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SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – I -Gravitation– SPH1111

1 Introduction

The application of Newton's law of gravity has enabled the acquisition of much of the detailed information we have about the planets in the Solar System, the mass of the Sun, and details of quasars; even the existence of dark matter is inferred using Newton's law of gravity.

Although we have not traveled to all the planets nor to the Sun, we know their masses. These masses are obtained by applying the laws of gravity to the measured characteristics of the orbit.

In space an object maintains its orbit because of the force of gravity acting upon it. Planets orbit stars, stars orbit galactic centers, galaxies orbit a center of mass in clusters, and clusters orbit in superclusters.

1.1 Gravitational potential energy

Gravitational potential energy is energy in an object that is held in a vertical position, due to the force of gravity working to pull it down. The amount of gravitational potential energy an object has depends on its height and mass. The heavier the object and the higher it is above the ground, the more gravitational potential energy it hold. Gravitational potential energy increases as weight and height increases. Gravitational potential energy is energy in an object that is held in a vertical position. Potential energy is energy that is stored in an object or substance. Elastic potential energy is energy stored in objects that can be stretched or compressed.

2. Newton's law of universal gravitation

Newton's law of universal gravitation is usually stated as that every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers

What is the Gravitational Constant?

The gravitational constant is the proportionality constant used in Newton’s Law of Universal Gravitation, and is commonly denoted by G. This is different from g, which denotes the acceleration due to gravity. In most texts, we see it expressed as:

$G = 6.673\times10\text{-}11\ N\ m^2\ kg^{-2}$

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It is typically used in the equation:

$$F = (G \times m_1 \times m_2) / r^2 \text{ , wherein}$$

F = force of gravity

G = gravitational constant

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F = (G x m1 x m2) / r2 , wherein

F = force of gravity

G = gravitational constant

m1 = mass of the first object (lets assume it’s of the massive one)

m2 = mass of the second object (lets assume it’s of the smaller one)

r = the separation between the two masses

As with all constants in Physics, the gravitational constant is an empirical value. That is to say, it is proven through a series of experiments and subsequent observations. Although the gravitational constant was first introduced by Isaac Newton as part of his popular publication in 1687, the Philosophiae Naturalis Principia Mathematica, it was not until 1798 that the constant was observed in an actual experiment. Don’t be surprised. It’s mostly like this in physics. The mathematical predictions normally precede the experimental proofs.

Anyway, the first person who successfully measured it was the English physicist, Henry Cavendish, who measured the very tiny force between two lead masses by using a very sensitive torsion balance. It should be noted that, after Cavendish, although there have been more accurate measurements, the improvements on the values (i.e., being able to obtain values closer to Newton's G) have not been really substantial.

3. The gravitational field intensity

The gravitational field intensity depends only upon the source mass and the distance of unit test mass from the source mass. The unit of gravitational field intensity is N/kg. The dimensional formula is given by $[M^0L^1T^{-2}]$. The formula is: weight/mass = gravitational field strength. On Earth the gravitational field strength is 10 N/kg. Other planets have different gravitational field strengths. The Moon has a gravitational field strength of 1.6 N/kg. The space around a body where the gravitational force exerted by it can be experienced by any other particle is known as the gravitational field of the body. The strength of this gravitational field is referred to as intensity, and it varies from point to point. A uniform gravitational field is one where the field lines are always the same distance apart - this is almost exactly true close to the Earth's surface (Figure 1(a)).

However if we move back and look at the planet from a distance the field lines clearly radiate outwards (Figure 1(b)), getting further apart as the distance from the Earth increases.

When viewed from an even greater distance the complete field can be seen (as shown in Figure 1(c)).

Such a field is called a radial field - the field intensity (g) decreasing with distance.

The separation of the field lines gives an indication of the strength of the field – if they are close together the field intensity is high and of they are far apart it is low.

Diagram 1(d) shows the distortion of the gravitational field lines by high- density rock. This was most important for the Apollo Moon landings where NASA discovered concentrations of massive rock below the lunar surface. The resulting variation in the gravitational acceleration at that point would have affected the approach of the lunar lander.

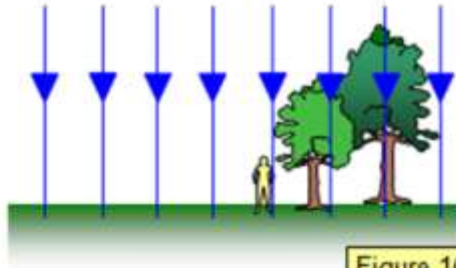


Figure 1(a)

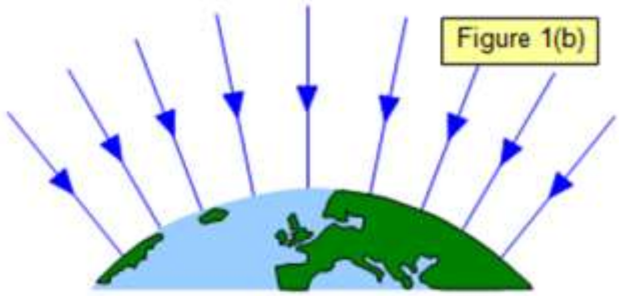


Figure 1(b)

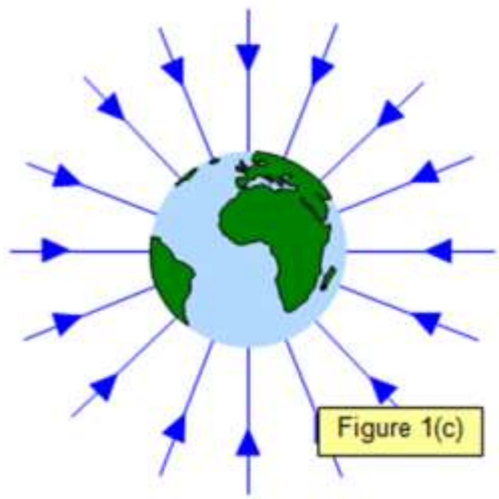


Figure 1(c)

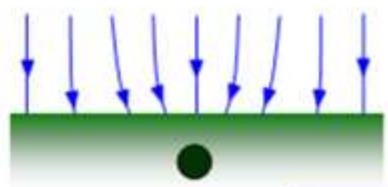


Figure 1(d)

4 Keplers Laws

In the early 1600s, Johannes Kepler proposed three laws of planetary motion. Kepler was able to summarize the carefully collected data of his mentor - Tycho Brahe - with three statements that described the motion of planets in a sun-centered solar system. Kepler's efforts to explain the underlying reasons for such motions are no longer accepted; nonetheless, the actual laws themselves are still considered an accurate description of the motion of any planet and any satellite.

Kepler's three laws of planetary motion can be described as follows:

- The path of the planets about the sun is elliptical in shape, with the center of the sun being located at one focus. (The Law of Ellipses)
- An imaginary line drawn from the center of the sun to the center of the planet will sweep out equal areas in equal intervals of time. (The Law of Equal Areas)
- The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun. (The Law of Harmonies)

The Law of Ellipses

Kepler's first law - sometimes referred to as the law of ellipses - explains that planets are orbiting the sun in a path described as an ellipse. An ellipse can easily be constructed using a pencil, two tacks, a string, a sheet of paper and a piece of cardboard. Tack the sheet of paper to the cardboard using the two tacks. Then tie the string into a loop and wrap the loop around the two tacks. Take your pencil and pull the string until the pencil and two tacks make a triangle (Fig 1). Then begin to trace out a path with the pencil, keeping the string wrapped tightly around the tacks. The resulting shape will be an ellipse. An ellipse is a special curve in which the sum of the distances from every point on the curve to two other points is a constant. The two other points (represented here by the tack locations) are known as the foci of the ellipse. The closer together these points are, the more closely that the ellipse resembles the shape of a circle. In fact, a circle is the special case of an ellipse in which the two foci are at the same location. Kepler's first law is rather simple - all planets orbit the sun in a path that resembles an ellipse, with the sun being located at one of the foci of that ellipse.

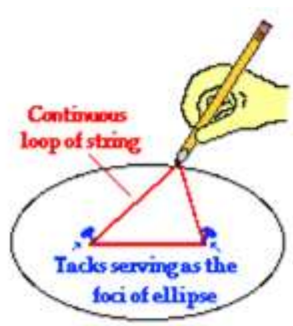
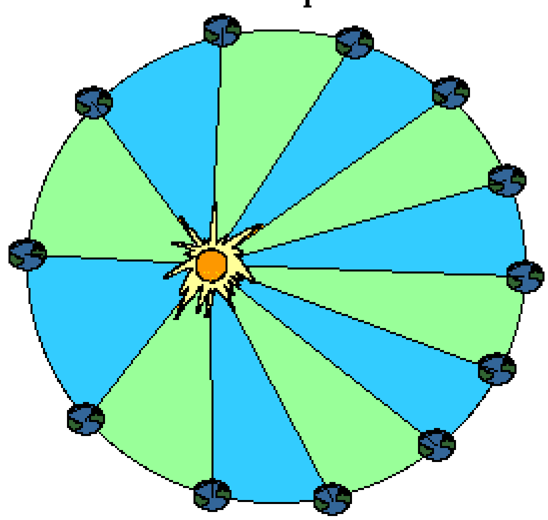


Fig 1 Keplers first law

The Law of Equal Areas

Kepler's second law - sometimes referred to as the law of equal areas - describes the speed at which any given planet will move while orbiting the sun. The speed at which any planet moves through space is constantly changing. A planet moves fastest when it is closest to the sun and slowest when it is furthest from the sun. Yet, if an imaginary line were drawn from the center of the planet to the center of the sun, that line would sweep out the same area in equal periods of time. For instance, if an imaginary line were drawn from the earth to the sun, then the area swept out by the line in every 31-day month would be the same. This is depicted in the diagram below. As can be observed in the diagram, the areas formed when the earth is closest to the sun can be approximated as a wide but short triangle; whereas the areas formed when the earth is farthest from the sun can be approximated as a narrow but long triangle. These areas are the same size. Since the base of these triangles are shortest when the earth is farthest from the sun, the earth would have to be moving more slowly in order for this imaginary area to be the same size as when the earth is closest to the sun.

The Law of Equal Areas



An imaginary line drawn from the sun to any planet sweeps out equal areas in equal amounts of time.

The Law of Harmonies

Kepler's third law - sometimes referred to as the law of harmonies - compares the orbital period and radius of orbit of a planet to those of other planets. Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The comparison being made is that the ratio of the squares of the periods to the cubes of their average distances from the sun is the same for every one of the planets.

5 Boys Method for the Determination of G

This method to determine the value of the universal gravitational constantuses two gold spheres each of massat either end of a bar suspended in the middle by a torsion wire. The bar is suspended between lead masses A and B each of massas shown in the diagram.The forces acting on the spheres are shown in Fig 2

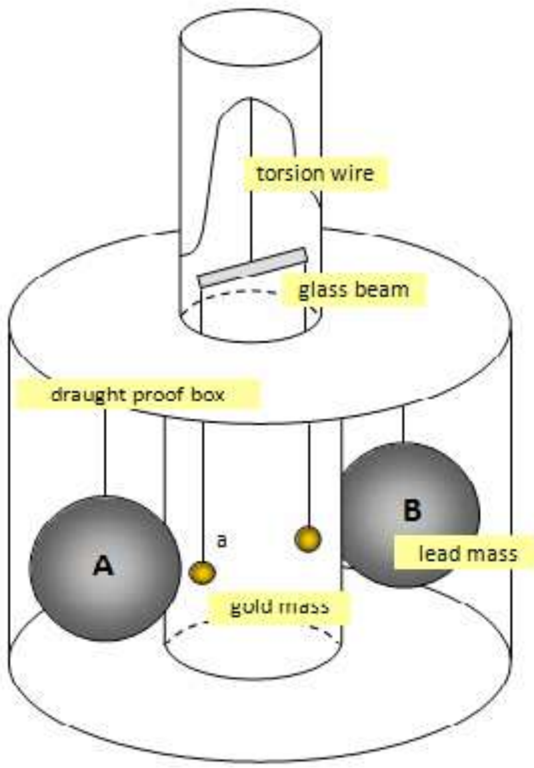


Fig 2 The forces acting on the spheres

The forces of gravitational attraction between the gold masses and the lead masses causes the bar to twist through an angle

The torque on the beam is given by $2\times\frac{Gml/2}{d^2}$ and equating this to the restoring torque $c\theta$, where c is the restoring force per radian of turn exerted by the torsion bar The forces of gravitational attraction between the gold masses and the lead masses causes the bar to twist through an angle

$$\frac{Gml/2}{d^2}=c\theta$$

Then $G=\frac{c\theta d^2}{mMl}$.

6. Gravitational Potential

The amount of work done in moving a unit test mass from infinity into the gravitational influence of source mass is known as gravitational potential.

Simply, it is the gravitational potential energy possessed by a unit test mass

$\Rightarrow V = U/m$

$\Rightarrow V = -GM/r$

⇒ Important Points:

The gravitational potential at a point is always negative, V is maximum at infinity.

The SI unit of gravitational potential is J/Kg.

7 Gravitational Potential of a Spherical Shell

Consider a thin uniform spherical shell of the radius (R) and mass (M) situated in space. Now,

Case 1: If point 'P' lies Inside the spherical shell (r<R):

As $E = 0$, V is a constant.

The value of gravitational potential is given by, $V = -GM/R$.

Case 2: If point 'P' lies on the surface of the spherical shell (r=R):

On the surface of the earth, $E = -GM/R^2$.

over a limit of (0 to R) we get,

Gravitational Potential (V) = $-GM/R$.

Case 3: If point 'P' lies outside the spherical shell (r>R):

Outside the spherical shell, $E = -GM/r^2$.

Using the relation $V=-\int \vec{E}.dr$ over a limit of (0 to r) we get,

$V = -GM/r$.

8. Gravitational Potential of a Uniform Solid Sphere

Consider a thin uniform solid sphere of the radius (R) and mass (M) situated in space. Now,

Case 1: If point ‘P’ lies Inside the uniform solid sphere ($r < R$):

Inside the uniform solid sphere, E = -GMr/R3.

Using the relation V=−∫E⃗.dr→V=-\mathop{\int }\vec{E}.\overrightarrow{dr}V=−∫E.dr

over a limit of (0 to r).

The value of gravitational potential is given by,

V = -GM [(3R2 – r2)/2R2]

Case 2: If point ‘P’ lies On the surface of the uniform solid sphere (r = R):

On the surface of a uniform solid sphere, $E = -GM/R^2$. over a limit of (0 to R) we get,

$V = -GM/R$.

Case 3: If point ‘P’ lies Outside the uniform solid sphere (r> R):

Using the relation over a <u>limit of (0 to r)</u> we get, $V = -GM/R$.

Case 4: Gravitational potential at the centre of the solid sphere is given by $V = -3/2 \times (GM/R)$.

Solved Problems

Example 1. Calculate the gravitational potential energy of a body of mass 10Kg and is 25m above the ground.

Solution:

Given, Mass m = 10 Kg and Height h = 25 m

G.P.E is given as,

$U = m \times g \times h = 10$ Kg 9.8 m/s^2 $\times$ 25 m = 2450 J.

Example 2. If the mass of the earth is 5.98 ×10^{24} Kg and the mass of the sun is 1.99 × 10^{30} Kg and earth is 160 million Kms away from the sun. Calculate the GPE of the earth.

Solution:

Given, the mass of the Earth (m) = 5.98 × 10^{24} Kg and mass of the Sun (M) = 1.99 × 10^{30} Kg

The gravitational potential energy is given by:

U = -GMm/r

$U = 6.673 * 10^{-11} * 5.98 * 10^{24} * 1.99 * 10^{30}/(160 * 10^{9}) = 8.29 \times 10^{8}$ J

Example 3. A basketball weighing 2.2 kg falls off a building to the ground 50 m below. Calculate the gravitational potential energy of the ball when it arrives below.

Solution:

GPE = (2.2 kg)(9.8 m/s^2)(50 m) = 1078 J.

Example 4: A 2 kg body free falls from rest from a height of 12 m. Determine the work done by the force of gravity and the change in gravitational potential energy. Consider the acceleration due to gravity to be 10 m/s^2.

Solution:

Since, W = mgh

Substituting the values in the above equation, we get

W = 2 × 12 × 10 = 240 N

The change in gravitational potential energy is equal to the work done by gravity.

Therefore, ΔEP = 100 Joule.

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DEPARTMENT OF PHYSICS

UNIT – II - Elasticity – SPH1111

1 Introduction

A body can be deformed (i.e., changed in shape or size) by the suitable application of external forces on it. A body is said to be perfectly elastic, if it regains its original shape or size, when the applied forces are removed. This property of a body to regain its original state or condition on removal of the applied forces is called elasticity. The opposite of elasticity is plasticity; when something is stretched, and it stays stretched, the material is said to be plastic. When energy goes into changing the shape of some material and it stays changed, that is said to be plastic deformation.

A body which does not tend to regain its original shape or size, even when the applied forces are removed, is called a perfectly plastic body. No body, in nature, is either perfectly elastic or perfectly plastic. Quartz fibre is the nearest approach to a perfectly elastic body. Hooke's law states that the strain of the material is proportional to the applied stress within the elastic limit of that material.

When the elastic materials are stretched, the atoms and molecules deform until stress is been applied and when the stress is removed they return to their initial state as in Fig.1

Mathematically, Hooke's law is commonly expressed as:

$$F = -k.x$$

In the equation,

F is the force

x is the extension length

k is the constant of proportionality known as spring constant in N/m

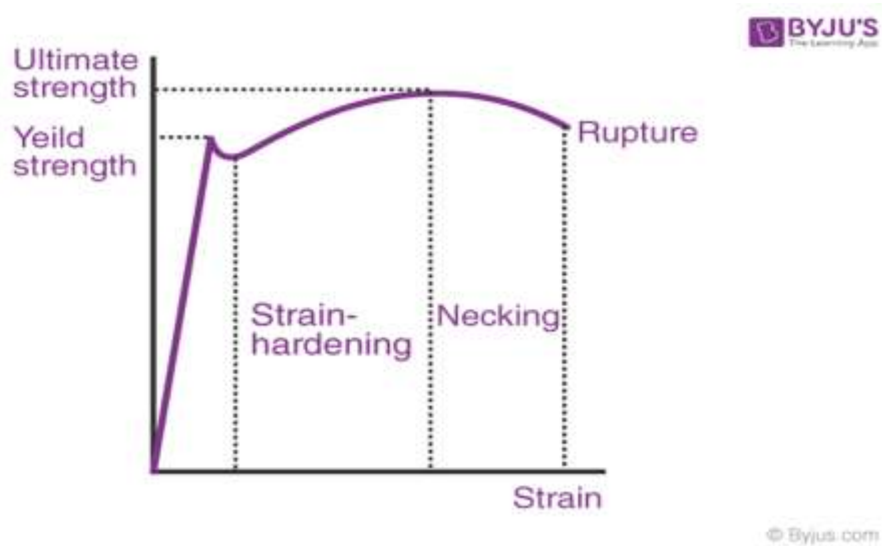


Fig.1 Stress strain diagram

The material exhibits elastic behaviour up to the yield strength point, after which the material loses elasticity and exhibits plasticity.From the origin till the proportional limit nearing yield strength, the straight line implies that the material follows Hooke’s law. Beyond the elastic limit between proportional limit and yield strength, the material loses its elastic nature and starts exhibiting plasticity.

The area under the curve from origin to the proportional limit falls under the elastic range. The area under the curve from a proportional limit to the rupture/fracture point falls under the plastic range. The ultimate strength of a material is defined based on the maximum ordinate value given by the stress-strain curve (from origin to rupture). The rupture strength is given by the value at a point of rupture .

The applications of Hooke’s Law is as follows:

- Hooke’s Law is used all branches of science and engineering
- It is used as a fundamental principle behind manometer, spring scale, balance wheel of the clock.
- Foundation for seismology, acoustics and molecular mechanics.

2. Stress and Strain

Stress : When an external force is applied on a body, there will be relative displacement of the particles and due to the property of elasticity, the particles tend to regain their original positions.

Stress is defined as the restoring force per unit area.

Strain: When a deforming force is applied, there is a change

in length, shape or volume of the body. The ratio of the change in any

dimension to its original value is called strain.

It is of three types-

(1)Longitudinal strain: The ratio of change in length () to original length (L) is called longitudinal strain (/L)

(2) Volume strain (Bulk strain): The ratio of change in volume (v) to original volume (V) is called volume strain (v/ V).

(3) Let ABCD be a body with the side CD fixed .Suppose

a tangential force F is applied on the upper face AB. The shape of the body is changed to A'B CD. The body is sheared by an angle o. This angle o measured in radians is called the shearing strain.

3 Modulii of Elasticity

Modulus of Elasticity

In general, the elastic modulus is the measure of an object's or substance's resistance to being deformed elastically when stress is applied.

The modulus of elasticity is a specific material constant; it does not theoretically depend on the sample's geometry.

The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region. A stiffer material will be characterized by a higher elastic modulus.

Definition of the Elastic Modulus

The elastic modulus is defined as $$E = \frac{\sigma}{\varepsilon} = \text{const}$$

where is stress the force causing the deformation divided by the area to which the force is applied and strain is the ratio of the change in some parameter caused by the deformation to the original value of the parameter. If is measured in Pa (pascal), then – since is a dimensionless measure – the units of λ will also be in Pa.

Relations between Elastic constants E,G,K and n

The total number of elastic constants are four. i.e E, G, K and v. It may be seen that not all of these constants are independent of the others. Infact given any two of them, the other two can be determined. Further, it may be noted that the value of the elastic constants E, G and K are always be positive values.

1.The relation between modulus of elasticity (E) and modulus of rigidity(G) is given by

E = 2G (1 + n) or

G = E/[2(1 +n)]

2.The relation between modulus of elasticity (E) and Bulk modulus (K) is given by

E = 3K (1 - 2 n)

Using the above two relations we may derive antheor relation without poisson's ratio.

3.The relation between modulus of elasticity (E), modulus of rigidity(G) and Bulk modulus (K) is given by

E = 9KG/ (3K+G) or

1/E =1/3G + 1/9K

4.The relation between modulus of rigidity(G) and Bulk modulus (K) is given by

K= 2G (1 + n)/ 3(1 - 2 n)

4. Torsional pendulum

A torsional pendulum, or torsional oscillator, consists of an extended mass suspended from a thin rod or wire. When the mass is twisted about the axis of the wire, the wire exerts a torque on the mass, tending to rotate it back to its original position. If twisted and released, the mass will oscillate back and forth, executing simple harmonic motion.

A torsional pendulum consists of a disk (or some other object) suspended from a wire, which is then twisted and released, resulting in an oscillatory motion. The oscillatory motion is caused by a restoring torque which is proportional to the angular displacement,

$$\tau_R = I\frac{d^2\theta}{dt^2} = -\kappa\theta$$

I is the rotational inertia of the disk about the twisting axis, k (kappa) is the torsional constant (equivalent to the spring constant). This equation is exactly the same as SHM we have already discussed. By direct comparison the period of the torsional pendulum is given by,

$$T = 2\pi\sqrt{\frac{I}{\kappa}}$$

and we can write

$$\theta(t) = A\cos(\omega t + \phi)$$

Similar to the simple pendulum, so long as the angular displacement is small (which means the motion is SHM) the period is independent of the displacement. Torsional pendulums are also used as a time keeping devices , as in for example, the mechanical wristwatch .

Procedure: (for performing in lab)

Determination of moment of inertia using torsion pendulum with identical masses

The radius of the suspension wire is measured using a screw gauge.

The length of the suspension wire is adjusted to suitable values like 0.3m,0.4m,0.5m,.....0.9m,1m etc. The disc is set in oscillation.Find the time for 20 oscillations twice and determine the mean period of oscillation ' T0 '. The two identical masses are placed symmetrically on either side of the suspension wire as close as possible to the centre of the disc, and measure d1 which is the distance between the centres of the disc and one of the identical masses.

Find the time for 20 oscillations twice and determine the mean period of oscillation ' T1 '. The two identical masses are placed symmetrically on either side of the suspension wire as far as possible to the centre of the disc, and measure d2 which is the distance between the centres of the disc and one of the identical masses.

Find the time for 20 oscillations twice and determine the mean period of oscillation ' T2 '. Find the moment of inertia of the disc using the given formulae.

Observations:

Length of the suspension wire=................m

Radius of the suspension wire=..............m

Mass of each identical masses=.............kg

d1=...........m

Calculations:

T0 = ...s

T1 = ...s

T2 = ...s

Moment of inertia of the given disc,

$$I_0 = 2m\left(d_2^{\,2} - d_1^{\,2}\right)\frac{T_0^{\,2}}{\left(T_2^{\,2} - T_1^{\,2}\right)} = \ldots\ldots\ldots\ldots\, kgm^2$$

d2=..........m

Length of the suspension wire 'l'(m)	Time for 20 oscillations in seconds									Period of oscillation (s)			$T_0^2/(T_2^2-T_1^2)$	$l/(T_2^2-T_1^2)$ (ms^{-2})
	Without mass			With masses at d_1			With mass at d_2			T_0	T_1	T_2		
	1	2	Mean	1	2	Mean	1	2	Mean					

5 Rigidity Modulus -Static Torsion

Aim:

To determine the rigidity modulus of the material of a given cylindrical rod through telescope and scale method.

Apparatus:

Searle's static torsion apparatus: rod with attached pulley, weight hanger, slotted weights, telescope, mirror and scale.

Theory:

Shear modulus, or rigidity modulus n is defined as the ratio of stress F/A to strain Δx/l when a shearing force F is applied to a rigid block of height l and area A. Δx is the deformation of the block, and

$$n = \frac{F/A}{\Delta x / l}$$

This is similar to what happens when a torque τ is applied to a rigid rod of length *l* and radius *r*. Looking at the cross-section of the rod, consider a ring of width *dr'* at radius *r'* , which will have area *2πr'dr'*, with force applied tangentially. The weighted average force over the cross-sectional area *A* of the rod is then

$$\frac{1}{A}\int_0^r \frac{\tau}{r'} 2\pi r' dr' = \frac{1}{\pi r^2} 2\pi r \tau = \frac{2\tau}{r}$$

If the torque deforms the rod by twisting it through a small angle θ, the deformation distance (corresponding to Δx) at the outside edge of the rod is approximately θr. The definition of the rigidity modulus n becomes

$$n = \frac{F/A}{\Delta x/l} = \frac{\frac{2\tau}{r}/\pi r^2}{\theta r/l} = \frac{2\tau l}{\pi r^4 \theta}$$

In our apparatus the torque τ is supplied by hanging a weight of mass M from a string wound round a pulley of radius R, so τ =MgR and our definition of rigidity modulus n becomes

$$n = \frac{2MgR}{\pi r^4}\frac{l}{\theta}$$

Now suppose we mount a small mirror on the rod at distance l from its fixed end, and look at a centimeter scale in the mirror through an adjacent telescope, both at distance D from the mirror. When the rod deforms and the mirror rotates through a small angle θ , we look at a point on the scale a distance approximately S=2Dθ from the original point, which was aligned with the telescope. We can measure D and S and substitute θ =S/2D in our definition of rigidity modulus n, to get

$$n = \frac{4MgR}{\pi r^4}\frac{lD}{S}$$

SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – III – Bending of Beams – SPH1111

1. Introduction

In solid mechanics, a **bending moment** is the reaction induced in a structural element when an external force or **moment** is applied to the element, causing the element to bend. The most common or simplest structural element subjected to **bending moments** is the beam.

Shear Force and Bending Moment Diagrams for a Simply-Supported Beam Under A Uniform Load

After the support reactions are calculated, the shear force and bending moment diagrams can be drawn in F ig. 1

Shear force is the force in the beam acting perpendicular to its longitudinal (x) axis. For design purposes, the beam's ability to resist shear force is more important than its ability to resist an axial force. Axial force is the force in the beam acting parallel to the longitudinal axis.

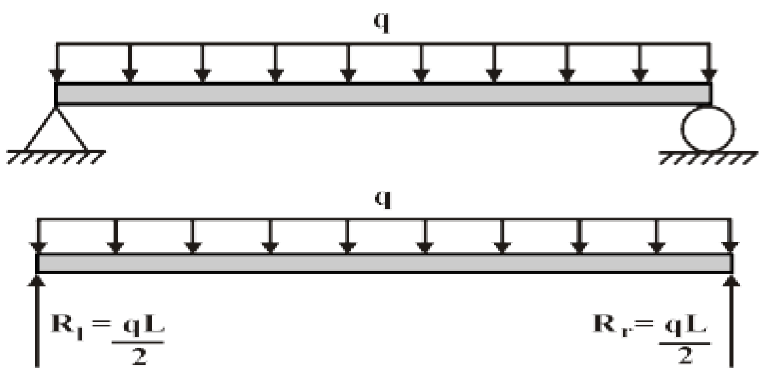


Fig. 1 Drawing of a simply-supported beam of length L under a uniform load

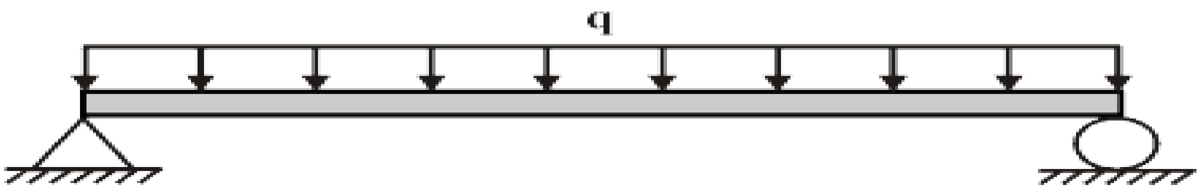
2 Shear Force and Bending Moment

Shear Force and Bending Moment Diagrams for a Simply-Supported Beam Under A Uniform Load

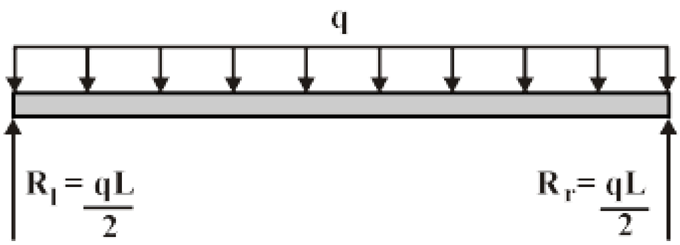
After the support reactions are calculated, the shear force and bending moment diagrams can be drawn.

Shear force is the force in the beam acting perpendicular to its longitudinal (x) axis. For design purposes, the beam's ability to resist shear force is more important than its ability to resist an axial force. ***Axial force*** is the force in the beam acting parallel to the longitudinal axis.

The following is a drawing of a simply-supported beam of length L under a uniform load, q:



This beam has the following support reactions:



where R_l and R_r are the reactions at the left and right ends of the beam, respectively.

The shear forces at the ends of the beam are equal to the vertical forces of the support reactions. The shear force F(x) at any other point x on the beam can be found by using the following equation.

$$F(x) = R_l - qx = \frac{qL}{2} - qx = q\left(\frac{L}{2} - x\right)$$

3. BENDING OF BEAMS

Beams: A beam is defined as a rod or bar. Circular or rectangular of uniform cross section whose length is very much greater than its other dimensions, such as breadth and thickness. It is commonly used in the construction of bridges to support roofs of the buildings etc. Since the length of the beam is much greater than its other dimensions the shearing stresses are very small.

Assumptions:

While studying about the bending of beams, the following assumptions have to be made.

1. The length of the beam should be large compared to other dimensions.

2. The load(forces) applied should be large compared to the weight of the beam

3. The cross section of the beam remains constant and hence the geometrical moment of inertia ig also remains constant

4. The shearing stresses are negligible

5. The curvature of the beam is very small

4 Bending of a Beam and neutral axis

Let us consider a beam of uniform rectangular cross section in the figure. A beam may be assumed to consist of a number of parallel longitudinal metallic fibers placed one over the other and are called as filaments as shown in the figure 2.

Let the beam be subjected to deforming forces as its end as shown in the figure. Due to the deforming force the beam bends. We know the beam consist of many filaments. Let us consider a filament AB at the beam. It is found that the filaments (layers) lying above AB gets elongated, while the filaments lying below AB gets compressed. Therefore the filaments i.e layer AB which remains unaltered is taken ass the reference axis called neutral axis and the plane is called neutral plane. Further, the deformation of any filaments can be measured with reference to the neutral axis.

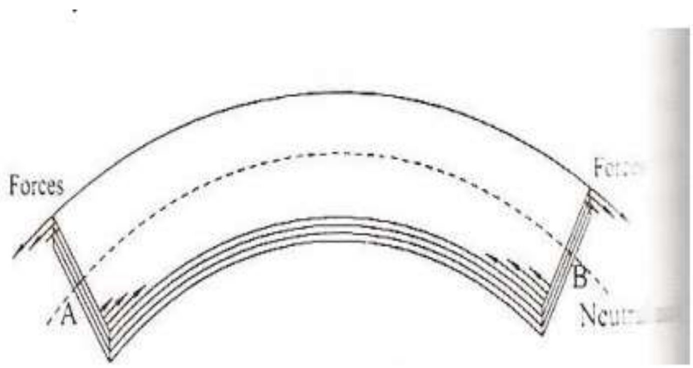


Fig 2. Bending of a Beam and neutral axis

4. EXPRESSION FOR BENDING MOMENT

Let us consider a beam under the action of deforming forces. The beam bends into a circular arc as shown in the figure. Let AB be the neutral axis of the beam. Here the filaments above AB are elongated and the filaments below AB are compressed. The filament AB remains unchanged as in Fig.3**.** Let PQ be the chosen from the neutral axis. If R is the radius of curvature of the neutral axis and θ is the angle subtended by it at its center of curvature'C'

Then we can write original length

$PQ=R\theta$ ………………………………………………………. 1

Let us consider a filament P'Q' at a distance 'X' from the neutral axis.

We can write extended length

$P'Q'=(R+x)\theta$ ………………………………………………2

From equations 1 and 2 we have,

Increase in length=P'Q'-PQ

On increase in its length=(R=x)θ-Rθ

Increase in length=xθ ……………………………………3

We know linear strain=increase in length\original length

Linear strain=xθ\Rθ=x\R ………………………………4

We know, the youngs modulus of the material

Y=stress\linear strain

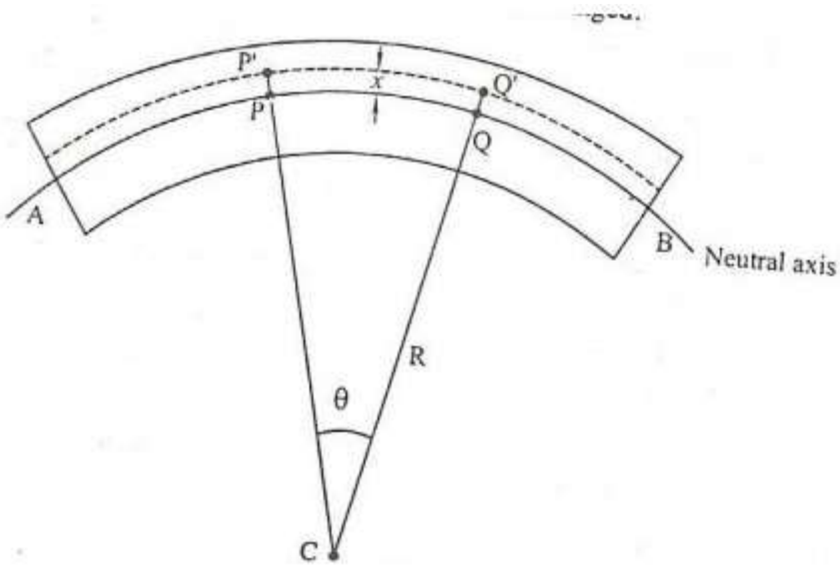


Fig.3 EXPRESSION FOR BENDING MOMENT

Or

stress=y*linear strain …………………….5

Substituting 4 in 5, we have

Stress=Yx\R

If δA is the area of cross section of the filament P'Q', then,

The tensile force on the area δA=stress*Area

Ie. Tensile force=(Yx\R).δa

We know the memont of force= force*Perpendicular distance

Moment of the tensile force about the neutral axis AB or

$$PQ = \frac{Yx}{R}.\delta A.x$$

$$PQ = \frac{Y}{R}.\delta A.x^2$$

The moment of force acting on both the upper and lower halves of the neutral axis can be got by summing all the moments of tensile and compressive forces about the neutral axis

$\therefore$ The moment of all the forces about the neutral axis $= \frac{Y}{R}\sum x^2\delta A$

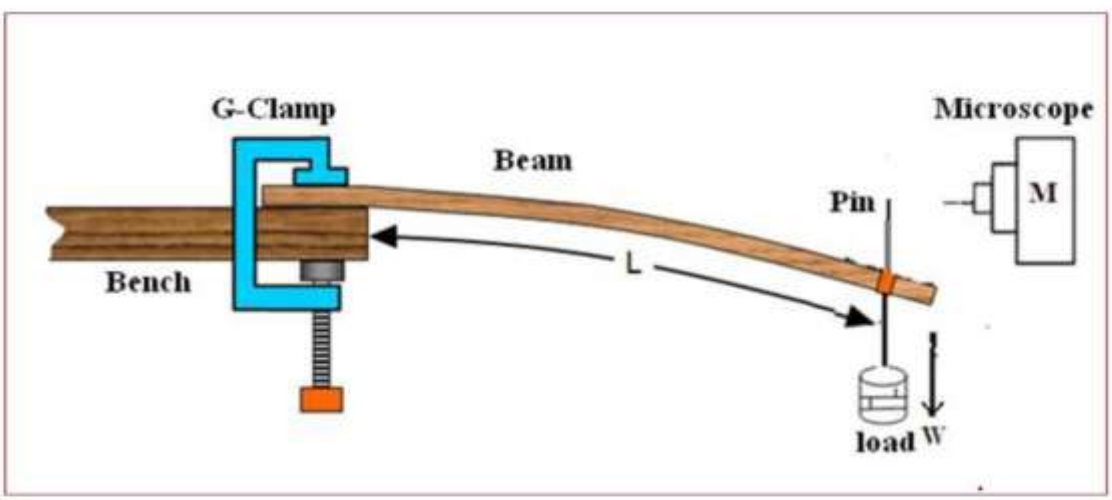
Here $I_g = \sum x^2\delta A = AK^2$ is called as the geometrical moment of inertia.

Where, A is the total area of the beam and K is the radius of Gyration.

$\therefore$ Total Moment of all the forces Or Internal bending Moment $= \frac{YI_g}{R} \longrightarrow 6$

The depression produced $y = \frac{Wl^3}{3Y\,\pi r^4/4} = \frac{4Wl^3}{3\pi r^4 Y}$

Experimental determination of Young's modulus by Cantilever Depression



The observations are tabulated as follows:

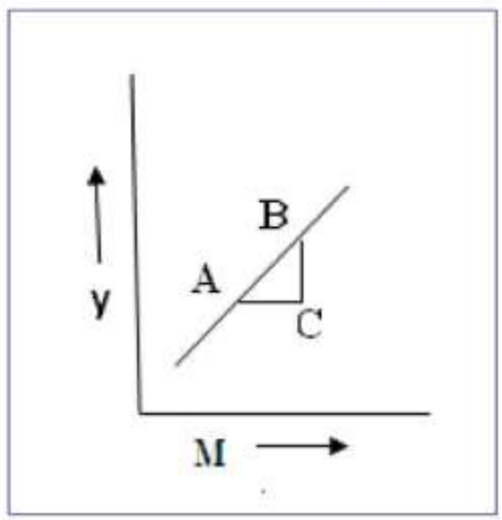
Load $\times 10^{-3}$Kg	Microscope reading						Mean $\times 10^{-2}$m	Depression 'Y' For Mass 'M' $\times 10^{-2}$m
	Loading			Unloading				
	MSR $\times 10^{-2}$m	VSC Div	TR $\times 10^{-2}$m	MSR $\times 10^{-2}$m	VSC Div	TR $\times 10^{-2}$m		
W								
W+50								
W+100								
W+150								
W+200								
W+250								

Depression '*y*'

$$y = \frac{4 W l^3}{Y b d^3}$$

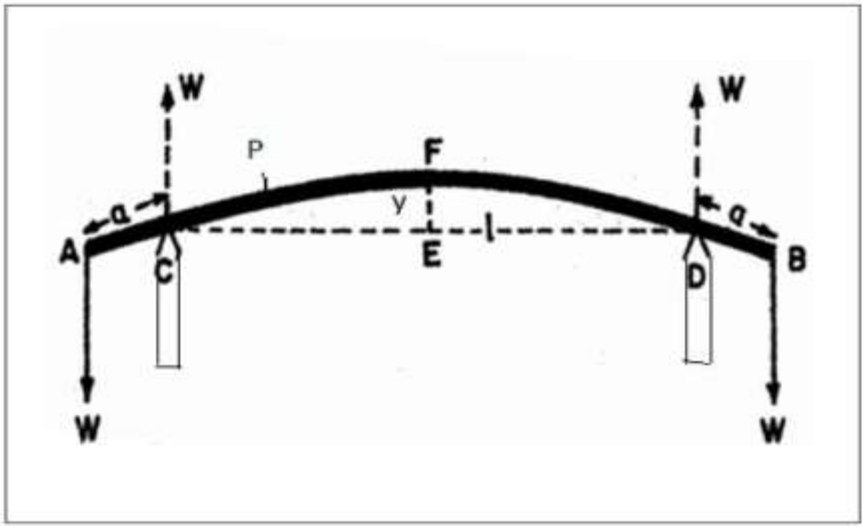
$$\because W = mg$$

$$Young's\ \text{modulus}\ Y = \frac{4 mg l^3}{b d^3 y}$$



Uniform Bending

Elevation at the centre of the beam loaded at both ends.



W – the load applied at both ends

l - distance b/w C & D

a – distance b/w A & C and B & D

Since the beam is symmetrically loaded at the ends, the reaction produced at each knife edges is equal to **W**

- At the equilibrium position of the section PA of the beam two equal forces, the applied load W at A (download) and the normal reaction W at C (upward) are acting in the opposite direction constitute a couple.

The External bending moment = Wa ....(1)

$$Internal\ bending\ moment = \frac{YI_g}{R} \quad \text{..................(2)}$$

Where, R is the radius of curvature.

At Equilibrium,

External bending moment = Internal bending moment

$$Wa = \frac{YI_g}{R} \quad \text{................(3)}$$

Since, Wa is a constant with R as also constant. Therefore, the beam bends into an arc of a circle of radius R. Hence the bending in this case is said to be uniform.

From the figure, applying theorem of Intersecting Chord, EG*FE = CE*ED

$$(2R-y)y = \frac{l}{2} \times \frac{l}{2}$$

If, R>>>y then 2R-y = 2R

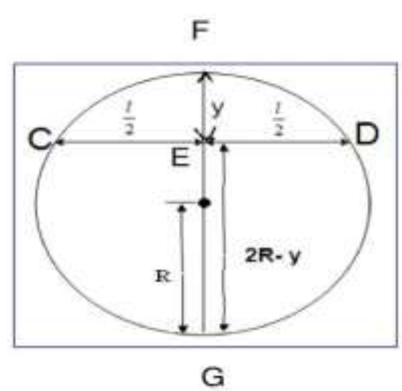
$$2Ry = \frac{l^2}{4}$$

$$\therefore R = \frac{l^2}{8y} \quad \text{................(4)}$$

Substituting (4) in (3)

$$Wa = \frac{YI_g(8y)}{l^2}$$

$\therefore$ **The Elevation** $\quad y = \dfrac{Wal^2}{8YI_g}$



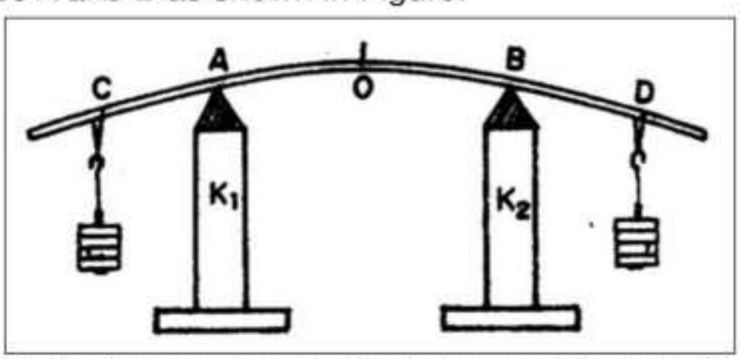
Procedure

- A slotted loads are attached to the hangers.
- The microscope is adjusted such that the horizontal cross-wire coincides with the tip of the image of the pin and the readings on the vertical scale are recorded.
- Equal weights in steps of 50g are added to both hangers simultaneously and the reading of the microscope in the vertical scale is to be noted.
- The experiment is to be repeated for decrease in the weightsfrom each hangers
- The observations are recorded and the mean elevation (y) at the mid point of the bar is determined.

Experiment

Construction:

A rectangular beam AB of uniform – section is supported horizontally on two knife – edges A and B as shown in Figure.



Two weight hangers of equal masses are suspended at the ends of the beam.

A pin is arranged vertically at the mid-point of the beam.

A microscope is focused on the tip of the pin.

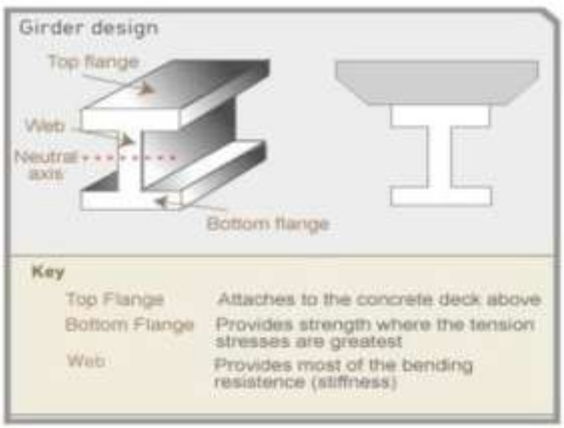
Procedure

- A slotted loads are attached to the hangers.
- The microscope is adjusted such that the horizontal cross-wire coincides with the tip of the image of the pin and the readings on the vertical scale are recorded.
- Equal weights in steps of 50g are added to both hangers simultaneously and the reading of the microscope in the vertical scale is to be noted.
- The experiment is to be repeated for decrease in the weightsfrom each hangers
- The observations are recorded and the mean elevation (y) at the mid point of the bar is determined.

Procedure

s.no	*Load* Kg	*Microscope reading*						*mean*	*Elevation (y)*	(M/y)
		Loading			*Unloading*					
		MSR Cm	*VSC div*	*TR div*	*MSR cm*	*VSC div*	*TR div*	$X10^{-2}m$	metre	Kg/m
1	*W*									
2	*W+50*									
3	*W+100*									
4	*W+150*									
5	*W+200*									

- The cross section of the girder takes the shape of the capital letter I as shown in fig.
- The vertical plate in the middle is known as the web and the top and bottom plates are referred to as flanges, steel is one of the most common material used to make I- beams, since it can withstand very heavy loads, although other materials, such as aluminium are sometimes used.



GIRDER

- A girder is a support beam used in construction.
- Girder is the term used to denote the main horizontal support of a structure, which supports smaller beams.
- A girder is commonly used more in the building of bridges and planes.

I-Shape Girders

- The girders with upper and lower section broadened and the middle section tapered, so that it can withstand heavy loads over it is called as I-shape girders.

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SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – IV - Surface Tension and Physics of Low Pressure– SPH1111

1 INTRODUCTION

Surface tension is defined as, The ratio of the surface force F to the length L along which the force acts. ... F is the force per unit length. L is the length in which force act. T is the surface tension of the liquid. Surface tension has the dimension of force per unit length, or of energy per unit area. The two are equivalent, but when referring to energy per unit of area, it is common to use the term surface energy, which is a more general term in the sense that it applies also to solids. The cause of surface tension is often explained roughly as follows. Molecules within a liquid are subject to intermolecular forces whose exact nature and origin need not concern us other than to say that they are principally van der Waals forces and they hold the liquid together and prevent it from evaporating. A molecule deep within the liquid is surrounded in all directions by other molecules, and so the net force on it averages zero. But a molecule on the surface experiences forces from beneath the surface, and consequently it tends to get dragged beneath the surface. This results in as few molecules as possible remaining on the surface; i.e. it results in the surface contracting to as small an area as possible consistent with whatever other geometrical constraints may exist. That is, the surface appears to be in a state of tension causing it to contract to the least possible area.

his tension can be described qualitatively thus. In Figure XX.1, the dashed line is an imaginary line drawn in the surface of a liquid. The liquid to the left of the line is being pulled to the right as indicated by the red arrows; the liquid to the right of the line is being pulled equally to the left as indicated by the green arrows. The force per unit length perpendicular to a line drawn in the surface of the liquid is the surface tension. Its SI unit is newtons per metre, and its CGS unit is dynes per centimetre. The dimensions are MT^{-2}.

2 Excess Pressure Inside Drops and Bubbles

The pressure inside a spherical drop is greater than the pressure outside. The way in which the excess pressure P depends on the radius a of the drop, and the surface tension γ and density ρ of the liquid is amenable to dimensional analysis. One can suppose that P∝aαγβρδ, after which I leave it to the reader to show that α=−1,β=1,δ=0, and therefore P∝γ/a

However, it is also quite easy to calculate the excess pressure (other than as a mere proportionality) in terms of the surface tension and the radius of the drop. In Figure I have divided a spherical drop of radius a into two hemispheres, and we are going to consider the equilibrium of the upper hemisphere.

The upper hemisphere is being pulled down by surface tension all round the base of the hemisphere, and this downward force is equal to the circumference of the base times the surface tension, or 2πγa. If the excess pressure inside the drop is P, the upward component of the force due to this pressure is equal to P times the area of the base, πa2. In case this is not obvious, consider an elemental area dA as shown, at a spherical angle θ from the top of the drop. The force on this element is equal to PdA. The upward component of this force is P$\cos\theta$dA, and this is equal to P times the horizontal projection of dA. Now you are welcome to do a nice double integration over the hemisphere, but since this (i.e " this is equal to P times the horizontal projection of dA ") is true for every elemental area over the surface of the hemisphere, the total upward force must be equal to P times the area of the base. Thus $2\pi\gamma a=\pi a2P$, and so the excess pressure inside the drop is

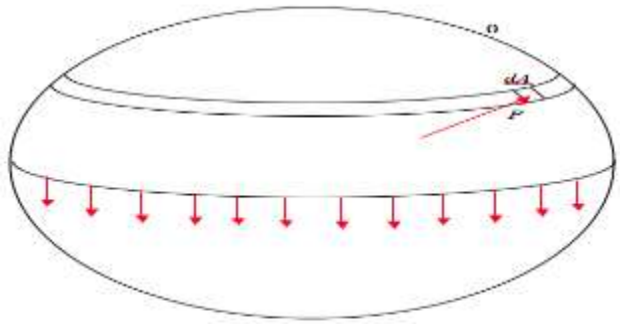


FIGURE XX.2

The smaller the drop, the greater will be the excess pressure. You may regard this as an explanation as to why droplets cannot form from a vapour unless there is a dust nucleus of finite size for them to condense upon. Of course, two molecules colliding with each other cannot in any case coalesce unless there is something to remove or absorb the kinetic energy.

What about the pressure inside a spherical bubble of air (or other gas) under water (or other liquid)? If we are hasty, we might suggest that, since this is the opposite situation to a liquid drop in air, maybe the pressure is less inside an underwater bubble. This would be a very hasty conclusion, and quite wrong. If you go through exactly the same argument as we did for a drop, considering the equilibrium of one hemisphere, you will see immediately that there is (as for the drop) an excess pressure inside the bubble. And exactly the same would apply to a spherical drop of one liquid under the surface of a second liquid, if the two liquid are immiscible. But, rather than just repeat the identical derivation, let's try a different approach.

Let us imagine that we have a bubble of radius a in a liquid of surface tension γ, and suppose that we are able, by means of a fine syringe, to inject some more air inside so as to increase the radius of the bubble by da at constant pressure and temperature. The surface area of a sphere of radius ‘a’ is $A=4\pi a2$, so, if we increase the radius by da we increase the surface area by $8\pi ada$, and we increase the volume by $4\pi a2da$. The work done against the surface tension is $8\pi\gamma ada$, and this must also be equal to $4\pi Pa2da$, where P is the excess pressure inside the bubble. What about a hollow spherical soap bubble in air? Here the soap has two surfaces – inside and out. If you repeat either of the above derivations to this case, you will see that the excess pressure inside a hollow spherical soap bubble is

$$P=4\gamma/a$$

3 Variation of Surface Tension with Temperature

As a fluid is heated it becomes less viscous, and it seems logical that the surface tension will decrease. This is in fact the case in general: it becomes zero at the critical temperature. The apparatus figure1 below can be used to investigate the variation of surface tension with temperature.

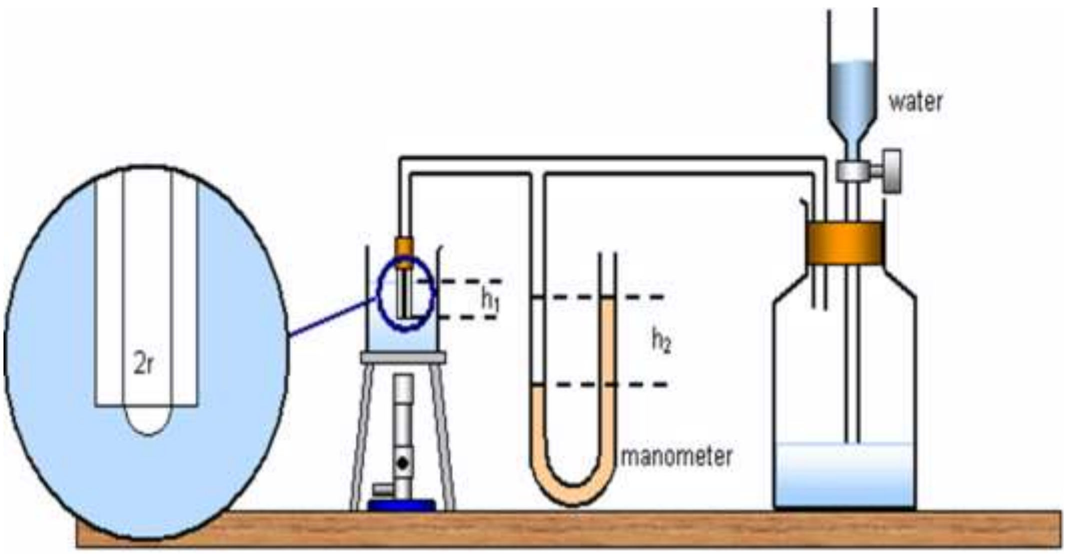
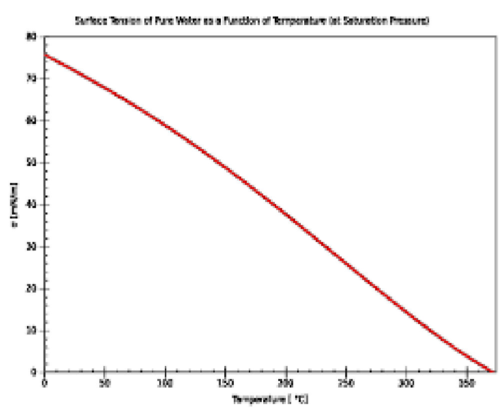


Fig. 1 Jaegers experiment

Water drips into a large flask (right hand side), forcing bubbles of air out of the capillary tube on the left (shown magnified) with lower end submerged to a depth h.

The bubble will free itself from the bottom of the capillary tube when the angle it's radius equals the internal radius of the tube (the angle of contact is then 0 degrees). Hence the surface temperature can be found, and repeating the experiment for a range of temperatures enables us to plot a graph of the surface tension of water against temperature. The graph below is obtained.



4 Physics of Low Pressure

Applications

Vacuum pumps have numerous industrial and scientific applications.

They are used for composite moulding, flight instruments, production of vacuum tubes and electric lamps, CRT's, semiconductor processing, electron microscopy, photolithography, uranium enrichment, print presses, glass and stone cutting factories, cabinetry fabrication, and medical applications that require suction. Medical applications include: radiopharmacy, radiosurgery and radiotherapy; mass spectrometers, instruments that analyse solid, gas, liquid, surface and bio materials.

Vacuum pumps are also used for decorative vacuum coatings on metal, glass and plastics, energy saving and durability of glass, ophthalmic coating, hard coatings for Formula One engine components, dairy equipment such as milking machines, vacuum impregnation of electric motor windings or wood, trash compactors, air conditioning service, sewage systems, vacuum engineering, fusion research and freeze drying.

5. Molecular Pump Working and Theory

Gaede and then Langmair developed the idea of a molecular pump.

Theory of Molecular Pump

Whenever a surface moves very near to a static surface, then the gaseous molecules in between the space of these two surfaces get a motion along with the motion of the moving surface.

This phenomenon happens due to the viscous property of the gaseous molecules. For this phenomenon to happen the distance between the static and moving surfaces must be less than 0.03 mm. Practically the force acting on the gaseous molecules to move them is the viscous force. As a result, the gaseous molecules achieve the velocity of the moving surface.

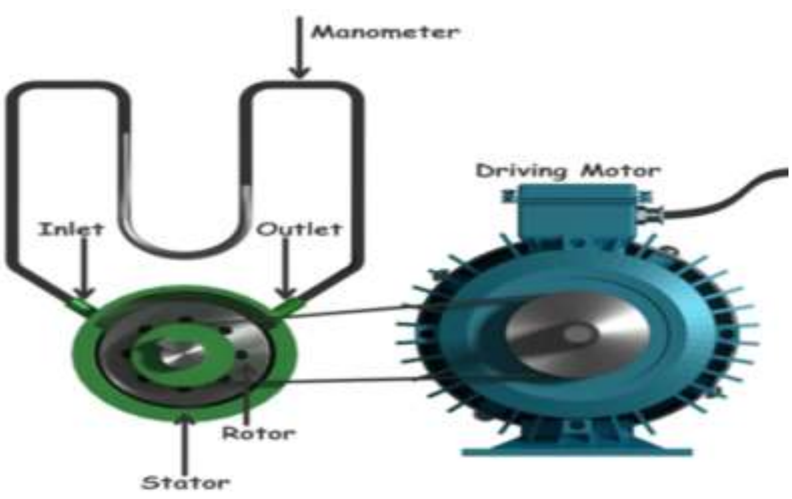


Fig. 3 Molecular pump

Basic Construction of a Molecular Pump

The inner wall of a hollow metallic cylinder serves as the static surface of the molecular pump. We call it the stator of the pump. There is a solid cylinder fitted inside the hollow cylinder. The diameter of the solid cylinder is so chosen that the gap between the inner wall of the stator and the periphery of the solid cylinder becomes very narrow. During the operation of the molecular pump, the solid cylinder rotates. This is the reason we call it the rotor of the pump. Working Principle of Molecular Pump

The direction of the rotation of the rotor is such that its outer surface always moves from inlet to outlet on the wider space section of the molecular pump. For that reason, in our model of the molecular pump, the rotation must be clockwise.Now we connect a manometer in between the inlet and outlet of the pump.

During rotation of the rotor at required high speed, we can clearly observe and measure the pressure difference between the inlet and outlet of the diffusion pump with the help of that manometer. The difference between the Mercury levels in the manometer indicates the pressure difference between the inlet and outlet of the pump.

6. Diffusion Pump Working

Principle and Theory

The working principle of a diffusion pump depends on the inter diffusion phenomenon between two different gasses. Gaede had developed this type of pump in the year 1815. After that Langmuir had developed the practical and commercial version of this diffusion pump.Whatever may be the type of a diffusion pump but the basic principle is the inter diffusion between two gasses. During the diffusion process, the gas of high concentration diffuses to the gas of low concentration. That means a gas always tries to flow from the space of higher partial pressure to the space of lower partial pressure.

Basic Construction of a Diffusion Pump

The figure below shows a simple diffusion pump. Warren had developed this model of the pump. Sometimes we also call a diffusion pump as a diffusion condensation pump. From the name diffusion condensation pump it is obvious that there must be an arrangement of liquid in the pumping system. For better understanding the working principle of a diffusion pump, let us mark the different sections of the pump with different numerical numbers. 1 is a glass or metal conical pot. There is one bend tube marked with 2, fitted on the top of the cone. After bending, the cross-section of this tube suddenly increases. Let us mark this bigger cross-sectional portion of the bent tube with numeric 3.

The cross-section of the lower portion of the tube has become again reduced and ultimately connected to the conical pot.

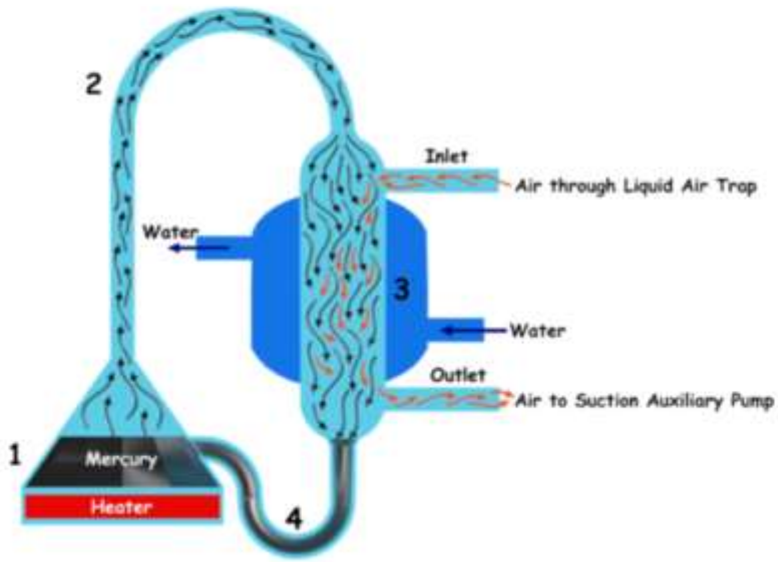


Fig. 4 Diffusion pump

In general, asbestos fibers cover the portion of the tube marked with numeric 2.

The asbestos fibers act as the heat insulator of this tube. There is one inlet at the upper portion of section 3. Also, there is one outlet from the lower portion of the same section 3. The circulating water surrounds the tube of section 3 serves as the water-cooling system.

Working Principle of Diffusion Pump

Now we connect the inlet to the vessel in which we have to create a vacuum by this diffusion pump. Although, we generally do not connect the inlet directly to the vessel, we use a liquid air trap in between the inlet of the pump and the vessel. Now we heat up the mercury inside the conical jar with the help of an external heater. As a result, heat vaporizes the mercury. This mercury vapor then goes up through the tube, marked as 2. Then it ultimately reaches the wider cross-sectional portion of the tube of the section marked as 3. Here, the vapor gets suddenly a wider space to expand. The expanded vapor traps the air molecules coming through the inlet. The trapping of air molecules is due to the diffusion process. The sudden expansion of the mercury vapor reduces the pressure of the system. After that, due to the water cooling system, the temperature of the mercury vapor reduces in section 3. The mercury vapor comes down to the lower portion of the tube of section 3 and also during its journey it gets cooled down because of the water cooling. At the lower portion of the tube of section 3, the mercury vapor gets condensed to liquid mercury.

Therefore, it is collected in the form of liquid mercury to the conical jar through the pipe of section 4. Since the mercury vapor becomes liquid in the lower portion of section 3 the air molecules which have been trapped due to diffusion with the mercury vapor gets separated and come out through the outlet of the pump. We generally use an auxiliary pump in addition to that system to collect the exhausted air from the diffusion pump.

7. McLeod Gauge

McLeod gauge amplifies the low pressure and was developed to extend the range of vacuum measurement significantly. The McLeod Gauge measures the vacuum pressure in the range between 10-1 and 10-5 torr. This can be used as a primary standard device for calibrating other low-pressure gauges.

Working Principle

McLeod gauge is essentially a mercury manometer in which a volume of gas is compressed before measurement. It operates by compressing a low-pressure gas of known volume into a smaller volume so that its pressure is sufficiently higher enough to be read. The resultant final volume and pressure provide the indication of applied low pressure.

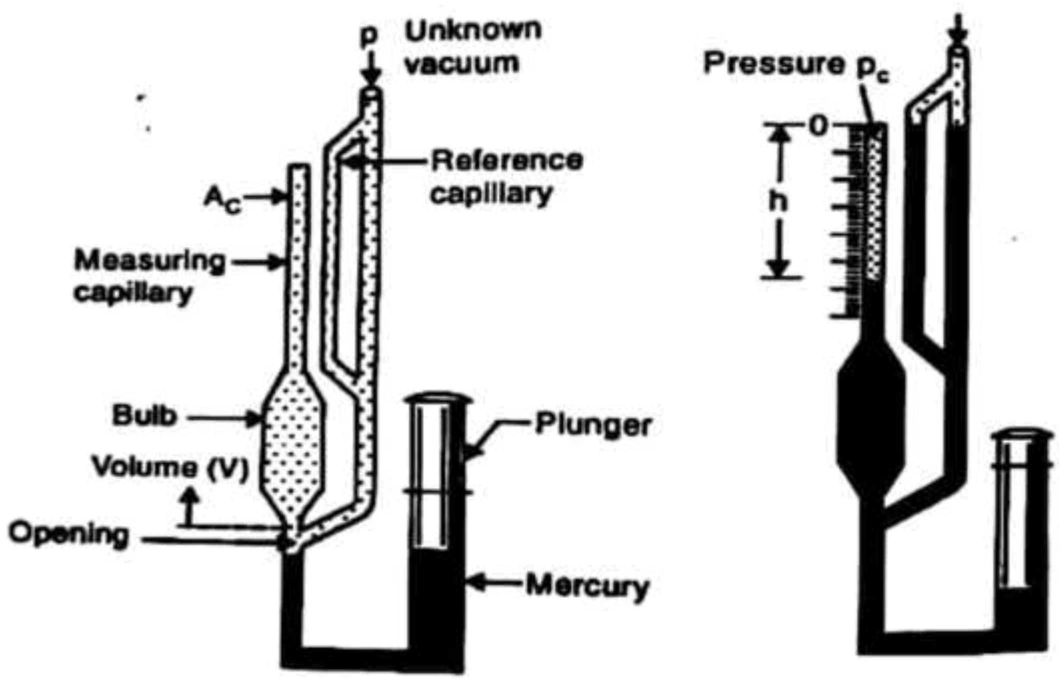


Fig. 4 McLeod gauge

The McLeod gauge consists of a reservoir containing mercury. A plunger is attached on the top of the reservoir which is used to raise or lower the level of mercury into the reference column and bulb. Above the reservoir, there is a bulb and reference column.

The point of connection of bulb and reference column is the opening or cut-off point. The other end of the reference column is open to vacuum pressure and it has a reference capillary. The reference capillary has a zero reference point up to which the mercury is raised. The mercury rises in the capillary as much as it rises in the column but only the volume differs. The reference column is attached to a measuring capillary which is a sealed chamber and from which the final volume of gas is read. The unknown vacuum pressure source is connected to the reference column and the pressure is applied. The level of mercury is adjusted so that it at the opening or cut-off point. Now, the unknown pressure, p, fills the bulb and capillary. The volume of unknown pressure is the volume of bulb and capillary which is given by V.

The mercury is forced into the bulb and capillary by operating the plunger. Once the level of mercury crosses the cut-off point or opening, it stops the entry of applied pressure into the bulb and measuring capillary. The level of mercury is raised until it reaches the zero reference point. The pressure and volume of gas trapped in measuring capillary are read and unknown vacuum pressure is calculated.

Advantages

1. McLeod gauge is an inexpensive standard that measures vacuum pressure without any electronics or sophisticated equipment.

2. It is used for calibrating other low pressure measuring gauges.

3. It is not influenced by gas composition.

4. The readings obtained from McLeod gauge do not require any correction

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DEPARTMENT OF PHYSICS

UNIT – V - Viscosity – SPH1111

1. Introduction

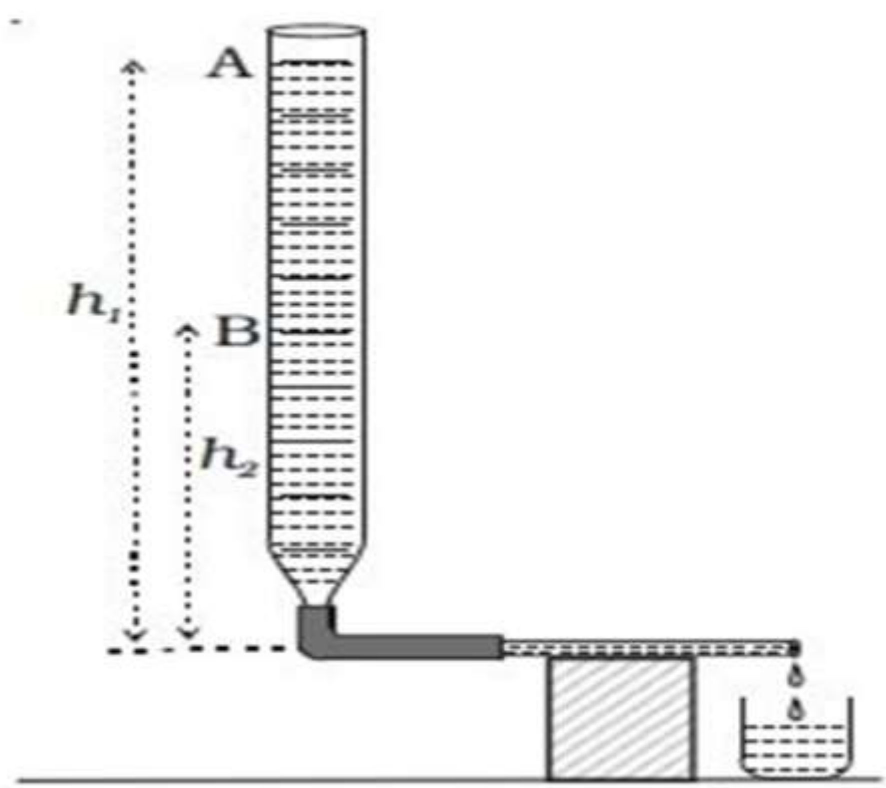
If at any point, the velocity of every passing fluid particle remains the same, the flow is called the streamline flow or the steady flow. Any flow which is not streamline is known as the turbulent flow. The path taken by a fluid particle in steady flow is known as a streamline. If at any point, the velocity of every passing fluid particle remains the same, the flow is called the streamline flow or the steady flow. Any flow which is not streamline is known as the turbulent flow. The path taken by a fluid particle in steady flow is known as a streamline.

The coefficient of viscosity is defined as the force of friction that is required to maintain a difference of velocity of 1cm/s between parallel layers of fluid. The unit is usually expressed in poise or centipoise.

The SI unit for dynamic viscosity η is the Pascal-second (Pa-s), which corresponds to the force (N) per unit area (m2) divided by the rate of shear (s-1). Just as in the definition of viscosity.

Viscosity is caused by friction within a fluid. It is the result of intermolecular forces between particles within a fluid.

2 Determination of coefficient of viscosity of water by Poiseuille's flow method



Determination of coefficient of viscosity of water by Poiseuille's flow method is as follows: A capillary tube of very fine bore is connected by means of a rubber tube to a burette kept vertically. The capillary tube is kept horizontal as shown in figure. The burette is filled with water and the pinch - stopper is removed. The time taken for water level to fall from A to B is noted. If V is the volume between the two levels A and B, then volume of liquid flowing per second is tV. If l and r are the length and radius of the capillary tube respectively, then V/t =8ηπPr4--------(1) If ρ is the density of the liquid then the initial pressure difference between the ends of the tube is P1=h1ρg and the final pressure difference P2=h2ρg. Therefore the average pressure difference during the flow of water is P where

P=2(P1+P2)

=[2(h1+h2)]ρg

Substituting in equation (1), we get

V/t =πhρgr4/8lη

or

η=πhρgr4t/8lV

3. STOKES METHOD

AIM

To determine the co-efficient of viscosity of the given liquid by stoke's method

APPARATUS REQUIRED

A long cylindrical glass jar, highly viscous liquid, metre scale, spherical ball, stop clock, thread.

FORMULA

Where

η - Coefficient of viscosity of liquid (N s m–2)

r → radius of spherical ball (m)

δ→ density of the steel sphere (kg m–3)

σ→ density of the liquid (kg m–3)

g → acceleration due to gravity (9.8 m s–2)

V → mean terminal velocity (m s–1

PROCEDURE

- **A long cylindrical glass jar with markings is taken.**
- **Fill the glass jar with the given experimental liquid.**
- **Two points A and B are marked on the jar. The mark A is made well below the surface of the liquid so that when the ball reaches A it would have acquired terminal velocity V.**
- **The radius of the metal spherical ball is determined using screw gauge.**
- **The spherical ball is dropped gently into the liquid.**
- **Start the stop clock when the ball crosses the point A. Stop the clock when the ball reaches B.**
- **Note the distance between A and B and use it to calculate terminal velocity.**
- **Now repeat the experiment for different distances between A and B. Make sure that the point A is below the terminal stage.**

S.No.	Distance covered by the spherical ball (d) (m)	Time taken (t) (s)	Terminal Velocity (V) d/t ($m\ s^{-1}$)
		MEAN	

CALCULATION

Density of the spherical ball δ = ________ kg m−3

Density of the given liquid σ = ________ kg m−3

Coefficient of viscosity of the liquid η = 2r2g(δ −σ) / 9V = = ________ N s m^{-2}

RESULT

The coefficient of viscosity of the given liquid by stoke's method η = ________ Nsm^{-2}

4. Variation of viscosity of liquid with temperature

With an increase in temperature, there is typically an increase in the molecular interchange as molecules move faster in higher temperatures. The gas viscosity will increase with temperature. . With high temperatures, viscosity increases in gases and decreases in liquids, the drag force will do the same. The viscosity of liquids decreases rapidly with an increase in temperature, and the viscosity of gases increases with an increase in temperature. Thus, upon heating, liquids flow more easily, whereas gases flow more sluggishly. Increasing temperature results in a decrease in viscosity because a larger temperature means particles have greater thermal energy and are more easily able to overcome the attractive forces binding them together.

The viscosity of a fluid is a measure of its resistance to deformation at a given rate. For liquids, it corresponds to the informal concept of "thickness": for example, syrup has a higher viscosity than water.

Viscosity can be conceptualized as quantifying the internal frictional force that arises between adjacent layers of fluid that are in relative motion. For instance, when a fluid is forced through a tube, it flows more quickly near the tube's axis than near its walls. In such a case, experiments show that some stress (such as a pressure difference between the two ends of the tube) is needed to sustain the flow through the tube. This is because a force is required to overcome the friction between the layers of the fluid which are in relative motion: the strength of this force is proportional to the viscosity.

A fluid that has no resistance to shear stress is known as an ideal or inviscid fluid. Zero viscosity is observed only at very low temperatures in superfluids. Otherwise, the second law of thermodynamics requires all fluids to have positive viscosity.

5 What is Streamline Flow?

Streamline flow in fluids is defined as the flow in which the fluids flow in parallel layers such that there is no disruption or intermixing of the layers and at a given point, the velocity of each fluid particle passing by remains constant with time. Here, at low fluid velocities, there are no turbulent velocity fluctuations and the fluid tends to flow without lateral mixing. Here, the motion of particles of the fluid follows a particular order with respect to the particles moving in a straight line parallel to the wall of the pipe such that the adjacent layers slide past each other like playing cards.

To understand the liquid flow pattern better, click on the links provided below:

Reynolds Number

Poiseuilles Law Formula

What are Streamlines?

Streamlines are defined as the path taken by particles of fluid under steady flow conditions. If we represent the flow lines as curves, then the tangent at any point on the curve gives the direction of the fluid velocity at that point.

As can be seen in the image above, the curves describe how the fluid particles move with respect to time. The curve provides a map for the flow of this given fluid, and for a steady flow. This map is stationary with time i.e., every particle passing a point behaves exactly like the previous particle that has just passed that point.

The streamlines in a laminar flow follow the equation of continuity, i.e., Av = constant, where, A is the cross-sectional area of the fluid flow, and v is the velocity of the fluid at that point. Av is defined as the volume flux or the flow rate of the fluid, which remains constant for steady flow. When the area of the cross-section is greater, the velocity of the liquid is lesser and vice versa.