Define retentivity.

PART- B

Marks 5 x 12 = 60

Note : i) Answer all Questions choosing any two sub divisions from each question.

ii) All sub divisions carry equal marks.

I a) List the conventions followed in S I.

b) Derive expressions for the magnitude and direction of the resultant of two forces acting at a point with an acute angle between them.

c) Describe an experiment to determine the mass of the given body using principle of moments.

II a) Describe an experiment to determine the Young's modulus of the material of a beam by uniform bending method.

b) Derive Poiseuille's formula for the co-efficient of viscosity of a liquid by dimensional method.

c) A capillary tube of bore 0.5 mm is dipped vertically in water of surface tension 0.072 Nm^{-1}. Find the height of capillary rise.

III a) A missile is fired at an angle of 40° to hit a target situated at a distance of 100 km. Find the velocity of projection of the missile.

b) Derive an expression for the angle of banking of a curved path.

c) Show that simple harmonic motion can be obtained by the projection of a uniform circular motion on any diameter.

IV a) Derive an expression for the angular momentum of a rigid body rotating about an axis.

b) Derive an expression for the orbital velocity of a satellite.

c) Derive the expression for the variation of acceleration due to gravity with altitude.

V. a) Explain the production of ultrasonic using Piezo electric generator.

b) A sonometer wire is loaded with a mass of 2 kg. The linear density of the wire is 2×10^{-3} kgm^{-1}. When an excited tuning fork is placed on the sonometer box, the resonating length is found to be 15.4 cm. Find the frequency of the tuning fork.

c) Explain the method of drawing hysteresis loop of a specimen taken in the form of a rod, using a solenoid.

FIRST SEMESTER

1004 ENGINEERING PHYSICS – I

MODEL QUESTION PAPER - II

Time : 3 Hrs Max Marks : 75

PART- A

Marks 15 x 1 = 15

Note : Answer any 15 Questions.

1. Write the two supplementary quantities.
2. Derive the dimensional formula for force.
3. Define coplanar forces.
4. Define moment of a couple.
5. Define Poisson's ratio.
6. What is the significance of Reynolds number?
7. Write any two practical applications of viscosity.
8. Define angle of contact.
9. Define time of flight of a projectile.
10. What is the relation between linear velocity and angular velocity?
11. What is banking of a curved path?
12. Define simple harmonic motion.
13. Define radius of gyration.
14. Write the Newton's second law of gravitation.
15. What is the difference between mass and weight of a body?
16. Define orbital velocity.
17. Write the relation between wavelength, frequency and velocity of a wave.
18. Write any two applications of ultrasonic.
19. Define reverberation time.
20. What is coercivity?

PART- B

Marks 5 x 12 = 60

Note : i) Answer all Questions choosing any two sub divisions from each question.

ii) All sub divisions carry equal marks.

I a) Explain multiples and sub-multiples and the corresponding prefixes of units.

b) Describe an experiment to verify Lami's theorem.

c) Find the magnitude and direction of the resultant of two forces 3 N and 4 N acting at a point, if the angle between the forces is 60°.

II a) Explain the elastic behaviour of a material with the help of stress – strain curve.

b) Describe an experiment to determine the coefficient of viscosity of a high viscous liquid by Stokes' method.

c) Derive an expression for the surface tension of the liquid by capillary rise method.

III a) Show that the path of a projectile is a parabola.

b) Derive expressions for the normal acceleration and centripetal force acting on a body executing uniform circular motion.

c) An aeroplane travelling in a curved path with a speed of 500 kmph tilts through an angle of 30°, for safe negotiation. What is the radius of the curve?

IV a) Derive an expression for kinetic energy of a rigid body rotating about an axis.

b) Explain geo – stationary and polar satellites.

c) Assuming the average radius of the earth as 6380 km, find the escape velocity of a body from the surface of the earth.

V a) Describe an experiment to determine the frequency of a tuning fork using sonometer.

b) Explain noise pollution and the measures to control the noise in machines.

c) Explain the uses of hysteresis loop in the selection of magnetic materials.

FIRST SEMESTER

PRACTICAL-I

MICROMETER (SCREW GAUGE)

Experiment No.

Date:

Aim:

To measure the thickness of the given irregular glass plate, using a micrometer. To measure area of the glass plate using a graph sheet and to calculate the volume of the glass plate.

Apparatus required:

Screw gauge, graph sheet and given glass plate.

Formula:

Volume of the glass plate = Thickness x area of the glass plate.

Thickness of glass plate = Observed Reading + Zero Correction

= {PSR+(HSC X LC)}+ZC

Where PSR = Pitch scale reading

HSC = Head scale coincidence

LC = Least Count

ZC = Zero Correction

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

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

Correct Reading (CR) = Observed Reading + zero Correction

Description:

The screw gauge consists of a screw working in a hollow cylindrical nut attached to one end of a frame G. On the hollow cylinder a scale is marked in mm. This scale is called the pitch scale (PS). There is a fixed stud A at one end of the frame and exactly opposite to A, there is a movable stud B of the screw. The other end of this screw has a head H. To the head, a hollow sleeve is attached. On the tapering of the sleeve 50 or 100 divisions are marked. This scale is called the Head Scale (HS). The Screw gauge head is having a ratchet arrangement, to avoid over-working of the screw.

Procedure:

i) To find the least count (LC):

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

First, the pitch of the screw is determined; by giving a known number of rotations to head scale and noting the distance advanced in pitch scale in mm. Then the number of divisions in the head scale is also noted.

The pitch and least count are determined using the formulae.

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

The Screw gauge is checked to find whether there is any initial (zero) error in the instrument. If there is 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 determined with the help of figures and formulae given.

iii) 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. 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 of the glass plate is calculated.

iv) 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.

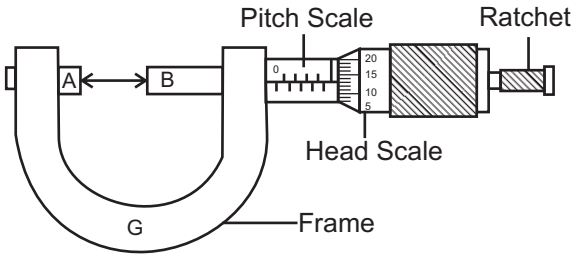
By multiplying the thickness of the glass plate and the area of the glass plate, the volume of the glass plate is determined.

Result:

The thickness of the given glass plate = $\times 10^{-3}$ m

The area of the glass plate = $\times 10^{-6}$ mm^2

The volume of the glass plate = $\times 10^{-9}$ mm^3



Observations:

(i) Least Count:

$$\text{Least count} = \frac{\text{Pitch of the screw}}{\text{No.of head scale division}}$$

$$\text{Pitch of the screw} = \frac{\text{Distance moved in the pitch scale}}{\text{No. of rotations given to HS}}$$

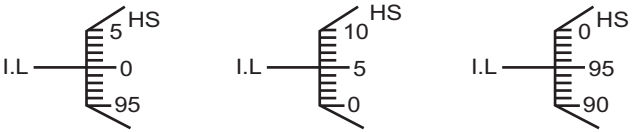
= mm

Number of head scale divisions(HSD)= div

$$\text{Therefore, Least Count (LC)} = \frac{\text{pitch}}{\text{No.of HSD}} = \quad \text{mm}$$

LC = mm

Three possible initial error and initial correction:



No error	Positive error	Negative error
No correction	Negative correction	Positive correction
	HSC = 5 div	HSC = 95 div
	ZE = + (HSC x LC)	ZE =-(100–HSC)x LC
	= +(5x 0.01 mm)	=- (10095)x0.01 mm
	= + 0.05 mm	=- 5 x 0.01 mm
	ZE = + 0.05 mm	ZE = -0.05 mm
	ZC =-0.05 mm	ZC = + 0.05 mm

(ii) Zero error and zero correction for the given screw gauge:

Tabular Column:

To find the thickness of the given glass plate:

LC = mm ZE = mm ZC = mm

Sl. No.	PSR	HSC	HSR = HSC X LC	OR = PSR + HSR	Thickness CR = OR +ZC
Unit	mm	div	mm	mm	mm
1.					
2.					
3.					
4.					
5.					

The average thickness of the given glass plate = mm

= x 10^{-3} m

Area of the glass plate using graph sheet = mm^2

= x 10^{-6} m^2

Volume of the glass plate = Thickness x Area

=

= m^3

VERNIER CALIPERS

Experiment No:

Date:

Aim:

To measure the length and diameter of the given solid cylinder using vernier calipers and to calculate the volume of the solid cylinder.

Apparatus required:

Vernier calipers and solid cylinder.

Formula:

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

Where

l = length of the cylinder

r = radius of the cylinder

Length / diameter of the solid cylinder = Observed reading + Zero correction

= {MSR + (VSC x LC)} + ZC

Where MSR = Main Scale Reading

VSC = Vernier Scale Coincidence

LC = Least Count

ZC = Zero Correction

Vernier Scale Reading (VSR) = Vernier Scale Coincidence (VSC) x Least Count (LC)

Observed Reading (OR) = Main Scale Reading (MSR) + Vernier Scale Reading (VSR)

Correct Reading(CR) = Observed Reading(OR)+Zero Correction (ZC)

Description:

The vernier calipers consists of main scale (MS) graduated in cm along the lower edge of the frame and inches along the upper edge of the frame. To one end of the frame, two fixed jaws are provided. There are two movable jaws, which slide over the main scale, and it can be fixed at any point using a screw S. The movable jaw attachment carries a vernier scale (VS).

Procedure:

i) To find the Least Count:

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

$$\text{Least Count (LC)} = \frac{1}{n} \text{ x value of 1MSD}$$

ii) To find the Zero Error (Z.E) and Zero Correction(Z.C):

The instrument is checked to find whether there is any initial error. If there is any initial error, suitable correction is to be made.

When the two jaws are in contact, the graduations are made such that the zero of the MS coincides with the zero of the VS. Now the instrument has no error.

If the zero of the VS is on the right side of the zero of the MS, it has positive error. Then the zero correction is negative.

If the zero of the VS is on the left side of the zero of the MS, it has negative error. Then zero correction is positive.

In each case, note the division of the vernier scale which is coinciding with any one of the main scale divisions. This is vernier scale coincidence (VSC). Applying this in the given formula, the value of zero error is determined. Hence zero correction (ZC) is also determined.

iii) 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.

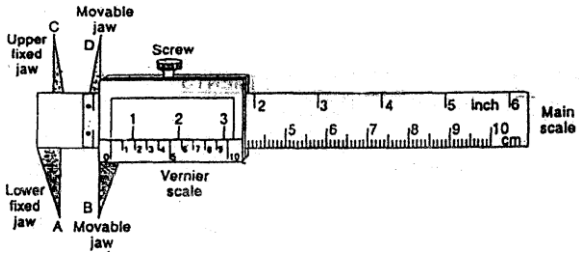
Similarly the readings for diameter of the solid cylinder are taken by placing the cylinder suitably in between the lower fixed jaws and the readings are noted in the tabular column II.

Result:

The length of the solid cylinder l = x 10^{-2} m

The diameter of the solid cylinder d = x 10^{-2} m

The volume of the solid cylinder v = x 10^{-6} m^3



Observations:

(i) Least count:

Value of 10 MSD = cm

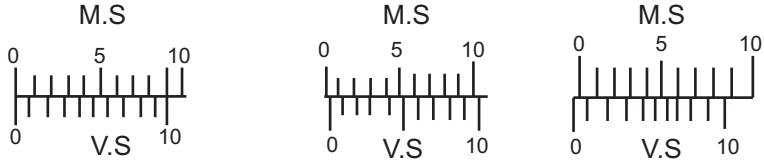
Value of 1 MSD = cm

No. of division on the vernier scale (n) =

(ii) The three possible initial error and initial correction:

Least Count (LC) = $\frac{1}{n}$ x value of 1 MSD= = cm

No error	Positive error	Negative error
No correction	Negative correction	Positive correction



VSC = 3 div	VSC = 7 div
ZE = + (VSC) x LC	ZE = -(10-VSC) x LC
= + 3 x 0.01 cm	= - (10-7) x 0.01cm
= + 0.03 cm	= - 0.03 cm
ZC = - 0.03 cm	ZC = + 0.03 cm

Zero error and zero correction of the given vernier calipers:

Tabular column I:

To find the length of the solid cylinder

LC = cm ZE = cm ZC = cm

Sl. No	MSR	VSC	VSR = VSC x LC	OR = MSR + VSR	Length CR = OR + ZC
Unit	cm	div	cm	cm	cm
1					
2					
3					
4					
5					

The average length of the solid cylinder (L)= cm

= x 10^{-2} m

Tabular column II:

To find the diameter of the solid cylinder

LC = cm ZE = cm ZC = cm

Sl. No	MSR	VSC	VSR = VSC x LC	OR = MSR + VSR	Diameter CR = OR + ZC
Unit	cm	div	cm	cm	cm
1					
2					
3					
4					
5					

The average diameter of the solid cylinder (D) = cm

= x 10^{-2} m

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

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

= **m^3**

CONCURRENT FORCES

Experiment No:

Date:

Aim:

To verify 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:

1) 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.
2) To verify Lami's theorem, it is to be shown that

$$\frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma}$$

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 supported vertically on a wall. The two smooth pulleys are fixed at the two top corners of the board, so that they can rotate freely. The two weight hangers P and Q are attached to the two ends of a long thread, after passing through the pulleys. The third weight hanger R is attached to the middle of the thread as shown in the figure.

Procedure:

The weights in the hangers P, Q and R are adjusted such that the point O is at rest. A small displacement is given to the system so as to overcome the friction in the pulleys. 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.

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. Also the $\angle$COD is measured and entered in the tabular column I.

According to parallelogram law, the diagonal OD gives the resultant of P and Q, whereas 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.

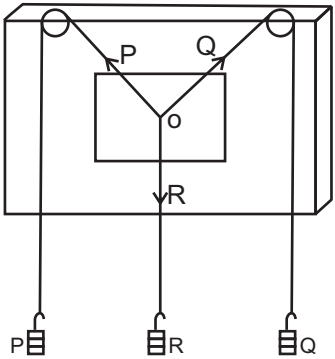
Result:

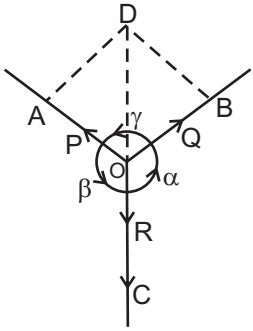
1) In the tabular column I, in all cases, it is seen that Resultant = Equilibrant i.e. OD = OC and also COD = 180°, which verifies parallelogram law of forces.

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.

$$\text{i.e } \frac{P}{\sin \alpha} = \frac{Q}{\sin \beta} = \frac{R}{\sin \gamma}$$





Tabular Column I:

To verify parallelogram law of forces

Scale : 0.05 kg.wt = 1 cm

Sl No.	Force P	Line OA	Force Q	Line OB	Force R	Equili-brant OC	Resultant OD	∠COD
Unit	kg. wt	cm	kg. wt	cm	kg. wt	cm	cm	degree
1.								
2.								
3.								

Tabular Column II:

To verify Lami's Theorem

Sl No.	Forces			Angles			$\frac{P}{\sin\alpha}$	$\frac{Q}{\sin\beta}$	$\frac{P}{\sin\gamma}$
	P	Q	R	α	β	γ			
Unit	kg . wt	kg . wt	kg . wt	degree	degree	degree	kg. wt	kg. wt	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 = °

$$\frac{P}{\sin\alpha} =$$

$$\frac{Q}{\sin\beta} =$$

$$\frac{R}{\sin\gamma} =$$

POISEUILLE'S METHOD

Experiment No.:

Date:

Aim:

To determine the coefficient of viscosity of water by capillary flow method, using graduated burette without stopper.

Apparatus required:

Burette stand, graduated burette without stopper, Capillary tube, rubber tube, beaker, stop watch, water, funnel, wooden bench, etc.

Formula:

The coefficient of viscosity of the water

$$\eta = \frac{\pi \rho g r^4 H t}{8 l v}$$

Where

ρ = density of water

g = acceleration due to gravity

r = radius of the capillary tube

l = length of the capillary tube

v = volume of water comes out of the capillary flow (5 cc)

t = time taken for 5 cc flow of water

H = the average pressure head height of the liquid levels from the capillary tube.

$$H = \frac{h_1 + h_2}{2} - h_3$$

h_1 = height of initial level from the experimental table

h_2 = height of final level from the experimental table

h_3 = height of the axis of capillary tube from the table

Description:

The graduated burette without stopper is mounted vertically in the stand. A rubber tube is connected to the bottom of the burette. To the other end of the tube, a capillary tube is inserted and placed in a perfectly horizontal position.

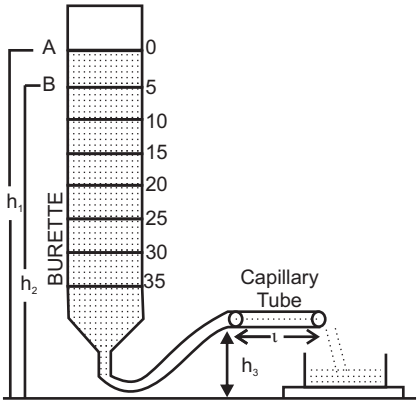
Procedure:

Pure water is poured into the burette using a funnel. The height of the liquid level in the burette is adjusted such that there is a streamline flow of water through the capillary tube i.e. 5 to 8 drops per minute. This can be achieved by raising or lowering the capillary tube. When the water level in the burette comes to zero mark a stop watch is started and the time for the water level to reach 5 cc, 10 cc, 15 cc, 20 cc and 25 cc mark is noted and entered in the tabular column I.

From the above readings, the time of flow of 5 cc water (t) at various ranges like 0 cc to 5 cc, 5 cc to 10 cc, 10 cc to 15 cc, 15 cc to 20 cc and 20 cc to 25 cc are tabulated in tabular column II. In each case the heights of the respective initial levels and final levels from the experimental table are noted. The average pressure head height is calculated and entered in the tabular column. Substituting the average value of Ht values in the formula given, the coefficient of viscosity of water is calculated.

Result:

The coefficients of viscosity of water = Nsm^{-2}



Observations:

Density of water	=	kgm^{-3}
Acceleration due to gravity g	=	ms^{-2}
Radius of the capillary tube r	=	m
Length of the capillary tube *l*	=	m

Volume of water comes out of the cap. flow v = 5 cc= $5\times10^{-6}m^3$

Tabular column I:

To note the time taken for the flow of water

Sl.No	Water level In the burette	Time of flow
	cc	s
1	0	
2	5	
3	10	
4	15	
5	20	
6	25	

Tabular column II:

Height of the axis of cap. tube from the table h_3 = m

Sl. No	Initial water level	Final Water level	Height of Initial level h_1	Height of final Level h_2	Ave. Pr. Head height $\frac{h_1 + h_2}{2} - h_3$	Time of Flow t	H.t
	cc	cc	m	m	m	s	ms

Mean

Calculation:

The coefficient of viscosity o fwater

$$\eta = \frac{\pi \rho g r^4 H t}{8\ l\ v}$$

COEFFICIENT OF VISCOSITY OF HIGH VISCOUS LIQUID – STOKES' METHOD

Experiment No.:

Date:

Aim:

To determine the coefficient of viscosity of high viscous liquid (Castor oil) by Stokes' method.

Apparatus Required:

A tall glass jar, castor oil, glass beads of different radii, stopwatch, screw gauge, etc.

Formula:

The coefficient of viscosity of the highly viscous liquid $\eta = \dfrac{2\,(\rho-\sigma)\,g\,(r^2 t)}{9h}$

Where

ρ = the density of the material of the solid sphere (glass beads)

σ = the density of the liquid (castor oil)

g = the acceleration due to gravity

r = the radius of the glass beads

t = the time taken by the solid sphere to travel the marked distance h, inside the high viscous liquid.

h = the distance between the marks B and C

Description:

The pure, transparent, high viscous liquid (castor oil) is taken in the tall glass jar. On the outer surface of the jar, two markings B and C are made at a distance of say 50 cm. The marking B should be well below the free surface of the liquid. Then only the sphere can attain terminal velocity when travelling from B to C.

Procedure:

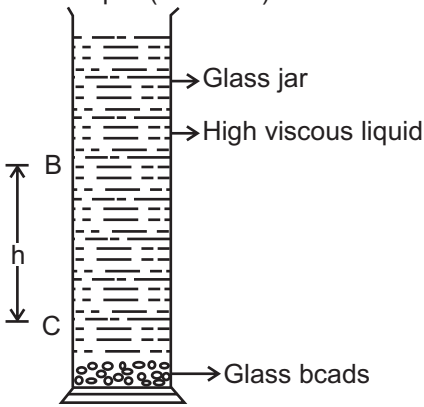
First the least count, zero error and zero correction of screw gauge are determined. Then using the screw gauge, the diameters of the given glass beads are measured. The radii of the beads are calculated. Values of ρ and σ are taken from standard tables.

The sphere is placed gently on the surface of the high viscous liquid and dropped. When it crosses the marking B,a stop clock is started and when it crosses the marking C, the clock is stopped. The time taken (t) to travel by the sphere from B to C is recorded in the tabular column. The

distance between B and C is noted as 'h'. The same procedure is repeated for all the given spheres. Then the coefficient of viscosity of highly viscous liquid (castor oil) is calculated, using the formula.

Result:

The coefficient of viscosity of the high viscous liquid (castor oil) = $N\,s\,m^{-2}$



Observations:

The density of the material solid sphere (glass beads) ρ= $kg\,m^{-3}$

The density of the viscous liquid (castor oil) σ = $kg\,m^{-3}$

The acceleration due to gravity g = $m\,s^{-2}$

The distance between B and C h = $x\,10^{-2}\,m$

$$\text{Pitch of the screw} = \frac{\text{Distance moved in pitch scale}}{\text{No. of rotations given to HS}}$$

(I) Least Count: Least Count = Pitch / No.of Head Scale Divisions

= mm = mm

$$\text{Therefore, Least Count (LC)} = \frac{\text{pitch}}{\text{No.of HSD}} = \text{-------}\ mm$$

Number of head scale divisions(HSD) = div

LC = mm

(ii) Zero Error and Zero Correction:

Tabular column I:

To find the radii of the solid spheres (glass beads)

LC = mm; ZE = mm; ZC = mm

Solid sphere	Sl. No.	PSR	HSC	HSR = (HSC x LC)	OR = PSR + HSR	CR = OR + ZC	Mean diameter d	Radius r = d/2
	Unit	mm	div	mm	mm	mm	mm	mm
Bead 1	1.							
	2.							
	3.							
	4.							
	5.							
Bead 2	1.							
	2.							
	3.							
	4.							
	5.							
Bead 3	1.							
	2.							
	3.							
	4.							
	5.							

Tabular column II:

To find r^2t

Glass beads	Radius r	Radius^2 r^2	Time taken t	r^2t
Unit	mm	mm^2		mm^2
Bead 1				
Bead 2				
Bead 3				

The average of r^2t = mm^2

= $x\,10^{-6}\,m^2$

Calculation:

The coefficient of viscosity of the highly viscous liquid

$$\text{(castor oil) } \eta = \frac{2}{9}\,\frac{(\rho-\sigma)\,g\,(r^2\,t)}{h}$$

=

= **Nsm^{-2}**

SURFACE TENSION

Experiment No.:

Date:

Aim:

To determine the surface tension of water by capillary rise method.

Apparatus required:

Beaker with water, capillary tube, pointer, travelling microscope, retort stand with clamp, two holed rubber cork, wooden bench, etc.

Formula:

$$\text{The surface tension of water } T = \frac{hr\rho g}{2}$$

where

h= height of the liquid rise in the capillary tube

r = radius of the capillary tube

ρ= density of water

g= acceleration due to gravity

Description:

A capillary tube of uniform cross sectional area is cleaned well and clamped vertically with one end inside the water taken in a beaker. Due to surface tension, water rises to a definite height into the tube. This is called capillary rise. If there is any air bubble inside the tube, it should be removed. A pointer is mounted vertically so that its lower end just touches the surface of water in the beaker.

Procedure:

The least count of the microscope is determined as in the case of vernier calipers.

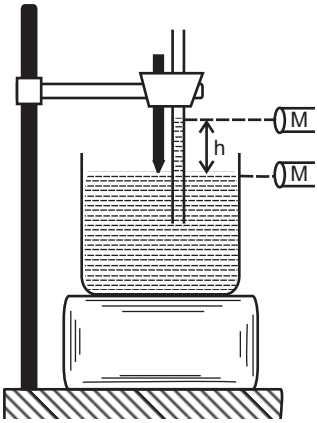
The microscope is adjusted such that the horizontal cross wire is tangential to the lower meniscus of the liquid inside the capillary tube. The MSR and VSC from the vertical scale of the microscope are noted. Then the beaker of water is removed, without disturbing the pointer. Now the microscope is focussed so that the horizontal cross wire is tangential to the tip of the pointer. The MSR and VSC readings are noted in the tabular column. The difference between these two observed readings (O.R) gives the height of capillary rise 'h'.

The capillary tube is mounted horizontally and the microscope is focussed to one end of the tube, so that we can see the bore of the capillary tube in the field of view.

Now, the horizontal cross wire is made tangential to one side of the bore (AA'). The readings are noted in the tabular column from the vertical scale. Using the minute adjustment screw of the microscope, the horizontal cross wire is made tangential to the other side of the bore (BB') and the readings are noted. The difference between these two observed readings (O.R) gives the diameter of the capillary tube. Hence the radius of the capillary tube is determined.

Then the surface tension of water is calculated using the formula.

Result:



The surface tension of water is found to be = $N\,m^{-1}$

Observations:

Density of water = kgm^{-3}

Acceleration due to gravity g = m^{-2}

To find Least count of microscope:

Least count:

Value of 20 MSD = cm

value of 1 MSD = cm

$$\text{Least Count (LC)} = \frac{1}{n} \times \text{value of 1MSD}$$

No.of divisions on the vernier scale (n) =

=

= cm

Tabular column I:

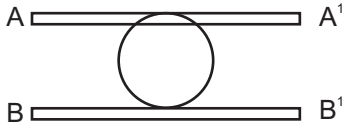
To find the height of capillary rise h

Position	Microscope Readings				Height of the capillary rise h = (x ~ y)
	MSR	VSC	VSR = VSC x LC	OR = MSR + VSR	
Unit	cm	div	cm	cm	cm
Horizontal cross wire at the lower meniscus				x=	
Horizontal cross wire at the tip of the pointer				y =	

Least count = cm

Height of the liquid rise in the capillary tube(h) = cm

= $\times 10^{-2}$ m



Tabular column II

To find the radius of capillary tube r :

Least count = cm

Position	Microscope Readings				Diameter 2r = (A ~ B)
	MSR	VSC	VSR = VSC x LC	OR = MSR + VSR	
Unit	cm	div	cm	cm	cm
AA'				A =	
BB'				B =	

The diameter of the capillary tube d = cm

The radius of the capillary tube r = d/2 = cm

r = x 10^{-2} m

Calculation:

$$\text{The surface tension of water } T = \frac{hr\rho g}{2}$$

Height of the liquid rise in the capillary tube h= x 10^{-2} m

Radius of the capillary tube r = x 10^{-2} m

Density of the water ρ = kg m^{-3}

$$T = \frac{hr\rho g}{2} = \qquad Nm^{-1}$$

SONOMETER

Experiment No.:

Date:

Aim:

To find the frequency of the given tuning fork using a sonometer.

Apparatus Required:

The frequency of the tuning fork $n = \frac{1}{2}\sqrt{\left(\frac{M}{l^2}\right)\frac{g}{m}}$

Sonometer, screw gauge, tuning fork, hammer, weight hanger set and paper rider.

Formula:

Where

M = total mass at the end of the sonometer wire.
i.e. Mass of the weight hanger + Mass placed on it

g = acceleration due to gravity.

m = linear density of the wire
i.e., mass per unit length of the wire.

ℓ = first resonating length.

The linear density of the wire, $m = \pi r^2 \rho$

Where

ρ = density of the material of the wire.

r = radius of the sonometer wire.

Description:

A sonometer consists of a hollow wooden box about one metre with bridges A and B fixed at two ends on the top surface. A uniform wire is stretched over the two bridges, one end of the wire being fixed to the nail at one end of the box. The other end passes over a smooth pulley and carries a weight hanger on which weights can be placed. M and N are two movable bridges in between the fixed bridges A and B. By changing their position, the length of the vibrating segment of the wire can be altered.

Procedure:

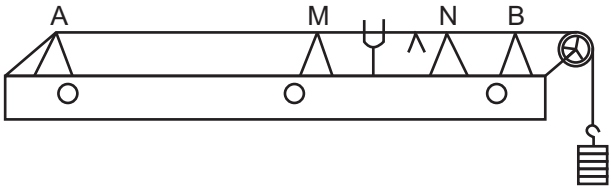
A suitable load say 0.5 kg is placed on the hanger. The two movable

bridges M and N are placed close to each other. A light paper rider is placed at the centre of the segment MN of the sonometer wire. The given tuning fork is excited and its stem is pressed on the sonometer box. The length of the vibrating segment MN is gradually increased by moving the bridge M or N, till the paper rider flutters violently and fall down. The first resonating length ℓ between M and N is measured using the metre scale fixed on the sonometer box. The load is changed to 1 kg, 1.5 kg, 2 kg, 2.5 kg, 3 kg etc and in each case the resonating length is determined and M/ℓ^2 is calculated.

The diameter d of the wire is found using a screw gauge. The radius of the wire r is calculated. The mass per unit length of the wire is $m = \pi r^2 \rho$. Here ρ is the density of the material of the wire.

The frequency of the given turning fork is calculated by substituting the values of M/ℓ^2 and 'm' in the formula.

Result:



The frequency of the given tuning fork (n) = Hz.

Observations:

Acceleration due to gravity g= ms^{-2}

Density of the material of the wire (steel) ρ= $kg\,m^{-3}$

$$\text{Pitch of the screw} = \frac{\text{Distance moved in Pitch scale}}{\text{No.of rotations given to HS}} =$$

(i) Least Count:Least Count = Pitch / No.of Head Scale Divisions

$$\text{Therefore, Least Count (LC)} = \frac{\text{pitch}}{\text{No. of HSD}} = \quad \text{mm}$$

= ---------- mm = mm

Number of head scale divisions(HSD) = div

LC = mm

(ii) Zero Error and Zero Correction:

Tabular column I:

To find $\frac{M}{\ell^2}$

Sl. No.	Mass placed at the end of the sonometer wire [mass of the hanger + mass placed on the hanger] M		First resonating length ℓ		ℓ^2	$\frac{M}{\ell^2}$
Unit	Kg		cm	m	m^2	kg m^{-2}
1.	Hanger + 0.5	1.0				
2.	Hanger + 1.0	1.5				
3.	Hanger + 1.5	2.0				
4.	Hanger + 2.0	2.5				
5.	Hanger + 2.5	3.0				

Tabular Column II:

To find the diameter of the wire

LC = mm ZE = mm ZC = mm

Sl. No.	PSR	HSC	HSR = HSC X LC	OR = PSR + HSR	CR = OR +ZC
Unit	mm	div	mm	mm	mm
1.					
2.					
3.					
4.					
5.					

Mean

The average diameter of the wire = m m

Radius of the wire r = d/2 = m m

R = x 10^{-3} m

Calculation:

The Mass per unit length of the wire m $= \pi r^2 \rho$

$=$

$=$ kg m^{-1}

The frequency of the tuning fork $n = \frac{1}{2}\sqrt{\left(\frac{M}{l^2}\right)\frac{g}{m}}$

$=$

$=$ Hz

DEFLECTION MAGNETOMETER
(TAN A – POSITION)
COMPARISON OF MAGNETIC MOMENTS

Experiment No.:

Date:

Aim:

To compare the magnetic moments of the given two bar magnets using a deflection magnetometer in Tan A position, by equal distance method.

Apparatus Required:

$$\frac{m_I}{m_{II}} = \frac{\tan\theta_I}{\tan\theta_{II}}$$

Deflection magnetometer, two bar magnets, metre scale, etc.

Formula:

The ratio of the magnetic moments of two given short bar magnets where

m_I = the magnetic moment of first magnet

m_{II} = the magnetic moment of second magnet

θ_I = mean deflection for first magnet

θ_{II} = mean deflection for second magnet

Description:

The magnetometer is arranged in tan A position. For arranging tan A position the following adjustments are to be made.

I) The magnetometer is placed on a horizontal table and the arms of the

magnetometer are kept along the east-west direction and it is adjusted so that the arms are parallel to the length of the aluminium pointer.

ii) Without disturbing the adjustment, the compass box is slowly rotated until the pointer reads 0° – 0°.

Procedure:

Equal distance method:

The magnetometer is arranged in tan A position. One of the two given bar magnets of magnetic moment m_I is placed on one side (Eastern arm) of the two arms with its axis along the east-west direction in the magnetometer. The distance of the magnet is suitably adjusted so that the deflection lies between 30° and 60°. The distance between the centre of the magnet and the centre of the magnetometer is measured as'd'. The readings of both the ends of the pointer are taken as θ_1 and θ_2. The magnet is reversed from pole to pole, in the same place and two more readings θ_3 and θ_4 are taken.

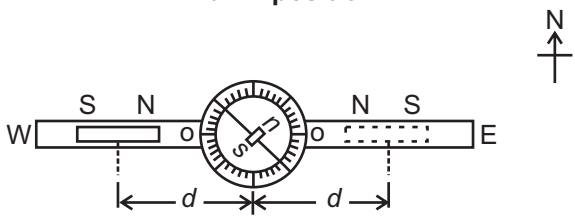
The magnet is then kept at the same distance on the other side of the arm (Western arm) and four deflections $\theta_5, \theta_6, \theta_7$ and θ_8 are noted, as mentioned above. The average of the eight deflections is found and taken as θ_I. The same procedure is repeated with the second magnet of magnetic moment m_{II}, keeping at the same distance and the average deflection θ_{1I} is found. The experiment is repeated for different values of d and the readings are tabulated. The ratio of magnetic moments (m_I/ m_{II}) is calculated using the formula.

Result:

i) The magnetic moments of the given two bar magnets are compared.

ii) The ratio of the magnetic moments of two given bar magnets by equal distance method =

Tan A position:



Equal distance method.

To find $\frac{m_I}{m_{II}}$ by equal distance method

Distance d	Magnetic Moment	Deflections in degrees									$\frac{m_I}{m_{II}} = \frac{\tan\theta_I}{\tan\theta_{II}}$
		Eastern arm				Western arm					
		Direct		Reversed		Direct		Reversed		Mean	
		θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ	
	m_I									θ_I=	
	m_{II}									θ_{II}=	
	m_I									θ_I=	
	m_{II}									θ_{II}=	
	m_I									θ_I=	
	m_{II}									θ_{II}=	
	m_I									θ_I=	
	m_{II}									θ_{II}=	

Average of $\frac{m_I}{m_{II}} =$

Calculation:

a.) d = cm

$$\frac{m_I}{m_{II}} = \frac{\tan\theta_I}{\tan\theta_{II}} =$$

b.) d = cm

$$\frac{m_I}{m_{II}} = \frac{\tan\theta_I}{\tan\theta_{II}} =$$

c.) d = cm

$$\frac{m_I}{m_{II}} = \frac{\tan\theta_I}{\tan\theta_{II}} =$$

d.) d = cm

$$\frac{m_I}{m_{II}} = \frac{\tan\theta_I}{\tan\theta_{II}} =$$

MODEL QUESTION PAPER

1. Measure the thickness of the given irregular glass plate using micrometer. Determine the area of the glass plate using a graph sheet and calculate the volume of the glass plate.
2. Measure the length and diameter of the given solid cylinder using vernier calipers and then calculate the volume of the solid cylinder.
3. Verify the parallelogram law of forces and Lami's theorem using concurrent forces.
4. Determine the coefficient of viscosity of water by capillary flow method, using graduated burette.
5. Determine the coefficient of viscosity of a high viscous liquid by Stokes' method.
6. Determine the surface tension of water by capillary rise method.
7. Determine the frequency of the given tuning fork using sonometer.
8. Compare the magnetic moments of the two bar magnets using deflection magnetometer in Tan-A position, by equal distance method.

SEMESTER II

UNIT I

HEAT

1.1. TRANSFER OF HEAT

Introduction:

Heat is a form of energy, which is responsible for the hot condition or the cold condition of a body. Since it is a form of energy, the quantity of heat is measured in 'joule' with symbol 'J'.

We can realize the hotness or coldness of a body by our sense of touch. But there should be a method to determine the degree of hotness or coldness.

Temperature is a measure of the relative degree of hotness or coldness of the body. For quantitative measurement of temperature some standard temperatures are required, which can be easily reproduced in any laboratory. Generally, we take the melting point of ice as lower fixed point and the boiling point of water (steam point) as upper fixed point.

To measure the temperature, different scales are in use.

1. Centigrade scale :

In this scale, the temperature is measured in 'degree Celsius' with symbol °C. In this scale, the lower fixed point is taken as 0 °C for ice point and the upper fixed point is taken a 100° C for steam point.

2. Fahrenheit scale :

In this scale, the temperature is measured in 'degree Fahrenheit' with symbol °F. Here, the lower fixed point (ice point) is taken as 32 °F and the upper fixed point (steam point) is taken as 212 °F.

3. Absolute scale or Kelvin scale:

In this scale, the temperature is measured by the unit 'kelvin' with symbol 'K'. Usually, the temperatures are measured in centigrade scale in laboratories. To convert the temperature from centigrade scale to Kelvin scale, we have to add 273.15, because 0 K corresponds to -273.15 °C.

Ex: The room temperature $= 32\,^{\circ}C$

$= (32 + 273.15)\,K = 305.15\,K$

The relation between Celsius 'C', Kelvin 'K' and Fahrenheit 'F' is

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

Heat Transfer:

There are three methods of transfer of heat from one place to another. They are Conduction, Convection and Radiation. Conduction takes place both in solids and fluids. Convection cannot occur in solids. Radiation does not require the presence of any medium.

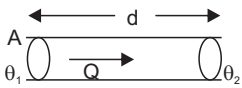
Conduction:

In Conduction, the molecules of the body are responsible for the heat transfer. Here there is no actual movement of molecules from one place to another place. When a rod is heated at one end, the molecules at the hot end vibrate about their mean position and transfer the heat energy to the neighbouring molecules and thus the heat energy reaches the other end of the rod.

Conduction is the process by which heat is transmitted from one point to another without the actual movement of the particles from their equilibrium positions. Conduction takes place in solids, liquids and gases.

Confficient of thermal conductivity:

Let us consider a metallic rod of cross sectional area A. Let the two ends be separated by a distance d, maintained at temperatures θ_1 and θ_2. Let θ_1 be greater than θ_2. Heat flows from the end at the higher temperature to the end at the lower temperature.



When the steady state is reached, the quantity of heat Q conducted is

i) directly proportional to the area of cross section A

ii) directly proportional to the difference in temperature between the ends $(\theta_1 - \theta_2)$

iii) directly proportional to the time for which the heat is conducted(t)

iv) and inversely proportional to the distance between the two ends.

$$\text{Hence } Q \propto A \frac{(\theta_1 - \theta_2)t}{d} \quad \text{or}$$

$$Q = \lambda A \frac{(\theta_1 - \theta_2)t}{d}$$

where λ is a constant known as the coefficient of thermal conductivity of the material and $(\theta_1-\theta_2)/d$ is known as temperature gradient.

$$\text{when } A = 1, \qquad \frac{(\theta_1 - \theta_2)}{d} = 1 \qquad \text{and } t = 1, \qquad \text{then } Q = \lambda$$

Hence, Coefficient of thermal conductivity (λ) of the material of a conductor is defined as the quantity of heat conducted per second per unit area per unit temperature gradient at the steady state.

unit of λ :

$$Q = \lambda A \frac{(\theta_1 - \theta_2)t}{d} \qquad \text{or}$$

$$\lambda = \frac{Qd}{A(\theta_1 - \theta_2)t}$$

Substituting the units,

$$\text{Unit of } \lambda = \frac{Jm}{m^2Ks} = Js^{-1}\, m^{-1}\, K^{-1} = Wm^{-1}K^{-1} \qquad (\text{as } Js^{-1} \text{ is } W)$$

Selection of good and poor thermal conductors:-

Substance	**λ ($Wm^{-1}K^{-1}$)**	**Substance**	**λ ($Wm^{-1}K^{-1}$)**
Silver	420	Water	0.6
Copper	390	Red brick	0.6
Aluminium	240	Rubber	0.5
Steel	14	Wood	0.04 to 0.1
Lead	35	Glass	0.8
Concrete	1.1	Ebonite	0.2

We require both good and poor thermal conductors according to the need. Materials having higher values of coefficient of thermal conductivity are termed as good thermal conductors and the materials having lower values of coefficient of thermal conductivity are called as poor thermal conductors or insulators. The presence of free electrons in metals helps the easy transfer of heat from one part of the metal to the other part. So, all metals are good thermal conductors of heat. Some important materials and their values of coefficient of thermal conductivity are listed above.

Uses of thermal conductors:-

1. Handles made of wood or ebonite are provided for cookers and hot water vessels.
2. Hot water bottles made of rubber are able to keep hot water at high temperature for a considerable period of time.
3. Use of double windows with a thin layer of air enclosed in between them keep the room warm in cold countries.
4. Wool, cork and ebonite are used for the purpose of heat insulation in refrigeration.
5. Woolen clothes are used in winter to keep the body warm.
6. Sawdust and jute sheet is used to cover ice to prevent it from melting.
7. Vessels made of copper, aluminum, etc., are used for cooking purpose as they easily conduct heat.
8. Copper is used in boilers and radiators, because of its good conductivity.

Convection:-

In the case of heat transfer by convection, there is actual movement or motion of molecules of the fluid (liquid or gas).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.

Convection is the process in which heat is transmitted from one place to the other by the actual movement of heated particles.

Convection takes place only in liquids and gases. It cannot take place in solids.

Applications of Convection.

1. The wind flow is due to the convection currents in the atmosphere. During day time, parts of earth get heated by the Sun. As the air expands, it rises up and its place is taken by the flow of air from colder areas.
2. The land breeze and sea breeze are due to the convection in the atmosphere. During day time, land mass is heated to a higher level than the sea. So, the warm air over the land rises giving place to the cool air flow from the ocean. This gives the sea breeze. During night time, the land mass cools quickly than the water in the sea. So, cool air flows from land mass towards sea which gives the land breeze.

Radiation:-

For heat transfer by radiation, no medium is required. The heat from the Sun is received by earth only by radiation. Both heat and light travel through space with same velocity and they are similar in nature. Both are generated and transmitted in the same way. They are transverse waves and electro-magnetic in character, but they differ in wavelength and frequency. The thermal radiations are detected in the 'infra-red" region of the electro-magnetic spectrum.

Radiation is the process by which heat energy is transmitted from one place to another without the aid of an intervening material medium.

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 travels with the velocity of light, which is $3 \times 10^8 ms^{-1}$.
2. Thermal radiation obeys the same laws of reflection, refraction etc., as light.
3. Thermal radiation travels through vaccum.
4. It obeys the law of inverse square, as light.
5. It travels in straight lines.
6. When thermal radiation falls on any body, which can absorb it, then converted into ordinary heat, which raises its temperature.
7. It is absorbed by dark rough surfaces and reflected by light smooth surface.

Applications of Radiation.

1. White coloured dresses are used in hot countries to keep the inside cool.
2. In some countries, shining aluminium sheets are used to cover the roof of the house to reflect back the radiant heat and to keep the inside cool.
3. A cooking vessel is painted black at the bottom for greater absorption of heat, but polished at the top to minimize radiation losses.
4. In cold countries, hot air or water runs through the pipes along the walls inside a building and the radiant heat energy keeps the occupants warm by 'Central Heating'.

1.2 KINETIC THEORY OF GASES

A gas consists of a large number of particles called molecules. The molecules are in the state of continuous motion. The pressure of a gas is due to the collision of individual molecules on the walls of the container. The behaviour of the gas can be explained on the basis of kinetic theory of gases The kinetic theory of gases has found better applications to explain various properties of gases. This theory was developed by Clausius, Boltzmann and Maxwell

1. Postulates of Kinetic Theory of gases:-

1. A gas consists of large number of tiny, rigid particles called molecules.
2. The gas molecules are identical in all respects, like mass, size, etc.
3. The molecules are perfectly elastic spheres.
4. The molecules are in random motion and travel with all possible velocities in all possible directions.
5. The molecules collide with each other and also with the walls of the container.
6. Between two successive collisions, the molecules travel in the straight line.
7. The average distance between two successive collisions is called the mean free path.
8. The time of collision is negligible when compared to the time taken by the molecule to travel its mean free path.

9. The volume of the molecules is negligible when compared to the volume of the gas.
10. The force of attraction between the molecules is negligible.
11. As the molecules of a gas are always in random motion, the energy of the gas is in the form of kinetic energy and it is directly proportional to the absolute temperature of the gas. When the temperature of the gas remains constant, the molecular velocities will not change.

Mean square velocity and Root Mean Square velocity (R.M.S. velocity) :-

Let c_1, c_2, c_3 .... c_n be the velocities of 1st ,2nd ,3rd.....nth molecule present in the gas, then the mean square velocity is,

$$\overline{C^2} = \frac{C_1^2 + C_2^2 + C_3^2 + ... + C_n^2}{n}$$

The mean square velocity is defined as the average of the square of velocities of all the molecules.

Now R.M.S. velocity is obtained by taking square root of the mean square velocity of the molecules.R.M.S velocity is

$$\sqrt{\overline{C^2}} = \sqrt{\frac{C_1^2 + C_2^2 + C_3^2 + ... + C_n^2}{n}}$$

The R.M.S. velocity is defined as the square root of the average of squares of velocities of all molecules

Expression for the pressure of a gas :-

Consider a cubical vessel of side one metre containing a perfect gas. The gas contains n-number of molecules and m be the mass of each molecule. The molecules are in continuous motion and they collide with the wall of the container. The force experienced by the wall per unit area, due to the molecular collision gives the pressure of the gas.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Consider a single molecule moving in the X-direction with velocity v. It collides with the wall BCGF of the container and then it rebounds with velocity -v.

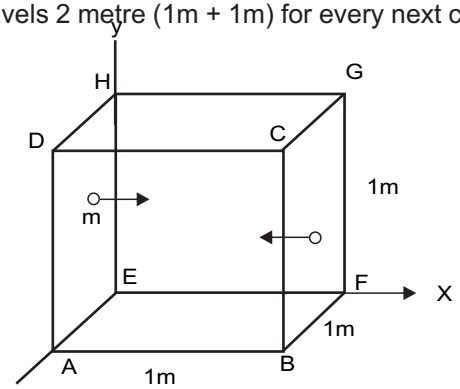
The momentum of the molecule before collision = mv

The momentum of the molecule after collision = - mv

$\therefore$ The change in momentum for single molecule = mv - (-mv)

= 2mv.

After recoil from the wall BCGF, the molecule travels towards the wall AEHD and collide then rebound back to the wall BCGF. So, the molecule travels 2 metre (1m + 1m) for every next collision on the same wall.



Time required to travel 2m for next collision } t = distance/ velocity= 2 /v second

The rate of change is momentum = change in momentum/ time taken

$$= \frac{2mv}{2/v} = mv^2$$

According to Newton's second law of motion,

Force = Rate of change in momentum.

$\therefore$ Force acting on the wall due to 1 molecule= mv^2

An average n/3 molecules can be considered to move in each of the three directions X, Y and Z.

The force acting on the wall due to n/3 molecules = n/3 (mv^2)

Pressure on the wall = Force / Area

$$= \frac{(n/3)mv^2}{1}$$

{Since the area of any side A = 1 x1 = 1 m^2}
Since the pressure will be the same on all sides,

Pressure of the gas P = (⅓) nmv^2

But all the molecules are not moving with the same velocity v.
Let $c_1, c_2, c_3 \ldots\ldots\ldots\ldots c_n$ be the velocities of the molecules,

The mean square velocity $\overline{C^2} = (C_1^2 + C_2^2 + C_3^2 \ldots\ldots + C_n^2)/n$

Substituting this average square of the velocity $\overline{C^2}$ for v^2

Then, Pressure of the gas $P = \frac{1}{3} nm \overline{C^2}$

As we have taken m as the mass of each molecule and there are n molecules in the gas,

The total mass of the gas present in the vessel of 1 m^3 volume = nm

But, mass per unit volume of the gas = nm = ρ the density of the gas.

$\therefore$Pressure of the gas $P = \frac{1}{3}\rho\overline{C^2}$

Relation between Pressure and kinetic Energy of a Gas:

Consider a perfect gas having unit volume with density ρ and $\overline{C^2}$ be the mean square velocity of gas molecules, then

$\therefore$pressure of the gas $\rho = \frac{1}{3}P\overline{C^2}$

$\therefore$ The Pressure , $P = \frac{1}{3}M\overline{C^2}$

The density $\rho = \frac{M}{V} = M$ {Since volume V=1 m^3}

Dividing and multiplying by 2,

$$P = \frac{2}{2} X \frac{1}{3} M\overline{C^2} = \frac{2}{3} x \frac{1}{2} M\overline{C^2}$$

The mean Kinetic energy per unit volume of the gas

$$K.E. = \frac{1}{2} M\overline{C^2}$$

The Pressure $P = \frac{2}{3}$ K.E

The pressure of a gas is equal to two third of the mean kinetic energy per unit volume of the gas.

But, the mean square velocity of the molecules $\overline{C^2}$ is directly proportional to the absolute temperature of the gas.

Hence, the pressure of a gas is directly proportional to the absolute temperature of the gas.

Mean kinetic energy per molecule of the gas:

One mole of any gas contains N (Avogadro) number of molecules, so the gas equation from kinetic theory of gas is

$$P = \frac{1}{3}\frac{M\overline{C^2}}{V}$$

[But M = Nm]

$$PV = \frac{Nm\overline{C^2}}{3} \quad - (1)$$

For ideal gas, the equation is PV = RT - (2)

From (1) and (2) $PV = \frac{Nm\overline{C^2}}{3} = RT$

$$m\overline{C^2} = \frac{3RT}{N}$$

Kinetic energy of one molecule $\frac{1}{2}m\,\overline{C^2} = \frac{3RT}{2N}$

(Dividing by 2 on both sides)

$$KE = \frac{3}{2}\frac{RT}{N}$$

$$= \frac{3}{2}KT$$

where 'K' is the Boltzmann constant which is equal to

$$K = \frac{R}{N} = 1.38 \times 10^{-23}\ JK^{-1}$$

Worked Problems:

1. Find the r.m.s. velocity of hydrogen molecule at S.T.P.if density of hydrogen is 0.0899 kgm^{-3} at S.T.P.

Given: $\rho = 0.0899$ kgm^{-3}

Known: At S.T.P, P = 0.76m of Hg = 0.76 x 13.6 x 10^3 x 9.8

$P = \frac{1}{3}\rho\overline{C^2}$, R.M.S. Velocity, $C = \sqrt{3P/\rho}$

$$\text{R.M.S. Velocity, } C = \frac{3 \times 0.76 \times 13.6 \times 10^3 \times 9.8}{0.0899} = 1.838 \times 10^3 \text{ ms}^{-1}$$

2. The root mean square velocity of argon gas molecule at S.T.P. is 434ms^{-1}. Find the density of argon gas at S.T.P.

Given; R.M.S. Velocity, c = 434 ms^{-1}

Known At S.T.P P = 0.76m of Hg

$$P = \frac{1}{3}\rho C^2$$

$$\rho = \frac{3P}{C^2}$$

$$\rho = \frac{3 \times 0.76 \times 13.6 \times 10^3 \times 9.8}{434 \times 434}$$

$$= 1.6133 \text{kgm}^{-3}$$

3. Find the temperature at which the root mean square velocity of hydrogen will double its value at S.T.P. pressure remaining constant.

Let t-be the temperature at which the r.m.s. velocity of hydrogen will double its value at S.T.P. Let C_0 and C_t be the R.M.S Velocity of molecules at S.T.P and at temperature 't'. i.e. $c_t = 2c_0$

Known, $c \alpha \sqrt{T}$ $C_t \alpha \sqrt{(273 + t)}$ and $c_0 \alpha \sqrt{273}$

$C_t = 2C_o = \sqrt{(273 + t)}$

$2 \times \sqrt{273} = \sqrt{273 + t}$

Squaring both sides

$4 \times 273 = 273 + t$

$\therefore t = 1092 - 273 = 819$ K or 546 ° C

1.3 SPECIFIC HEAT CAPACITY

When a substance is heated, it gains heat and its temperature increases. The quantity of heat gained by different substances is specified in terms of the value known as specific heat capacity.

Specific heat of solid and liquid:

To increase the temperature of a substance, heat energy should be supplied to it. It is found that the quantity of heat energy supplied to the substance (or) taken by the substance (Q) 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.

$Q \alpha m (T_2 - T_1)$

(or) $Q = S\, m\, (T_2 - T_1)$ (1)

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

In equation (1) when m = 1 kg and $(T_2 - T_1) = 1$ K, then,

$Q = S$

$\therefore$ Specific heat capacity of solid or liquid (or substance) is defined as the quantity of heat energy required to increase the temperature of 1 kg of the substance through 1 K.

Unit for specific heat capacity:

We know $Q = Sm (T_2 - T_1)$

$$\therefore S = \frac{Q}{m (T_2 - T_1)}$$

Substituting the respective units in R.H.S, the unit for specific heat capacity is $\frac{\text{joule}}{\text{kilogram. kelvin}}$ with symbol J kg^{-1} K^{-1}.

For example, the specific heat capacity of water is 4190 J kg^{-1} K^{-1}. It means, to increase the temperature of 1 kg of water through 1 K, 4190 J of heat energy is required.

Similarly, the specific heat capacity of copper is 385 J kg^{-1} K^{-1}. It means, to increase the temperature of 1 kg of copper through 1 K, 385 J of heat energy is required.

Specific heat capacities of a gas :

When a solid or liquid is heated, its temperature alone is increased, neglecting the little increase in its volume. But, when a gas is heated, its pressure and volume change in addition to its temperature.So, to study the effect of heating on a gas, we have to keep either the pressure or volume of the gas as constant. Accordingly, for each and every gas, there are two specific heat capacities.

1. *Specific heat capacity at constant pressure (C_p)* :

The specific heat capacity of a gas at constant pressure is the quantity of heat energy required to increase the temperature of one mole of the gas through 1K, when the pressure is kept constant.

***2. Specific heat at constant volume (C_v)* :**

The specific heat capacity of a gas at constant volume is the quantity of heat energy required to increase the temperature of one mole of the gas through 1K, when the volume is kept constant.

The unit for C_p and C_v is $J\,K^{-1}\,mol^{-1}$

Ratio of specific heat capacities (γ) :

For a gas, the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume is a constant. i.e.

$$\frac{\text{Specific heat capacity at constant pressure } (C_p)}{\text{Specific heat capacity at constant volume } (C_v)} = \gamma\,(\text{constant})$$

Since C_p is always greater than C_v, the value of γ is always greater than one for any gas.

3. Ratio between C_p and C_v

The ratio of the specific heat capacity of gas at constant pressure to the specific heat capacity of gas at constant volume is a constant and is denoted by the letter (γ)

$$\text{Then, } \gamma = \frac{C_p}{C_v}$$

When a gas is heated at constant volume the heat supplied to the gas is wholly used to raise the temperature of the gas whereas when the gas is heated at constant pressure, a part is used to external work to keep the pressure constant.

For monoatomic gases γ = 5/3 for diatomic gases, γ = 7/5 and for triatomic gases γ = 4/3

Explanation for C_p greater than C_v :

The Specific heat capacity of a gas at constant pressure (C_P) is the heat energy required to increase the temperature of 1 mole of a gas through 1K, at constant pressure.

The Specific heat capacity of a gas at constant volume (C_v) is the heat energy required to increase the temperature of 1 mole of a gas through 1K, at constant volume.

When a gas is heated, keeping the volume of the gas as constant, the entire heat energy supplied is used only to increase its internal energy i.e. temperature.

When a gas is heated, keeping the pressure of the gas as constant, the supplied heat energy is simultaneously used for two purposes.A part of heat energy is used to increase the temperature of the gas and rest of the energy is used to do the external work of pushing the piston up, to maintain the constant pressure.Hence, in this case more heat energy is to be supplied to the gas.Thus C_P is greater than C_v.

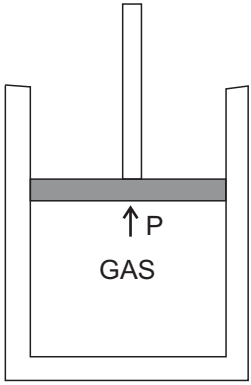
Meyer's relation C_p- C_v = R (Relation between C_p and C_v)

Consider 1 mole of a perfect gas inside a cylinder in which there is a tight piston moving without any friction.The internal energy of the gas is directly proportional to its absolute temperature. Let dQ_1 be the heat energy supplied to the gas at constant volume. Consequently, the temperature increases by dT.

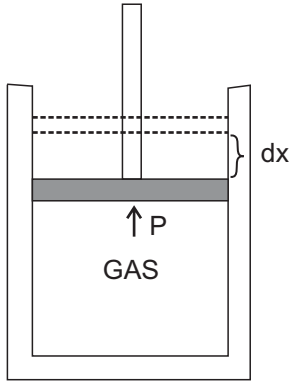
We know, quantity of heat supplied =

mass x specific heat capacity x increase in temperature

So, $dQ_1 = 1\, C_v dT$ (1)



dQ_1



dQ_2

Here, the entire heat is used to increase the temperature of the gas i.e. to increase the internal energy of the gas and no external work is done.

Let us now consider one mole of a perfect gas enclosed in a cylinder as before. Let the pressure and volume of the gas be P and V_1 respectively. Let A be the area of the piston. A quantity of heat dQ_2 be given to the gas at constant pressure, such that the increase in temperature is same dT.

Now $dQ_2 = 1\, C_P dT$ (2)

As the pressure of the gas is constant, the volume increases to V_2. So, some external work is done by the gas on the piston. Here the heat supplied is used for two purposes.

A portion of the heat dQ_2 is used to increase the internal energy and the rest is used to do external work. i.e. dQ_2 is used to

(i) to increase the temperature of the gas by dT. and

(ii) to push the piston up.

$\therefore dQ_2 = dQ_1 +$ work done in pushing the piston up.

$dQ_2 = dQ_1 + \{\text{Force x displacement of the piston}\}$ (3)

We know that, Pressure = Force / Area

$\therefore$ Force acting on the piston = Pressure x Area = PA

Let dx be the distance moved by the piston, as shown in fig (ii). Therefore (3) becomes,

$dQ_2 = dQ_1 + P\,A\,dx.$ But $A\,dx = dV$

where $dV = V_2 - V_1$ is the increase in volume of the gas.

$$dQ_2 = dQ_1 + P\,dV \qquad (4)$$

Using (2) & (1), (4) becomes,

$$1\,C_P\,dT = 1\,C_v\,dT + P\,dV$$

$$C_P\,dT = C_v\,dT + P\,dV$$

$$(C_P - C_v)\,dT = P\,dV$$

The equation for a perfect gas is $PV = RT$

On differentiating, $P\,dV = R\,dT$

So, the above expression becomes

$$(C_P - C_V).\,dT = R.dT; \qquad (C_P - C_V) = R.\frac{dT}{dT}; \qquad \text{But}.\frac{dT}{dT} = 1$$

$$\therefore (C_P - C_V) = R$$

Note: Since value of the Universal gas constant R is positive, the value of C_P is always greater than C_v for any gas.

Value of Universal Gas Constant: (R)

Calculate the value of R from the gas equation PV = RT (OR) Calculate the universal gas constant of given gas, given one gram molecule of at gas at N.T.P. occupies a volume of 22.4 litres.

AT N.T.P. Pressure P = 0.76m of Hg

$= 0.76 \times 13.6 \times 10^3 \times 9.8$

Volume V = 22.4 litres

$= 22.4 \times 10^{-3} m^3$

Temperature T = 273 K

Gas equation PV = RT

R = PV/T

$$= \frac{0.76 \times 13.6 \times 10^3 \times 9.8 \times 22.4 \times 10^{-3}}{273}$$

Universal gas constant R = $8.31\ JK^{-1}$ per gram mole

(or) R = $8310\ JK^{-1}$ per k. mole

Worked Examples:

1. *A gas at 1.5 atmospheres occupies a volume of $2m^3$ at 25^oC. What will be the volume of gas at 40^oC and at 3 atmospheres?*

Gas equation, $PV = RT$ (or) $\frac{PV}{T} = R$

Also $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$P_1 = 1.5$ Atm.pre., $T_1 = 25°C + 273 = 298K$

$P_2 = 3$ Atm.pre., $T_2 = 40°C + 273 = 313K$

And $V1 = 2\ m^3$

$V_2 = (P_1\ V_1\ T_2)/P_2\ T_1 = (1.5 \times 2 \times 313) / (3 \times 298)$

$= 1.05\ m^3$

2. *The ratio between two specific heats of a gas is 1.36. The specific heat capacity of the gas at constant volume is 23094 JK-1 per k. mole. Find the value of Universal gas constant.*

$C_p / C_v = 1.36$ and $C_v = 23094\ JK^{-1}$ per k.mole

$C_P = 1.36 \times C_v = 1.36 \times 23094$

$= 31407.84\ JK^{-1}$ per k mole.

By Mayers relation $C_P - C_V = R$

i.e., $R = 31407.84 - 23094$

$R = 8313.84\ JK^{-1}$ per k. mole

3. *Find the specific heat capacity at constant pressure of helium if C_v= 12525 JK^{-1} per k. mole. One gram molecule of the gas occupies 22.42 litres at NTP Given g = $9.8ms^{-2}$ and density of mercury = $13600\ kgm^{-3}$*

Given; $C_V = 12525\ JK^{-1}$ per k. mole

$V = 22.42$ litres $22.42 \times 10^{-3}m^3$

At. N.T.P. $P = 0.76 \times 136000 \times 9.8$ and $T = 273$ K

Gas equation $PV = RT$

$$R = \frac{PV}{T} = \frac{0.76 \times 136000 \times 9.8 \times 22.42 \times 10\text{-}3}{273}$$

$= 8.313JK^{-1}$ permole

$= 8313\ JK^{-1}$ k mole-1

By Meyer's relation, $C_p - C_v = R$

$$C_P = R + C_V$$

$$= 8313 + 12525$$

i.e., $C_P = 20838\ JK^{-1}$ per k. mole

4. The ratio of two specific heats of Ammonia is 1.31 and universal gas constant is 8314 JK^{-1} per k.mole. Calculate the specific heat of the gas at constant pressure and at constant volume.

The ratio, $C_p / C_v = \gamma$, $C_P = \gamma C_V$

By Meyer's Relation, $C_P - C_V = R$, $C_P = R + C_V$

Then $R + C_V = \gamma C_V$

$$R = \gamma C_V - C_V = C_V (\gamma - 1)$$

$$C_V = R / (\gamma - 1) = 8314 / (1.31\ \ 1)$$

i.e., $C_V = 26819\ JK^{-1}$ per k. mole

$$C_P = R + C_V = 8314 + 26819$$

i.e., $C_P = 35133\ JK^{-1}$ per k. mole

QUESTIONS

Part -A

1) What is of Heat?
2) What is temperature?
3) What are the three important scales of temperature?
4) Define Conduction.
5) Define Convection.
6) Define Radiation.
7) Give examples for two good and two poor thermal conductors.
8) Define the coefficient of thermal conductivity.
9) Give the relation between pressure and kinetic energy of a gas.
10) Define mean square velocity of molecules.
11) Define Root Mean Square velocity of molecules.
12) Give the relation between two specific heats of a gas with universal gas constant.

13) State any two postulates of kinetic theory of gases.
14) Define mean free path.
15) Define specific heat capacity of a solid.
16) Define specific heat capacity of a liquid
17) Define specific heat capacity of a gas at constant pressure.
18) Define specific heat capacity of a gas at constant volume
19) Define ratio of specific heat capacities of gases.

Part –B

1) Explain the process of conduction, convection and radiation.
2) Explain the selection and uses of good and poor thermal conductors.
3) List the properties and uses of thermal radiation.
4) List the postulates of kinetic theory of gases.
5) Derive an expression for the pressure of a gas on the basis of Kinetic theory of gases.
6) Derive the relation between pressure and kinetic energy and absolute temperature of a gas.
7) Derive the expression for the mean kinetic energy per molecule of a gas.
8) Derive Meyer's relation between two specific heat capacities Cp and Cv of a perfect gas. (or) Derive Cp-Cv=R, for a perfect gas.
9) Calculate the value of universal gas constant from the equation PV = RT.

Exercise problems:

1. Find the RMS velocity of hydrogen molecules at S.T.P., if the density of hydrogen is 0.0899 kg m^{-3} at S.T.P.

   (Ans: 1838.52 m s^{-1})

   (Hint: - S.T.P. means standard temperature and pressure Standard pressure = 1 atmospheric pressure = 76 cm of mercury P = $h\rho g$ = 0.76 x13,600 x 9.81 = 101396.16 N m^{-2})
2. At atmospheric pressure, the density of Nitrogen gas is 1.25 kg m^{-3}. Find the R.M.S. velocity of Nitrogen molecules.

   (Ans: 493.05 m s^{-1})
3. The density of carbon dioxide gas at S.T.P. is 1.977 kg m^{-3}.Find the R.M.S. velocity of carbon dioxide molecules.

   (Ans: 392.05 m s^{-1})

4. Calculate R.M.S. velocity of air molecules at N.T.P., if the density of air is 1.29 kg m^{-3}.

(Ans: 485.35 m s^{-1})

5. The density of Helium gas at S.T.P. is 0.1786 kg m^{-3}.Calculate the RMS velocity of Helium molecules.

(Ans: 1304.4 m s^{-1})

6. The molecular weight of carbon di-oxide is 44.Calculate the RMS velocity of CO_2 molecules at N.T.P.

(Ans: 393.32 m s^{-1})

7. The specific heat capacity of a gas at constant volume is 23,094 J K^{-1} k mol^{-1}.The ratio of specific heat capacities of the gas is 1.36.Calculate the specific heat capacity of the gas at constant pressure and also the value of the universal gas constant R for that gas.

(Ans: 8313.84 J K^{-1} k mol^{-1})

8. The specific heat capacity of Helium gas at constant volume is 12,525 J K^{-1} k mol^{-1}.Find the specific heat capacity of the gas at constant pressure. 1 gram molecule of the gas occupies 22.4 litres at N.T.P.

(Ans: 20836.2 J K^{-1} k mol^{-1})

9. The ratio of specific heat capacities of Helium is 1.667.Calculate its specific heat capacity at constant volume and at constant pressure.Given R = 8.3151 J K^{-1} mol^{-1}.

(Ans:C_v = 12.430 J K^{-1} mol^{-1} & C_p = 20.72 J K^{-1} mol^{-1})

10 Calculate the value of gas constant for nitrogen if its density is 1.251 kgm^{-3} at N.T.P. (Molecular mass of nitrogen is 28g.)

(Ans: R=8.3048 $JK^{-1}mol^{-1}$)

Brain Teasers:

1) Calculate the value of gas constant for hydrogen, given density of hydrogen at NTP is 0.09 kgm^{-3} and molecular mass is 2 g

(Ans: R=8.140 J.K^{-1} mol^{-1})

2) The ratio of the specific heats of methane is 1.313. The specific heat capacity at constant pressure is 35200 JK^{-1} per k mole. Calculate the value of specific heat at constant volume and hence calculate the value of gas constant.

(Ans: C_V=26808.8 JK^{-1} k.mol^{-1}R= 8911JK^{-1} k. mol^{-1})

UNIT - II

THERMODYNAMICS, LIQUEFACTION OF GASES & NON-CONVENTIONAL ENERGY

2.1 THERMODYNAMICS

Introduction:

Energy exists in various forms in nature. They are mechanical energy (kinetic and potential), heat energy, electrical energy, radiant energy, chemical energy, etc.

In a hydroelectric power station, mechanical energy is converted into electrical energy. In a steam engine, heat energy is converted into mechanical energy. When a metal piece is hammered mechanical energy is converted into heat energy.

Thermodynamics deals with the conversion of heat energy into mechanical energy and vice versa. But in a mere general sense, it includes the relation of heat to other forms of energy like electrical energy, chemical energy, etc. In our discussions we will be concerned mainly about the conversion of heat energy into mechanical energy.

The science of thermodynamics is guided by the three laws of thermodynamics which will be discussed here.

Zeroth Law:-

Consider a gas enclosed in a cylinder fitted with a piston. If the pressure and volume of the enclosed gas is P and V at the temperature of the surroundings, these values of P and V will remain constant as long as the external conditions of temperature and pressure remain unaltered. The gas is said to be in thermal equilibrium with the surroundings.

If two systems A and B are separately in thermal equilibrium with a third system C, then the three systems (A, B and C) are in thermal equilibrium with each other.

Zeroth Law of thermodynamics states that two systems which are individually in thermal equilibrium with a third one, are also in thermal equilibrium with each other.

First Law of Thermodynamics:-

When a certain quantity of heat is supplied to a system, the whole of the heat energy may not be converted into work. Part of the heat may be used in doing external work and the rest of the heat might be used in increasing the internal energy of the molecules. Let the quantity of heat supplied to the system be ΔQ, ΔW is the work done by the system and ΔU is the change in internal energy of the system.

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

Hence the first law of thermodynamics states that the amount of heat energy supplied to a system is equal to the sum of the change in internal energy of the system and the work done by the system.

According to First Law of Thermodynamics, heat energy can be converted into mechanical work and vice versa.

ISOTHERMAL AND ADIABATIC CHANGES:

In general, when a quantity of heat is given to the gas a part of the heat is used to increase the internal energy of the gas and the rest is used to do external work by the gas. Let dQ be the quantity of heat given to the gas, dE the increase in internal energy and W, the external workdone by the gas. Then

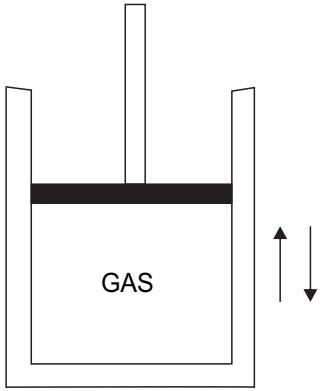
$$dQ = dE + W$$

This equation is called Gas - energy equation.

Isothermal Change

Any change in the pressure and volume of a gas at constant temperature is called as isothermal change.

Consider a gas inside the cylinder with a piston moving in it without friction. When the gas is compressed slowly, the temperature of the gas increases due to the workdone on the gas. If the cylinder and the piston are madeup of conducting materials then the gas gives out the excess heat to the surroundings. Hence there is no rise in temperature.



When the piston moves upwards slowly, the gas expands and the temperature of gas decreases due to the work done by the gas. Then the gas gained shortage of heat from the surroundings. Hence the temperature and therefore there is no change in internal energy. The gas-energy equation for Isothermal change becomes,

dQ = change in internal energy + External work for isothermal change, dQ = O + W

For a perfect gas, isothermal change can be represented by the equation,

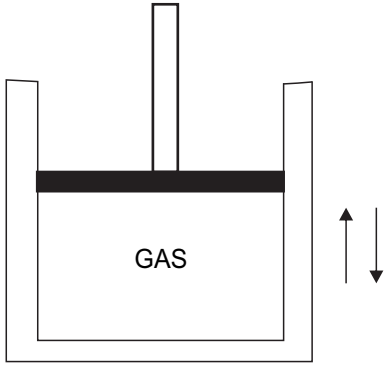
PV = a constant Also $P_1V_1 = P_2V_2$

2. Adiabatic Change :

When the pressure and volume of a gas change, but no heat is allowed to enter or leave the gas, the change. is called as adiabatic change.

Consider a gas inside the cylinder with a pistion moving in it without friction. When the gas is compressed suddenly, the temperature of the gas is increased and the work is done on the gas. Similarly when the piston moves upwards suddenly, the temperature of the gas is decreased and work is done by the gas. Due to the sudden compression or expansion, the gas neither gives out heat to the surroundingsnor receives heat from the surroundings, when the cylinder and the piston are made of non conducting materials.

During the adiabatic change, no heat leaves or enters the gas. That is dQ = O. The work is done at the cost of internal energy. The gas energy equation, for the adiabatic change becomes,



dQ = Change in internal energy + External work

0 = dE + W (or) W = dE

For a perfect gas, adiabatic change can be represented by the equation,

$$PV^{\gamma} = \text{a constant} \qquad \text{Also} \qquad P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

The equation relating the temperature and volume of the gas is

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

The equation relating the temperature and pressure of the gas is

$$T_1^{\gamma}\,P_1^{1-\gamma} = T_2^{\gamma}\,P_2^{1-\gamma}$$

Where $\gamma = C_P / C_V$ is the ratio of the two specific heat capacities of the gas.

3. Worked Problems:

1. A gas at 2 ATP is compressed to half of its original volume. Calculate the final pressure, if the compression is (i) isothermal and (ii) adiabatic (γ = 1.4)

   Let V be the original volume

   Given; P_1 = 2 atmosphere, V_1 =V and V_2 = ½ V

1) For Isothermal change, the equation is $P_1V_1 = P_2V_2$

$$\therefore P_2 = \frac{P_1V_1}{V_2} = \frac{2 \times V}{(1/2)V} = 4 \text{ atmospheric pressure}$$

ii)Adiabatic equation is $P_1V_1^{\gamma} = P_2V_2^{\gamma}$

$$\therefore P_2 = \frac{P_1V_1^{\gamma}}{v_2^{\gamma}} = \frac{2 \times V^{\gamma}}{\frac{v^{\gamma}}{2}} = \frac{2 \times v^{\gamma} \times 2^{\gamma}}{v^{\gamma}}$$

$$= 2 \times 2^{\gamma} = 2 \times 2^{1.4}$$

$= 2 \times 2^{1.4} = 5.278$ Atmospheric Pressure.

2. Air at a pressure of 0.75 m of mercury and of volume 1 litre is compressed to a pressure of 1.5 m of mercury under isothermal process. Calculate the resulting volume.

The equation for Isothermal change is $P_1V_1 = P_2V_2$

Given; $P_1 = 0.75$m of Hg

$P_2 = 1.5$m of Hg

$V_1 = 1$ litre

$\therefore V_2 = (P_1 V_1)/P_2 = (0.75 \times 1)/1.5 = 0.5$ litre

3. A certain mass of gas at 3 atmosphere is compressed adiabatically to half of its volume. Calculate the resulting pressure if $\gamma = 1.4$

Given; $V_1 = V$, $V_2 = ½ V$ and $P_1 = 3$ At. pr.

$P_2 = P_1V_1^{\gamma}/V_2^{\gamma}$

$P_2 = P_1V^{\gamma}/(½V)^{\gamma}$

$P_2 = (3 \times V^{1.4})/(½V)^{1.4} = 3 \times 2^{1.4} = 7.92$ At. pr.

Second Law of Thermodynamics:-

A heat engine is mainly used for the conversion of heat energy into mechanical work. A refrigerator is a device used to cool a certain space below the temperature of its surroundings. The first law does not contradict the existence of 100% efficient heat engine or a refrigerator, which are not attainable in practice. These phenomena led to the formulation of second law of thermodynamics. There are two versions of this second law of thermodynamics.

a. Clausius Statement:

It is impossible for a self acting mechanism working in a cyclic process unaided by an external agency to transfer heat from a body at a lower temperature to the body at a higher temperature.

This part of the law is applicable in the case of ice plants and refrigerators. i.e., Heat itself cannot flow from a body at a lower temperature to a body at a higher temperature, on its own.

b. Kelvin's Statement:

It is impossible to derive a continuous supply of work from a body by cooling it to a temperature lower than that of its surroundings.This part of the law is applicable in the case of Heat engines. In a heat engine the working substance does some work and rejects the remaining heat to the sink. The temperature of the source must be higher than the surroundings. The engine will not work when the temperatures of the source and the sink are same.

4. Concept of Carnot's reversible Heat Engine and Efficiency:-

A machine that converts heat continuously into work is called a heat engine. Carnot conceived a theoretical engine which is free from all the defects of the practical engines. It is an ideal heat engine which has maximum efficiency.

For any engine, there are three essential requisites. They are

1. Source: The source should have a fixed higher temperature from which the heat engine can draw heat. The source has unlimited thermal capacity so that it can deliver any amount of heat required by the engine continuously, at constant temperature.
2. Sink: The sink should be at a fixed lower temperature to which any amount of heat can be rejected. The sink has unlimited capacity to receive the heat and its temperature remains constant.
3. Working substance: The working substance is usually a perfect gas inside a cylinder with non-conducting sides and conducting bottom. A perfect non-conducting and frictionless piston is fitted into the cylinder. A perfectly non-conducting stand is also provided so that the working sub stance can undergo adiabatic operation.

The ratio of part of heat converted into work to the part of heat absorbed from the source is the efficiency of the engine.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$\text{Efficiency } \eta = \frac{(Q_1 - Q_2)}{Q_1}$$

where 'Q_1' is the Quantity of heat absorbed by the substance
'Q_2' is the Quantity of heat rejected to the sink
and 'Q_1 -Q_2' is the Quantity of heat converted into work.

2.2. LIQUEFACTION OF GASES

The work on the liquefaction of gases started in 1823 by Faraday. Gases like chlorine, hydrogen chloride, hydrogen sulphide, sulphur dioxide, ammonia and carbon dioxide were liquefied under high pressure with the aid of simple freezing mixtures. But this method cannot be used to liquefy oxygen, nitrogen, hydrogen and helium.

In 1863, Andrews had discovered the phenomenon of critical state of the gas. According to Andrew's discovery, a gas cannot be liquefied when it is at above a particular temperature. That particular temperature is called critical temperature. The pressure and volume of the gas corresponding to that temperature are called the critical pressure and critical volume. After Andrew's discovery, the liquefaction was done easily by cooling the gas below its critical temperature, even though the process is difficult to liquefy oxygen, nitrogen, hydrogen and helium since they have very low critical temperatures. For example, the critical temperature for oxygen is - 119°C and for hydrogen is - 240° C.

Then in 1877, Pictet liquefied the oxygen by cascade (step by step) process in which low temperatures are obtained in step by step by the evaporation of suitable liquids. In 1896, Linde performed a process to liquefy air by using Joule - Thomson effect.

Critical constants:

The critical temperature, critical pressure and critical volume are called critical constantsT_C

1. **Critical Temperature (T_c)**: The critical temperature of gas is defined as that temperature above which the gas cannot be liquefied however great the pressure applied may be.
2. **Critical pressure (P_c)**: The critical pressure is the minimum pressure required to liquefy a gas when it is at its critical temperature.
3. **Critical volume (V_c)**: The critical volume is the volume of unit mass of a gas when it is at its critical temperature and critical pressure.

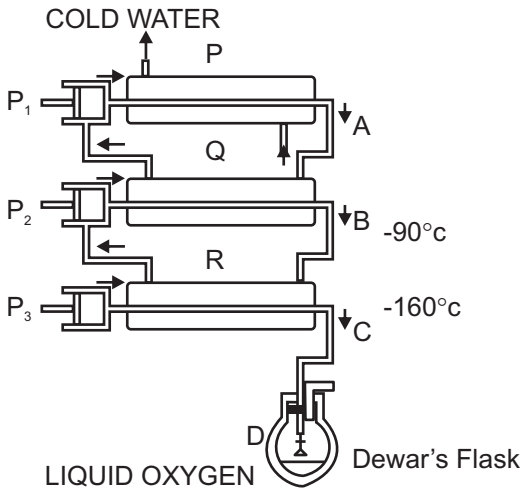
Note: Below the critical temperature the gas is termed as vapour and above the critical temperature it is termed as gas. The gas can be liquefied easily when it is in the state of vapour. Gases like oxygen, nitrogen, hydrogen and helium are termed as permanent gases since they have very low critical temperatures.

2. Cascade Process - Liquefaction of oxygen:

The critical temperatures for oxygen -119°C and critical pressure is 49.7 atm.

Principle: When a liquid is allowed to evaporate under reduced pressure, it produces high cooling.

The apparatus arrangement used in this process is shown in the figure. It consists of three narrow tubes. A,B and C enclosed by three outer jackets P, Q and R respectively. The narrow tubes and the outer jackets are linked with the compression pumps P_1, P_2 and P_3 as shown in the figure. The methyl chloride gas of critical temperature 145° C is compressed by the pump P_1 through the tube A. It is cooled by the cold water circulating in the jacket P. Here the methyl chloride reaches the temperature lower than its critical temperature. Then it is liquefied under high pressure. The liquid methyl chloride is collected in the jacket Q and evaporates under reduced pressure lowering the temperature to -90° C.



The ethylene gas of critical temperature 10° C is compressed by the pump P_2 through the tube B. It is cooled to -90° C by liquid methyl chloride. Then it is liquefied under high pressure. The liquid ethylene is collected in the jacket R and evaporates under reduced pressure lowering the temperature to -160° C.

The oxygen gas of critical temperature - 119° C is compressed to 50 atmospheric pressure by the pump P_3 and passed through the tube C. It is cooled to - 160° C by liquid ethylene in R. Then it is liquefied and the liquid oxygen is collected in the Dewar flask D.

Disadvantage: The lowest temperature obtained in this process is - 160° C. Therefore the cascade process cannot be used to liquefy hydrogen and helium whose critical temperatures are lower than - 160° C.

3. Joule - Thompson Effect:

Using the principle of Joule - Thompson effect, air, hydrogen and helium were also liquefied. Joule performed an experiment to study the effect of change in the temperature of a gas when it is allowed to pass through a porous plug from the high pressure side to the low pressure side.

Joule - Thompson effect: When a gas is allowed to expand from a high pressure side to a low pressure side through a porous or nozzle or jet then it produces intense cooling, if the temperature of the gas is less than the temperature of inversion. This effect is called Joule - Thompson effect.

Temperature of inversion: If a gas is at a particular temperature no cooling or heating is observed when it is passed through the porous plug. If the temperature of the gas on the high pressure side is more than that temperature, heating will takes place instead of cooling. That particular temperature is called the temperature of inversion.

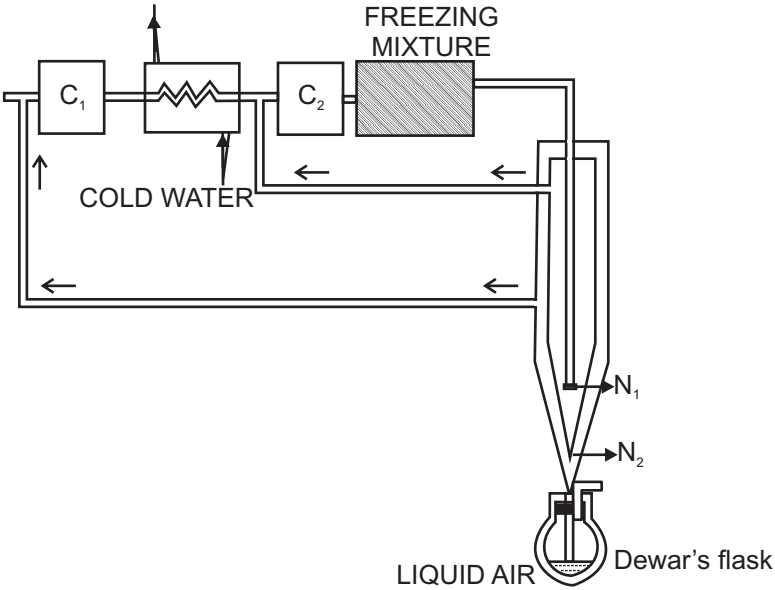
Temperature inversion may be defined as the temperature at which there neither cooling nor heating due to June Thomson effect.

4. Linde's Process - Liquefaction of Air:

The principle of Joule - Thompson effect is used in this process. The apparatus arrangement used in this process is shown in the figure. It consists of two compressors C_1 and C_2, a cold water jacket, freezing mixture jacket, narrow tube having nozzle N_1 and a wide tube having nozzle N_2.

Air is compressed to 25 atmospheres by the compressor C_1. The compressed air is passed through a tube surrounded by a cold water

jacket. Again this air is compressed to 200 atmospheres by the compressor C_2. This compressed air is passed through a spiral tube surrounded by a freezing mixture jacket. Now the air reaches to a temperature of -20° C. This cooled air at high pressure is allowed to expand through a nozzle N_1 and it is further cooled by Joule - Thompson effect. This cooled air is circulated back to the compressor C_2 and is compressed again.



As the process continues, after a few cycles, the air gets cooled to a sufficiently low temperature. Finally the air expands from high pressure side to the low pressure side through the nozzle N_2. Again the temperature is reduced by Joule - Thompson effect and the air gets liquefied. The liquid air is collected in the Dewar flask. The unliquefied air is again circulated back to the compressor C_1 and the process is repeated. The whole apparatus arrangement is packed in cotton or thermal wool to avoid any conduction and radiation.

2.3. NON CONVENTIONAL ENERGY

Introduction:

Energy is an important input for all sectors of a country's economical development. For India, the energy needs is increasing rapidly day by day. It is a well-known fact that the currently available conventional energy resources like coal, oil, natural gas, etc., are depleting very fast. 54% of our energy need is provided by coal, which may be available for another 80 years at the current rate of usage. 32% of energy need is fulfilled by oil, which may last up to 22 years and the rest 14% is met by hydro, nuclear, natural gas, etc. So, we will have to increasingly depend on other non conventional energy resources like solar, wind, tidal, geothermal, hot dry rock, bio mass, etc.

The sources of energy utilised by human beings fall into two categories:

1. **Non-renewable** energy resources are sources of power that cannot be replaced once they are used, because the energy source has taken millions of years to form (ex. coal, oil).These energy resources are also called as **finite** energy resources.
2. **Renewable** energy resources are sources of power that quickly replenish (fill again) themselves and can be used again and again repeatedly (ex. Wind, tidal). These energy resources are also called as **infinite** energy resources.

Conventional or Non – renewable sources of energy:

The conventional or non – renewable energy sources are classified as primary and secondary energy sources. The primary energy sources are which provide a net supply of energy, like coal, oil, natural gas, uranium, etc. These fuels are called primary fuels, from which the energy yield ratio is very high. i.e., the energy required to obtain these fuels is much less than what they can produce by combustion or nuclear reaction. The secondary fuels like wood, animal wastes, agricultural wastes, etc., produce no net energy.

Non – conventional or renewable sources of energy:

To meet our future energy requirements, we have to tap other available non conventional or renewable energy sources. The renewable sources of energy are also called as non conventional (or) alternate

sources of energy. They are Solar, Wind, Tidal, Geothermal, Bio mass, Hot dry rock, Chemical, etc. Various technologies are designed and developed to tap these earth's natural energy resources which are renewable. They are called renewable because, they are available in plenty and freely.

Solar energy:

The sun is a large sphere of very hot gases, the energy being generated by various kinds of nuclear fusion reactions.

Sun gives us 1000 times more power than we need. Therefore, solar energy can be a major source of power. Even if we could tap one thousandth of solar power, that will meet our requirements. But so far it could not be developed on a large scale.

Energy produced and radiated by the sun, which reaches the earth, is termed as “Solar energy”. Energy is radiated by the sun, as electromagnetic waves. Solar energy, received in the form of electro magnetic radiation, can be converted directly or indirectly into other forms of energy, such as heat and electricity, which can be utilised by human being. Since the sun can radiate energy at constant rate for a few billion years, it may be regarded as an inexhaustible source of useful energy.

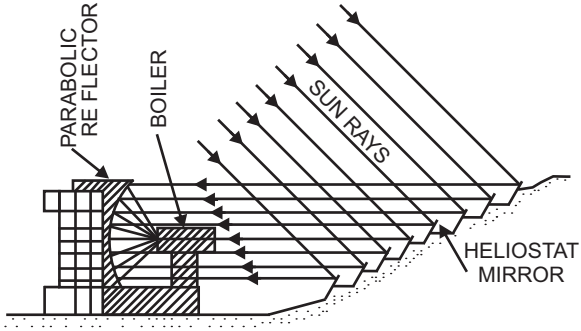
As India is situated near equator, where sunlight is abundant for a major part of the year, utilising the solar energy to a greater extent is the best option available to us.

Some important applications of solar energy are

(I) Solar water heating, (ii) Heating and cooling of residential buildings, (iii) salt production by evaporation of sea water, (iv) Solar cookers, (v) Solar furnaces, (vi) Solar pumps for water pumping and (vii) Solar electric power generation.

From solar energy electricity can be produced with the help of photovoltaic or solar cells. The solar cells directly generate electricity by photovoltaic process. When the photons from the sun's light is absorbed by special type of semi conducting material they create free electrons.

These free electrons induce higher energy electrons to flow out of the semiconductor. The flow of higher energy electrons in the circuit constitutes the electric current.



Solar water heating system

This system is used to drive turbo-generators to produce electricity. A plant of this type is operating in France and produces 1000 KW.

2. Wind energy:

Wind is basically caused by the solar energy irradiating the earth. Energy of wind can be economically used for the generation of electrical energy. Wind is caused due to two main factors:

(a) Due to air in motion. Air motion arises from a pressure gradient. The surface winds flow from the poles toward the equator. Solar radiation heats the air near the equator, and this low density heated air buoyed up. At the surface, it is displaced by cooler, more dense higher pressure air flowing from the poles. In the upper atmosphere near the equator the air tend to flow towards the poles and away from the equator. The net result is a flow of surface winds from north to south in the northern hemisphere. Similarly the flow of surface winds is from south to north in the southern hemisphere of the earth.

(b) Due to the rotation of the earth with respect to atmosphere, and its motion around the sun.

Wind energy which is an indirect source of solar energy conversion can be utilized to run windmill, which in turn drives a generator to produce electricity. Wind can also be used to provide mechanical power, such as for water pumping.

Some characteristics of wind energy are stated below:

(i) It is a renewable source of energy.

(ii) Wind-power systems are non-polluting, so it does not affect the environment.

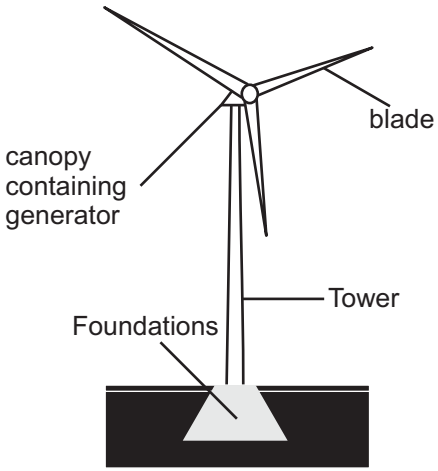
(iii) Wind energy systems avoid fuel provision and transport.

(iv) Large areas are needed to install wind forms for electrical power generation and wind energy needs storage means because of its irregularity in the speed of flow.

(v) Manufacture and implementation of wind farms can be costly.

As our country has lot of wind throughout the year, the energy in the wind can be used to generate power that can be used for domestic and industrial uses. The wind mill is the form in which we can convert the wind energy to electricity. The potential of wind energy is of the order of 1.6×10^7MW.

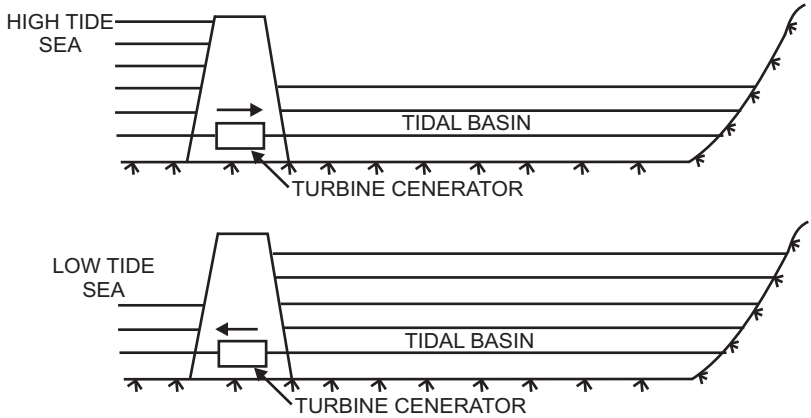
The wind mill generally consists of a turbine (a dynamo which can produce electricity when rotated) connected to large rotating blades. The blades rotate by using the wind.



The setting up cost of these windmills is high but the running cost is very low. Use of this would help in producing cheap power. Tamilnadu has set up a large number of wind mills in the state especially in places like Tiruppur, Muppandal in Kanyakumari, Coimbatore and their surroundings.

3. Tidal energy:

Tide is a periodic rise and fall of the water level of sea due to gravitational effect of the sun and moon on the water of the earth. Due to fluidity of water mass, there is a periodic rise and fall in levels of sea water which is in rhythms with the daily cycle of rising and setting of sun and moon. As the earth rotates, the position of a given area relative to the moon changes, and thus a periodic succession of high and low tides occur. This periodic rising and falling of the water level of sea is known as tidal power.



The large scale up and down movement of sea water due to tide represents an unlimited source of energy. If some part of the vast energy can be converted into electrical energy it would be an important source of hydro – power. Using a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator. Water at the time of a high tide is at a higher level and can be let into a basin to be stored at a high level there. The same water can be let back into the sea during the low tide through the turbines, thus producing power.

The advantages of tidal power are

1) It is free from pollution, as it does not use any fuel and does not produce any unhealthy waste like gases, ash, atomic refuse, etc.
2) These power plants do no demand large area of valuable land because they are on the bays (Sea shore).

Its own limitations are

1) Sea water is corrosive and it was feared that the machinery may get corroded. But using vinyl paint exhibited good results.
2) Cost is not favourable compared to the other sources of energy and it is feared that the tidal power plant would hamper the other natural uses such as fishing or navigation.

3. Geothermal energy:

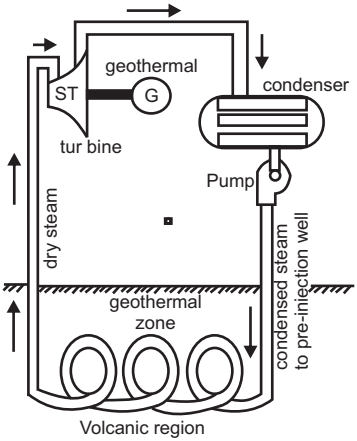
Energy present as heat (i.e. thermal energy) in the earth's crust, in the upper most 10 km or so of the crust constitutes a potentially useful and almost inexhaustible source of energy.

Geothermal source is defined as " all of the heat stored in the earth's crust above 15° C to a depth of 10 km". It occurs when the immense heat energy in the core of earth rises closer to the surface of the earth due to cracks or faults in the crust and heats the surrounded rock. These are tapped to use the stored heat energy, for power generation and several other uses, depending upon the temperature of occurrence and other parameters.

Hot molten rock, called "Magma" is commonly present at depths greater than 24 to 40 km. The hot magma near the surface solidifies into igneous rock which is formed by volcanic action. The heat of the magma is conducted upward to this igneous rock. Ground water that finds its way down to this rock through fissures (cracks) in it, will be heated by the heat of the rock or by mixing with hot gases and steam let out from the magma. The heated water will then rise convectively upward into a porous and permeable reservoir above the igneous rock. The reservoir is capped by a layer of impermeable solid rock that traps the hot water in the reservoir. The solid rock, however, has fissures that act as vents of the giant underground boiler. The vents show up at the surface as geysers or hot spring. A well taps steam from the fissures for use in a geothermal power plant.

Geothermal energy has the highest energy density and it is classified as renewable because the earth's interior will continue to be hot for an indefinite future.

But it is very expensive to set up, and works in areas of volcanic activity. Dangerous underground gases have to be disposed of very carefully in this source of energy.

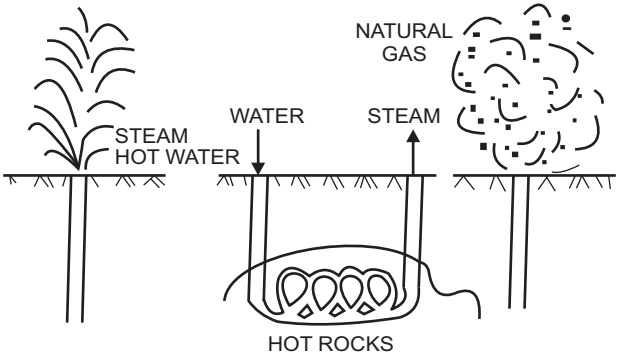


Geothermal power stations use the naturally produced steam to drive turbines and generators. Once used, the steam turns back into water and is pumped back into the ground again to be reheated by the earth.

4. Hot dry rock resources (HDR):

This system is composed of hot dry rock (HDR) without underground water. They represent the largest geothermal resource available. The hot rock, occurring at moderate depths, has very low permeability and needs to be fractured to increase its heat transfer to surface. Hot dry rocks exist because they are impermeable to water or because water does not have access to them. Heat is recovered from such hot dry rocks by breaking up or cracking the rock to make it permeable and then introducing water from the surface. The water is heated up by the rock and is returned to the surface where the heat is utilized.

There are two methods to tap this geothermal energy. One possible method is to detonate a high explosive at the bottom of a well drilled into the rock. This may be a nuclear explosive. Another method is to use hydraulic fracturing to produce the heat transfer surface and permeability required to extract energy at a high rate from hot dry rock. Heat can then be extracted from the hot rock by circulating water through the crack. The thermal energy of HDR is used in a power plant to produce electricity.



The limitation of HDR is, two wells are to be drilled deeper and in much harder rock. This is expected to make the exploitation very costly, unless the underground rock targeted is very hot.

5. Energy from Bio mass:

Biomass is organic matter produced by plants, both terrestrial and aquatic and their derivatives. It includes forest crops and residues, crops grown especially for their energy content on energy farms and animal manure. Biomass can be considered a renewable energy source because plant life renews and adds to itself every year. Biomass means organic matter in which photo chemical approach is used to harness solar energy by photo synthesis. Solar energy is stored in the form of chemical energy.

Solar energy ⟶ Photosynthesis ⟶ Biomass ⟶ Energy conversion

Biomass resources fall into three categories:

(I) Biomass in its traditional solid mass (wood and agriculture residue) - In this category biomass is burnt directly to get the energy.

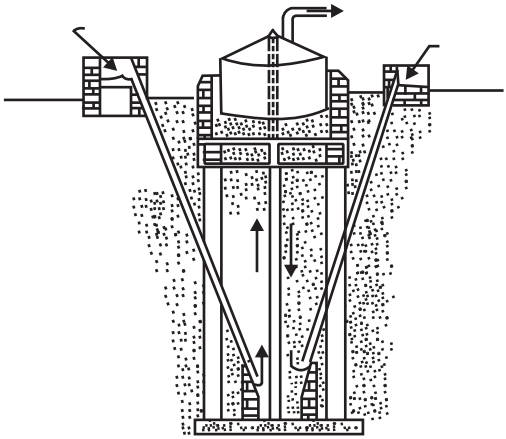
(ii) Biomass in non-traditional form (converted into liquid fuels) – In this category, the biomass is converted into ethanol and methanol to be used as liquid fuels in engines.

(iii) The third category is to ferment the biomass to obtain a gaseous fuel called bio-gas.

Biomass conversion can take many forms: (1) direct combustion, such as wood waste and bagasse, (2) thermochemical conversion, and (3) biochemical conversion.

Biomass includes wood waste which has potential of generating substantial electric power. All these biomass are highly dispersed and bulky and contain large amounts of water (50 to 90%).Thus it is not economical to transport them over long distances, and conversion into usable energy must take place close to the source, which is limited to particular regions. When biomass is burnt, it gives off atmospheric pollutants, including greenhouse gases and biomass is only a renewable resource if crops are replanted.

Rotting plants can produce methane gas that is the same as “natural gas”. This gas can be collected from such places and piped to people's homes for heating or cooking or burnt in a small power station to produce electricity.



Gobar gas plant

Wastes that are degradable can be used for generation of power. Gobar gas which is produced from the wastes of animals has been used as a substitute for LPG in villages for a long time.

The waste is fed through the inlet pipe. The waste is fed till the partition wall is submerged in the waste. The methane gas bubbles out and is collected and taken out for use through a pipe provided at the top of the drum. The outlet pipe is lower than that of inlet pipe to facilitate the used waste to flow out easily.

Procedure:

The anode and cathode of a P-N junction diode can be identified by seeing a colour band or spot on the cathode. Also the cathode may be having pointed edge in some type.

For forward biasing, the connections are given neatly as shown in the diagram. Suitable ranges of meters, resistance and power supply can be selected.

The current flowing through the diode is noted for various values of p.d. applied across the diode and the readings are noted in the tabular column. With these readings, a neat graph is drawn by taking forward voltage applied across the diode in X - axis and forward current flowing through the diode (in mA) along Y - axis.

This curve is called as the forward characteristics of the diode. From this graph, the approximate voltage above which the diode current sharply increases, can be determined, which gives the "Knee Voltage" of the diode.

For germanium diode, the knee voltage is 0.3 volt and for silicon diode the knee voltage is 0.7 volt, which is almost equal to the barrier potential.

In the <u>upper region of the curve</u>, two perpendicular lines OA and AB are drawn to find the dynamic forward resistance, as shown in the model graph. In this OA gives the value of small change in p.d. applied across the diode (Δv) and AB gives the corresponding change in the current flowing through the diode (Δi). These values are determined.

Then the dynamic forward resistance of the diode is determined by using the given formula.

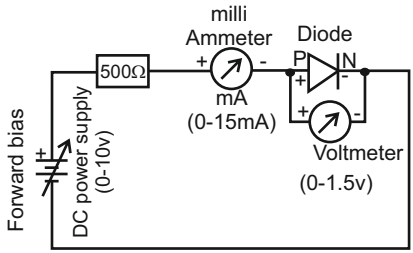
Result:

The forward characteristics of a P-N Junction diode is drawn.

From the graph,

(i) The dynamic forward resistance r = ohm

(ii) The knee voltage V_k = volt



Circuit diagram for drawing the forward characteristics of P-N junction diode.

Tabular column:

Readings for drawing the forward characteristics of P-N junction diode

Sl. No.	**P.d applied across the diode (v)**		**Current flowing through the diode (i)**	
Unit	div	volt	div	milliampere (mA)
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				

Calculation:

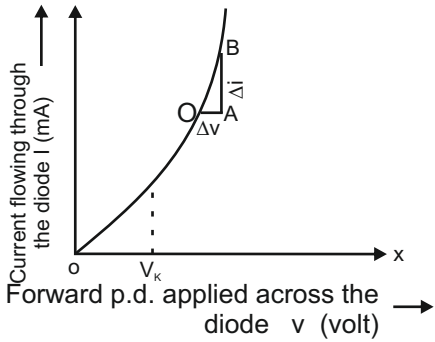
From graph,

ΔV = div ; Δi = div

For calculating ΔV in volt

In X – axis 10 div = volt ; 1 div = volt

$\therefore \Delta V$ = div = x = volt



For calculating Δi in mA

In Y – axis 10 div = mA ; 1 div = mA

$\therefore \Delta i$ = div = x = mA

= x 10^{-3} A

(i) The dynamic forward resistance is $r = \frac{\Delta v}{\Delta i} =$

= ohm

(ii) The knee voltage is V_k = div

= x

= volt

LOGIC GATES

Experiment No.

Date:

Aim:

To find the output condition for different combinations of the inputs for NOT gate and two inputs AND, OR, NAND and NOR logic gates, using I C Chips.

Apparatus required:

Logic gate apparatus kit with chip mounting base, integrated circuit chips (IC chips) for the above logic gates.

Description:

The logic gate kit consists of required DC power supply, light emitting diodes (LEDs), to indicate the input and the output signal, toggle switches to provide various combinations of input and breadboard to mount the desired IC chip.

In the kit when the LED glows, the corresponding condition is “ON”, and the binary is 1. If the LED does not glow the corresponding condition is “OFF”, and the binary is 0.

Procedure:

(a)NOT gate:

It is the simplest form of the logic gates. It has only one input and one output. The function of this gate is to produce one logic level from the opposite logic level. i.e. If the input condition is “ON”, the output condition will be “OFF” and if the input condition is “OFF”, the output condition will be “ON”.

The NOT gate is available in IC chip number 7404. The pin configuration for the power supply, ground, input and output of the IC chip is given in the figure and the Boolean expression is also given.

The 7404 IC is mounted on the base provided in the kit. Suitable input level is given and the corresponding output level is noted in the truth table of NOT gate.

The function of this gate is inverting or complementing the input signal. So, this gate is also called as a 'Complementer or Inverter gate'.

(b) AND gate:

This gate has two or more inputs and only one output. The function of this gate is to produce a true condition on its output, if and only if all its input conditions are true. i.e., the output of the gate is in “ON” condition if and only if all its inputs are in “ON” condition.

The two inputs AND gate is available in IC chip number 7408. The pin configuration for the power supply, ground, input and output of the IC chip is given in the figure and the Boolean expression is also given.

The 7408 IC is mounted on the base provided in the kit. Suitable combinations of input levels are given and the corresponding output levels are noted in the truth table of AND gate.

This gate is also called as a 'Multiplier gate'.

(c) OR gate:

This gate has two or more inputs and only one output. The function of this gate is to produce the true condition on its output, when one or more of its input conditions are true. i.e., The output of the gate is in “ON” condition if any one of its inputs is in “ON” condition.

The two inputs OR gate is available in IC chip number 7432. The pin configuration for the power supply, ground, input and output of the IC chip is given in the figure and the Boolean expression is also given.

The 7432 IC is mounted on the base provided in the kit. Suitable combinations of input levels are given and the corresponding output levels are noted in the truth table of OR gate.

This gate is also called as a 'Adder gate'.

These above three gates are called 'Basic Gates'.

(d) NAND gate:

It is a combination of AND and NOT gates. The output of NAND gate is complementation of that of an AND gate.

The two inputs NAND gate is available in IC chip number 7400. The pin configuration for the power supply, ground, input and output of the IC chip is given in the figure and the Boolean expression is also given.

The 7400 IC is mounted on the base provided in the kit. Suitable combinations of input levels are given and the corresponding output levels are noted in the truth table of NAND gate.

e) NOR gate:

This gate is a combination of NOT and OR gates. The output of the NOR gate is Complementation of that of an OR gate.

The two inputs NOR gate is available in IC chip number 7402. The pin configuration for the power supply, ground, input and output of the IC chip is given in the figure and the Boolean expression is also given.

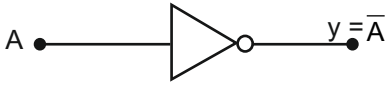
The 7402 IC is mounted on the base provided in the kit. Suitable combinations of input levels are given and the corresponding output levels are noted in the truth table of NOR gate.

These above two gates are known as 'Universal gates'.

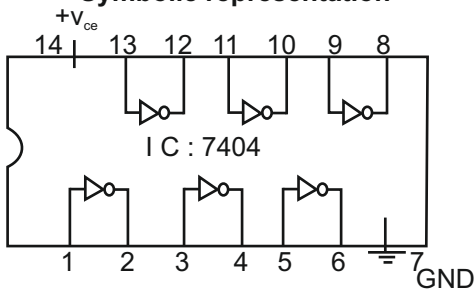
Result:

Thus the output condition for different combinations of the inputs for NOT gate and two inputs AND, OR, NAND and NOR logic gates are noted in the truth table.

a) NOT gate:



Symbolic representation



NOT gate IC chip

IC No: 7404

Pin configuration:

Input pins : 1,3,5,9,11,13

Output pins : 2,4,6,8,10,12

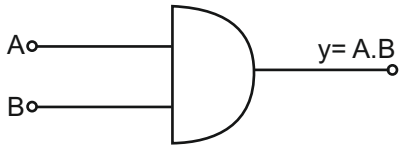
Ground pin : 7

Power pin (+ V_{cc}): 14

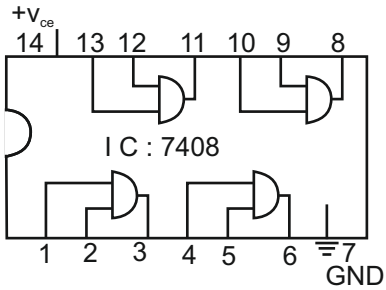
Truth table for NOT gate

INPUT	OUTPUT
A	Y = $\overline{A}$
0	
1	

b) AND gate:



Symbolic representation



Two input AND gate IC chip

IC No: 7408

Pin configuration:

Inputpins : 1,2,4,5,9,10,12,13

Output pins : 3,6,8,11

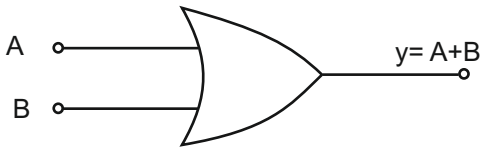
Ground pin : 7

Power pin (+ V_{cc}): 14

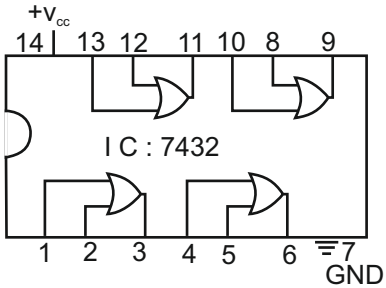
Truth table for AND gate

INPUTS		OUTPUT Y = A.B
A	B	
0	0	
0	1	
1	0	
1	1	

c) OR gate:



Symbolic representation



Two input OR gate IC chip
IC No: 7432

Pin configuration:

Inputpins:1,2,4,5,9,10,12,13

Output pins: 3,6,8,11

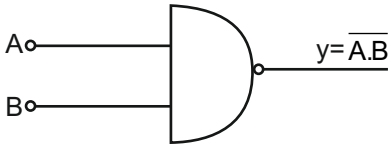
Ground pin : 7

Power pin (+ V_{cc}): 14

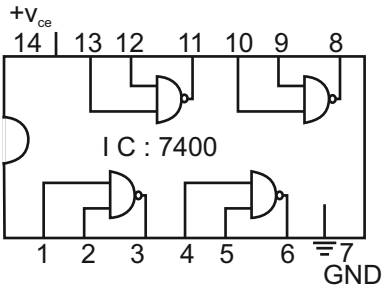
Truth table for OR gate

INPUTS		OUTPUT Y = A + B
A	B	
0	0	
0	1	
1	0	
1	1	

d) NAND gate:



Symbolic representation



Two input NAND gate IC chip

IC No: 7400

Pin configuration:

Inputpins:1,2,4,5,9,10,12,13

Output pins: 3,6,8,11

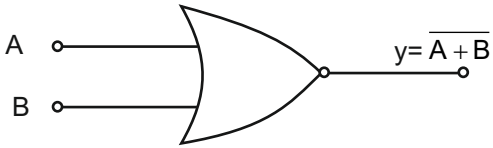
Ground pin : 7

Power pin (+ V_{cc}): 14

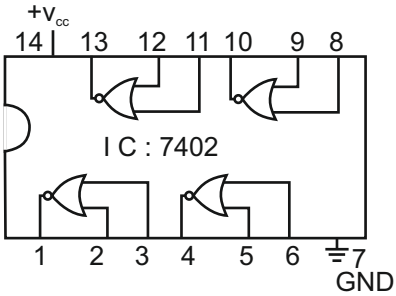
Truth table for NAND gate

INPUTS		output $y = \overline{A.B}$
A	**B**	
0	0	
0	1	
1	0	
1	1	

e) NOR gate:



Symbolic representation



Two input NOR gate IC chip

IC No: 7402

Pin configuration:

Inputpins:2,3,5,6,8,9,11,12

Output pins: 1,4,10,13

Ground pin : 7

Power pin (+ V_{cc}): 14

Truth table for NOR gate

INPUTS		output $y = \overline{A+B}$
A	**B**	
0	0	
0	1	
1	0	
1	1	

MODEL QUESTION PAPER

1. Determine the refractive index of the given transparent liquid using traveling microscope.
2. Draw the V – I characteristics of the solar cell.
3. Measure the angle of the prism and the angle of minimum deviation using spectrometer and then calculate the refractive index of glass.
4. Verify the laws of resistances by connecting the two given standard resistances (i) in series and (ii) in parallel, using Ohm's law.
5. Determine the unknown resistance of the given wire, using metre bridge.
6. Compare the electro motive forces (e.m.fs) of the given two cells, using potentiometer.
7. Determine the specific heat capacity of water, using Joule's calorimeter.
8. Determine the electro chemical equivalent (e.c.e.) of copper using Copper Voltameter.
9. Draw the voltage – current characteristics of a P-N junction diode in forward bias and then find the 'dynamic forward resistance' & 'knee voltage' from the graph.
10. Find the output conditions for different combinations of the input for NOT gate (7404) and 2 inputs AND, (7408) OR, (7432) NAND (7400) & NOR (7402) logic gates using IC chips.