HIGHER SECONDARY

FIRST YEAR

இயற்பியல்

PHYSICS

STUDY MATERIAL

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“வாழ்நாள் முழுவதும் ஒவ்வொரு மணித்துளியும் நேர்மையாய், உண்மையாய் உழைக்கின்றவர்களின் கரங்களே தூய்மையான கரங்கள்.”

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UNIT – I (NATURE OF PHYSICAL WORLD AND MEASUREMENT)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

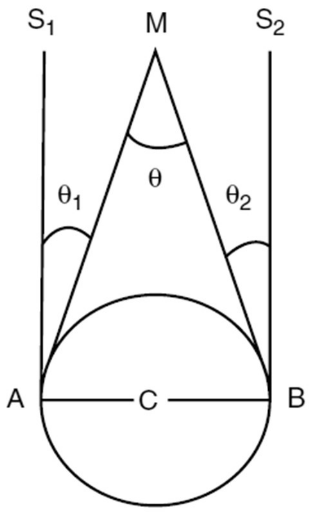
1. Briefly explain the types of physical quantities.

Physical quantities are classified into two types. They are fundamentaland derivedquantities.

Fundamental or base quantities**are quantities which cannot be expressed in terms of any other physical quantities.**
These are **length, mass, time, electric current, temperature, luminous intensity and amount of substance.**

Quantities that **can be expressed in terms of fundamental quantities**are called derived quantities. For example, **area, volume, velocity, acceleration, force.**

2. How will you measure the diameter of the Moon using parallax method?



1. **C is the centre of the Earth. A and B** are two diametrically **opposite places on the surface of the Earth**. From A and B, the parallaxes θ_1 and θ_2 respectively of Moon M with respect to some **distant star are determined with the help of an astronomical telescope.** Thus, the total parallax of the Moon subtended on Earth $\angle AMB = \theta_1 + \theta_2 = \theta$.
2. If θ is measured in radians, then $\theta = \frac{AB}{AM}$; AM≈MC
$\theta = \frac{AB}{MC} \Rightarrow MC = \frac{AB}{\theta}$.Knowing the values of AB and θ, we can calculate the distance MC of Moon from the Earth.

3. Write the rules for determining significant figures.

1. All **non-zero digits** are significant. Ex.**1342** has **four** significant figures
2. All **zeros between two non-zero** digits are significant.
Ex. **2008 has four** significant figures.
3. All **zeros to the right of a non-zero** digit but to the left of a decimal point are significant. Ex. **30700. has five** significant figures.
4. The **number without a decimal point**, the terminal or trailing zero(s) are not significant. Ex. **30700 has three** significant figures.
All zeros are significant if they come from a measurement
Ex. **30700 m** has **five** significant figures

5. If the number is **less than 1,** the zero (s) on the right of the decimal point but to left of the **first non-zero digit are not significant.** Ex. **0.00345** has **three** significant figures.
6. All zeros to the right of a decimal point and to the right of non-zero digit are significant. Ex. **40.00 has four** significant figures and **0.030400** has **five** significant figures.
7. The number of significant figures **does not depend on the system of units** used1.53 cm, 0.0153 m, 0.0000153 km, all have **three** significant figures.

4. What are the limitations of dimensional analysis?

1. This method gives **no information about the dimensionless constants** in the formula like 1, 2, ...π,e, etc.
2. This method **cannot decide whether the given quantity is a vector or a scalar.**
3. This method is **not suitable to derive relations** involving **trigonometric, exponential and logarithmic functions.**
4. It **cannot be applied** to an equation involving **more than three physical quantities.**
5. It can only **check on whether a physical relation** is **dimensionally correct** but not the correctness of the relation. For example, using dimensional analysis, $s = ut + \frac{1}{3}at^2$ is dimensionally correct whereas the correct relation is $s = ut + \frac{1}{2}at^2$

5. Define precision and accuracy. Explain with one example.

Precision: The **closeness of two or more measurements** to each other.

Accuracy:

The **closeness of a measure value to the actual value** of the object being measured is called accuracy.

Example: The true value of a certain length is near **5.678 cm.** In one experiment, using a measuring instrument of resolution 0.1 cm, the **measured value is found to be 5.5 cm.**

In another experiment using a measuring instrument of greater resolution, say 0.01 cm, the **length is found to be 5.38**cm. We find that the **first measurementis more accurate** as it is closer to the true value, but it has lesser precision. On the contrary, the **second measurement is less accurate,** but it is more precise.

6. Define the terms i) Unification ii) Reductionism

1. Attempting **to explain diverse physical phenomena** with a **few concepts** and lawsis **unification.**
2. An attempt **to explain a macroscopic system** in terms of its microscopic constituentsis **reductionism.**

7. What are the features involved in the scientific methods?

1. Systematic observation 2. Controlled experimentation
3. Qualitative and quantitative reasoning
4. Mathematical modeling 5. Prediction and verification

8. How can we relate physics with chemistry?

Physics in relation to Chemistry:

1. In physics, we **study the structure of atom, radioactivity, X-ray diffraction** etc. Such studies have enabled researchers in **chemistry to arrange elements in the periodic table** on the basis of their **atomic numbers.**
2. Physics helped **to know the nature of valence** and **chemical bonding** and to understand the **complex chemical structures.**
3. Inter-disciplinary branches like Physical chemistry and Quantum chemistry play important role.

9. What is the necessity of relating physics with biology?

Physics in relation to biology:

A microscope designed using physics principles. The invention of the **electron microscope has made it possible to see even the structure of a cell.**

1. X-ray and neutron diffraction techniques have helped us to understand **the structure of nucleic acids**, which help to control vital life processes.
2. X-rays are used for **diagnostic purposes.** Radio-isotopes are used in **radiotherapy for the cure of cancer and other diseases.**

10. What is the necessity of relating physics with oceanography?

1. Oceanographers seek to understand the **physical and chemical processes of the oceans.**
2. They measure parameters such as **temperature, salinity, current speed, gas fluxes, chemical components.**

11. Define Physical quantity. Write its example.

Quantities that can be measured, and in terms of which, **laws of physics** are described are called physical quantities.

Examples are **length, mass, time, force, energy**, etc.

12. Define unit. What are its types?

An arbitrarily chosen **standard of measurement of a quantity**, which is accepted internationally is called unit of the quantity.

1. Fundamental unit 2. Derived unit

13. What are the advantages of SI system?

1. SI system makes **use of only one unit for one physical quantity**, which meansa rational system of units
2. SI system, all the **derived units can be easily obtained from basic and supplementary**units, which means it is a coherent system of units.
3. It is a **metric system which means that multiples and submultiples** can beexpressed as **powers of 10.**

14. Define SI standard for length

One metre is the length of the path travelled by light in vacuum in 1/299,792,458 of a second.

15. Define SI standard for mass

One kilogram is the mass **of the prototype cylinder of platinum iridium** alloy (whose **height is equal to its diameter**), preserved at the International Bureau of Weights and Measures at Serves, near Paris, France.

16. Define SI standard for time

One second is the duration of 9,192,631,770 periods of radiation corresponding to the **transition between the two hyperfine levels of the ground state of Cesium-133 atom.**

17. Define one radian

One radian is the angle subtended at the centre of a circle by an arc **equal in length to the radius of the circle.**

18. Define steradian

One steradian is the solid angle subtended at the centre of a sphere, by that surface of the sphere, which is **equal in area, to the square of radius of the sphere.**

19. What is the principle of screw gauge? Write its least count.

The principle of the instrument is the magnification of linear motion using the **circular motion of a screw. The least count of the screw gauge is 0.01 mm**

20. What is parallax?

Parallax is the name given to the **apparent change in the position** of an object **with respect to the background**, when the object is seen from two different positions.

21. What is parsec? Write the value of parsec.

1 parsec (Parallactic second) (Distance at which an arc of length 1 AU subtends an angleof 1 second of arc)

1 parsec = 3.08×10^{16} m =3.26 light year.

22. Define light year

Light year (**Distance travelled by light in vacuum in one year**)

1 Light Year = 9.467×10^{15} m

23. Define astronomical unit

Astronomical unit (the mean distance of the Earth from the Sun)

1 AU = 1.496×10^{11} m

24. What are systematic errors?

Systematic errors are **reproducible inaccuracies that are consistently in the same direction**. These occur often due to a problem that persists throughout the experiment.

25. How to minimize the systematic error?

Systematic errors are difficult **to detect and cannot be analyzed statistically**, because allof the data is in the same direction.

26. What is personal error?

These errors are due **to individuals performing the experiment, may be due to incorrect initial setting up of the experiment** or **carelessness**of the individual making the observationdue to improper precautions.

27. What are least count errors? How is it minimized?

Least count is the **smallest value**that can be **measured by the measuring instrument**, and the error due to this measurement is least count error. The instrument's resolution hence isthe cause of this error. Least count error can be reduced by using a **high precision instrument for the measurement**

28. What are Random errors? How is it minimized?

Random errors may arise due to **random and unpredictable variations** in experimental conditions like pressure, temperature, voltage supply

Random errors can be evaluated through **statistical analysis** and can be reduced by averaging over a **large number of observations.**

29. What are Gross errors? How is it minimized?

Reading an instrument **without setting it properly**. It can be minimized only when an **observer is careful and mentally alert.**

30. What is relative error or fractional error?

The **ratio of the mean absolute error to the mean value**. Relative error = $\frac{\Delta a_m}{a_m}$

31. What is percentage error?

The **relative error expressed as a percentage**. Percentage error = $\frac{\Delta a_m}{a_m}$ x 100%

32. Define significant figure or digits.

The digits that are known reliably plus the first uncertain digit are known as significantfigures or significant digits.

33. Define dimensions.

The dimensions of a physical quantity are the powers to which the units of basequantities are raised to represent a derived unit of that quantity. Velocity = Displacement / Time V= [L] / [L]; V= $[M^0LT^{-1}]$

34. Define Dimensional formula and dimensional equation.

Dimensional formula is an expression which shows how and which of the fundamentalunits are required to represent the unit of a physical quantity. For example, **$[M^0LT^{-2}]$ is the dimensional formula of acceleration.**

When the dimensional formula of a physical quantity is expressed in the form of an equation, such an equation is known as the dimensional equation. Example, **acceleration = $[M^0LT^{-2}]$.**

35. Define dimensional constant and dimensionless constant

Dimensional Constant

Physical quantities which possess **dimensions and have constant** values are called dimensional constants. Examples are **Gravitational constant, Planck's constant etc.**

Dimensionless Constant

Quantities which **have constant values** and also **have no dimensions** are calleddimensionless constants. Examples are **π, e, numbers** etc.

36. Define dimensional variable and dimensionless variable

Dimensional variables

Physical quantities, which **possess dimensions and have variable** values are called**dimensional variables**. Examples are **length, velocity, and acceleration etc.**

Dimensionless variables

Physical quantities which **have no dimensions**, but **have variable** values are called **dimensionless variables**. Examples are **specific gravity, strain, refractive index etc.**

37. Name the SI unit for electric current and give a definition for it.

One ampere is the constant current, which when maintained in each of the **two straight parallel conductors of infinite length** and negligible cross section, held one metre apart in vacuum shall produce a force per unit length of **2×10^{-7} N/m** between them.

38. What is the SI unit of temperature and define it.

One kelvin is the fraction of $\left(\frac{1}{273.16}\right)$of the thermodynamic temperature of the triple point of the water.

39. What is mean absolute error?

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

40. What are the uses of dimensional analysis?

1. Convert a physical quantity from **one system of units to another**.
2. **Check the dimensional correctness** of a given physical equation.
3. Establish **relations among various physical quantities.**

41. Write principle of homogeneity of dimensions.

The principle of homogeneity of dimensions' states that the**dimensions of all the terms in a physical expression should be the same.** For example, in the **physical expression$v^2 = u^2 + 2as$**, the dimensions of v^2, u^2 and 2 as are the same and equal to **$[L^2T^{-2}]$.**

CONCEPTUAL QUESTIONS

42. Why is it convenient to express the distance of stars in terms of light year (or) parsec rather than in km?

1. Starts are very far away. So, it will be hard to measure in km. The large distances cannot be expressed in km.
2. Ex. If we express the distance of our next nearest big galaxy Andromeda in terms of km we get, **24,030,255,3795,53,923,000km** but in light years we get 2.5 million light years). This shows the light year representations is more convenient that the others.

43. If humans were to settle on other planets which of the fundamental quantities will be in trouble? Why?

The time will be trouble for humans to settle on other plants. Because each and everyplanet has its own year length. So, day and night changes. Some of the planets moves very slow.

44. Having all units in atomic standards is more useful. Explain.

All units in atomic standard are more useful because the units do not charge with time. This unit is very accurate one.

45. Why dimensional methods are applicable only up to three quantities?

1. If a quantity depends on more than three factors, having dimensions, the formulacannot be derived.
2. This is because, equating the powers of M, L and T on either side of the dimensional equation, then we can obtain three equations from which we can compute threeunknown dimensions.

FIVE MARKS QUESTION WITH ANSWER QUESTIONS

46. i) Explain the use of screw gauge and vernier caliper in measuring smaller distances.

ii) Write a note on triangulation method and radar method to measure largerdistances.

Measurement of small distances:

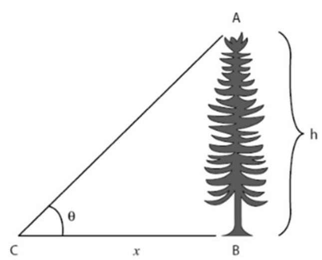
1. **Screw gauge:** The screw gauge is an instrument used for measuring accurately the **dimensions of objects up to a maximum of about 50 mm.** The principle of the instrument is the magnification of linear motion using the circular motion of a screw. The least count of the screw gauge is 0.01 mm
2. **Vernier caliper:** A vernier caliper is a **versatile instrument** for measuring the **dimensions of an object** namely diameter of a hole, or a depth of a hole.

Measurement of large distances:

3. For measuring larger distances such as the height of a tree, distance of the **Moonor a planet from the Earth,** some special methods are adopted. **Triangulation method, parallax method and radar method are used to determine very large distances.**

Triangulation method for the height of an accessible object:

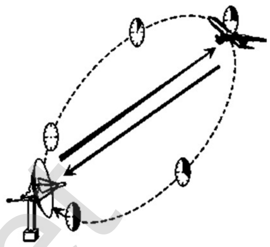
1. Let **AB = h be the height of the tree** or tower to be measured.
Let C be the point of observation at distance *x* from B. Place a range finder at C and measure the angle of elevation, ∠ACB = θ as shown in Figure.
From right angled triangle ABC,



$\tan\theta = \frac{AB}{BC} = \frac{h}{x}$ (or) height $h = x \tan \theta$

Knowing the distance *x*, the height h can be determined.

RADAR method:



1. The word RADAR stands for **Radio Detection and Ranging**. Radar can be used**to measure accurately the distance of a nearby planet** such as Mars. In this method, **radio waves are sent from transmitters which, after reflection from the planet, are detected by the receiver**.
2. By measuring, the time interval (t) between the instants the radio waves are sent and received, the distance of the planet can be determined as d= $\frac{v \times t}{2}$. where **v is the speed of the radio wave.**

   As the time taken (t) is for the distancecovered during the forward and backward path of the radio waves, it is divided by 2 to get the actual distance of the object. This method can also be **used to determine the height, at which an aero-plane flies from the ground.**

47. Explain in detail the various types of errors.

Random error, systematic error and gross error are the three possible errors

Systematic errors:

Systematic errors are reproducible inaccuracies that are consistently in thesame direction.

Instrumental errors:

When an **instrument is not calibrated properly**at the time of manufacture, these errors can be corrected by **choosing the instrument carefully.**

Imperfections in experimental technique or procedure:

These errors **arise due to the limitations in the experimental** arrangement. To overcome these, necessary correction has to be applied.

Personal errors:

These errors are due to individuals performing the experiment, may be due to **incorrect initial setting up of the experiment or carelessness** of the individual making the observation due to improper precautions

Errors due to external causes:

The **change in the external conditions** during an experiment can cause error in measurement. For example, **changes in temperature, humidity, or pressure during measurements** may affect the result of the measurement.

Least count error:

Least count is the smallest value that can be measured by the measuring instrument, and the error due to this measurement is least count error.

Random errors:

1. Random errors may arise due **to random and unpredictable variations**in experimental conditions like pressure, temperature, voltage supply etc.
2. Errors may also be due to **personal errors** by the observer who performs the experiment. Random errors are sometimes called **"chance error"**
3. It can be minimized by **repeating the observations a large number of measurements** are made and then the arithmetic mean is taken.

Gross Error:

The error caused due to the shear **carelessness of an observer** is called gross error. These errors can be minimized only when an observer is **careful and mentally alert.**

48. What do you mean by propagation of errors? Explain the propagation of errorsin addition and multiplication.

1. A number of measured quantities may be involved in the final calculation of an experiment. Different types of instruments might have been used for taking readings. Then we may have to look at the errors in measuring various quantities, collectively.

   The error in the final result depends on

   i. The errors in the individual measurements ii. On the nature of mathematical operations performed to get the final result. So we should know the rules to combine the errors. The various possibilities of the propagation or combination of errors in different mathematical operations are discussed below:

(i) Error in the sum of two quantities:

Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively.

Then, measured value of A = $A \pm \Delta A$; Measured value of B = $B \pm \Delta B$

Consider the sum, $Z = A + B$

The error ΔZ in Z is then given by

$Z \pm \Delta Z = (A \pm \Delta A) + (B \pm \Delta B)$; $= (A + B) \pm (\Delta A + \Delta B)$

$= Z \pm (\Delta A + \Delta B)$ (or) $\Delta Z = \Delta A + \Delta B$

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

(ii) Error in the difference of two quantities:

Let ΔA and ΔB be the absolute errors in the two quantities, A and B, respectively. Then,

Measured value of A = A ± ΔA; Measured value of B = B ± ΔB

Consider the difference, Z = A – B

The error ΔZ in Z is then given by

Z ± ΔZ = (A ± ΔA) – (B ± ΔB); = (A − B) ± ΔA ± ΔB

= Z ± ΔA ± ΔB(or) ΔZ = ΔA + ΔB

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

(iii) Error in the product of two quantities:

Let ΔA and ΔB be the absolute errors in the two quantities A, and B, respectively. Consider the product Z = AB

The error ΔZ in Z is given by Z ± ΔZ = (A ± ΔA) (B ± ΔB)

= (AB) ± (A ΔB) ± (B ΔA) ± (ΔA . ΔB)

Dividing L.H.S by Z and R.H.S by AB, we get, $1 \pm \frac{\Delta Z}{Z} = 1 \pm \frac{\Delta B}{B} \pm \frac{\Delta A}{A} \pm \frac{\Delta A}{A} \cdot \frac{\Delta B}{B}$

As ΔA /A, ΔB / B are both small quantities,

their product term $\frac{\Delta A}{A} \cdot \frac{\Delta B}{B}$ can be neglected.

The maximum fractional error in Z is $\frac{\Delta Z}{Z} = \pm\left(\frac{\Delta A}{A} + \frac{\Delta B}{B}\right)$

49. Write short notes on the following.
a. Unit b. Rounding – off c. Dimensionless quantities

a. Unit:

1. **The digits that are known reliably plus the first uncertain digit** are known as significant figures or significant digits. The units in which the fundamental quantities are measured are called fundamental or base units and the units of measurement of all other physical quantities, which can be obtained by a suitable multiplication or division of powers of fundamental units, are called derived units.

b. Rounding – off:

1. The result given by a **calculator has too many figures**. In no case should the result have **more significant figures than the figures involved in the data used for calculation**. The result of calculation with numbers containing more than one uncertain digit should be rounded off.

c. Dimensionless quantities:

1. Physical quantities which **have no dimensions**, but **have variable** values are called dimensionless variables. Examples are **specific gravity, strain, refractive index etc...**
2. Quantities which **have constant values** and also have **no dimensions** are calleddimensionless constants. Examples are **π, e, numbers etc.**

50. Write the rules for rounding off.

1. If the digit to be dropped is **smaller than 5**, then the preceding digit should be left unchanged.
   Ex. i) 7.32 is rounded off to 7.3 ii) 8.94 is rounded off to 8.9
2. If the digit to be dropped is **greater than 5**, then the preceding digit should beincreased by 1
   Ex. i) 17.26 is rounded off to 17.3 ii) 11.89 is rounded off to 11.9
3. If the digit to be **dropped is 5 followed by digits other than zero**, then the preceding digit should be **raised by1**
   Ex. i) 7.352, on being rounded off to first decimal becomes 7.4
   ii) 18.159 on being rounded off to first decimal, become 18.2
4. If the digit to be **dropped is 5 or 5 followed by zeros**, then the preceding digit is notchanged if it **is even**
   Ex. i) 3.45 is rounded off to 3.4 ii) 8.250 is rounded off to 8.2
5. If the digit to be dropped is 5 or 5 followed by zeros, then the preceding digit is raised by 1 if **it is odd**
   Ex. i) 3.35 is rounded off to 3.4 ii) 8.350 is rounded off to 8.4

UNIT – II (KINEMATICS)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. **Explain what is meant by Cartesian coordinate system?**
   At any given **instant of time**, the frame of reference with respect to which the **position of the object is described** in terms of position coordinates (x, y, z) (i.e., distances of the given position of an object along the x, y, and z–axes.) is called "Cartesian coordinate system"

2. **Define a vector. Give examples**
   It is a quantity which is described by **both magnitude and direction**. Geometrically a vector is a directed line segment. **Examples Force, velocity, displacement, position vector, acceleration, linear momentum and angular momentum**

3. **Define a scalar. Give examples**
   It is a property which can be described **only by magnitude**. In physics a number of quantities can be described by scalars. **Examples Distance, mass, temperature, speed and energy**

4. **Write a short note on the scalar product between two vectors.**
   The scalar product (or dot product) of two vectors is defined as **the product of themagnitudes of both the vectors and the cosine of the angle** between them. $\vec{A}.\vec{B}$ = ABcosθ. Here, A and Bare magnitudes of $\vec{A}$ and $\vec{B}$.
   Properties:
   The product quantity $\vec{A}$and $\vec{B}$is always a scalar. The **scalar product** is **commutative.**

5. **Write a short note on vector product between two vectors.**
   The vector product or cross product of two vectors is defined as another **vector havinga magnitude equal to the product of the magnitudes of two vectors** and the sine of the angle between them.$\vec{C}$= $\vec{A}$x$\vec{B}$ = (AB sin θ)n

6. **How do you deduce that two vectors are perpendicular?**
   If two vector $\vec{A}$ and $\vec{B}$ are **perpendicular to each other their scalar product**.
   $\vec{A}.\vec{B}$ =0, because cos90^0 = 0.

7. **Define displacement and distance.**
   Distance is the actual path length travelled by an object in the given interval of timeduring the motion. It is a positive scalar quantity.

Displacement the shortest **distance between these two positions** of the object and its direction is from the initial to final position of the object, during the given interval of time. It is a **vector quantity.**

8. **Define velocity and speed.**
Velocity: The **rate of change of displacement** of the particle.
Velocity = Displacement / time taken. Unit: ms^{-1}. Dimensional formula: LT^{-1}
Speed: The **distance travelled in unit time**. It is a **scalar quantity.**

9. **Define acceleration.**
The acceleration of the particle at an instant is equal to **rate of change of velocity. It is a vector quantity. SI Unit: ms^{-2}. Dimensional formula: $M^0L^1T^{-2}$**

10. **What is the difference between velocity and average velocity?**
Velocity is **the rate at which the position changes**. But the average velocity is the **displacement or position change per time ratio**.

11. **Define a radian?**
The length of the arc divided by the radius of the arc. One radian is the **anglesubtended at the center of a circle by an arc that is equal in length to the radius of the circle.**

12. **Define angular displacement and angular velocity.**
Angular displacement: The angle described by the particle about the axis of rotation in a given time is called angular displacement. The unit of angular displacement is radian.
Angular velocity (ω):
The rate of change of angular displacement is called angular velocity.
The **unit of angular velocity is radian per second (rad s^{-1}).**

13. **What is non uniform circular motion?**
If the speed of the object in **circular motion is not constant**, then we have non-uniform circular motion. For example, **when the bob attached to a string moves in vertical circle.**

14. **Write down the kinematic equations for angular motion.**
1.$\omega = \omega_0 + \alpha t$ 2. $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ 3. $\omega^2 = \omega_0^2 + 2\alpha\theta$ 4. $\theta = \frac{(\omega + \omega_0)t}{2}$

15. **Write down the expression for angle made by resultant acceleration and radiusvectorin the non-uniform circular motion.**
$\tan\theta = \frac{a_t}{\frac{v^2}{r}}$, θ = Resultant acceleration angle, $\frac{v^2}{r}$ = Centripetal acceleration
a_t = Resultant acceleration

16. What is meant by Right handed Cartesian co-ordinate system?

The x, y and zaxes are drawn in **anticlockwise direction then the coordinate** system is called as **"right– handed Cartesian coordinate system".**

17. What is point mass?

The mass of any object be assumed to be concentrated at a point. Then this idealized mass is called "point mass". It has no internal structure like shape and size.

18. Define linear motion. Give an example.

An object is said to be in linear motion if it moves in a straight line.

Examples

i) An athlete running on a straight track

ii) A particle falling vertically downwards to the Earth.

19. Define circular motion. Give an example.

Circular motion is defined as a motion described by an **object traversing a circular path.**

Examples

1) The whirling motion of a stone attached to a string

2) The motion of a satellite around the Earth

20. Define rotational motion. Give an example.

If any **object moves in a rotational motion about an axis**, the motion is called 'rotation'.

Examples

i) Rotation of a disc about an axis through its center

ii) Spinning of the Earth about its own axis.

21. What is meant by motion in one dimension?

One dimensional motion is the motion of a **particle moving along a straightline**

Examples

i) Motion of a train along a straight railway track.

ii) An object falling freely under gravity close to Earth.

22. What is meant by motion in two dimensions?

If **a particle is moving along a curved path in a plane**, then it is said to be in two dimensional motion.

Examples

i) Motion of a coin on a carrom board.

ii) An insect crawling over the floor of a room.

23. What is meant by motion in three dimensions?

A **particle moving in usual three dimensional space** has three dimensional motion

Examples

i) A bird flying in the sky. ii) Random motion of a gas molecule.

iii) Flying of a kite on a windy day.

24. Define magnitude of a vector.

The **length of a vector** is called magnitude of the vector. It is always a positive quantity. Sometimes the **magnitude of a vector is also called 'norm' of the vector.** Denoted by 'A'

25. What is meant by equal vectors?

Two vectors $\vec{A}$ and $\vec{B}$ are said to be equal when they have equal **magnitude and samedirection** and represent the same physical quantity.

26. Define parallel and anti-parallel vectors.

Two vectors $\vec{A}$ and $\vec{B}$ act in the **same direction** along the same line or on **parallel lines**, then the angle between them is 0^0

Two vectors $\vec{A}$ and $\vec{B}$ are said to be **anti–parallel when they are in opposite directions** along the same line or on parallel lines. Then the angle between them is 180^0

27. Define work done by a force.

The work done by a force $\vec{F}$to move an object through a small displacement $\overrightarrow{dr}$ is defined as, $\vec{W}= \vec{F}.\overrightarrow{dr}$. W = F dr cos θ

28. What is retardation?

If the **velocity is decreasing with respect to time**, then the acceleration.

29. What is instantaneous velocity?

The instantaneous velocity at an instant *t* or simply 'velocity' at an instant *t* is definedas limiting value of the average velocity as Δ*t* →0, evaluated at time *t*.

$$\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$$

30. Define momentum

The linear momentum or simply momentum of a particle is defined as **product of mass with velocity**. It is denoted as '$\vec{p}$'. **Momentum is also a vector quantity.**

31. What is meant by velocity of one object with respect to another?

When two objects A and B are moving with different velocities, then the velocity of oneobject A with respect to another object B is called relative velocity of object A with respect to B.

32. Write the kinetic equations for linear motion.

i) v = u + at   ii) $s = ut + \frac{1}{2} at^2$ iii) $v^2 = u^2 + 2as$ iv) $s = \frac{(u+v)t}{2}$

33. What is meant by projectile?

When an **object is thrown in the air with some initial velocity** and then allowed to move under the action of gravity alone, the object is known as a projectile

34. Give some examples for projectile motion.

1. An object dropped from window of a moving train
2. A bullet fired from a rifle.
3. A ball thrown in any direction.
4. A javelin or shot put thrown by an athlete.
5. A jet of water issuing from a hole near the bottom of a water tank.

35. Define Time of flight

The **time taken for the projectile to complete its trajectory** or time taken by the **projectile to hit the ground** is called time of flight.

36. What is Horizontal range?

The horizontal distance covered by the **projectile from the foot of the tower** to the point where the projectile hits the ground is called horizontal range

37. Define maximum height.

The **maximum vertical distance travelled by the projectile** during its journey is calledmaximum height.

38. Define horizontal range.

The **maximumhorizontal distance between the point of projection** and the point on thehorizontal plane where the projectile hits the ground is called horizontal range (R).

39. Define Time of flight.

The total time taken by the **projectile from the point of projectiontill ithits the horizontal plane** is called time of flight.

40. Define Uniform circular motion.

When a point **object is moving on a circular path with a constant** speed, it covers equaldistances on the circumference of the circle in equal intervals of time.

41. Write the assumptions need to study about the projectile motion.

i) **Air** resistance is neglected.

ii) The effect due **to rotation of Earth and curvature of Earth** is negligible.

iii) The **acceleration due to gravity is constant** in magnitude and direction atall points of the motion of the projectile.

42. How are two vectors expressed in a Cartesian system? Explain the additionand subtraction using components.

i) The two vectors $\vec{A}$ and $\vec{B}$ in a Cartesian coordinate system can be expressed as $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$, $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$

ii) Then the addition of two vectors is equivalent to adding their corresponding x, y and z components.

$\vec{A}+\vec{B} = (A_x+B_x)\hat{i} + (A_y+B_y)\hat{j} + (A_z+B_z)\hat{k}$

iii) Similarly, the subtraction of two vectors is equivalent to subtracting the corresponding x, y and z components.

$\vec{A}-\vec{B} = (A_x-B_x)\hat{i} + (A_y-B_y)\hat{j} + (A_z-B_z)\hat{k}$

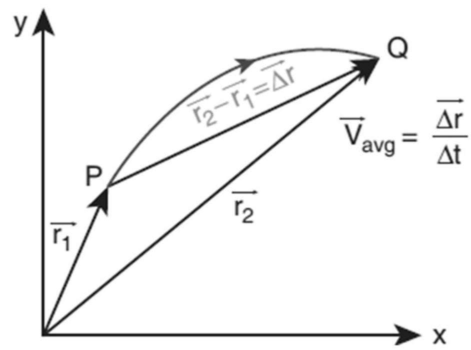
The above rules form an analytical way of adding and subtracting two vectors.

43. Define average velocity and represent it graphically.

The average velocity is defined as ratio of the displacement vector to the corresponding

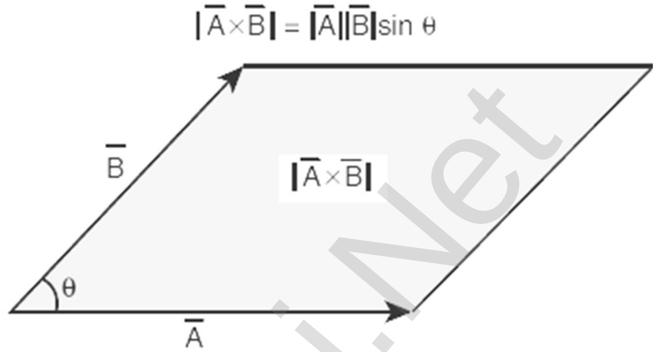
time interval $\vec{v}_{avg} = \frac{\Delta\vec{r}}{\Delta t}$

It is a vector quantity. The direction of average velocity is in the direction of the displacement vector ($\Delta\vec{r}$).

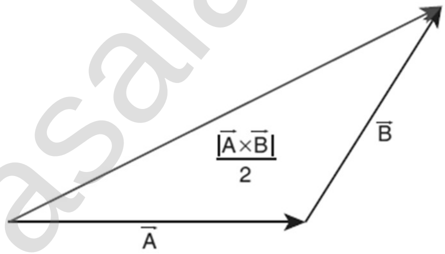


44. Obtain an expression for the area of triangle in terms of the cross product of two vectors representing the two sides of the triangle.

If two vectors $\vec{A}$ and $\vec{B}$ form adjacent sides in a parallelogram, then the magnitude of $|\vec{A} \times \vec{B}|$ will give the area of the parallelogram as represented graphically in Figure.

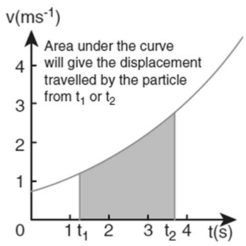


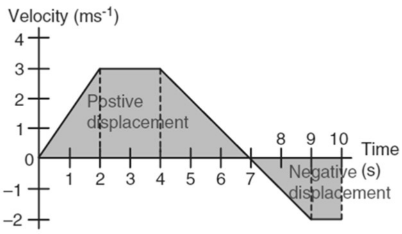
It divides a parallelogram into two equal triangles as shown in the Figure, the area of a triangle with $\vec{A}$ and $\vec{B}$ as sides is $\frac{1}{2}|\vec{A} \times \vec{B}|$



45. What does the slope of 'position – time' graph represent? Which physical quantity is obtained from it?

i) Graphically the slope of the position-time graph will give the velocity of the particle. At the same time, if velocity time graph is given, the distance and displacement are determined by calculating the area under the curve. velocity is given by $\frac{dx}{dt}$ = therefore, dx = vdt





ii) By integrating both sides,

$\int_{x_1}^{x_2} dx = \int_{x_1}^{x_2} v dt$ integration is equivalent to area under the given curve. So, the term $\int_{t_1}^{t_2} v\, dt$ represents the area under the curve as a function of time.

iii) Since the left-hand side of the integrationrepresents the displacement travelled by the particle from time t_1 to t_2, the area under the velocity time graph will give the displacement of the particle.

iv) If the area is negative, it means that displacement is negative, so the particlehas travelled in the negative direction

46. Define the term relative velocity. How can it be obtained vertically, when the two objects with uniform velocities move in same direction?

i) When **two objects A and B** are moving with **different velocities**, then the velocity of one object A with respect to another object B is called **relative velocity of object A with respect to B.**

ii) Consider **two objects A and B moving with uniform velocities** V_A and V_B, as along **straight tracks in the same direction** $\vec{V}_A$, $\vec{V}_B$, with respect to ground.

iii) The relative velocity of object A with respect to object B is $\vec{V}_{AB} = \vec{V}_A - \vec{V}_B$. The relative velocity of object B with respect to object A is $\vec{V}_{BA} = \vec{V}_B - \vec{V}_A$

iv) Thus, **if two objects are moving in the same direction**, the magnitude of relativevelocity of one object with respect to another is equal to the difference in magnitude of two velocities.

47. Write the expression for the magnitude and direction of the relative velocity

i) Consider the velocities $\vec{V}_A$ and $\vec{V}_B$ at an angle θ between their directions. The relative velocity of A with respect to B, $\vec{V}_{AB} = \vec{V}_A - \vec{V}_B$

Then, the magnitude and direction of $\vec{V}_{AB}$ is given by

$v_{AB} = \sqrt{v_A^2 + v_B^2 - 2v_A v_B \cos\theta}$ and $\tan\beta = \frac{v_B \sin\theta}{v_B - v_A co}$

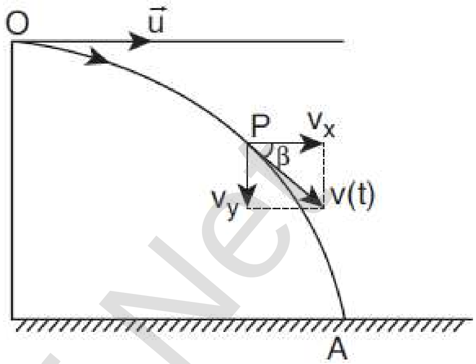
(Here β is angle between $\vec{V}_{AB}$ and $\vec{V}_B$)

ii) When **θ = 0, the bodies move along parallel straight lines** in the same direction, we have $v_{AB} = (v_A - v_B)$ in the direction of $\vec{V}_A$. Obviously $v_{BA} = (v_B + v_A)$ in thedirection of $\vec{V}_B$.

iii) When **θ = 180, the bodies move along parallel straightlines** in oppositedirections, we have $v_{AB} = (v_A + v_B)$ in the direction of $\vec{V}_A$. Similarly, $v_{BA} = (v_B - v_A)$ in the direction of $\vec{V}_B$.

iv) If **the two bodies are moving at right angles to each other, then θ = 90.** Themagnitude of the relative velocity of A with respect to B = $V_{BA} = \sqrt{v_A^2 + v_B^2}$

48. Derive the expression for a body projected horizontally?



i) At any instant t, the projectile has velocity components along both *x*-axis and y-axis. The resultant of these two components gives the velocity of the projectile at that instant *t*, as shown in Figure.

ii) The velocity component at any *t* along horizontal (*x*-axis) is $v_x = u_x + a_x t$ Since, $u_x = u$, $a_x = 0$, we get $v_x = u$.

iii) The component of velocity along vertical direction (y-axis) is $v_y = u_y + a_y t$

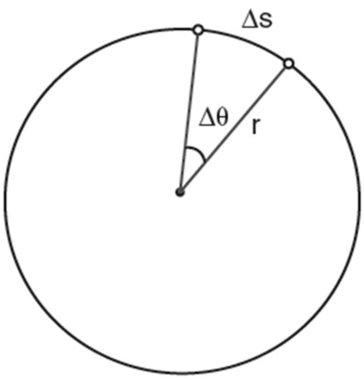
Since, $u_y = 0$, $a_y = g$, we get $v_y = gt$

Hence the velocity of the particle at any instant is $\vec{v} = u\hat{i} + gt\hat{j}$

The speed of the particle at any instant *t* is given by $v = \sqrt{v_x^2 + v_y^2}$

$v = \sqrt{u^2 + g^2t^2}$

49. Derive the relation between linear velocity and angular velocity.



1) Consider an object moving along a circle of radius r. In a time Δ*t*, the object travels. An arc distance Δs as shown in Figure. The corresponding angle subtended is Δθ

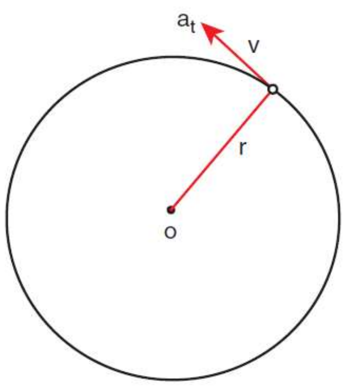
2) The Δs can be written in terms of Δθ as,

$\Delta s = r\Delta\theta$In a time Δ*t*, we have $\frac{\Delta_s}{\Delta_t} = r\frac{\Delta\theta}{\Delta t}$

In the limit Δ*t* ⟶0, the above equation becomes $\frac{ds}{dt} = r\omega$ ---------(1)

3) Here $\frac{ds}{dt}$ is linear speed (*v*) which is tangential to the circle andω is angular speed. So equation (1) becomes v = rω*.* Which gives the relation between linear speed and angular speed.

50. Find the expressions tangential acceleration.



i) In general, the relation between linear and angular velocity is given by $\vec{v} = \vec{\omega} \times \vec{r}$. For circular motion equation reduces to equation v = rω. since $\vec{\omega}$ and $\vec{r}$are perpendicular to each other. Differentiating the equation v = rω with respect to time, we get (since r is constant)

$\frac{dv}{dt} = r\frac{d\omega}{dt} = r\,\alpha$

ii) Here $\frac{dv}{dt}$is the tangential acceleration and is denoted as a_t. $\frac{d\omega}{dt}$ is the angular acceleration. Then eqn. $\vec{v} = \vec{\omega} x \vec{r}$ becomes $a_t = r\,\alpha$ iii) The tangential acceleration a_t experienced by an object is circular motion as shown in Figure.

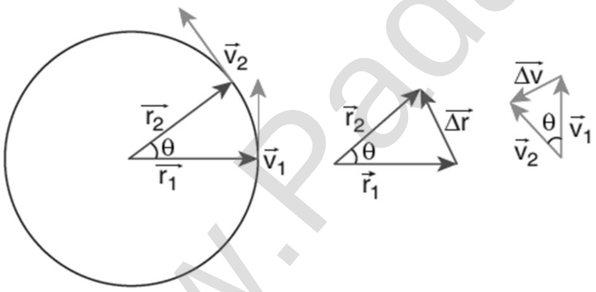
51. Derive an expression for the centripetal acceleration of a body moving in a circular path of radius ‘r’ with uniform speed.

i) The centripetal acceleration is derived from a simple geometrical relationship between position and velocity vectors.

ii) Let the directions of position and velocity vectors shift through the same angle θ in a small interval of time Δt,

iii) For uniform circular motion, $r = |\vec{r_1}| = |\vec{r_2}|$ and $v = |\vec{v_1}| = |\vec{v_2}|$. If the particle moves from position vector $\vec{r_1}$ to $\vec{r_2}$, the displacement is given by $\Delta\vec{r} = \vec{r_2} - \vec{r_1}$ and the change in velocity from $\vec{v_1}$ to $\vec{v_2}$ is given by $\Delta\vec{v} = \vec{v_2} - \vec{v_1}$.

iv) The magnitudes of the displacement Δr and of Δv satisfy the following relation $\frac{\Delta r}{r} = -\frac{\Delta v}{v} = \theta$



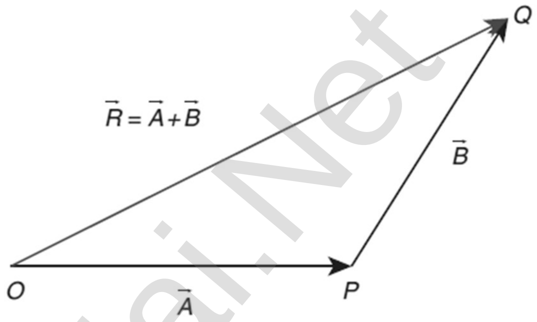
v) Here the negative sign implies that Δv points radially inward, towards the center of the circle. $\Delta v = v\left(\frac{\Delta r}{r}\right)$ then, $a = \frac{\Delta v}{\Delta t} = \frac{v}{r}\left(\frac{\Delta v}{\Delta t}\right)$; $= -\frac{v^2}{r}$

vi) For uniform circular motion $v = \omega r$, where ω is the angular velocity of the particle about the center. Then the centripetal acceleration can be written as $a = -\omega^2 r$

FIVE MARKS QUESTION WITH ANSWER QUESTIONS

52. Explain in detail the triangle law of addition.

1) Represent the vectors $\vec{A}$ and $\vec{B}$ by the two adjacent sides of a triangle taken in the same order. Then the resultant is given by the third side of the triangle taken in the opposite order.

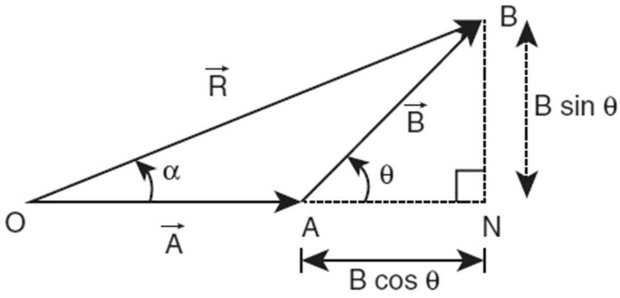


2) The **head of the first vector $\vec{A}$ is connected to the tail of the second vector $\vec{B}$. Let θ be the angle between $\vec{A}$ and $\vec{B}$. Then $\vec{R}$ is the resultant vector connecting the tail** of the first vector $\vec{A}$ to the head of the second vector $\vec{B}$.

3) The magnitude of $\vec{R}$(resultant) is given geometrically by the length of $\vec{R}$(OQ) and the direction of the resultant vector is the angle between $\vec{R}$ and $\vec{A}$ Thus we write $\vec{R} = \vec{A} + \vec{B}$. $\because \overrightarrow{OQ} = \overrightarrow{OP} + \overrightarrow{PQ}$

Magnitude of resultant vector:

4) Consider the triangle ABN, which is obtained by extending the side OA to ON. ABN is a right angled triangle.



$\cos\theta = \frac{AN}{B} \therefore AN = B\cos\theta$ *and*

$\sin\theta = \frac{BN}{B} \therefore BN = B\sin\theta$

For ΔOBN,

we have $OB^2 = ON^2 + BN^2$

$\Rightarrow R^2 = (A + B\cos\theta)^2 + (B\sin\theta)^2$

$\Rightarrow R^2 = A^2 + B^2\cos^2\theta + 2AB\cos\theta + B^2\sin^2\theta$

$\Rightarrow R^2 = A^2 + B^2(\cos^2\theta + \sin^2\theta) + 2AB\cos\theta$

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

which is the magnitude of the resultant of A and B

Direction of resultant vectors:

5) If θ is the angle between $\vec{A}$ and $\vec{B}$, then

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

If $\vec{R}$ makes an angle α with $\vec{A}$, then in ΔOBN, $\tan\alpha = \frac{BN}{ON} = \frac{BN}{OA+AN}$

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

53. Discuss the properties of scalar and vector products.

Properties of scalar products

1) The product **quantity $\vec{A}.\vec{B}$ is always a scalar.** It is positive if the angle betweenthe vectors is acute (i.e., < 90°) and negative if the angle between them is obtuse (i.e. 90°<θ< 180°).

2) The **scalar product is commutative**, i.e. $\vec{A}.\vec{B} = \vec{B}.\vec{A}$

3) The **vectors obey distributive law** i.e. $\vec{A}.(\vec{B}+\vec{C}) = \vec{A}.\vec{B} + \vec{A}.\vec{C}$

4) The angle between the vectors $\theta = \cos^{-1}\left[\frac{\vec{A}.\vec{B}}{AB}\right]$

5) The **scalar product of two vectors will be maximum** when Cos θ = 1, i.e. $\theta = 0^0$, i.e., when the vectors are parallel; $(\vec{A}.\vec{B})_{max} = AB$

6) The **scalar product of two vectors will be minimum**, when Cos θ = –1, i.e. $\theta = 180^0$ $(\vec{A}.\vec{B})_{min} = -AB$ when the vectors are anti-parallel.

7) If **two vectors $\vec{A}$and $\vec{B}$, are perpendicular** to each other than their scalar Product $\vec{A}.\vec{B}= 0$, because Cos 90^0 =0. Then the vectors $\vec{A}$and $\vec{B}$. are said to be mutually orthogonal.

8) The scalar product of a vector with itself is termed as self–dot product and isgiven by $(\vec{A})^2 = \vec{A}.\vec{A}$ = AA Cos θ = A^2. Here angle θ = 0°

The **magnitude or norm of the vector $\vec{A}$ is $|\vec{A}|$ = A = $\sqrt{\vec{A}.\vec{A}}$**

9) In case of a unit vector $\hat{n}$, $\hat{n}.\hat{n}$= 1 x 1 x Cos 0 = 1.

For example, $\hat{\imath}.\hat{\imath} = \hat{\jmath}.\hat{\jmath} = \hat{k}.\hat{k} = 1$

10) In the case of **orthogonal unit vectors**$\hat{\imath}$,$\hat{\jmath}$and $\hat{k}$, $\hat{\imath}.\hat{\jmath} = \hat{\jmath}.\hat{k} = \hat{k}.\hat{\imath}$ = 1.1 Cos90^0 = 0

11) In terms of components the scalar product of $\vec{A}$and $\vec{B}$can be written

As $\vec{A}.\vec{B} = (A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}).(B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k})$

$= A_xB_x + A_yB_y + A_zB_z$with all other terms zero.

The magnitude of vector $|\vec{A}|$is given by $|\vec{A}| = A = \sqrt{A_x^2 + A_y^2 + A_z^2}$

Properties of vector (cross) product.

1) **The vector product of any two vectors** is always another vector whose direction is **perpendicular to the plane** containing these two vectors, i.e., orthogonal to both the vectors $\vec{A}$and $\vec{B}$, even though the vectors $\vec{A}$and $\vec{B}$may or may not be mutually orthogonal.

2) The **vector product of two vectors is not commutative**, i.e., $\vec{A}x\vec{B} \neq \vec{B}x\vec{A}$

But, $\vec{A}x\vec{B} = -[\vec{B}x\vec{A}]$. Here it is worthwhile to note that

$|\vec{A}x\vec{B}| = |\vec{B}x\vec{A}|$ = AB Sin θ.

i.e. in the case of the product vectors $\vec{A}x\vec{B}$ and $\vec{B}x\vec{A}$, the magnitudes are equal but directions are opposite to each other

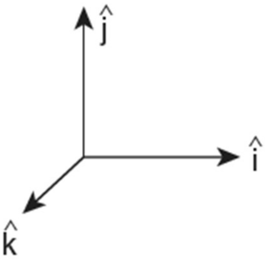
3) The **vector product of two vectors will have maximum magnitude** when sin θ = 1, i.e., θ = 90^0 i.e., when the vectors $\vec{A}$ and $\vec{B}$, are orthogonal to each other. $(\vec{A}x\ \vec{B})_{max} = AB\hat{n}$

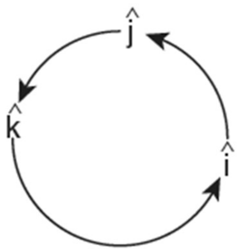
4) The **vector product of two non–zero vectors will be minimum** when sin θ = 0, i.e.,θ = 0^0 or 180^0 $[\vec{A}\ x\ \vec{B}]_{min}$ = 0 i.e., the vector product of two non–zero vectors vanishes, if the vectors are either parallel or anti-parallel.

5) The self–cross product, i.e., **product of a vector with itself is the null vector** $\vec{A}\ x\ \vec{A}$ **= AA** Sin θ $\hat{n} = \vec{0}$ In physics the null vector $\vec{0}$ is simply denoted as zero.

6) The self–vector products of unit vectors are thus zero.
$\hat{\imath}x\hat{\imath} = \hat{\jmath}x\hat{\jmath} = \hat{k}\,x\hat{k} = \vec{0}$

7) In the case of orthogonal unit vectors, $\hat{\imath}$, $\hat{\jmath}$, $\hat{k}$ in accordance with the right-hand screw rule: $\hat{\imath}\ x\hat{\jmath} = \hat{k}$, $\hat{\jmath}\ x\hat{k} = \hat{\imath}$, $\hat{k}\ x\hat{\imath} = \hat{\jmath}$. Also, since **the cross product is not commutative,**
$\hat{\jmath}\ x\hat{\imath} = -\hat{k}$, $\hat{k}\ x\hat{\jmath} = -\hat{\imath}$ and $\hat{\imath}\ x\hat{k} = -\hat{\jmath}$





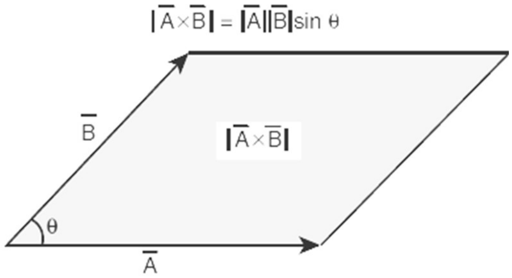
8) In terms of components, the vector product of two vectors $\vec{A}$ and $\vec{B}$

$$\vec{A}x\ \vec{B} = \begin{vmatrix} \vec{\imath} & \vec{\jmath} & \vec{k} \\ A_X & A_Y & A_Z \\ B_X & B_Y & B_Z \end{vmatrix}$$

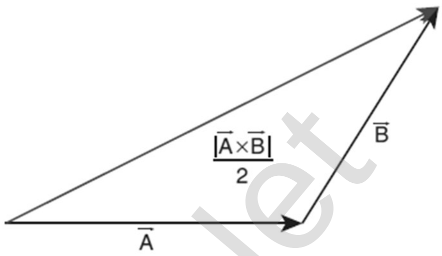
$= \vec{\imath}\ (A_yB_z - A_zB_y) + \vec{\jmath}(A_zB_x - A_xB_z) + \vec{k}(A_xB_y - A_yB_x)$

Note that in the $\vec{\jmath}^{th}$ component the order of multiplication is different than $\vec{\imath}^{th}$ and $\vec{k}^{th}$ components.

9) If two vectors $\vec{A}$ and $\vec{B}$ form adjacent sides in a parallelogram, then the **magnitude of $|\vec{A}\ x\ \vec{B}|$ will give the area of the parallelogram** as represented graphically in Figure.



10) It divide a parallelogram into two equal triangles as shown in the Figure, the area of a triangle with $\vec{A}$ and $\vec{B}$ as sides is $\frac{1}{2}|\vec{A} \times \vec{B}|$ number of quantities used in Physics are defined through vector products.



Particularly physical quantities Representingrotational effects like torque, angular momentum, are defined through vector products.

54. Derive the kinematic equations of motion for constant acceleration.

Consider an object moving in a straight line with uniform or constant acceleration 'a'. Let **u be the velocity of the object** at time t = 0, and v be velocity of the body at a latertime t.

Velocity - time relation:

1) The acceleration of the body at any instant is given by the **first derivative ofthe velocity with respect to time**, a $=\frac{dv}{dt}$ or dv = a .dt

Integrating both sides with the condition that as time changes from 0 to t, the velocitychanges from u to v. For the constant acceleration,

$\int_u^v dv = \int_0^t adt$

$= a \int_u^v dt \Rightarrow [v]_u^v = a\,[t]_0^t$ --------(1)

v – u = at (or) v = u + at

Displacement – time relation:

2) The velocity of the body is given by **the first derivative of the displacement with respect to time**. v $= \frac{ds}{dt}$ or ds = v dt and since v = u + at We get ds = (u + at) dt. Assume that initially at time t = 0, the particle started from the origin. At a later time, t, the particle displacement is s. Further assuming that acceleration is time independent, we have $\int_0^s ds$ $=\int_0^t udt + \int_0^t atdt$ or

$s = ut + ½ at^2$ ------------(2)

Velocity – displacement relation:

3) The acceleration is given by the **first derivative of velocity with respect to time.** a $= \frac{dv}{dt} = \frac{dv}{ds}\frac{ds}{dt} = \frac{dv}{ds}$ v[since ds / dt = v where s is distance traversed] This is rewritten as a $= \frac{1}{2}\frac{dv^2}{ds}$ or ds $= \frac{1}{2a}$ d(v^2)

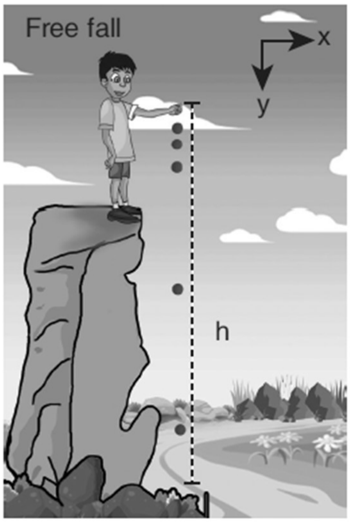
4) Integrating the above equation, using the fact when the velocity changes from u^2 to v^2, displacement changes from 0 to s,

we get $\int_0^s ds = \int_u^v \frac{1}{2a} d(v^2)$; $s = \frac{1}{2a}(v^2 - u^2)$; $v^2 = u^2 + 2as$ -----------(3)

5) We can also derive the displacement s in terms of initial velocity u and finalvelocity v. From the equation (1) we can write, at = v – u
Substitute this in equation (2), we gets = ut + ½ (v – u)t
$s = \frac{(u+v)t}{2}$ ---------------(4)
The equations (1), (2), (3) and (4) are called kinematic equations of motion, and have a wide variety of practical applications.
Kinematic equations:
$v = u + at$; $s = ut + \frac{1}{2}at^2$; $v^2 = u^2 + 2as$; $s = \frac{(u+v)t}{2}$

55. Derive the equations of motion for a particle (a) falling vertically(b) projected vertically

Case (1): A body falling from a height h



1. Consider an object of mass m falling from a height h.
Assume there is no air resistance. For convenience, let us choose the downward direction as positive y-axis as shown in the Figure.
2. The object experiences acceleration 'g' due to gravity which is constant near the surface of the Earth. We can use kinematic equations to explain its motion. We haveThe acceleration $\vec{a} = g\hat{j}$
By comparing the components, we get
$A_x = 0$, $a_y = g$, $a_z = 0$ Let us take for simplicity,
$a_y = a = g$
3. If the particle is thrown with initial velocity 'u' downward which is in negative y axis, then velocity and position at of the particle any time t is given by
$v = u + gt$ ------------------(1)
$y = ut + \frac{1}{2}gt^2$ ------------- (2)
4. The square of the speed of the particle when it is at a distance y from the hill-top, is$v^2 = u^2 + 2gy$ -------------(3)
Suppose the particle starts from rest. Then u = 0
5. Then the velocity v, the position of the particle and v2 at any time t are given by (for a point y from the hill-top)

$v = gt$ ----------- (4)
$y = \frac{1}{2}gt^2$ ----------(5)
$v^2 = 2gy$ -----------(6)

6. The time (t =T) taken by the particle to reach the ground (for which y =h), is givenby using equation (5),

   $h = y = \frac{1}{2} gT^2$ ----------(7)

   $T = \sqrt{\frac{2h}{g}}$ -----------(8)

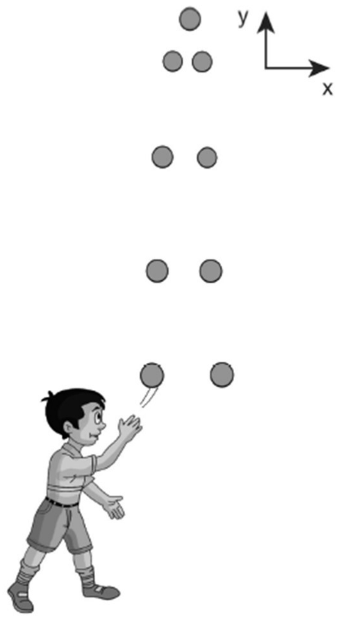
   The equation (8) implies that greater the height(*h*), particle takes more time(*T*) to reach the ground. For lesser height(*h*), it takes lesser time to reach the ground.

   The speed of the particle when it reaches the ground (y = h) can be found usingequation (6), we get $v_{ground} = \sqrt{2gh}$ ----------- (9)

7. The above equation implies that the body falling from greater height (h) will have higher velocity when it reaches the ground.

   The motion of a body falling towards the Earth from a small altitude h << R), purelyunder the force of gravity is called free fall. (Here R is radius of the Earth)

Case (ii): A body thrown vertically upwards



1. Consider an object of mass mthrown vertically upwards with an initial velocity u. Let us neglect the air friction.
2. In this case we choose the vertical direction as positive y axis as shown in the Figure then the acceleration a = − g (neglect air friction) and *g* points towards the negative yaxis.
3. The kinematic equations for this motion are,

   $v = u - gt$ -----------------(10)

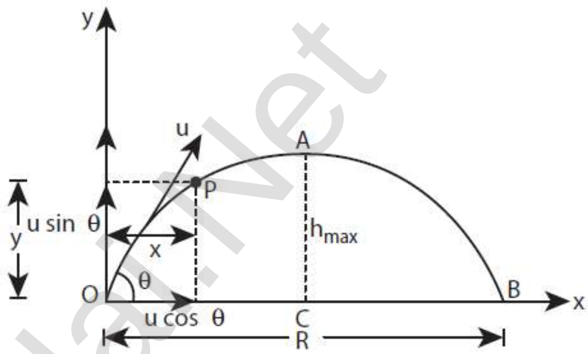
   $y = ut - \frac{1}{2} gt^2$ ------------ (11)

   The velocity and position of the object at any time t are,

   $v^2 = u^2 - 2gy$ ------------(12)

56. Derive the equation of motion, range and maximum height reached by theparticle thrown at an oblique angle $\theta$with respect to the horizontal direction.

i) Consider an object thrown with initial velocity $\vec{u}$at an angle θ with the horizontal. then,$\vec{u}$ = $u_x\hat{i} + u_y\hat{j}$where u_x= u Cos θ is the horizontal component and u_y= u sin θ the vertical component of velocity.



ii) u_x remains constant throughout the motion.u_y changes with time under the effect of acceleration due to gravity. First itdecreases, becomes zero at the maximum height, after which it again increases till the prose reach be ground.

iii) Hence after the time t, the velocity along horizontal motion

$v_x = u_x + a_x t = u_x$ = u cos θ

The horizontal distance travelled by projectile in time t is

$s_x = u_x t + \frac{1}{2} a_x t^2$. Here, s_x = x, u_x = u cos θ, a_x = 0

iv) Thus, x = u cos θ. t or $t = \frac{x}{u\, Cos\theta}$ ------------- (1)

Next, for the vertical motion $v_y = u_y + a_y t$ Here $u_y = u\, sin\theta$, $a_y = -g$ (Acceleration due to gravity acts opposite to the motion).

Thus, v_y = u Sin θ – gt ------------------(2)

The vertical distance travelled by the projectile in the same time *t* is

$s_y = u_y t + \frac{1}{2} a_y t^2$ Here, s_y = y, u_y = u sin θ, $a_x = -g$

Then, y = u Sin θ t – ½ gt² --------------- (3)

v) Substitute the value of *t* from equation (1) in equation (3), we have

$$y = u \,Sin\, \theta \frac{x}{u\, Cos\theta} - \frac{1}{2} g \frac{x^2}{u^2 Cos^2\theta}$$

$$y = x \tan\theta - \frac{1}{2} g \frac{x^2}{u^2 Cos^2\theta} \quad \text{-----------------(4)}$$

Thus, the path followed by the projectile is an inverted parabola.

Maximum height (h_{max})

The **maximum vertical distance travelled by the projectile** during its journey is calledmaximum height. This is determined as follows:

For the vertical part of the motion, $v_y^2 = u_y^2 + 2a_y s$

Here, $u_y = u\, sin\theta$, $a = -g$, s = h_{max}, and at the maximum height v_y= 0

Here, $(0)^2 = u^2 \sin^2 = gh_{max}$ (or) $h_{max} = \frac{u^2 \sin^2\theta}{2g}$

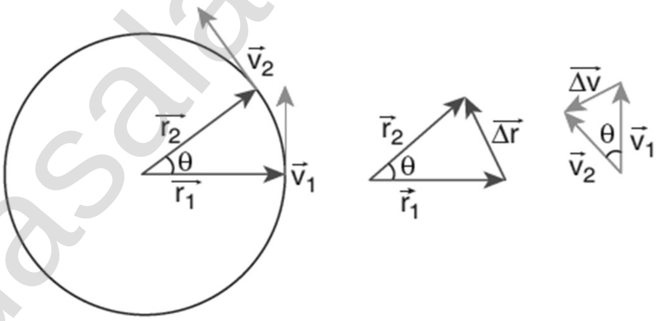
Horizontal range (R)

The maximum horizontal distance between the point of projection and the point on the horizontal plane where the projectile hits the ground is called horizontal range (R). This is found easily since the horizontal component of initial velocity remains thesame. We can write Range R = Horizontal component of velocity x time of flight =*u* cos θx T_f

$$R = u\cos\theta \times \frac{2u\sin\theta}{g} = \frac{2u^2\sin\theta\cos\theta}{g} \quad R = \frac{u^2\sin 2\theta}{g}$$

57. Derive the expression for centripetal acceleration.

When a body is in uniform circular motion. Its speed remains constant, but its velocity changes continuously due to the change in its direction. Hence the motion is accelerated. A body undergoing uniform circular motion is acted upon by an acceleration which is directed along the radius towards the centre of the circular path. The acceleration is called centripetal acceleration.



i) The centripetal acceleration is derived from a simple geometrical relationship between position and velocity vectors.

ii) Let the directions of position and velocity vectors shift through the same angle θ in asmall interval of time Δt,

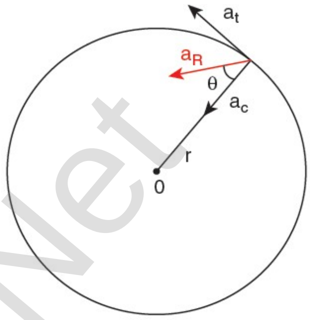
iii) For uniform circular motion, r = $|\vec{r_1}| = |\vec{r_2}|$ and v = $|\vec{v_1}| = |\vec{v_2}|$. If the particle moves from position vector $\vec{r_1}$ to $\vec{r_2}$, the displacement is given by $\Delta\vec{r} = \vec{r_2} - \vec{r_1}$ and the change in velocity from $\vec{v_1}$ to $\vec{v_2}$ is given by $\Delta\vec{v} = \vec{v_2} - \vec{v_1}$.

iv) The magnitudes of the displacement Δr and of Δ*v* satisfy the following relation $\frac{\Delta r}{r} = -\frac{\Delta v}{v} = \theta$

v) Here the negative sign implies that Δ*v* points radially inward, towards the center of the circle. $\Delta v = v\left(\frac{\Delta r}{r}\right)$ then, $a = \frac{\Delta v}{\Delta t} = \frac{v}{r}\left(\frac{\Delta v}{\Delta t}\right)$; $= -\frac{v^2}{r}$

vi) For uniform circular motion *v* = ω*r*, where ω is the angular velocity of the particle about the center. Then the centripetal acceleration can be written as $a = -\omega^2 r$

58. Derive the expression for total acceleration in the non-uniformcircular motion.



1) Consider a particle moving along a circular path of radius r with a variable speed v. As the speed of the particle changes so acceleration has a tangential component, $a_t = \frac{dv}{dt} r\alpha$; $a_t = r\alpha$
2) As the direction of motion changes continuously, so the acceleration has a radial component (i.e.) Centripetal acceleration $a_c = \frac{v^2}{r}$
3) The resultant acceleration is obtained by vector sum of centripetal and tangential acceleration.
4) The magnitude of this resultant acceleration is given by $a_R = \sqrt{a_t^2 + \left(\frac{v^2}{r}\right)^2}$

59. Define the term motion and explain the different types of motion.

An object is said to be in motion if it changes its position with respect to its surroundings with the passage of time.

a) Linear motion

An object is said to be in linear motion if it moves in a straight line.

Examples

1) An athlete running on a straight track
2) Aparticle falling vertically downwards to the Earth.

b) Circular motion

Circular motion is defined as a motion described by an object traversing a circular path.

Examples

1) The whirling motion of a stone attached to a string
2) The motion of a satellite around the Earth

c) Rotational motion

If any object moves in a rotational motion about an axis, the motion is called 'rotation'.

Examples

i) Rotation of a disc about an axis through its center
ii) Spinning of the Earth about its own axis.

d) Vibratory motion

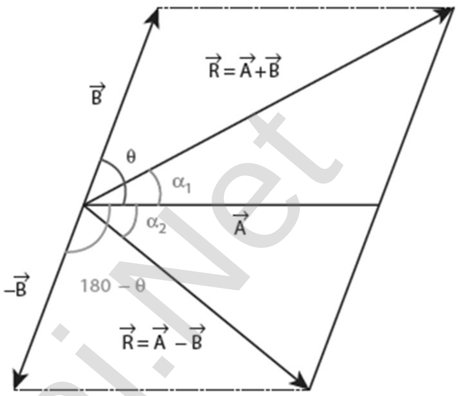
If an object or particle executes a to–and– fro motion about a fixed point, it is said tobe in vibratory motion.

Examples i) Vibration of a string on a guitar
ii) Movement of a swing

60. Explain the subtraction of vectors.

i) For two non-zero vectors $\vec{A}$ and $\vec{B}$ which are inclined to each other at an angle θ, the difference $\vec{A} - \vec{B}$ is obtained as follows. First obtain $-\vec{B}$ as in Figure. The angle between $\vec{A}$ and $-\vec{B}$ is 180 – θ. The difference $\vec{A} - \vec{B}$ is the same as the resultant o $\vec{A}$ and $-\vec{B}$.

We can write $\vec{A} - \vec{B} = \vec{A} + (-\vec{B})$ and using the equation, we have



ii) $|\vec{A} + \vec{B}| = \sqrt{A^2 + B^2 + 2AB\,\text{Cos}\theta}$, we have $|\vec{A} - \vec{B}| = \sqrt{A^2 + B^2 + 2AB\,\text{Cos}(180 - \theta)}$

iii) since, cos (180 − θ) = −cosθ. we get,

$|\vec{A} - \vec{B}| = \sqrt{A^2 + B^2 - 2AB\,\text{Cos}\theta}$

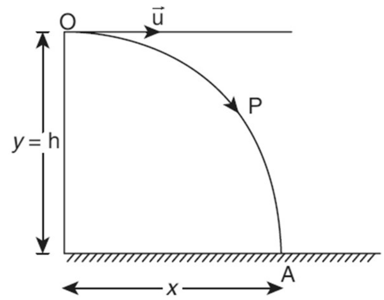
Again, from the Figure 2.19, and using an equation similar to equation

$\tan\alpha_2 = \frac{B\sin(180-\theta)}{A+B\cos(180-\theta)}$

iv) But sin (180 − θ) = sinθ, hence we get, $\tan\alpha_2 = \frac{B\sin\theta}{A-B\cos\theta}$

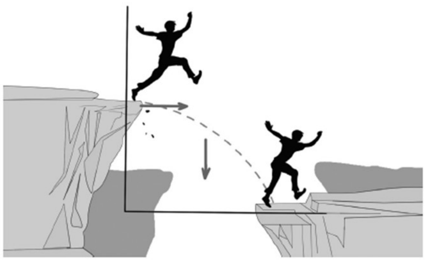
61. Find horizontal range and time of flight projectile in horizontal projection.

Consider a projectile, say a ball, thrown horizontally with an initial velocity $\vec{u}$ from the top of a tower of height h (Figure)



1. As the ball moves, it covers a horizontal distance due to its uniform horizontal velocity *u*, and a vertical downward distance because of constant acceleration due to gravity g.

2. Thus, under the combined effect the ball moves along the path OPA. The motion is in a 2-dimensional plane. Let the ball take time *t* to reach the ground at point A,



Then the horizontal distance travelled by the ball is *x* (t) = *x*, and the vertical distance travelled is y (t) = y

Motion along horizontal direction:

3. The particle has zero acceleration along *x* direction. So, the initial velocity u_x remainsconstant throughout the motion. The distance traveled by the projectile at a time *t* is given by the equation

$x = u_x t + \frac{1}{2} at^2$ Since a = 0 along *x* direction, we have $x = u_x t$ -------------(1)

Motion along downward direction:

4) Here u_y= 0 (initial velocity has no downward component), a = g (we choose the +ve y-axis in downward direction), and distance y at time tFrom equation, y = $u_y t + \frac{1}{2} at^2$, we get y = ½ gt^2 ---------(2)
Substituting the value of t from equation (1) in equation (2) we have

$$y = \frac{1}{2} g \frac{x^2}{u_x^2} = \left(\frac{g}{2u_x^2}\right)x^2$$

y = Kx^2 ------------- (3), where K = $\frac{g}{2u_x^2}$

5) Equation is the equation of a parabola. Thus, the path followed by the projectile is a parabola (curve OPA in the Figure)

Time of Flight:

h be the height of a tower. Let T be the time taken by the projectile to hit the ground, after being thrown horizontally from the tower.$s_y = u_y t + \frac{1}{2} at^2$ s_y=h, t=T, u_y=0 (i.e no initial vertical velocity)

$$T = \sqrt{\frac{2h}{g}}$$

6) Thus, the **time of flight for projectile motion depends on the height of the tower,** but is independent of the horizontal velocity of projection.

Horizontal range:

The **horizontal distance covered by the projectile from the foot of the tower to the point where the projectile hits the ground** is called horizontal range. For horizontal motion, we have $s_x = u_x t + \frac{1}{2} at^2$.Here, s_x= R (range), $u_x = u$, a = 0 (no horizontal acceleration) *T* is time of flight. Then horizontal range = uT.

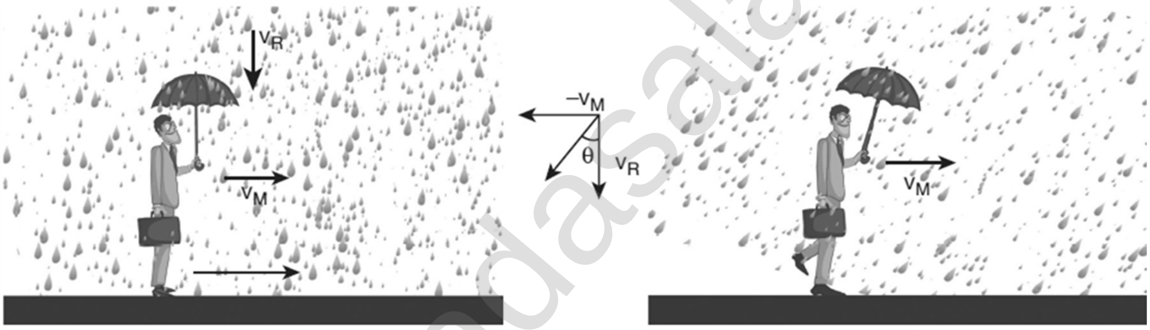
7) Since the time of flight T = $\sqrt{\frac{2h}{g}}$, we substitute this and

we get the horizontal range of the particle as R = $u\sqrt{\frac{2h}{g}}$.

8) The above equation implies that the range R is directly proportional to the initial velocity *u* and inversely proportional to acceleration due to gravity g.

62. A man moving in rain holds an umbrella inclined to the vertical though therain drops are falling vertically. Why?

1. Consider a person moving horizontally with velocity $\vec{V}_M$. Let rain fall vertically with velocity $\vec{V}_R$.
2. An umbrella is held to avoid the rain. Then the relative velocity of the rain with respect to the person is,$\vec{V}_{RM} = \vec{V}_R - \vec{V}_M = \vec{OB} + \vec{OC} + \vec{OD}$which has magnitude$V_{RM} = \sqrt{v_R^2 + v_M^2}$ $\tan\theta = \frac{DB}{OB} = \frac{v_M}{v_R}$and direction $\theta = \tan^{-1}\left(\frac{v_M}{v_R}\right)$with the vertical as shown in Figure.
4. In order to save himself from the rain, he should hold an umbrella at an angle θ with the vertical.



UNIT – III (LAWS OF MOTION)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. Explain the concept of inertia. Write two examples each for inertia of motion, inertia of rest and inertia of direction.

This inability of objects to move on its own or change its state of motion is called inertia. Inertia means resistance to change its state.

Examples:

Inertia of Rest:

i. Passengers experience a **backward push in a sudden start of bus.**

ii. Tightening of seat belts in a **car when it stops quickly.**

Inertia of Motion:

i. Passengers experience a forward push during a sudden brake in bus.

ii. Ripe fruits fall from the trees in the **direction of wind.**

Inertia of Direction:

i. A **stone moves tangential to Circle.**

ii. When a **car moves towards** left, we turn to the right.

2. State Newton's second law.

The force acting on an object is equal to **the rate of change of its momentum.** $\vec{F} = \frac{d\vec{p}}{dt}$

3. Define One Newton.

One Newton is defined as the **force which acts on 1 kg of mass to givean acceleration** 1 m s^{-2} in the direction of the force.

4. Show that impulse is the change of momentum.

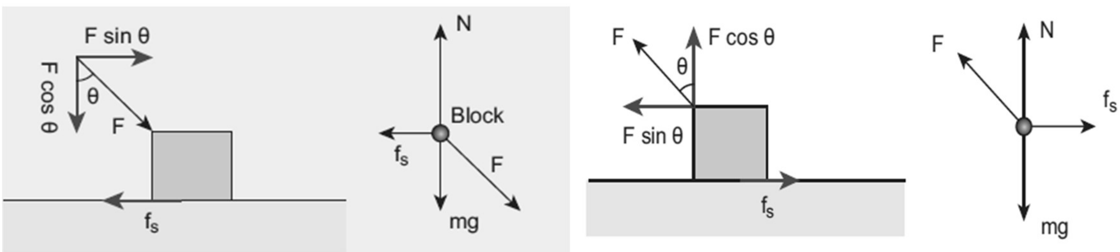
The integral $\int_{t_i}^{t_f} F\,dt = J$is called the impulse and it is **equal to change in momentum** of the object.

Proof: If the force is constant over the time interval, then

$\int_{t_i}^{t_f} F\,dt = F\int_{t_i}^{t_f} dt = F\,(t_f - t_i)$

$F\Delta t = \Delta p$ is called the impulse and it is equal to change in momentum of the object.

5. Using free body diagram, show that it is easy to pull an object than to push it.



6. Explain various types of friction. Suggest a few methods to reduce friction.

Static Friction ($\vec{f_s}$):

1. Static friction is the **force which opposes the initiation of motion** of an object on the surface.
2. When the object is at **rest on the surface, only two forces act on** it. They are the **downward gravitational force and upward normal force**.
3. The resultant of these two forces on the object is zero.

Kinetic Friction ($\vec{f_k}$):

1. When an object slides, the **surface exerts a frictional force** called kinetic friction *(fk)*
2. If the external force acting on the object is **greater than maximum static friction**, the objects begin to slide.
3. The kinetic friction **does not depend on velocity**.

Rolling Friction:

The force of friction that comes into act when a wheel rolls over a surface. Methods to reduce friction:

1. By using Lubricant's friction 2. By using ball bearings.

7. What is the meaning by 'pseudo force'?

Centrifugal force is called as a 'pseudo force'. A pseudo force has **no origin. A pseudo force is an apparent force** that acts on all masses whose motion is described using non inertial frame of reference such as a rotating reference frame.

8. State the empirical laws of static and kinetic friction.

i) The magnitude of static frictional force $f_s$satisfies the following empirical relation.**$0 \leq f_s \leq \mu_s N_s$**where μ_s is the coefficient of static friction.

ii) The force of static friction can take any value from zero to $\mu_s N$.

iii) **If the object is at rest and no external force is applied on the object**, the static frictionacting on the object is zero ($f_s = 0$).

iv) If the **object is at rest**, and there is an external **force applied parallel** to the surface, then the force of static friction acting on the object is exactly equal to the external force applied on the object ($f_s = F_{ext}$). But still the static friction $f_s$is less than $\mu_s N$.

v) When object begins to slide, the static friction (fs) acting on the object attains maximum.

vi) The static and **kinetic frictions depend on the normal force** acting on the object.

vii) The static friction **does not depend upon the area of contact.**

9. State Newton's Third law.

For **every action** there is an **equal and opposite reaction**.

10. What are inertial frames?

1. If an object is free from all forces, then it moves with constant velocity or remains atrest when seen from inertial frames.
2. Thus, there exists some special set of frames in which if an object experiences no force It moves with constant velocity or remains at rest.

11. Under what condition will a car skid on a leveled circular road?

If the static friction is not able to provide enough centripetal force to turn, the vehicle will start to skid. $\mu < \frac{v^2}{rg}$ (skid)

12. Define impulse.

If a **very large force acts on an object for a very short duration**, then the force is called impulsive force or impulse.

13. State Newton's First law.

Every object continues to be in the **state of rest or of uniform motion** unless there is external force acting on it.

14. Define Inertia of rest, motion and direction.

The inability of an **object to change its state of rest** is called **inertia of rest.**

The inability of an **object to change its direction of motion** on its own is called **inertia of direction.**

The inability of an **object to change its state of uniform speed** on its own is called **inertia of motion.**

15. What is free body diagram? What are the steps to be followed for developingfree body diagram?

Free body diagram is a **simple tool to analyze the motion of the object** using **Newton'slaws.** The following systematic steps are followed for developing the free body diagram:

1. **Identify the forces** acting on the object.
2. **Represent the object** as a point.
3. **Draw the vectors** representing the forces acting on the object.

16. What is the concurrent force?

A collection of forces is said to be concurrent, if the **lines of forces act at a common point.**

17. State Lami's theorem.

The magnitude of each **force of the system is proportional to sine of theangle between the other two forces**. The constant of proportionality is same for all three forces. $\frac{|\vec{F}_1|}{\text{Sin}\alpha} = \frac{|\vec{F}_2|}{\text{Sin}\beta} = \frac{|\vec{F}_3|}{\text{Sin}\gamma}$

18. State the law of conservation of total linear momentum.

If there are **no external forces acting on the system**, then the **total linear momentum ofthe system ($\vec{p}_{tot}$) is always a constant vector.**
In other words, the total linear momentum of the system is conserved in time.

19. What is the role of air bag in a car?

cars are designed with air bags in such a way that when the car meets with an accident, the **momentum of the passengers will reduce slowly so that the average force acting on them will be smaller.**

20. Define frictional force.

Which always opposes the relative motion between an object and the surface where it is placed. If the **force applied is increased, the object moves** after a certain limit.

21. Define Angle of Friction.

The angle of friction is defined as the **angle between the normal force(N) and the resultant force (R**) of normal force and maximum friction force f_s^{max})

22. Define Angle of repose.

The same as angle of friction. But the difference is that the angle of repose refers to **inclinedsurfaces and the angle of friction is applicable** to any **type of surface.**

23. What are the applications of angle of repose?

1. The angle of inclination of **sand trap** is made to be **equal to angle of repose.**
2. Children are fond of **playing on sliding board**. Sliding will be easier when the **angle of inclination of the board is greater** than the **angle of repose.**

24. How does the rolling wheel's work in suitcase?

1. In **rolling motion** when a **wheel moves on a surface**, the point of **contact with surface is always at rest.**
2. Since the point of **contact is at rest**, there is **no relative motion** between the **wheel andsurface**. Hence the **frictional force is very less.**

25. Where does the friction force act?

Walking is possible because of frictional force. Vehicles (bicycle, car) can move because of **the frictional force between the tyre and the road**. In the braking system, kinetic friction plays amajor role.

26. How did the ball bearing reduce kinetic friction?

If ball bearings are **fixed between two surfaces**, during the **relative motion only the rolling friction comes to effect and not kinetic friction.**

27. What is the reason for force changes the velocity of the particle?

1. The magnitude of the velocity can be **changed without changing the direction of the velocity.**
2. In this case the particle will move in the same direction but with acceleration.
3. The direction of motion alone can be **changed without changing the magnitude (speed).**
4. **Both the direction and magnitude (speed) of velocity** can be changed. If this happens **non circular motion occurs.**

28. Define Centripetal force.

If a particle is in **uniform circular motion**, there must be **centripetalacceleration towards the center of the circle**. If there is acceleration, then there must be some force acting on it with respect to an inertial frame. This force is called centripetal force.

29. How is the centripetal force act in whirling motion?

In the case of **whirling motion of a stone tied to a string**, the centripetal force on the particle is provided by the **tensional force on the string**. In circular motion in an **amusement park, the centripetal force is provided by the tension in the iron ropes.**

30. How did the car move on circular track?

When a car is moving on a circular track the centripetal force is given by the **frictional force between the road and the tyres.**

Frictional force = mv^2/rm-mass of the car, v-speed of the carr-radius of curvature of track, even when the **car moves on a curved track**, the car experiences the **centripetal force which is provided by frictional force between the surface and the tyre of the car.**

CONCEPTUAL QUESTIONS:

31. Why it is not possible to push a car from inside?

1. When you push on the car from inside, the reaction force of your pushing is **balanced out by our body moving backward.**
2. The seat behind you **pushes against to bring things to static equilibrium.** So, we can'tpush a car from inside.

32. There is a limit beyond which the polishing of a surface increase frictionalresistance rather than decreasing it why?

1. Friction arises due to molecular adhesion. For more polishing the **molecules of the surface come closer.**
2. They offer greater resistance to surface.

33. Can a single isolated force exist in nature? Explain your answer.

No, a single isolated force cannot exist in nature. Because it will beviolation of Newton's third law.

34. Why does a parachute descend slowly?

A parachute is a device used **to slow down on object that is falling towards the ground**. When the parachute opens, the **air resistance increases**. So, the person can land safely.

35. When walking on ice one should take short steps. Why?

To **avoid slipping**, take smaller steps. Because these steps causes more normal force and there by **more friction.**

36. When a person walks on a surface, the frictional force exerted by the surfaceon the person is opposite to the direction of motion. True or false?

False.

37. Can the coefficient of friction be more than one?

Yes, $\mu > 1$, friction is stronger than the normal force.

38. Can we predict the direction of motion of a body from the direction of force onit?

In free body diagrams, the force of friction is always parallel to the surface of contact. The force **of kinetic friction** is always opposite the direction of motion.

39. The momentum of a system of particles is always conserved. True or false?

True

40. Why is it dangerous to stand near the open door of moving bus?

It is dangerous to stand near the open door (or) steps while travelling in the bus. When thebus takes a sudden turn in a curved road, due to centrifugal force the person is pushed away from the bus. Even though centrifugal force is a pseudo force, its effects are real.

41. When a cricket player catches the ball, he/she pulls his /her hands graduallyin the direction of the ball's motion. Why?

1. If he stops his hands soon after catching the ball, the ball comes to rest very quickly.
2. It means that the momentum of the ball is brought to rest very quickly.
3. So the average force acting on the body will be very large.
4. Due to this large average force, the hands will get hurt.
5. To avoid getting hurt, the player brings the ball to rest slowly

42. A man jumping on concrete floor is more dangerous than in sand floor, why?

1. Jumping on a concrete cemented floor is more dangerous than jumping on the sand.
2. Sand brings the body to rest slowly than the concrete floor, so that the average force experienced by the body will be lesser.

FIVE MARKS QUESTION WITH ANSWER QUESTIONS:

43. Prove the law of conservation of linear momentum. Use it to find the recoilvelocity of a gun when a bullet is fired from it.

i) The force on each particle (Newton's second law) can be written as $\vec{F}_{12} = \frac{d\vec{p}_1}{dt}$ and $\vec{F}_{21} = \frac{d\vec{p}_2}{dt}$

ii) Here $\vec{p}_1$is the momentum of particle 1which changes due to the force $\vec{F}_{12}$exertedby particle 2. Further $\vec{p}_2$ is the momentum of particle 2. These changes due to $\vec{F}_{21}$ exertedby particle 1.

$\frac{d\vec{p}_1}{dt} = -\frac{d\vec{p}_2}{dt}$; $\frac{d\vec{p}_1}{dt} + \frac{d\vec{p}_2}{dt} = 0$; $\frac{d}{dt}(\vec{p}_1 + \vec{p}_2) = 0$

iii) It implies that $\vec{p}_1 + \vec{p}_2$= constant vector (always).

iv) $\vec{p}_1 + \vec{p}_2$is the total linear momentum of the two particles ($\vec{p}_{tot} = \vec{p}_1 + \vec{p}_2$). It is also called as total linear momentum of the system. Here, the two particles constitute thesystem.

v) If there are no external forces acting on the system, then the total linear momentum ofthe system ($\vec{p}_{tot}$) is always a constant vector.

Examples:

Consider the firing of a gun. Here the system is Gun+bullet. Initially the gun and bullet are at rest, hence the total linear momentum of the system is zero. Let $\vec{p}_1$ be the momentum of the bullet and $\vec{p}_2$ the momentum of the gun before firing. Since initially both are at rest, $\vec{p}_1 = 0$, $\vec{p}_2 = 0$. Total momentum before firing the gun is zero, $\vec{p}_1 + \vec{p}_2 = 0$. According to the law of conservation of linear momentum, total linear momentum has to be zero after the firing also.

When the gun is fired, a force is exerted by the gun on the bullet in forward direction. Now the momentum of the bullet changes from $\vec{p}_1$ to $\vec{p}_1'$. To conserve the total linear momentum of the system, the momentum of the gun must also change from $\vec{p}_2$ to $\vec{p}_2'$.

Due to the conservation of linear momentum, $\vec{p}_1' + \vec{p}_2' = 0$. It implies that $\vec{p}_1' = -\vec{p}_2'$, the momentum of the gun is exactly equal, but in the opposite direction to the momentum of the bullet. This is the reason after firing, the gun suddenly moves backward with the momentum $(-\vec{p}_2)$. It is called 'recoil momentum'. This is an example of conservation of total linear momentum.

44. What are concurrent forces? State Lami's theorem.

A collection of forces is said to be concurrent, if the lines of forces act at a common point. If they are in the same plane, they are concurrent as well as coplanar forces. If a system of three concurrent and coplanar forces is in equilibrium, then Lami's theoremstates that **the magnitude of each force of the system is proportional to sine of the angle between** the other two forces. The constant of proportionality is same for all three forces. $\frac{|\vec{F}_1|}{\text{Sin}\alpha} = \frac{|\vec{F}_2|}{\text{Sin}\beta} = \frac{|\vec{F}_3|}{\text{Sin}\gamma}$

Example:

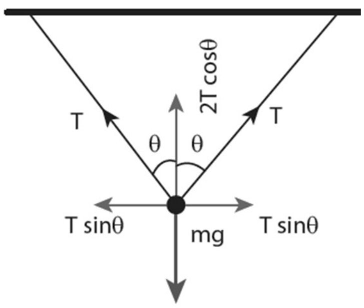
A baby is playing in a swing which is hanging with the help of two identical chains is at rest. Identify the forces acting on the baby. Apply Lami's theorem and find out the tension acting on the chain.

Solution

The baby and the chains are modeled as a particle hung by two strings as shown in the figure. There are threeforces acting on the baby.

i) Downward gravitational force along negative y direction (mg)

ii) Tension (T) along the two strings This three forces are coplanar as well as concurrent as shown in the following figure



By using Lami's theorem

$$\frac{T}{\text{Sin}(180-\theta)} = \frac{T}{\text{Sin}(180-\theta)} = \frac{mg}{\text{Sin}(2\theta)}$$

Since Sin (180 – θ) = Sin θ and

Sin (2θ) = 2sin θcos θ

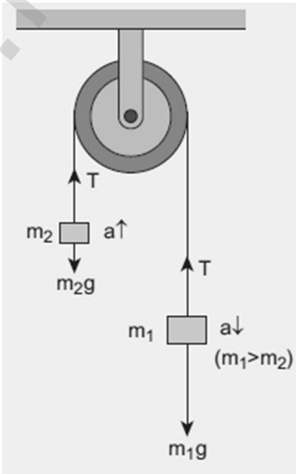
We get, $\frac{T}{\sin\theta} = \frac{mg}{2\sin\theta\cos\theta)}$;

From this, the tension on each string is

$T = \frac{mg}{2\cos\theta}$

45. Explain the motion of blocks connected by a string in i) Vertical motion ii) Horizontal motion.

Case 1: Vertical motion:

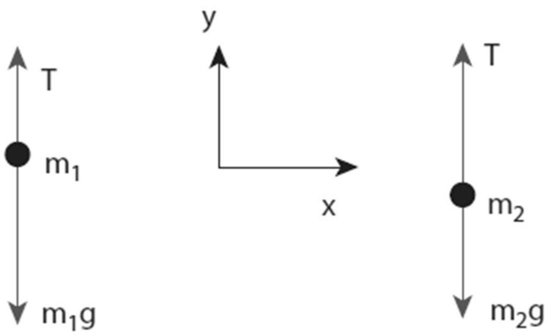


i) Consider **two blocks of masses m_1 and m_2 ($m_1 > m_2$)** connected by a light and inextensible string that passes over a pulley.

ii) Let the tension in the string be Tand acceleration *a*. When the system is released, both the blocks start moving, m_2 vertically upward and m_1 downward with same acceleration. The gravitational force m_1g on mass m_1 is used in lifting the mass m_2. Applying Newton's second law for mass m_2,

$T\hat{j} - m_2g\hat{j} = m_2a\hat{j}$

iii) The left-hand side of the above equation is the total force that acts on m_2 and the right-hand side is the product of mass and acceleration of m_2 in y direction.



By comparing the components on both sides, we get

$T - m_2g = m_2a$ ------------ (1)

Similarly, applying Newton's second law for mass m_1

$T\hat{j} - m_1g\hat{j} = -m_1a\hat{j}$

As mass m1 moves downward ($-\hat{j}$), its acceleration is along($-\hat{j}$)

iv) By comparing the components on both sides, we get

$T - m_1g = -m_1a$; $m_1g - T = m_1a$ ------------ (2)

Adding equations (1) and (2), we get

$m_1g - m_2g = m_1a + m_2a$; $(m_1 - m_2)g = (m_1 + m_2)a$ ------ (3)

From equation (3), the acceleration of both the masses is

$a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) g$ -----(4)

If both the masses are equal ($m_1 = m_2$), from equation (4) a = 0

v) This shows that if the masses are equal, there is no acceleration and the system as a whole will be at rest. To find the tension acting on the string, substitute the acceleration from the equation (4) into the equation (1).

$T - m_2g = m_2\left(\frac{m_1-m_2}{m_1+m_2}\right)g$; $T = m_2g + m_2\left(\frac{m_1-m_2}{m_1+m_2}\right)g$ --- (5)

By taking m2g common in the RHS of equation (5)

$T = m_2g\left(1 + \frac{m_1-m_2}{m_1+m_2}\right)$;

$T = m_2g\left(\frac{m_1+m_2+m_1-m_2}{m_1+m_2}\right)$

$T = \left(\frac{2m_1m_2}{m_1+m_2}\right)g$

Case 2: Horizontal motion:

i) In this case, mass m_2 is kept on a horizontal table and mass m_1 is hanging through asmall pulley. Assume that there is no friction on the surface.

ii) As both the blocks are connected to the un-stretchable string, if m_1 moves with an acceleration *a* downward then m_2 also moves with the same acceleration *a* horizontally.

The forces acting on mass m_2 are

(i) Downward gravitational force (m_2g)

(ii) Upward normal force (N) exerted by the surface

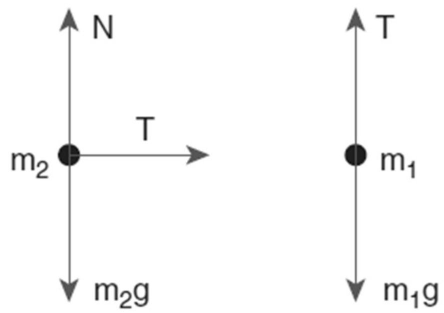
(iii) Horizontal tension (T) exerted by the string

The forces acting on mass m_1 are

(i) Downward gravitational force (m_1g)

(ii) Tension (T) acting upwards

The free body diagrams for both the masses



Applying Newton's second law for m_1

$T\hat{j} - m_1g\hat{j} = m_1a\hat{j}$

By comparing the components on both sides of the above equation,

$T - m_1g = -m_1a$ ------------ (1)

Applying Newton's second law for m_2

$T\hat{i} - m_2a\hat{i}$, By comparing the components on both sides of above equation,

$T = m_2a$ -------------(2)

There is no acceleration along y direction for m_2.

$N\hat{j} - m_2g\hat{j} = 0$, By comparing the components on both sides of the above equation

$N - m_2g = 0$; $N = m_2g$ ------------- (3)

By substituting equation (2) in equation (1), we can find the tension T

$m_2a - m_1g = -m_1a$; $m_2a + m_1a = m_1g$; $a = \frac{m_1}{m_1+m_2}g$ ----------(4)

Tension in the string can be obtained by substituting equation (4) in equation (2) $T = \frac{m_1 m_2}{m_1+m_2} g$

Comparing motion in both cases, it is clear that the tension in the string for horizontal motion is half of the tension for vertical motion for same set of masses and strings.

46. Briefly explain the origin of friction. Show that in an inclined plane, angle of friction is equal to angle of repose.

i) If a very gentle force in the horizontal direction is given to an object at rest on thetable, it does not move.

ii) It is because of **the opposing force exerted by the surface on the object which resists its motion.**

iii) **This force is called the frictional force which always opposes the relative motion between an object and the surface** where it is placed.

iv) Consider an inclined plane on which an object is placed. Let the angle which this planemakes with the horizontal be θ . For small angles of θ , the object may not slide down.

v) As **θ is increased, for a particular value of θ , the object begins to slide down.** This valueis called angle of repose. Hence, the angle of repose is the angle of inclined plane with the horizontal such that an object placed on itbegins to slide.

vi) Consider the various forces in action here. The **gravitational force mg is resolvedinto components parallel (mg sin θ) and perpendicular (mg cos θ) to the inclinedplane.**

vii) The **component of force parallel to the inclined plane (mg sin θ) tries to move theobject down**. The component of force perpendicular to the inclined plane (mg cos θ) is balanced by the Normal force (N).

$N = mg \cos \theta$ -------------(1)

When the object just begins to move, the static friction attains its maximum value,

$f_s = f_s^{max} = \mu_s N$. This friction also satisfies the relation

$f_s^{max} = \mu_s mg \sin\theta$ ------------ (2)

Equating the right hand side of equations (1) and (2), we get

$(f_s^{max}) / N = \sin \theta / \cos \theta$

From the definition of angle of friction, we also know that $\tan \theta = \mu_s$ in which θ is the angle of friction.

47. State Newton's three laws and discuss their significance.

Newton's First Law:

i) Every **object continues to be in the state of rest or of uniform motion** (constant velocity) unless there is external force acting on it.

ii) This inability of objects to move on its own or change its state of motion is calledinertia. Inertia means resistance to change its state.

Newton's Second Law:

i) The force acting on an object is equal to **the rate of change of its momentum** $\vec{F} = \frac{d\vec{p}}{dt}$

ii) In simple words, whenever **the momentum of the body changes, there must be a forceacting on it. The momentum of the object** is defined as $\vec{p} = m\vec{v}$. In most cases, the mass of the object remains constant during the motion. In such cases, the above equation gets modified into a simpler form $\vec{F} = \frac{d(m\vec{v})}{dt} = m\frac{d\vec{v}}{dt} = m\vec{a}$.

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

Newton's Third law:

i) Newton's third law assures that the forces occur as equal and opposite pairs. An isolated force or a single force cannot exist in nature.

ii) Newton's third law states that **for every action there is an equal and opposite reaction.**

iii) Here, **action and reaction pair of forces do not act on the same body but on two different bodies.**

iv) Any one of the forces can be called as an action force and the other the reaction force. Newton's third law is valid in both inertial and non-inertial frames.

v) These action-reaction forces are not cause and effect forces. It means that whenthe object 1 exerts force on the object 2, the object 2 exerts equal and opposite force on the body 1 at the same instant.

48. Explain the similarities and differences of centripetal and centrifugal forces.

Centripetal force	Centrifugal force
It is a real force which is exerted on the body by the external agencies like gravitational force, tension in the string, normal force etc.	It is a pseudo force or fictitious force which cannot arise from gravitational force, tension force, normal force etc.
Acts in **both inertial and non-inertial Frames**	**Acts only in rotating frames** (non-inertial frame)
It acts towards the axis of rotation or center of the circle in circular motion	It **acts outwards from the axis of rotation** or radiallyoutwards from the center of the circular motion
$\left\|F_{cp}\right\|$ = mω^2r = $\frac{mv^2}{r}$	$\left\|F_{cf}\right\|$ = mω^2r = $\frac{mv^2}{r}$
Real force and has real effects.	**Pseudo force but has real effects**
Origin of **centripetal force is interactionbetween two objects**	Origin of centrifugal force is inertia. It does notarise from interaction.
In inertial frames centripetal force has to be included when free body diagrams are drawn.	In an inertial frame the object's inertial motionappears as centrifugal force in the rotating frame. In inertial frames there is no centrifugal force.In rotating frames, both centripetal andcentrifugal force have to be included when freebody diagrams are drawn.

49. Briefly explain 'centrifugal force' with suitable examples.

i) Consider the case of a whirling motion of a stone tied to a string. Assume that the stonehas angular velocity ω in the inertial frame (at rest).

ii) If the motion of the stone is observed from a frame which is also rotating along with thestone with same angular velocity ω then, the stone appears to be at rest.

iii) This implies that in addition to the inward centripetal force $-m\omega^2 r$ there must be an equal and opposite force that acts on the stone outward with value $+m\omega^2 r$.

iv) So the **total force acting on the stone in a rotating frame is equal to zero ($-m\omega^2r+m\omega^2r= 0$).**

v) This **outward force $+m\omega^2$r**is called the **centrifugal force.**

50. Briefly explain 'Rolling Friction'.

i) One of the important applications is suitcases with rolling on coasters. Rolling wheels makes it easier than carrying luggage.

ii) When an object moves on a surface, essentially it is sliding on it. But wheels move on the surface through rolling motion.

iii) In rolling motion when a wheel moves on a surface, **the point of contact with surfaceis always at rest.**

iv) **Since the point of contact is at rest,** there is no relative motion between the wheel andsurface. Hence the **frictional force is very less**. At the same time if an object moves**without a wheel,** there is a relative motion between the object and the surface.

v) As a result **frictional force is larger**. This makes it **difficult to move the object.**

vi) Ideally in pure rolling, motion of the point of contact with the surface should beat rest, but in practice it is not so.

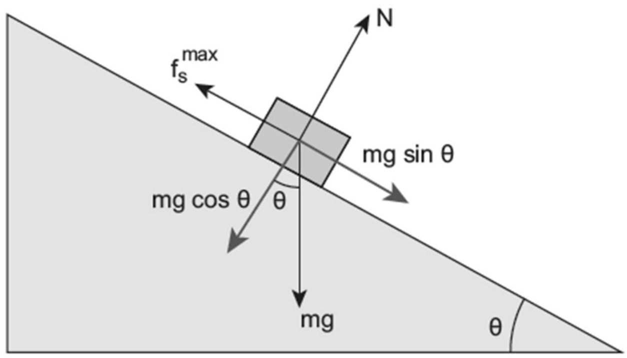
vii) Due to the elastic nature of the surface at the point of contact there will be somedeformation on the object at this point on the wheel or surface.

viii) **Due to this deformation, there will be minimal friction between wheel and surface. It is called 'rolling friction'.** In fact, 'rolling friction' is much smaller than kinetic friction.

51. Describe the method of measuring angle of repose.

i) Consider an inclined plane on which an object is placed. Let the angle which this planemakes with the horizontal be θ . For small angles ofθ,the object may not slide down.

ii) As θ is increased, for a particular value of θ , the object begins to slide down. This value is called angle of repose. Hence, the angle of repose is the angle of inclined plane with the horizontal such that an object placed on itbegins to slide.



iii) Consider the various forces in action here. **The gravitational force mg is resolved into components parallel (mg sin θ) and perpendicular (mg cos θ) to the inclinedplane.**

iv) **The component of force parallel to the inclined plane (mg sin θ)** tries to move the object down. **The component of force perpendicular to the inclined plane (mg cos θ)** is balanced by the Normal force (N).

$$N = mg \cos\theta \quad \text{------------(1)}$$

When the object just begins to move, the static friction attains its maximum value,

$f_s = f_s^{max} = \mu_s$ N. This friction also satisfies the relation

$f_s^{max} = \mu_s$ mg sinθ ------------ (2)

Equating the right hand side of equations (1) and (2), we get

(f_s^{max}) / N = sin θ / cos θ

From the definition of angle of friction, we also know that tan **θ** = μ_s in which **θ** is the angle of friction. Thus **the angle of repose is the same as angle of friction.**

52. Explain the need for banking of tracks.

i) In a leveled circular road, skidding mainly depends on the coefficient of static friction μ_s The coefficient of static friction depends on the nature of the surface which has a maximum limiting value.

ii) To avoid this problem, usually the **outer edge of the road is slightly raised compared to inner edge**

iii) This is called banking of roads or tracks. This introduces an inclination, and the angle is called banking angle.

iv) Let the surface of the road make angle θ with horizontal surface. Then the normalforce makes the same angle θ with the vertical.

v) When the car takes a turn, there are two forces acting on the car:

a) **Gravitational force mg (downwards)**

b) **Normal force N (perpendicular to surface)**

vi) We can resolve the normal force into two components. Ncos θ and N sin θ

vii) The component Ncos θbalances the downward gravitational force 'mg' and component Nsin θ will provide the necessary centripetal acceleration. By usingNewton second law

N cos θ = mg ; N sin θ = $\frac{mv^2}{r}$

By dividing the equations we get, tan θ = $\frac{v^2}{rg}$

v = $\sqrt{\mathbf{rg\,tan\,\theta}}$

Need Banking of tracks:

1) The banking angle θ and radius of **curvature of the road or trackdetermines the Safe speed of the car at the turning. If the speed of car exceeds this safe speed**, then it starts to skid outward but frictional force comes into effect and provides an additional centripetalforce to prevent the outward skidding.

2) At the same time, if **the speed of the car is little lesser than safe speed, it starts to skid inward and frictional force comes into effect, which reduces centripetal force to prevent inward skidding.**

3) However if the speed of the vehicle is sufficiently greater than the correct speed, then frictional force cannot stop the car from skidding.

53. Calculate the centripetal acceleration of Moon towards the Earth?

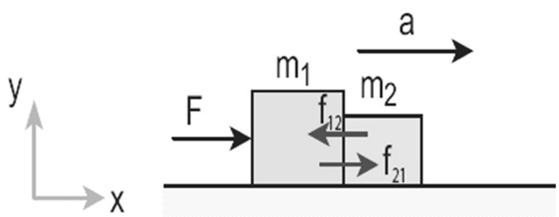
i) The centripetal acceleration is given by a = $\frac{v^2}{r}$. This expression explicitly dependson Moon's speed which is not trivial. We can work with the formula $\omega^2 R_m = a_m$

ii) a_m is centripetal acceleration of the Moon due to Earth's gravity.
ω is angular velocity. R_m is the distance between Earth and the Moon, which is 60 times the radius ofthe Earth.
$R_m = 60R = 60 \times 6.4 \times 10^6 = 384 \times 10^6$m
As we know the angular velocity $\omega = \frac{2\pi}{T}$ and
T =27.3 days =27.3 x 24 × 60 × 60 second = 2.358×10^6 sec
By substituting these values in the formula for acceleration
$a_m = \frac{(4\pi^2)(384 \times 10^6)}{(2.358 \times 10^6)^2}$ $\mathbf{a_m = 0.00272 ms^{-1}}$

The centripetal acceleration of Moon towards the Earth is $\mathbf{a_m = 0.00272 ms^{-1}}$

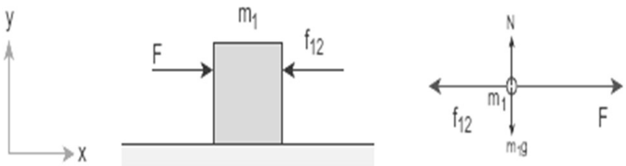
54. How will you confirm Newton's third law by the way of two bodies in contacton a horizontal surface?

i) Consider two blocks of masses m_1 and m_2 ($m_1 > m_2$) kept in contact with each otheron a smooth, horizontal frictionless surface as shown



ii) By the application of a horizontal force F, both the blocks are set into motion with acceleration 'a' simultaneously in the direction of the force F.

iii) To find the acceleration $\vec{a}$, Newton's second law has to be applied to the system(combined mass $m = m_1 + m_2$)
$\vec{F} = m\vec{a}$, If we choose the motion of the two masses along the positive x direction, $F\hat{i} = ma\hat{i}$



By comparing components on both sides of the above equation
F=ma where $m = m_1 + m_2$

The acceleration of the system is given by a = $\frac{F}{m_1 + m_2}$ -------- (1)

iv) The force exerted by the block m_1 on m_2 due to its motion is called force of contact ($\vec{f}_{21}$). According to Newton's third law, the block m_2 will exert an equivalent opposite reaction force ($\vec{f}_{12}$). on block m_1

$$F\hat{\imath} - f_{12}\hat{\imath} = m_1 a\hat{\imath}$$

By comparing the components on both sides of the above equation, we get $F - f_{12} = m_1 a$; $f_{12} = F - m_1 a$ ------------(2)

Substituting the value of acceleration from equation (1) in (2) we get,

$$f_{12} = F - m_1\left(\frac{F}{m_1+m_2}\right) ; f_{12} = F\left[1 - \frac{m_1}{m_1+m_2}\right]$$

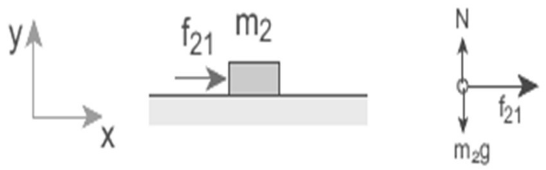
$$f_{12} = \frac{Fm_2}{m_1+m_2} \quad \text{----------(3)}$$

Equation (3) shows that the magnitude of contact force depends on mass m_2 whichprovides the reaction force. Note that this force is acting along the negative x direction.

In vector notation, the reaction force on mass m_1 is given by

$$\vec{f}_{12} = \frac{Fm_2}{m_1+m_2}\hat{\imath}$$

v) For mass m_2 there is only one force acting on it in the x direction and it is denoted by $\vec{f}_{21}$. This force is exerted by mass m_1. The free body diagram for mass m_2.



Applying Newton's second law for mass m_2.

$$f_{21}\hat{\imath} = m_2 a\hat{\imath}$$

By comparing the components on both sides of the above equation

$$f_{21} = m_2 a \quad \text{---------- (4)}$$

Substituting for acceleration from equation (1) in equation (4), we get

$$f_{21} = \frac{Fm_2}{m_1+m_2}$$

vi) In this case the magnitude of the contact force is $f_{21} = \frac{Fm_2}{m_1+m_2}$.

The direction of this force is along the positive x direction.

vii) In vector notation, the force acting on mass $m_2$exerted by mass $m_1$is

$\vec{f}_{21} = \frac{Fm_2}{m_1+m_2}\hat{\imath}$ Note : $\vec{f}_{12} = -\vec{f}_{21}$which confirms Newton's third law

55. Write the salient features of Static and Kinetic friction.

Static friction	Kinetic friction
It **opposes the starting of motion**	It **opposes the relative motion** of the objectwith respect to the surface
Independent of surface of contact	**Independent of surface of contact**
μ_s depends on the nature of materials inmutual contact	$\mu_k$depends on nature of materials andtemperature of the surface
Depends on the magnitude of applied Force	Independent of magnitude of applied force
It can take values from zero to $\mu_s N$	It can never be zero and always equals to $\mu_k N$ whatever be the speed (true <10 ms^{-1})
$f_s^{max} > f_k$	It is less than maximal value of static friction
$\mu_s > \mu_k$	Coefficient of kinetic friction is less than coefficient of static friction

56. Briefly explain what are all the forces act on a moving vehicle on a leveled circular road?

i) When a **vehicle travels in a curved path**, there must be a **centripetal force acting onit.** This centripetal force is provided by the frictional force between tyre and surface of the road.

ii) Consider a vehicle of mass 'm' moving at a speed 'v' in the circular track of radius 'r'.

There are **three forces acting on the vehicle** when it moves

1. **Gravitational force (mg) acting downwards**
2. **Normal force (mg) acting upwards**
3. **Frictional force (F_s) acting horizontally inwards along the road**

iii) Suppose the road is horizontal then the normal force and gravitational force areexactly equal and opposite. The **centripetal force is provided by the force of staticfriction F_s between the tyre and surface** of the road which acts towards the center ofthe circular track, $\frac{mv^2}{r} = F_s$,

the static friction can increase from zero to a maximum value

$F_s \leq \mu_s mg$

iv) The static friction would be able to provide necessary centripetal force to bend the car on the road. So **the coefficient of static friction between the tyre and the surface of the road determines what maximum speed the car can have for safe turn.** If the static friction is not able to provide enough centripetal force to turn, the vehicle will start to skid. if $\frac{mv^2}{r} > \mu_s mg$, of $\mu_s < \frac{v^2}{rg}$ (skid)

57. Find i) acceleration ii) speed of the sliding object using free body diagram.

i) To draw the free body diagram, the block is assumed to be a point mass Since the motion is on the inclined surface, we have to choose the **coordinate system parallel to theinclined surface** as shown in Figure.

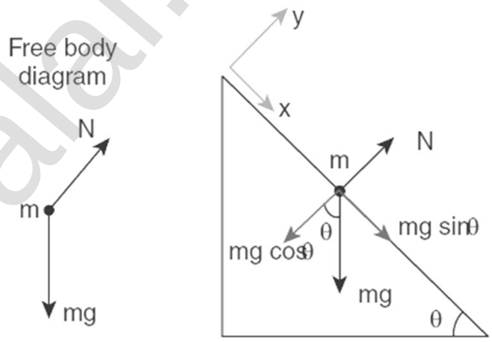
ii) The gravitational force mg is **resolved in to parallel component** mg sinθ along the inclined plane and **perpendicular component** mg cosθ perpendicular to the inclined surface Figure.

iii) Note that the angle made by the gravitational force (mg) with the perpendicular to the surface is equal to the angle of inclination θ

iv) There is **no motion (acceleration) along the y axis.** Applying Newton's second law inthe direction

$-mg\cos\theta\hat{j} + N\hat{j} = 0$ (No acceleration)

By comparing the components on both sides, $N - mg\cos\theta = 0$ $N = mg\cos\theta$



v) The magnitude of normal force (N) exerted by the surface is equivalent to $mg\ cos\theta$. The object slides (with an acceleration) along the x direction. Applying Newton's second law in the x direction $mg\sin\theta\hat{i} = ma\hat{i}$

By comparing the components on both sides, we can equate

$mg\sin\theta = ma$. The acceleration of the sliding object is $a = g\sin\theta$

vi) Note that the acceleration depends on the angle of inclination θ. If the angle θ is 90degrees, the block will move vertically with acceleration $a = g$. Newton's kinematic equation is used to find the speed of the object when it reaches the bottom. The acceleration is constant throughout the motion. $v^2 = u^2 + 2as$ along the x direction

vii) The acceleration a is equal to g sin θ. The initial speed (u) is equal to zero as it startsfrom rest. Here, s is the length of the inclined surface.

The speed (v) when it reaches the bottom is $v = \sqrt{2sg\sin\theta}$

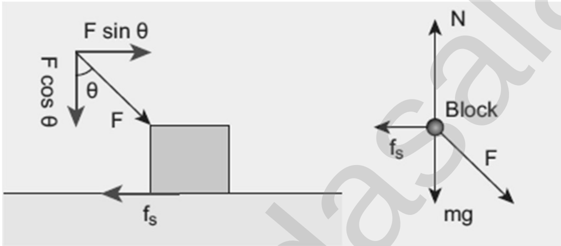
58. Using free body diagram, show that it is easy to pull an object than to push it.

When a body is pushed at an arbitrary angle θ. 0 to $\frac{\pi}{2}$, the applied force F can be resolved into two components as F sinθ parallel to the surface and F cosθ perpendicular to the surface as shown in Figure. The total downward force acting on the body is mg + Fcosθ. It implies that the normal force acting on the body increases. Since there is no acceleration along the vertical direction the normal force N is equal to $\mathbf{N_{push} = mg + F\cos\theta}$ **--------1**

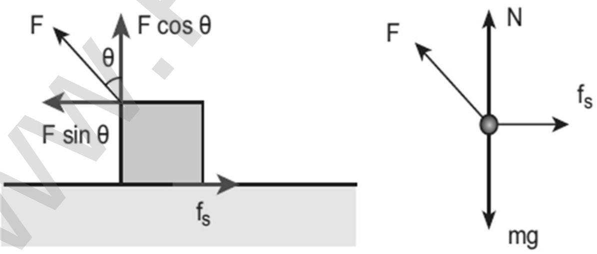
As a result, the maximal static friction also increases and is equal to

$f_s^{max} = \mu_s N_{Push} = \mu_s(mg + F\cos\theta)$ **---------2**

Equation (2) shows that a greater force needs to be applied to push the object into motion.



When an object is pulled at an angle θ, the applied force is resolved into two components as shown in Figure. The total downward force acting on the object is $\mathbf{N_{Pull} = mg - F\cos\theta}$ **---------3**



Equation (3) shows that the normal force is less than N_{push}. From equations (1) and (3), **it is easier to pull an object than to push to make it move.**

UNIT – IV (WORK, ENERGY AND POWER)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. Explain how the definition of work in physics is different from generalperception.

1. Generally, any activity can be called as work
2. But in physics, work is said to be done by the force when the force applied on a body displaces it.

2. Write the various types of potential energy. Explain the formulae.

1. The energy possessed by the body due to gravitational force gives rise togravitational potential energy U = mgh
2. The energy due to spring force and other similar forces give rise to elasticpotential energy. $U = \frac{1}{2} Kx^2$
3. The energy due to electrostatic force on charges gives rise to electrostaticpotential energy. U = – E. dr

3. Write the differences between conservative and Non-conservative forces. Give two examples each.

Conservative forces	Non-conservative forces
Work done is **independent of the path**	Work done **depends upon the path**
Work done in a **round trip is zero**	Work done in a **round trip is not zero**
Total energy **remains constant**	Energy is **dissipated as heat energy**
Work done is **completely recoverable**	Work done is **not completely recoverable**
Force is the negative gradient of potential energy	No such relation exists.
Examples : Elastic spring force, electrostatic force, magnetic force, magnetic force, gravitational force etc..	Examples : Frictional forces, Viscous force

4. Explain the characteristics of elastic and inelastic collision.

Elastic Collision	Inelastic Collision
Total **momentum** is **conserved**	Total **momentum** is **conserved**
Total **kinetic energy** is **conserved**	Total **kinetic energy** is **not conserved**
Forces involved are **conservative forces**	Forces involved are **non-conservative Forces**
Mechanical energy is **not dissipated**	**Mechanical energy** is **dissipated** into heat, light, sound etc.

5. Define the following
a) Coefficient of restitution b) Power c) Law of conservation of energy
d) Loss of kinetic energy in inelastic collision.

a) Coefficient of restitution:

It is defined as the ratio of velocity of separation (relative velocity) after collision to the velocity of approach (relative velocity) before collision,

i.e.,$e = \frac{\text{Velocity of separation (after collision)}}{\text{Velocity of approach (before collision)}} ; \frac{(v_2 - v_1)}{(u_1 - u_2)}$

b) Power:

The rate of work done or energy delivered.

Power (P) = $\frac{\text{Workdone (W)}}{\text{Time taken (t)}}$

c) Law of conservation of energy:

Energy can neither be created nor destroyed. It may be **transformed**from **one form to another but the total energy** of an isolated system remains constant.

d) Loss of kinetic energy in inelastic collision:

In perfectly inelastic collision, the loss in kinetic energy during collision is transformed to another form of energy like sound, thermal, heat, light etc. Let KE_ibe the total kinetic energy before collision and KE_f be the total kinetic energy aftercollision. Total kinetic energy before collision,

$KE_i = \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$ ----------(1)

Total kinetic energy after collision, $KE_f = \frac{1}{2}(m_1 + m_2)v^2$ ----------- (2)

Then the loss of kinetic energy is Loss of KE, $\Delta Q = KE_f - KE_i$

$= \frac{1}{2}(m_1 + m_2)v^2 - \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$ -------- (3)

Substituting equation $v = \frac{m_1 u_1 + m_2 u_2}{(m_1 + m_2)}$ in equation (3), and on simplifying (expand v by using the algebra $(a+b)^2 = a^2 + b^2 + 2ab$, we get

Loss of KE, $\Delta Q = \frac{1}{2}\left(\frac{m_1 m_2}{m_1 + m_2}\right)(u_1 - u_2)^2$

6. Define unit of power:

One watt is defined as **the power when one joule of work is done in one second. 1W = 1Js^{-1}**

7. Explain Work done.

i) Work is said to be done by the **force when the force applied on a bodydisplaces it.**

ii) **work done is a scalar quantity.** It has only magnitude and no direction.

iii) In SI system, **unit of work done is N m (or) joule (J).** Its dimensional formula is **ML^2T^{-2}**

8. When does work done becomes zero?

i) When the force is zero (F = 0).

ii) When the displacement is zero (dr = 0).

iii) When the force and displacement are perpendicular (θ = 90^0) to each other.

9. Define Work done by a constant force

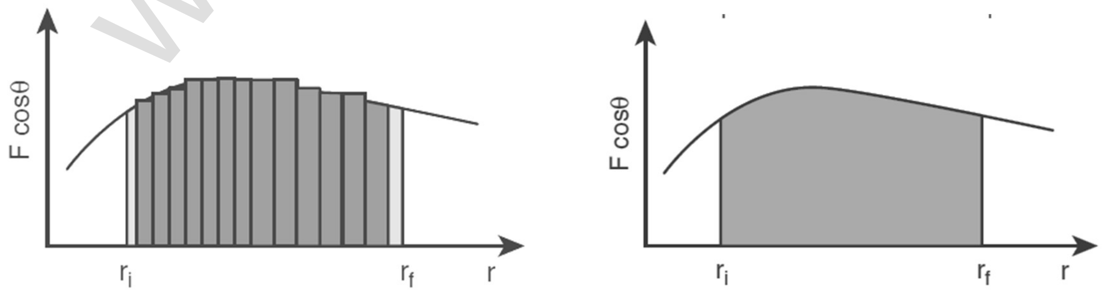
When a constant force F acts on a body, the small work done (dW) by the force inproducing a small displacement dr is given by the relation, dW= (F cosθ) dr

10. Define Work done by a variable force

When the component of a variable force F acts on a body, the small work done (dW) bythe force in producing a small displacement dr is given by the relation dW= (F cosθ) dr

[F cos θ is the component of the variable force F]

11. Give the graphical representations of the work done by a variable force.



12. Define Energy, Kinetic energy and Potential Energy

Energy: The **capacity to do work**, Dimension:ML^2T^{-2}, SI Unit: Nm or joule

Kinetic energy: The **energy possessed by a body due to its motion.**

Dimension:ML^2T^{-2}, SI Unit: Nm or joule

Potential Energy: The **energy possessed by the body by virtue of its position**

Dimension:ML^2T^{-2}, SI Unit: Nm or joule

13. Write the significance of kinetic energy in the work – kinetic energy theorem.

1. If the work done by **the force on the body is positive** then its **kinetic energy increases.**
2. If the work done by **the force on the body is negative** then its **kinetic energy decreases.**
3. If there is **no work done by the force** on the body then there is **no change** in its kinetic energy

14. Define Work – kinetic energy theorem.

The work done by the **force on the body changes the kinetic energy** of the body. This is called work-kinetic energy theorem.

15. Define elastic potential energy

The potential energy possessed by a spring due to a deforming force which stretches or**compresses the spring is termed** as elastic potential energy.

16. Define Conservative force

A force is said to be a conservative force if the work done by or against **the force in moving the body depends only on the initial and final positions of the body** and not on the nature of the path followed between the initial and final positions.

17. Define Non-conservative force

A force is said to be non-conservative if the work done by or against **the force in moving a body depends upon the path between the initial and finalpositions.** This means that the value of work done is different in different paths.

18. Define Average Power

The average power (P_{av}) is defined as **the ratio of the total work done to the total time taken.** $P_{av} = \frac{\text{Total work done}}{\text{Total time taken}}$

19. Define Instantaneous power

The instantaneous power (P_{inst}) is defined as **the power delivered at an instant** (as timeinterval approaches zero), $P_{inst} = \frac{dw}{dt}$

20. What is meant by collision?

Collision is a **common phenomenon that happens around us every now**and then. For example, **carom, billiards, marbles, etc.. Collisions can happen between two bodies with or without physical contacts.**

21. What is Elastic Collision?

In a collision, **the total initial kinetic energy of the bodies (before collision) is equal tothe total final kinetic energy of the bodies** (after collision) then, it is called as elastic collision.

i.e., **Total kinetic energy before collision = Total kinetic energy after collision**

22. What is Inelastic Collision?

In a collision, **the total initial kinetic energy of the bodies** (before collision) is **not equal to the total final kinetic energy of the bodies** (after collision) then, it is called as inelastic collision. i.e., **Total kinetic energy before collision ≠ Total kinetic energy after collision**

CONCEPTUAL QUESTIONS

23. Which is conserved in inelastic collision? Total energy or Kinetic energy?

The total energy of the system is conserved in inelastic collision. The kinetic energy is not conserved because it is carried by the moving objects or it is transformed into other form of energy.

24. Is there any net work done by external forces on a car moving with a constantspeed along a straight road?

At a constant speed, a car can be carrying around corners or driving in a curved path. That would cause all sorts of acceleration. But an object travelling at a constant speed, in a straight line and by Newton's first law of motion. If has no external force acting on it.

25. A charged particle moves towards another charged particle. Under what conditions the total momentum and the total energy of the system conserved?

1. If positive and negative charged particles move towards another
2. After collision the charged particles should stick together permanent.
3. So, they should move with common velocity under this situation the total momentum and total energy of the system is conserved.

FIVE MARKS QUESTION WITH ANSWER QUESTIONS

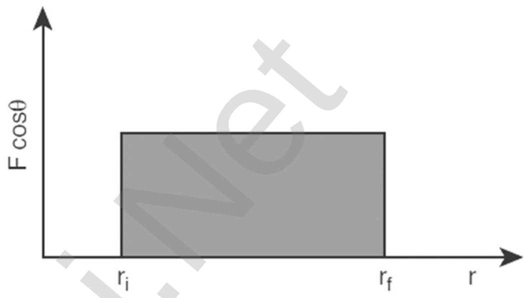
26. Explain with graphs the difference between work done by a constant force andby avariable force.

i) When a constant force F acts on a body, the smallwork done (dW) by the force in producing a small displacement dr is given by the relation, dW= (F cosθ) dr

ii) The total work done in producing a displacement frominitial position r_i to final position r_f is, $W = \int_{r_i}^{r_f} dW$;

$W = \int_{r_i}^{r_f} (F \cos\theta) dr = (F \cos\theta)$;

$\int_{r_i}^{r_f} dr = (F \cos\theta)(r_f - r_i)$



iii) The graphical representation of the work done by a constant force. The area under the graph shows the work done by the constant force.

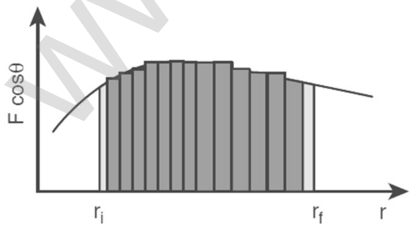
Work done by a variable force:

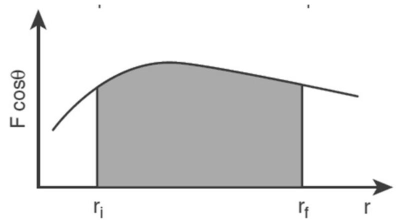
i) When the component of a variable force F acts on a body, the small work done (dW) bythe force in producing a small displacement dr is given by the relation dW = (Fcos θ)dr

[F cos θ is the component of the variable force F] where, F and θ are variables.

ii) The total work done for a displacement from initial position r_i to final position r_f is givenby the relation, $W = \int_{r_i}^{r_f} dW$; $= \int_{r_i}^{r_f} (F \cos\theta) dr$

iii) A graphical representation of the work done by a variable force. The area under the graph is the work done by the variable force.





27. State and explain work energy principle. Mention any three examples for it.

1) It states that work done by the force acting on a body is equal to the change produced inthe kinetic energy of the body.
2) Consider a body of mass m at rest on a frictionless horizontal surface.
3) The work (W) done by the constant force (F) for a displacement (s) in the samedirection is, W = Fs ------------ (1)

The constant force is given by the equation, F = ma --------- (2)

The **third equation of motion** can be written as, $v^2 = u^2 + 2as$

$a = \frac{v^2-u^2}{2s}$ ----------------- (3)

Substituting for a in equation (2), $F = m\left(\frac{v^2-u^2}{2s}\right)$ ------------ (4)

Substituting equation (4) in (1), $W = m\left(\frac{v^2}{2s}s\right) - m\left(\frac{u^2}{2s}s\right)$

$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ ------------------- (5)

The expression for kinetic energy:

i) The term ½ (mv^2) in the above equation is the kinetic energy of the body of mass (m) moving with velocity (v). $KE = \frac{1}{2}mv^2$---------------- (6)

ii) Kinetic energy of the body is always positive.

From equations (5) and (6)

$\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ --------------(7) thus, W = ΔKE

iii) The expression on the right-hand side (RHS) of equation (7) is the change inkinetic energy (ΔKE) of the body.

iv) This implies that **the work done by the force on the body changes the kinetic energyof the body**. This is called work-kinetic energy theorem.

significance of kinetic energy in the work – kinetic energy theorem:

1. If the work done by **the force on the body is positive** then its **kinetic energy increases.**
2. If the work done by **the force on the body is negative** then its **kinetic energy decreases.**
3. If there is **no work done by the force** on the body then there is **no change** in its kinetic energy

28. Arrive at an expression for power and velocity. Give some examples for the same.

i) The work done by a force $\vec{F}$for a displacement $d\vec{r}$ is $W = \int \vec{F}.d\vec{r}$ --- (1)

Left hand side of the equation (1) can be written as

$W = \int dW = \int \frac{dW}{dt}dt$ (multiplied and divided by dt) ------------- (2)

ii) Since, velocity $\vec{v} = \frac{d\vec{r}}{dt}$; $d\vec{r} = \vec{v}\,dt$. Right hand side of the equation (1) can bewritten as $\int \vec{F}.d\vec{r} = \int \left(\vec{F}.\frac{d\vec{r}}{dt}\right)dt = \int (\vec{F}.\vec{v})dt \quad \left[\vec{v} = \frac{d\vec{r}}{dt}\right]$ ---- (3)

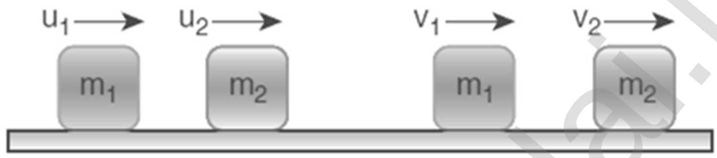
Substituting equation (2) and equation (3) in equation (1), we get

$\int \frac{dW}{dt}dt = \int(\vec{F}.\vec{v})dt$; $\int\left(\frac{dW}{dt} - \vec{F}.\vec{v}\right)dt = 0$

iii) This relation is true for any arbitrary value of dt. This implies that the term within thebracket must be equal to zero, i.e.,

$\frac{dW}{dt} = \vec{F}.\vec{v} = 0$ (or) $\frac{dW}{dt} = \vec{F}.\vec{v}$

29. Arrive at an expression for elastic collision in one dimension and discuss various cases.



Consider two elastic bodies of masses m_1 and m_2 moving in a straight line (along positivex direction) on a frictionless horizontal surface.

i) In order to have collision, we assume that the mass m_1 moves faster than mass m_2 i.e.,$\mu_1>\mu_2$ For elastic collision, the total linear momentum and kinetic energies of thetwo bodies before and after collision must remain the same.

From the law of conservation of linear momentum,

Total momentum before collision (*pi*) = Total momentum after collision (*pf*)

$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$ ———— (1) (or)

$\mathbf{m_1(u_1 - v_1) = m_2(v_2 - u_2)}$ ----------------- (2)

For elastic collision,

Total kinetic energy before collision KE_i= Total kinetic energy after collision KE_f

$\mathbf{\frac{1}{2} m_1u_1^2 + \frac{1}{2} m_2u_2^2 = \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2}$---------------- (3)

After simplifying and rearranging the terms,

$m_1(u_1^2 - v_1^2) = m_2(v_2^2 - u_2^2)$

Using the formula, $a^2 - b^2 = (a + b)(a - b)$, we can rewrite the above equation as

$\mathbf{m_1(u_1 + v_1)(u_1 - v_1) = m_2(v_2 + u_2)(v_2 - u_2)}$--------- (4)

Dividing equation (4) by (2) gives,

$$\frac{m_1(u_1+v_1)(u_1-v_1)}{m_1(u_1-v_1)} = \frac{m_2(v_2+u_2)(v_2-u_2)}{m_2(v_2-u_2)}$$

$\mathbf{u_1 + v_1 = v_2 + u_2}$, Re-arranging $\mathbf{u_1 - u_2 = v_2 - v_1}$ ------------- (5)

Equation (5) can be rewritten as $(u_1 - u_2 = -(v_1 - v_2)$

ii) This means that for any elastic head on collision, the relative speed of the two elastic bodies after the collision has the same magnitude as before collision but in opposite direction. Further note that this result is independent of mass.

Rewriting the above equation for v_1 and v_2 ,

$v_1 = v_2 + u_2 - u_1$ ------------ (6) or $\mathbf{v_2 = u_1 + v_1 - u_2}$ ---------------(7)

To find the final velocities v_1 and v_2:

Substituting equation (7) in equation (2) gives the velocity of m_1 as

$m_1(u_1 - v_1) = m_2 (u_1 + v_1 - u_2 - u_2)$

$m_1(u_1 - v_1) = m_2 (u_1 + v_1 - 2u_2)$

$m_1u_1 - m_1v_1 = m_2u_1 + m_2v_1 - 2m_2u_2$

$m_1u_1 - m_2u_1 + 2m_2u_2 = m_1v_1 + m_2v_1$

$(m_1 - m_2) u_1 + 2m_2u_2 = (m_1 + m_2)v_1$ (or)

$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \left(\frac{2m_2}{m_1 + m_2}\right)u_2$ ---------(8)

Similarly, by substituting (6) in equation (2) or substituting equation (8) in equation (7), we get the final velocity of m_2 as

$v_2 = \left(\frac{2m_1}{m_1 + m_2}\right)u_1 + \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_2$ ---------- (9)

Case 1: When bodies has the same mass i.e., $m_1 = m_2$,

Equation (8) $\dashrightarrow$ $v_1 = (0)u_1 + \left(\frac{2m_2}{2m_2}\right)u_2$; $v_1 = u_2$ ------------ (10)

Equation (9) $\dashrightarrow$ $v_2 = \left(\frac{2m_1}{2m_1}\right)u_1 + (0)\,u_2$; $v_2 = u_1$ ------------ (11)

The equations (10) and (11) show that in **one dimensional elastic collision, when two bodies of equal mass collide after the collision their velocities are exchanged.**

Case 2: When bodies have the same mass i.e., $m_1 = m_2$, and second body (usuallycalled target) is at rest ($u_2 = 0$),

By substituting $m_1 = m_2$ and $u_2 = 0$ in equations (8) and equations (9) we get,

From equation (8) $\dashrightarrow$ $v_1 = 0$ -------------(12)

From equation (9) $\dashrightarrow$ $v_2 = u_1$ ------------- (13)

Equations (12) and (13) show that when the first body comes to rest the second body moves with the initial velocity of the first body.

Case 3: The first body is very much lighter than the second body $\left(m_1 \ll m_2, \frac{m_1}{m_2} \ll 1\right)$ then the ratio $\frac{m_1}{m_2} \approx 0$. And also if the target is at rest (u_2=0)

Dividing numerator and denominator of equation (8) by m_2, we get

$v_1 = \left(\frac{\frac{m_1}{m_2} - 1}{\frac{m_1}{m_2} + 1}\right)u_1 + \left(\frac{2}{\frac{m_1}{m_2} + 1}\right)(0)$; $v_1 = \left(\frac{0-1}{0+1}\right)u_1$; $v_1 = -u_1$ ---------(14)

Similarly, Dividing numerator and denominator of equation (9) by m_2, we get

$v_2 = \left(\frac{2\frac{m_1}{m_2}}{\frac{m_1}{m_2} + 1}\right)u_1 + \left(\frac{1 - \frac{m_1}{m_2}}{\frac{m_1}{m_2} + 1}\right)(0)$; $v_2 = (o)u_1 + \left(\frac{1 - \frac{m_1}{m_2}}{\frac{m_1}{m_2} + 1}\right)(0)$; $v_2 = 0$ ---- (15)

The equation (14) implies that **the first body which is lighter returns back rebounds) in the opposite direction with the same initial velocity as it has a negative sign.**

The equation (15) implies that **the second body which is heavier in mass continuesto remain at rest even after collision.** For example, if a ball is thrown at a fixed wall, the ball will bounce back from the wall with the same velocity with which it was thrown but in opposite direction.

Case 4: The second body is very much lighter than the first body $\left(m_2 \ll m_1, \frac{m_2}{m_1} \ll 1\right)$then the ratio $\frac{m_2}{m_1} \approx 0$. And also if the target is at rest (u_2=0)

Dividing numerator and denominator of equation (8) by m_1, we get

$$v_1 = \left(\frac{1-\frac{m_2}{m_1}}{1+\frac{m_2}{m_1}}\right)u_1 + \left(\frac{2\frac{m_2}{m_1}}{1+\frac{m_2}{m_1}}\right)(0)\ ;$$

$$v_1 = \left(\frac{0-1}{0+1}\right)u_1 + \left(\frac{0}{1+0}\right)(0)\ ; \quad v_1 = u_1 \text{ -----------------(16)}$$

Similarly, Dividing numerator and denominator of equation (14) by m_1, we get

$$v_1 = \left(\frac{2}{1+\frac{m_2}{m_1}}\right)u_1 + \left(\frac{\frac{m_2}{m_1}-1}{1+\frac{m_2}{m_1}}\right)(0)\ ; \quad v_2 = \left(\frac{2}{1+0}\right)u_1;\ v_2 = 2u_1 \text{ ------(17)}$$

The equation (16) implies **that the first body which is heavier continues to move with the same initial velocity.**

The equation (17) suggests that **the second body which is lighter will move with twice the initial velocity of the first body.**

It means that **the lighter body is thrown away from the point of collision.**

30. What is inelastic collision? In which way it is different from elastic collision. Mention few examples in day to day life for inelastic collision.

1. In a collision, the total **initial kinetic energy of the bodies**(before collision) is **not equal to the total final kinetic energy of the bodies**(after collision) then, it is called as inelasticcollision. i.e.,
2. Momentum is conserved. **Kinetic energy is not conserved**in elastic collision. Mechanical energy is dissipated into heat, light, sound etc. When a light body collides against any massive body at rest it sticks to it.
3. **Total kinetic energy before collision ≠ Total kinetic energy after collision**

$$\begin{bmatrix}\text{Total kinetic energy}\\ \text{after collision}\end{bmatrix} - \begin{bmatrix}\text{Total kinetic energy}\\ \text{before collision}\end{bmatrix} = \begin{bmatrix}\text{Loss in energy during}\\ \text{collision}\end{bmatrix}$$

4. Even though **kinetic energy is not conserved**but the total energy is conserved.
5. Loss in kinetic energy during collision is transformed to another form of energy like sound, thermal, etc. If the **two colliding bodies stick together after collision such collisions**are known as completely inelastic collision or perfectly inelastic collision.
   For example, **when a clay putty is thrown on a moving vehicle**, the clay putty or (**Bubblegum**) sticks to the moving vehicle and they move together with the same velocity.

31. Deduce the relation between momentum and kinetic energy.

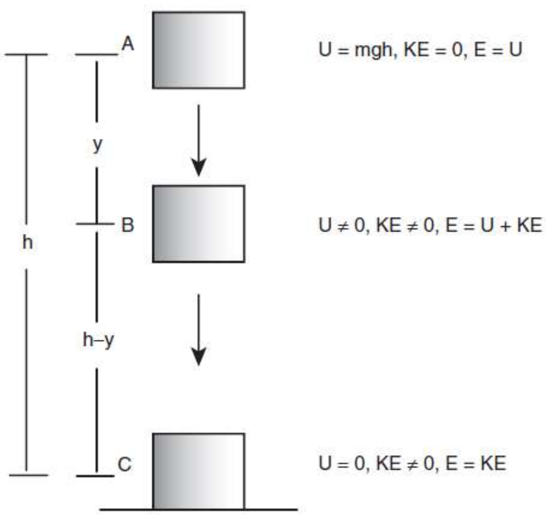
i) Consider an object of mass m moving with a velocity $\vec{v}$. Then its linear momentum is $\vec{p}$ = m$\vec{v}$ and its kinetic energy, KE = ½ mv²
KE = ½ mv²; = ½ m($\vec{v}.\vec{v}$) --------(1)

ii) Multiplying both the numerator and denominator of equation (1) by mass, mKE = $\frac{1}{2}\frac{m^2(\vec{v}.\vec{v})}{m}$;
= $\frac{1}{2}\frac{(m\vec{v}).(m\vec{v})}{m}$ [$\vec{p}$ = m$\vec{v}$]; = $\frac{1}{2}\frac{(\vec{p}).(\vec{p})}{m}$
= $\frac{\vec{p}^2}{2m}$; KE = $\frac{p^2}{2m}$

iii) Where $|\vec{p}|$is the magnitude of the momentum. The magnitude of the linear momentumcan be obtained by $|\vec{p}|$ = p = $\sqrt{2m(KE)}$

iv) Note that if kinetic energy and mass are given, only the magnitude of the momentumcan be calculated but not the direction of momentum. It is because the kinetic energyand mass are scalars.

32. State and prove the law of conservation of energy.



i) When an **object is thrown upwards its kineticenergy goes on decreasing**and consequently its **potential energy keeps increasing** (neglecting air resistance).

ii) When it **reaches the highest point its energy is completely potential**. Similarly, when the object falls back from a **height its kinetic energy increases whereas its potential energydecreases**.

iii) When **it touches the ground its energy is completely kinetic**. At the intermediate points the energy is both kinetic and potential.

iv) When **the body reaches the ground, the kinetic energy is completely dissipated into some other form of energy like sound**, heat, light and deformation of the body etc.

v) In this example the energy transformation takes place at every point. The sum of kinetic energy and potential energy i.e., **the total mechanical energy always remains constant**, implying that the total energy is conserved. This is stated as the law of conservation of energy.

vi) The law of conservation of energy states that **energy can neither be created nordestroyed. It may be transformed from one form to another but the total energy of an isolated system remains constant.**

vii) The figure illustrates that, if an object starts from rest at height h, the total energy is purely potential energy (U=mgh) and the kinetic energy (KE) is zero at h. **When theobject falls at some distance y, the potential energy and the kinetic energy are not zero**whereas, the total energy remains same as measured at height h. When the object is about to touch the ground, the potential energy is zero and total energy is purely kinetic.

33. Derive an expression for the velocity of the body moving in a vertical circle andalso find a tension at the bottom and the top of the circle.

1) A body of mass (m) attached to one end of a mass less and inextensible string executes circular motion in a vertical plane with the other end of the string fixed.

The length of the string becomes the radius ($\vec{r}$) of the circular path.

2) The motion of the body by taking the free body diagram (FBD) at a position where theposition vector ($\vec{r}$) makes an angle θ with the

vertically downward direction and the instantaneousvelocity.

3) There are two forces acting on the mass.

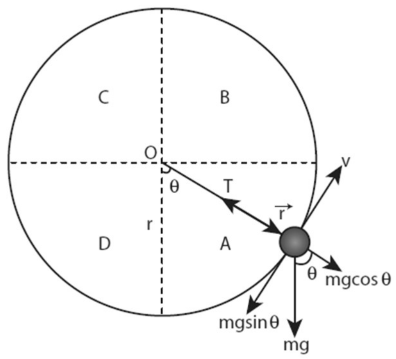
1. **Gravitational force which acts downward**
2. **Tension along the string.**

Applying Newton's second law on the mass,

In the tangential direction, mg sin θ = ma_t ;

mg sin θ = $-\, m\left(\frac{dv}{dt}\right)$

where , $a_t = -\left(\frac{dv}{dt}\right)$ is tangential retardation in



the radial direction, T – mg cos θ = m a_r ;

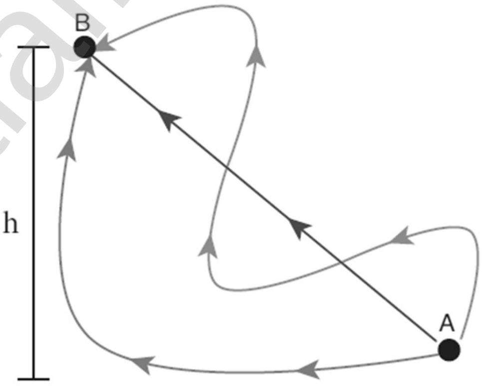
T – mg cos θ = $\frac{mv^2}{r}$

where , $a_r = \frac{v^2}{r}$ is the centripetal acceleration.

34. What is conservative force? State how it is determined from potential energy?

i) A force is said to be a conservative force if the work done by or against the force in moving the body depends only on the initial and final positions of the body and not on the nature of the path followed between the initial and final positions.

ii) Consider an object at point A on the Earth. It can be taken to another point B at a height habove the surface of the Earth by three paths.



iii) Whatever may be the path, the work done against the gravitational force is the same as long as the initial and final positions are the same.

iv) This is the reason why gravitational force is a conservative force.

v) Conservative force is equal to the negative gradient of the potential energy. In one dimensional case, $F_x = -\frac{dU}{dx}$

vi) Examples for conservative forces are elastic spring force, electrostatic force, magnetic force, gravitational force, etc.

35. Derive an expression for the potential energy of a body near the surface of the Earth.

1) The gravitational potential energy (U) at some height is equal to the amount of work required to take the object from ground to that height with constant velocity.

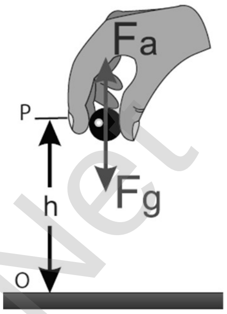
2) Consider a body of mass being moved from ground to the height h against the gravitational force.

3) The gravitational force $\vec{F}_g$acting on the body is,$\vec{F}_g$ = – mg$\hat{j}$ (as the force is in y direction; unit vector is used). Here, negative sign implies that the force is acting vertically downwards. In order to move the body without acceleration (or withconstant velocity), an external applied force $\vec{F}_a$equal in magnitudebut opposite to that of gravitational force $\vec{F}_g$has to be applied on the body i.e.,$\vec{F}_a - \vec{F}_g$This implies that $\vec{F}_a$ = – mg$\hat{j}$

4) The positive sign implies that the applied force is in vertically upward direction. Hence, when the body is lifted up its velocity remains unchanged and thus its kinetic energy also remains constant.

5) The gravitational potential energy (U) at some height h is equal to the amount of work required to take the object from the ground to that height h.U = $\int \vec{F_a}.d\vec{r}$

= $\int_0^h |\vec{F_a}|\,|d\vec{r}|\cos\theta$

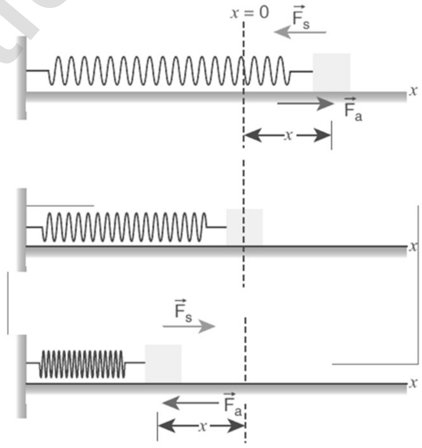


6) Since the displacement and the applied force are in the same upward direction, the anglebetween them, $\theta = 0$.

Hence Cos 0 = 1 and $|\vec{F_a}|$ = mg and $|d\vec{r}|$ = dr

U = mg $\int_0^h dr$; U = mg $[r]_0^h$; U = mgh

36. What is meant by elastic potential energy? Derive an expression for the elasticpotential energy of the spring?



1) The potential energy possessed by a spring due toa **deforming force which stretches orcompresses the spring is termed as elastic potential energy**. The work done by the applied force against the restoring force of the spring is stored as the elastic potential energy in the spring.

2) Consider a spring-mass system. Let us assume a mass, lying on a smooth m horizontal table. Here, x=0 is the equilibrium position. **One end of the spring is attached to a rigid wall** and the other end to the mass.

3) As long as the **spring remains in equilibrium position**, its potential energy is zero. Now an external force $\vec{F}_a$ is applied so that it is stretched by a distance (x) in the direction of the force.

4) There is a restoring force called spring force $\vec{F}_s$ developed in the spring which tries to bring the mass back to its original position. This **applied force and the spring force are equal in magnitude but opposite in direction**i.e., $\vec{F}_a = -\vec{F}_s$. According Hooke's law,

the restoring force developed in the spring is $\vec{F}_s = -k\vec{x}$

5) The negative sign in the above expression implies that the **spring force is always opposite to that of displacement**$\vec{x}$and k is the force constant. Therefore, applied force is $\vec{F}_a = +k\vec{x}$. **The positive sign**implies that the **applied force is in the direction of displacement $\vec{x}$. The spring force** is an example of variable force as it depends on thedisplacement $\vec{x}$.

Let the spring be stretched to a small distance $d\vec{x}$. The work done by theapplied force on the spring to stretch it by a displacement $\vec{x}$is stored as elastic potential energy U = $\int \vec{F}_a . d\vec{r}$

= $\int_0^x |\vec{F}_a| \, |d\vec{r}| \cos\theta$; = $\int_0^x F_a dx \cos\theta$

6) The applied force $\vec{F}_a$ and the displacement $d\vec{r}$(i.e., here dx) are in the same direction. As, the initial position is taken as the equilibrium position or mean position, x=0 is the lowerlimit of integration.

U = $\int_0^x kxdx$;

U = k $\left[\frac{x^2}{2}\right]_0^x$; U = ½ kx^2 ---------------(1)

7) If the initial position is not zero, and if the mass is changed from position x_i to x_f, thenthe elastic potential energy is

U = ½ k $(x_f^2 - x_i^2)$ -------------(2)

From equations (1) and (2), we observe that the potential energy of the stretched spring depends on the force constant kand elongation or compression x.

UNIT – V (MOTION OF SYSTEM OF PARTICLES AND RIGID BODIES)

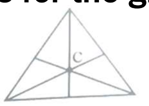
TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. Define center of mass.

A point where the entire mass of the body appears to be concentrated.

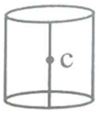
2. Find out the center of mass for the given geometrical structures.

a) Equilateral triangle
Lies in center

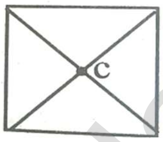


b) Cylinder

Lies on its central axis



c) Square
Lies at their diagonals meet



3. Define torque and mention its unit.

Torque is defined as the **moment of the external applied force about a point or axisof rotation**. The expression for torque is, $\vec{\tau} = \vec{r} x \vec{F}$. Its unit is Nm.

4. What are the conditions in which force cannot produce torque?

The torque is zero when $\vec{r}$ and $\vec{F}$are parallel or anti-parallel. If parallel, then θ=0 and sin 0 =0. If **anti-parallel, thenθ=180 and sin 180=0**. Hence, τ = 0. The torque is zero if the force acts at the reference point. i.e. as $\vec{r}$=0, τ = 0.

5. What is the relation between torque and angular momentum?

An external torque on a rigid body fixed to an axis produces **rate ofchange of angular momentum** in the body about that axis. $T = \frac{dL}{dt}$

6. What is equilibrium?

i) A rigid body is said to be in **mechanical equilibrium when both its linear momentumand angular momentum remain constant.**

ii) When all the forces act upon the object are balanced, then the object is said to be an equilibrium.

7. Give any two examples of torque in day-to-day life.

i) **Opening and closing of a door** about the hinges

ii) **Turning of a nut using a wrench**

iii) **Opening a bottle cap** (or) water top

8. How do you distinguish between stable and unstable equilibrium?

Stable equilibrium	Unstable equilibrium
Linear momentum and angular **momentum are zero.**	Linear momentum and angular **momentum are zero.**
The **body tries to come back to equilibrium**if slightly disturbed and released.	The **body cannot come back to equilibrium**if slightly disturbed and released.
The **center of mass of the body shifts slightly higher**if disturbed from equilibrium.	The **center of mass of the body shifts slightly lower**if disturbed from equilibrium.
Potential energy of the body is minimumand it **increases** if disturbed.	**Potential energy of the body is not minimum** and it **decreases** if disturbed

9. Define couple.

Pair of forces which are equal in magnitude but **opposite in direction**and separated by a **perpendicular distance**so that **their lines of action do not coincide** that causes a turning effect is called a couple

10. State principle of moments.

When an object is in equilibrium the sum of the anticlockwise moments about a turning point must be equal to the sum of the clockwise moments.

11. Define center of gravity.

The point at which the entire weight of the body acts irrespective of the position and orientation of the body.

12. Mention any two physical significance of moment of inertia.

i) For rotational motion, moment of inertia is a measure of rotational inertia.

ii) The moment of inertia of a body is not an invariable quantity. It depends not onlyon the mass of the body, but also on the way the mass is distributed around the axis of rotation.

13. What is radius of gyration?

The radius of gyration of an object is **the perpendicular distance from the axis ofrotation to an equivalent point mass**, which would have the same mass as well as the same moment of inertia of the object.

14. State conservation of angular momentum.

When no external torque acts on the body, the net angular momentum of a rotatingrigid body remains constant. This is known as law of conservation of angular momentum.

15. What are the rotational equivalents for the physical quantities,
(i) mass and (ii) force?

i) For mass : Moment of inertia , $I = mr^2$ ii) For Force : Torque $\tau = I\,\alpha$

16. What is the condition for pure rolling?

(i) The combination of translational motion and rotational motion about the center of mass. (or)

(ii) The momentary rotational motion about the point of contact.

17. What is the difference between sliding and slipping?

Sliding is the case when $v_{CM} > R\omega$(or $v_{TRANS} > v_{ROT}$). The translation is morethan the rotation.

Slippingis the case when $v_{CM} < R\omega$(or $v_{TRANS} < v_{ROT}$). The rotation is more than the translation.

18. What is rigid body?

A rigid body is the one which maintains its definite and fixed shape even when anexternal force acts on it.

19. Define Point Mass

A point mass is a hypothetical point particle which has nonzero mass and no size or shape.

20. State the rule which is used to find the direction of torque.

The direction of torque is found using right hand rule. This rule says that if **fingersof right hand are kept along the position vector** with palm facing the **direction of the force and when the fingers are curled** the thumb points to the direction of the torque.

21. When will a body have a precession?

The torque about the axis will rotate the object about it and **the torque perpendicularto the axis will turn the axis of rotation**. When both exist simultaneously on a rigidbody, the body will have a precession.

22. State Parallel axis theorem

The moment of inertia of a body about any axis is equal **to the sum of its moment of inertia** about a parallel axis through its center of mass and the product of the mass of the body and the **square of the perpendicular distance between the two axes. $I = I_C + Md^2$**

23. State Perpendicular axis theorem.

The moment of inertia of a plane laminar body about an axis perpendicular to its **planeis equal to the sum of moments of inertia** about **two perpendicular axes lying in the plane of the body** such that all the three axes are mutually perpendicular and have a common point. $\mathbf{I_Z = I_X + I_Y}$

24. Give the scalar relation between torque and angular acceleration.

The scalar relation between the torque and angular acceleration is $\tau = I\alpha$; I = Moment of inertia of the rigid body. The torque in rotational motion is equivalent to the force in linear motion.

25. Give the relation between rotational kinetic energy and angular momentum.

The angular momentum of a rigid body is, $L = I\omega$

The rotational kinetic energy of the rigid body is, $KE = \frac{1}{2} I\omega^2$

By multiplying the numerator and denominator of the above equation with I,

we get a relation between L and KE as, $KE = \frac{1}{2}\frac{I^2\omega^2}{I}$; $= \frac{1}{2}\frac{(I\omega)^2}{I}$; $KE = \frac{L^2}{2I}$

26. Obtain an expression for the power delivered by torque.

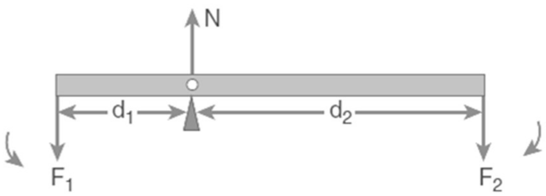
Power delivered is **the work done per unit time**. If we differentiate the expression for work done with respect to time, we get the instantaneous power (P).$P = \frac{dW}{dt} = \tau\frac{d\theta}{dt}$ ∵ ($dw = \tau\, d\theta$; $P = \tau\omega$

27. What are the conditions for neutral equilibrium?

1) Linear momentum and angular momentum are zero.
2) The body remains at the same equilibrium if slightly disturbed and released.
3) The center of mass of the body does not shift higher or lower if disturbed from equilibrium.
4) Potential energy remains same even if disturbed.

28. Explain the principle of moments.

1) Consider a light rod of negligible mass which is pivoted at a point along itslength. Let two parallel forces F_1 and F_2 act at the two ends at distances d_1 and d_2 from the Point of pivot and the normal reaction force N at the point of pivot as shown in Figure.



2) If the rod has to remain stationary in horizontal position, it should be in translational and rotational equilibrium. Then, both the net force and net torque must be zero.

For net force to be zero, $-F_1 + N - F_2 = 0$; $N = F_1 + F_2$

For net torque to be zero, $d_1 F_1 - d_2F_2 = 0$

$d_1 F_1 = d_2F_2$

The above equation represents the **principle of moments.**

29. Write the principles used in beam balance and define Mechanical Advantage.

i) This forms the principle for beam balance used for weighing goods with the condition $d_1 = d_2$; $F_1 = F_2$.

$\frac{F_1}{F_2} = \frac{d_2}{d_1}$

ii) If F_1 is the load and F_2 is our effort, we get advantage when, $d_1 < d_2$. This impliesthat $F_1 > F_2$. Hence, we could lift a large load with small effort. The ratio $\left(\frac{d_2}{d_1}\right)$ is called mechanical advantage of the simple lever. The pivoted point is called fulcrum.

Mechanical Advantage (MA) = $\frac{d_2}{d_1}$

30. Find the expression for radius of gyration.

1) A rotating rigid body with respect to any axis, is considered to be made up of pointmasses $m_1, m_2, m_3, \ldots m_n$ at perpendicular distances (or positions) $r_1, r_2, r_3 \ldots r_n$ respectively

2) The moment of inertia of that object can be written as,

$I = \Sigma m_i r_i^2 = m_1r_1^2 + m_2r_2^2 + m_3r_3^2 + \ldots + m_nr_n^2$

If we take all the n number of individual masses to be equal, $m = m_1 = m_2 = m_3 = \ldots\ldots m_n$ then

$I = mr_1^2 + mr_2^2 + mr_3^2 + \ldots mr_n^2$

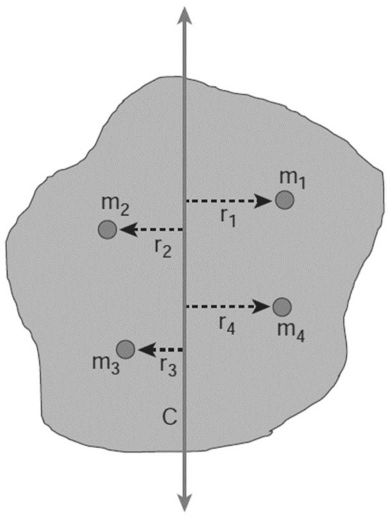
$I = m (r_1^2 + r_2^2 + r_3^2 + \ldots r_n^2)$

$= nm\left(\frac{r_1^2+r_2^2+r_3^2+\cdots+r_n^2}{n}\right)$

$I = MK^2$

where, nm is the total mass M of the body and K is the radius of gyration.

$K = \sqrt{\frac{r_1^2+r_2^2+r_3^2+\cdots+r_n^2}{n}}$



3) The expression for radius of gyration indicates that it is the root mean square (rms) distance of the particles of the body from the axis of rotation.

31. Derive an expression for work done by torque

i) Consider a rigid body rotating about a fixed axis. A point P on the body rotating about an axis perpendicular to the plane of the page. A tangential force F is applied on the body.

ii) It produces a small displacement, ds on the body. The work done (dw) by theforce is, dw = F ds

iii) As the distance ds, the angle of rotation dθ and radius r, are related by the expression, ds = r dθ

The expression for work done now becomes, dw = F ds; dw = F r dθ

iv) The term (Fr) is the torque τ produced by the force on the body.

dw = τdθ This expression gives the work done by the external torque τ, which acts on the bodyrotating about a fixed axis through an angle dθ.

32. Write the comparison of translational and rotational quantities?

S. No.	Translational Motion	Rotational motion about a fixed axis
1	Displacement, x	Angular displacement, θ
2	Time, t	Time, t
3	Velocity, v = $\frac{dx}{dt}$	Angular velocity, ω = $\frac{d\theta}{dt}$
4	Acceleration, a =$\frac{dv}{dt}$	Angular acceleration, α = $\frac{d\omega}{dt}$
5	Mass, m	Moment of inertia, I
6	Force, F = ma	Torque, τ = I α
7	Linear momentum, p = mv	Angular momentum, L = Iω
8	Impulse, F Δt = Δp	Impulse, τ Δ t = ΔL
9	Work done, w = F s	Work done, w = τ θ
10	Kinetic energy, KE = ½ Mv^2	Kinetic energy, KE = ½ I ω^2
11	Power, P = F v	Power, P = τω

CONCEPTUAL QUESTIONS:

33. When a tree is cut, the cut is made on the side facing the direction in whichthe tree is required to fall. Why?

The weight of tree exerts a torque about the point where the cut is made. This cause rotation of the tree about the cut.

34. Why does a porter bend forward while carrying a sack of rice on his back?

Due to the added weight of rice sack, centre of gravity of the combined body weight andthe carrying weight shifted to new position. Once he bends, the centre of gravity realigns as with the body's axis making his body balanced.

35. Why is it much easier to balance a meter scale on your finger tip than balancing on a Match stick?

Meter scale is longer and larger than a match stick. Meter scale's centre of gravity is higher but match stick has centre of gravity much lower as compared to scale. Higher the centre of gravity easier it is to balance.

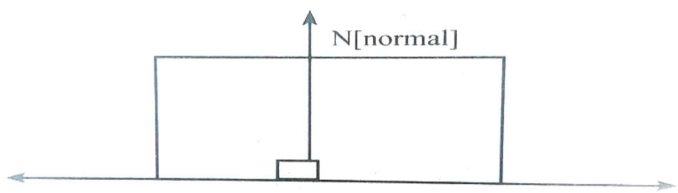
36. Two identical water bottles one empty and the other filled with water are allowed toroll down an inclined plane. Which one of them reaches the bottomfirst? Explain your answer.

1. Bottle filled with water rolls, faster than the empty bottle. Due to M.I. $I = mr^2$
2. When it rolls, **down it possesses translational KE and rotational KE**
3. For the **empty bottle 100% of the mass of the bottle spins** as the bottle rolls.
4. But for full bottle, much of the water in the bottle is efficiency sliding down without spinning.
5. Thus 100% of the mass of the sliding water goes into translational KE and full bottle have a greater speed.

37. A rectangle block rests on a horizontal table. A horizontal force is applied onthe block at a height h above the table to move the block. Does the line ofaction of the normal force N exerted by the table on the block depend on h?

The line of action of normal force N exerted by the table on the block does not depend on h because the reactionary force N exerted by the table which is directed vertically upward and passes through its centre of gravity. Since the block is in equilibrium, N = mg.

Friction is always perpendicular to the normal force N acting between the surface. It acts tangential to the surface of contact.



38. Three identical solid spheres move down through three inclined planes A, Band C all same dimensions. A is without friction, B is undergoing pure rollingand C is rolling with slipping. Compare the kinetic energies E_A, E_B and E_C atthe bottom.

The KE of A without friction $E_A = \frac{1}{2} m (2gh)$

The KE of B undergoes pure rolling $E_B = \frac{1}{2} m\left(\frac{2gh}{1+\frac{K^2}{R^2}}\right)$

The KE of C rolling with slipping EC = ½ m^2gh

39. Give an example to show that the following statement is false. 'any twoforces acting on a body can be combined into single force that would havesame effect'.

Lifting a table from the floor by two persons pushing the car by two persons.

FIVE MARKS QUESTION WITH ANSWER QUESTIONS

40. Explain the types of equilibrium with suitable examples

Translational equilibrium:

1) Linear momentum is constant 2) Net force is zero

Rotational equilibrium:

1) Angular momentum is constant 2) Net torque is zero

Static equilibrium:

1) Linear momentum and angular momentum are zero
2) Net force and net torque are zero

Dynamic equilibrium:

1) Linear momentum and angular momentum are constant
2) Net force and net torque are zero

Stable equilibrium:

1) Linear momentum and angular momentum are zero
2) The **body tries to come back to equilibrium if slightly disturbed** and released
3) The center of mass of the **body shifts slightly higher if disturbed** from equilibrium
4) Potential energy of the **body is minimum and it increases** if disturbed

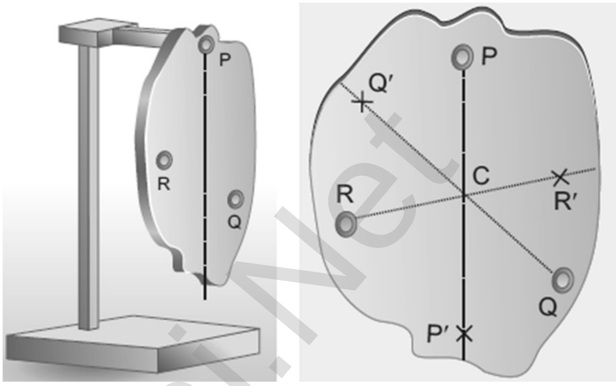
Unstable equilibrium:

1) Linear momentum and angular momentum are zero
2) **The body cannot come back to equilibrium if slightly disturbed** and released
3) The **center of mass of the body shifts slightly lower if disturbed** from equilibrium
4) Potential energy of the body is **not minimum and it decreases** if disturbed

Neutral equilibrium:

1) Linear momentum and angular momentum are zero
2) The **body remains at the same equilibrium if slightly disturbed** and released
3) The **center of mass of the body does not shift higher** or lower if disturbed from equilibrium
4) **Potential energy remains same even if disturbed**

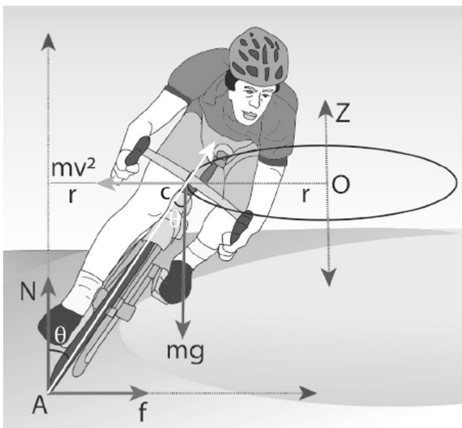
41. Explain the method to find the center of gravity of a irregularly shaped lamina.



1) The center of gravity of a uniform lamina of even an **irregular shape by pivoting it at various points by trial and error.**
2) The lamina remains horizontal **when pivoted at the point where the net gravitational force acts,** which is the center of gravity
3) When a body is supported at the center of gravity, **the sum of the torques acting on all the point masses of the rigid body becomes zero.** Moreover, the weight is compensated by the normal reaction force exerted by the pivot.
4) The body is in static equilibrium and hence it remains horizontal.
5) There is also another way to determine the center of gravity of an **irregular lamina.**
If we suspend the lamina from different points like P, Q, R, the vertical **lines PP', QQ', RR' all pass through the center of gravity.**
6) Here, reaction force acting at the point of suspension and the gravitational force acting at the center of gravity cancel each other and the torques caused by them also cancel each other.

42. Explain why a cyclist bends while negotiating a curve road? Arrive at theexpression for angle of bending for a given velocity.

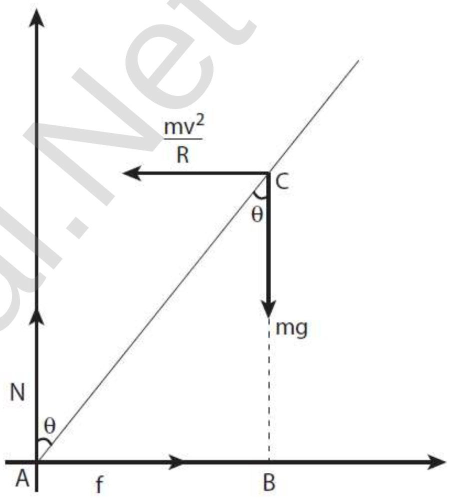
i) Let us consider a cyclist negotiating a circular level road (not banked) of radius r with a speed v.



ii) The cycle and the cyclist are considered as one system with mass m. **The center gravity of the system is C and it goes in a circle of radius r with center at O.**
iii) Let us choose the line OC as X-axis and the vertical line through O as Z-axis as shown in Figure
iv) The system as a frame is rotating about Z-axis. **The system is at rest in this rotating frame. To solve problems in rotating frame of reference,** we have to apply a centrifugal force (pseudo force) on the system which will be $\frac{mv^2}{r}$.This force will act through the center of gravity.

v) The **forces acting on the system are, (i) gravitational force (mg), (ii) normal force (N), (iii) frictional force (f) and (iv) centrifugal force** $\left(\frac{mv^2}{r}\right)$

vi) As the system is in equilibrium in the rotational frame of reference, the net external force and net external torque must be zero. Let us consider all torques about the point A in Figure



vii) For **rotational equilibrium, $\vec{\tau}_{net}$ = 0**. The torque due to the gravitational force about point A is (mgAB) which causes a **clockwise turn that is taken as negative.** The torque due to the centripetal force is$\left(\frac{mv^2}{r}BC\right)$which causes an anticlockwise turn that is taken as positive.

$- mgAB + \frac{mv^2}{r}BC = 0; mg\,AB = \frac{mv^2}{r}BC$

From ΔABC,

AB = ACsinθ and BC = ACcosθ;

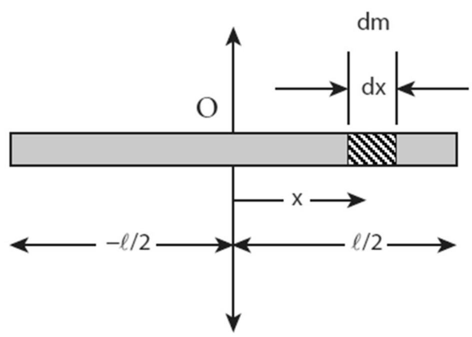
$mg\,AC\sin\theta = \frac{mv^2}{r}AC\cos\theta; \tan\theta = \frac{v^2}{rg}$

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

viii) While negotiating a circular level road of radius r at velocity v, a cyclist has to bend by an angle θ from vertical given by the above expression to stay in equilibrium (i.e. to avoid a fall).

43. Derive the expression for moment of inertia of a rod about its center and perpendicular to the rod.

1) Let us consider a uniform rod of mass (M) and length (*l*) as shown in Figure. Letus find an expression for moment of inertia of this rod about an **axis that passes through the center of mass and perpendicular tothe rod.**



2) First an origin is to be fixed for the coordinate system so that it coincides with thecenter of mass, which is also the geometric center of the rod. The rod is now along the x axis.

3) We take an infinitesimally small mass (dm) at a distance (x) from the origin. The moment of inertia (dI) of this mass (dm) about the axis is,

$dI = (dm)x^2$

As the mass is uniformly distributed, the mass per unit length (λ) of the rod is, $\lambda = \frac{mass}{length}$; $\boldsymbol{\lambda = \frac{M}{l}}$

The (dm) mass of the infinitesimally small length as, dm = λdx = $\frac{M}{l}$dx.

The moment of inertia (I) of the entire rod can be found by integrating dI, I = $\int dI = \int (dm)x^2$;

$\int \left(\frac{M}{l}dx\right) x^2$;

I = $\frac{M}{l}\int x^2 dx$

4) As the **mass is distributed on either side of the origin, the limits for integration aretaken from** $-\frac{l}{2}$ to $\frac{l}{2}$

I = $\frac{M}{l}\int_{-\frac{l}{2}}^{\frac{l}{2}} x^2 dx = \frac{M}{l}\left[\frac{x^3}{3}\right]_{-\frac{l}{2}}^{\frac{l}{2}}$

I = $\frac{M}{l}\left[\frac{l^3}{24} - \left(-\frac{l^3}{24}\right)\right] = \frac{M}{l}\left[\frac{l^3}{24} + \frac{l^3}{24}\right]$

I = $\frac{M}{l}\left[2\left(\frac{l^3}{24}\right)\right]$;

I = $\frac{1}{12}$ml^2

44. Derive the expression for moment of inertia of a uniform ring about an axispassing through the center and perpendicular to the plane.

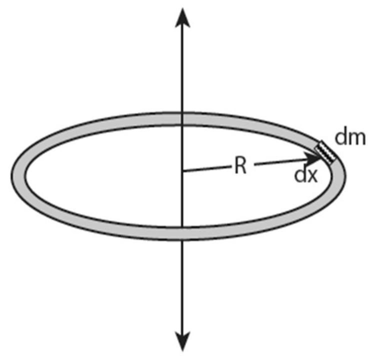
1) Consider a **uniform ring of mass M and radius R.** To find the moment of inertiaof the **ring about an axis passing through its center**and perpendicular to the plane, let us take an infinitesimally small mass (dm) of length (dx) of the ring.

2) This (dm) is located at a distance R, which is the radius of the ring from the axis as shown in Figure. The moment of inertia (dI) of this small mass (dm) is, **dI = (dm)R²**

The **length of the ring is its circumference (2πR)**. As the mass is uniformly distributed, the mass per unit length (λ) is, $\lambda = \frac{mass}{leng}$; $\lambda = \frac{M}{2\pi R}$

The (dm) mass of the infinitesimally small length as,

dm = λ, dx = $\frac{M}{2\pi R}$dx.



Now, the moment of inertia (I) of the entire ring is,

I = $\int dI = \int (dm)R^2$;

$\int \left(\frac{M}{2\pi R}dx\right) R^2$

I = $\frac{MR}{2\pi}\int dx$

To cover the entire length of the ring, the limits of integration are taken from 0 to 2πR

I = $\frac{MR}{2\pi}\int_0^{2\pi R} dx$; = $\frac{MR}{2\pi}[x]_0^{2\pi R}$;

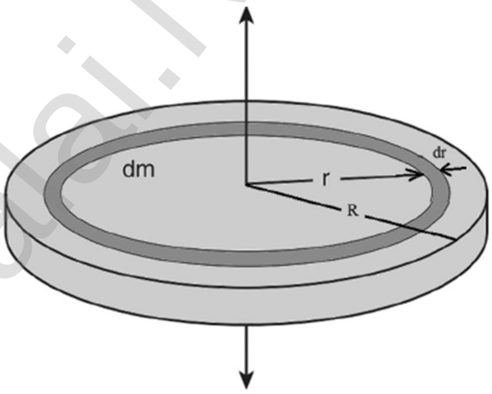
= $\frac{MR}{2\pi}[2\pi R - 0]$

I = MR^2

45. Derive the expression for moment of inertia of a uniform disc about an axispassing through the center and perpendicular to the plane.

i) Consider a **disc of mass M and radius R**. This disc is **made up of many infinitesimally small rings** as shown in Figure. Consider one such ring of mass (dm) and thickness (dr) and radius (r). The moment of inertia (dI) of this small ring is,

dI = $(dm)r^2$



ii) As the mass is uniformly distributed, the mass per unit area (σ) is, σ = $\frac{M}{\pi R^2}$

The mass of the infinitesimally small ring is, dm = σ 2 πrdr = $\frac{M}{\pi R^2}$ 2 πrdr

where, the term (2πr dr) is the area of this elemental ring (2πr is the length and dr isthe thickness)

dm = $\frac{2M}{R^2}$rdr ; dI = $\frac{2M}{R^2}$ r^3dr

The moment of inertia (I) of the entire disc is, I = $\int dI$

I = $\int_0^R \frac{2M}{R^2} r^3 dr$; = $\frac{2M}{R^2}\int_0^R r^3 dr$

I = $\frac{2M}{R^2}\left[\frac{r^4}{4}\right]_0^R$; = $\frac{2M}{R^2}\left[\frac{R^4}{4} - 0\right]$ I = ½ MR^2

46. Discuss conservation of angular momentum with example.

1) When no external torque acts on the body, **the net angular momentumof a rotatingrigid body remains constant**. This is known as law of conservation of angularmomentum. $\tau = \frac{dL}{dt}$ if τ =0 then, L = Constant

2) As the **angular momentum is L = Iω, the conservation of angular momentum couldfurther be written for initial and final situations** as, $I_i\omega_i = I_f\omega_f$ (or) Iω = constant

3) The above equations say that if I increase ω will decrease and vice-versa to keep theangular momentum constant.

4) There are several situations where the principle of conservation of angular momentum is applicable.

5) One striking Example: **The ice dancer spins slowly when the hands are stretched out and spins faster when the hands are brought close to the body. Stretching of hands away from body increases moment of inertia, thus the angular velocity decreases resulting in slower spin.**

6) When the **hands arebrought close to the body**, the moment of inertia **decreases, and thus the angular velocity increases** resulting in faster spin.

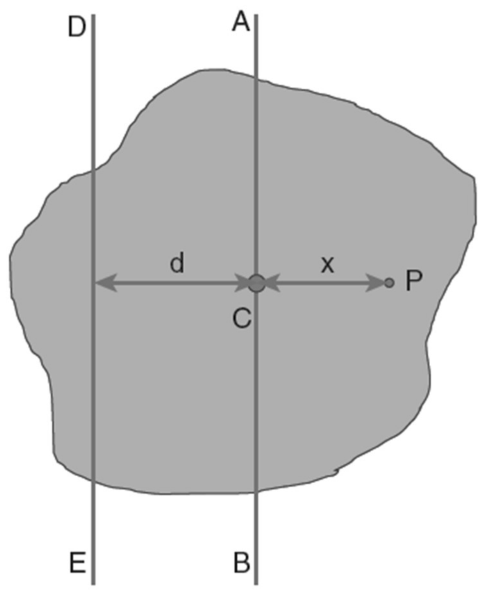
47. State and prove parallel axis theorem.

i) Parallel axis theorem states that **the moment of inertia of a body about any axis is equal to the sum of its moment of inertia about a parallel axis through its center of mass and the product of the mass of the body and the square of the perpendicular distance between the two axes.**

ii) If IC is the moment of inertia of the body of mass M about an axis passing through the center of mass, then the moment of inertia I about a parallel axis at a distance d from it is given by the relation,

$$I = I_C + Md^2$$

iii) let us consider a rigid body as shown in Figure. Its **moment of inertia about an axis AB passing through the center of mass is I_C.** DE is another axis parallel to AB at a perpendicular distance d from AB. The moment of inertia of the body about DE is I. We attempt to get an expression for I in terms of I_C. For this, let us consider a point mass m on the body at position x from its center of mass.



iv) The moment of inertia of the point mass about the axis DE is,

$m(x + d)^2$.The moment of inertia I of the whole body about DE is the summation of theabove expression.

$I = \Sigma m(x + d)^2$ This equation could further be written as,

$I = \Sigma m(x^2 + d^2 + 2xd)$

$I = \Sigma(mx^2 + md^2 + 2dmx)$

$I = \Sigma mx^2 + \Sigma md^2 + 2d\Sigma mx$

v) Here, Σmx^2 is the moment of inertia of the body about thecenter of mass. Hence, $I_C = \Sigma mx^2$

The term, $\Sigma mx = 0$ because, x can take positive and negative values with respect to the axis AB. The summation (Σmx) will be zero

Thus, $I = I_C + \Sigma md^2$; $I_C + (\Sigma m)d^2$

vi) Here, Σm is the entire mass M of the object (Σm =M)

$I = I_C + Md^2$

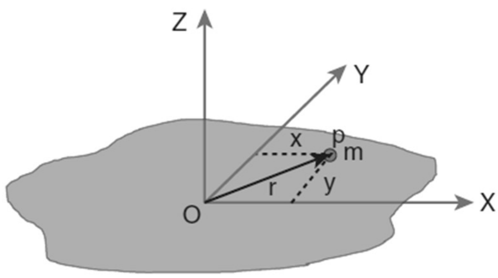
Hence, the parallel axis theorem is proved.

48. State and prove perpendicular axis theorem.

i) The theorem states **that the moment of inertia of a plane laminar body about an axis perpendicular to its plane is equal to the sum of moments of inertia about two perpendicular axes lying in the plane of the body such that all the three axes are mutually perpendicular and have a common point.**

ii) Let the **X and Y-axes lie in the plane and Z-axis perpendicular to the plane of thelaminar object.** If the moments of inertia of the body about X and Y-axes are $I_X$and $I_Y$respectively and $I_Z$is the moment of inertia about Z-axis, then **the perpendicularaxis theorem could be expressed as, $I_Z = I_X + I_Y$**

iii) To prove this theorem, let us consider a plane laminar object of negligible thicknesson which lies the origin (O). **The X and Y-axes lie on the plane and Z-axis is perpendicular** to it as shown in Figure. The lamina is considered to be made up of a large number of particles of mass m. Let us choose one such particle at a point P which has coordinates (x, y) at a distance r from O.



iv) The moment of inertia of the particle about Z-axis is, mr^2 the summation of the above expression gives the moment of inertia of the entire lamina about Z-axis as, $I_Z = \Sigma mr^2$

Here, $r^2 = x^2 + y^2$; Then, $I_Z = \Sigma m(x^2 + y^2)$

$I_Z = \Sigma mx^2 + \Sigma my^2$

In the above expression, the term Σmx^2 is the moment of inertia of the body about the Y-axis and similarly, the term Σmy^2 is the moment of inertia about X-axis. Thus, $I_X = \Sigma my^2$ and $I_Y = \Sigma mx^2$

Substituting in the equation for I_z gives, $I_Z = I_X + I_Y$

Thus, the perpendicular axis theorem is proved.

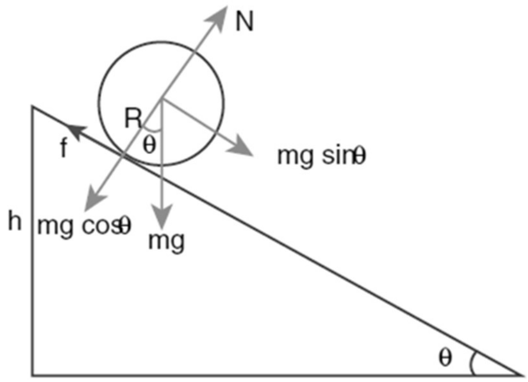
49. Discuss rolling on inclined plane and arrive at the expression for the acceleration.

1) Let us **assume a round object of mass m and radius R is rolling down an inclinedPlane without slipping** as shown in Figure. There are two forces acting on the object along the inclined plane.

2) One is the component **of gravitational force (mg sinθ)** and the other is **the static frictional force (f).** The other component of gravitation force (mg cosθ) is **cancelled by the normal force (N) exerted by the plane**. As the motion is happening along the incline, we shall write the equation for motion from the free body diagram (*FBD*) of the object.

3) For translational motion, mg sinθ is the supporting force and f is the opposing force, **mg sinθ – f = ma** -----(1)
For rotational motion, let us take the torque with respect to the center of the object.
Then mg sinθ cannot cause torque as it passes through it but the frictional force fcan set torque of Rf. Rf = Iα

4) By using the relation, a = r α, and moment of inertia I =mK^2, we get,



$Rf = mk^2\frac{a}{R}$; $f = ma\left(\frac{K^2}{R^2}\right)$

Now equation (1) becomes

$mg\sin\theta - ma\left(\frac{K^2}{R^2}\right) = ma$

$mg\sin\theta = ma + ma\left(\frac{K^2}{R^2}\right)$

$a\left(1+\frac{K^2}{R^2}\right) = g\sin\theta$

After rewriting it for acceleration,

we get, $a = \frac{g\sin\theta}{\left(1+\frac{K^2}{R^2}\right)}$

5) We can also find the expression for final velocity of the rolling object by using thirdequation of motion for the inclined plane. $v^2 = u^2 + 2as$. If the body starts rolling from rest, u = 0. When h is the vertical height of the incline, the length of the incline s is, $S = \frac{h}{\sin\theta}$;

$v^2 = 2\frac{g\sin\theta}{\left(1+\frac{K^2}{R^2}\right)}\left(\frac{h}{\sin\theta}\right) = \frac{2gh}{\left(1+\frac{K^2}{R^2}\right)}$

By taking square root, $v = \sqrt{\frac{2gh}{\left(1+\frac{K^2}{R^2}\right)}}$

6) The time taken for rolling down the incline could also be written from first equation of motion as, v = u + at. For the object which starts rolling from rest, u = 0. Then,

$t = \frac{v}{a}$; $t = \left(\sqrt{\frac{2gh}{\left(1+\frac{K^2}{R^2}\right)}}\right)\left(\frac{\left(1+\frac{K^2}{R^2}\right)}{g\sin\theta}\right)$

$t = \sqrt{\frac{2h\left(1+\frac{K^2}{R^2}\right)}{gSin^2\theta}}$

7) The equation suggests that for a given incline, the object with the least value of radius of gyration K will reach the bottom of the incline first.

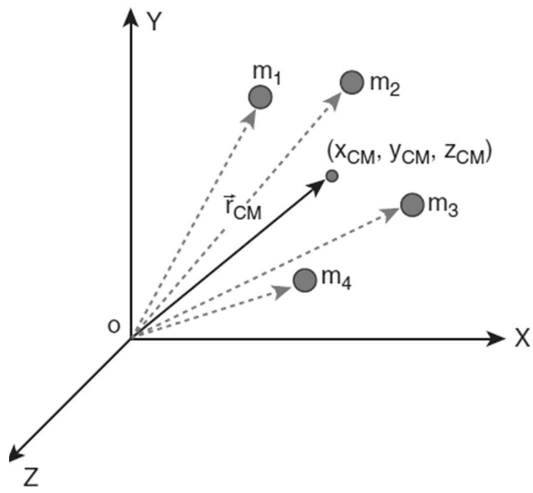
50. Derive an expression for the position vector of the center of mass of particle system.

i) To find the center of mass for a collection of n point masses, say, m_1, m_2, m_3 . . . m_n. we have to first choose an origin and an appropriate coordinate system as shown in Figure.

ii) Let, **x_1, x_2, x_3 . . . x_n be the X-coordinates of the positions of these point masses in the X -direction from the origin.** The equation for the x coordinate of the center of mass is, $x_{CM} = \frac{\Sigma m_i x_i}{\Sigma m_i}$

where, Σm_i is the total mass M of all the particles, (Σm_i= M).

Hence, $x_{CM} = \frac{\Sigma m_i x_i}{M}$



iii) Similarly, we can also find y and z coordinates of the center of mass for thesedistributed point masses as indicated in Figure.

$y_{CM} = \frac{\Sigma m_i y_i}{M}$; $z_{CM} = \frac{\Sigma m_i z_i}{M}$

iv) Hence, the position of center of mass of these point masses in a Cartesian coordinatesystem is (x_{CM}, y_{CM}, z_{CM}). In general, the position of center of mass can be written in a vector form as,

$\vec{r}_{CM} = \frac{\Sigma m_i \vec{r_i}}{M}$

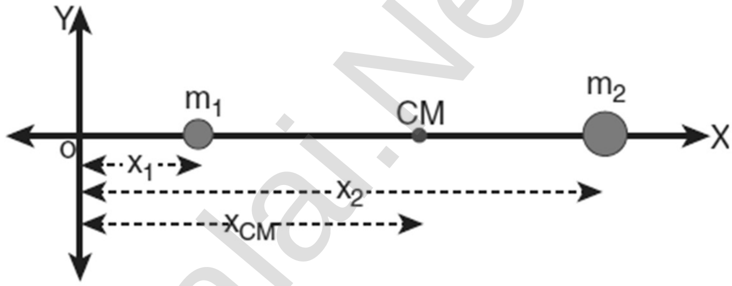
v) where, $\vec{r}_{CM} = x_{CM}\hat{i} + y_{CM}\hat{j} + z_{CM}\hat{k}$ is the position vector of the center of mass and $\vec{r}_i = x_i\hat{i} + y_i\hat{j} + z_i\hat{k}$ is the position vector of the distributed point mass; where, $\hat{i}$, $\hat{j}$ and $\hat{k}$ are the unit vectors along X, Y and Z-axes respectively.

51. Derive an expression for the center of mass of two-point masses.

Let the center of mass of two-point masses m_1 and m_2, which are at positions x_1 and x_2 respectively on the X-axis. For this case, we can express the position of center of mass in the following three ways based on the choice of the coordinate system.

(i) When the masses are on positive X-axis:

The origin is taken arbitrarily so **that the masses m_1 and m_2 are at positions x_1 and x_2 on the positive X-axis** as shown in Figure. **The center of mass will also be on the positive X-axis at x_{CM}** as given by the equation,

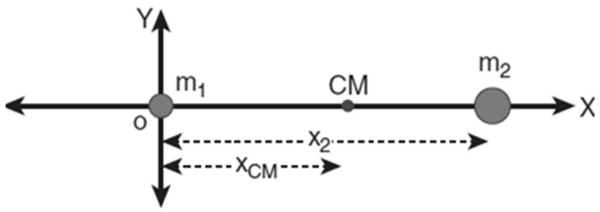


(a) When the masses are on positive X axis

$$x_{CM} = \frac{m_1x_1+m_2x_2}{m_1+m_2}$$

(ii) When the origin coincides with any one of the masses:

The calculation could be minimized if the origin of the coordinate system is made to coincide with any one of the masses as shown in Figure. When the origin coincides with the point mass m_1, its position x_1 is zero, (i.e. x_1 = 0).



(b) When the origin coincides with any one of the masses

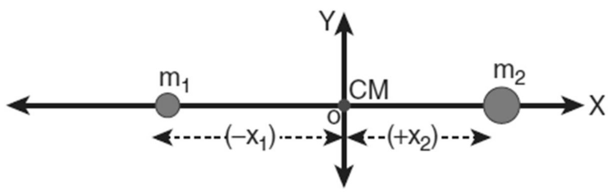
Then, $x_{CM} = \frac{m_i(0)+m_2x_2}{m_1+m_2}$

The equation further simplifies as,

$$x_{CM} = \frac{m_2x_2}{m_1+m_2}$$

iii) When the origin coincides with the center of mass itself:

If the origin of the coordinate system is made to coincide with the center of mass, then, x_{CM} = 0 and the mass m1 is found to be on the negative X-axis as shown in Figure. Hence, its position x_1 is negative, (i.e. $-x_1$).



(c) When the origin coincides with the center of mass itself

$0 = \frac{m_1(-x_1)+m_2x_2}{m_1+m_2}$; $0 = m_1(-x_1) + m_2x_2$

$m_1x_1 = m_2x_2$

The equation given above is known as principle of moments.

52. State in the absence of any external force the velocity of the centre of mass remains constant.

1) When a rigid body moves, its center of mass will also move along with the body. **For kinematic quantities like velocity (v_{CM}) and acceleration (a_{CM}) of the center ofmass, we can differentiate the expression for position of center of mass with respectto time once and twice respectively.** For simplicity, let us take the motion alongX direction only.

$$\vec{v}_{CM} = \frac{d\vec{x}_{CM}}{dt} \quad ; = \frac{\Sigma m_i\left(\frac{d\vec{x}_i}{dt}\right)}{\Sigma m_i}$$

$$\vec{v}_{CM} = \frac{\Sigma m_i \vec{v}_i}{\Sigma m_i}$$

$$\vec{a}_{CM} = \frac{d}{dt}\left(\frac{d\vec{x}_{CM}}{dt}\right) ; = \left(\frac{d\vec{v}_{CM}}{dt}\right) ; = \frac{\Sigma m_i\left(\frac{d\vec{v}_i}{dt}\right)}{\Sigma m_i}$$

$$\vec{a}_{CM} = \frac{\Sigma m_i a_i}{\Sigma m_i}$$

2) In **the absence of external force, i.e. $\vec{F}_{ext}$= 0, the individual rigid bodies of a systemcan move or shift only due to the internal forces.**

3) This will not affect the position of the center of mass. This means that **the center of mass will be in a state of rest or uniform motion**. Hence, $\vec{v}_{CM}$ will be zero when center of mass is at rest and constant when center of mass has uniform motion ($\vec{v}_{CM}$ = 0 or $\vec{v}_{CM}$ = constant). There will be no acceleration of center of mass, ($\vec{a}_{CM}$ = 0).

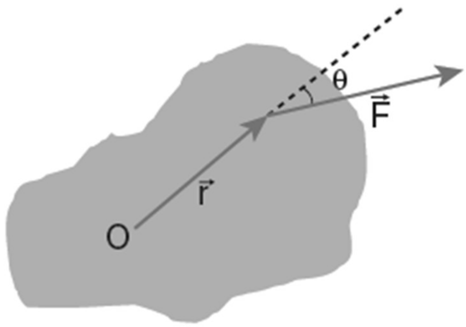
From equation $\mathbf{0} = \frac{\Sigma m_i \vec{v}_i}{\Sigma m_i}$ (or) constant; $\vec{v}_{CM} = \frac{\Sigma m_i \vec{v}_i}{\Sigma m_i}$; $\vec{a}_{CM} = 0$

4) Here, the individual particles may still move with their respective velocities andaccelerations due to internal forces.

53. Define Torque and derive its expression.

1) Torque is defined as the moment of the external applied force about a point or axisof rotation. The expression for torque is, $\vec{\tau} = \vec{r} \times \vec{F}$

2) where, $\vec{r}$ is the position vector of the point where the force $\vec{F}$ is acting on the body as shown in Figure.



3) Here, **the product of $\vec{r}$and $\vec{F}$is called the vector product or cross product.** The vector product of two vectors results in another vector that is perpendicular to both the vectors. Hence, torque ($\vec{\tau}$) is a vector quantity.

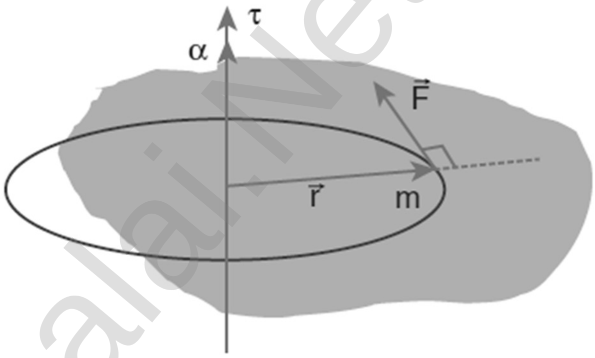
4) **Torque has a magnitude (rFsinθ) and direction perpendicular to, $\vec{r}$ and $\vec{F}$.** Its unit is N m. $\vec{\tau}$ = (rFsinθ)$\hat{n}$

5) Here, θ is the angle between $\vec{r}$ and $\vec{F}$ and $\hat{n}$ is the unit vector in the direction of $\vec{\tau}$.

54. Obtain the relation between torque and angular acceleration.

i) Let us consider a **rigid body rotating about a fixed axis.** A point mass m in the body will execute a circular motion about a fixed axis

ii) A tangential force $\vec{F}$ acting on the point massproduces the necessary torque for this rotation. This **force $\vec{F}$ is perpendicular to the position vector $\vec{r}$of the point mass.**



iii) The **torque produced by the force on the point mass m about the axis** can be written as, τ = r Fsin90 = r F; (sin90 =1)

τ = rma (F = ma)

τ =rmrα = mr²α (a = r α)

$\tau = mr^2\alpha$ ---------------(1)

iv) Hence, the torque of **the force acting on the pointmass produces an angular acceleration (α) in the point mass about the axis of rotation**. In vector notation,

$\vec{\tau} = (mr^2)\vec{\alpha}$ -------------(2)

v) The directions of τ and α are along the axis of rotation. If the direction of τ isin the direction of α, it **produces angular acceleration. On theother hand if, τ is opposite to α, angular deceleration or retardation is produced on the point mass.**

vi) The term mr² in equations 1 and 2 is called moment of inertia (I) of the point mass. A rigid body is made up of many such point masses. Hence, the moment of inertia of

a rigid body is the sum of moments of inertia of all such individual **point masses thatconstitute the body ($I = \Sigma m_i r_i^2$).Hence, torque for the rigidbody can be written as,** $\vec{\tau} = (\Sigma m_i r_i^2)\vec{\alpha}$; $\vec{\tau} = I\,\vec{\alpha}$

55. Discuss the pure rolling and find the condition for rolling without slipping and sliding.

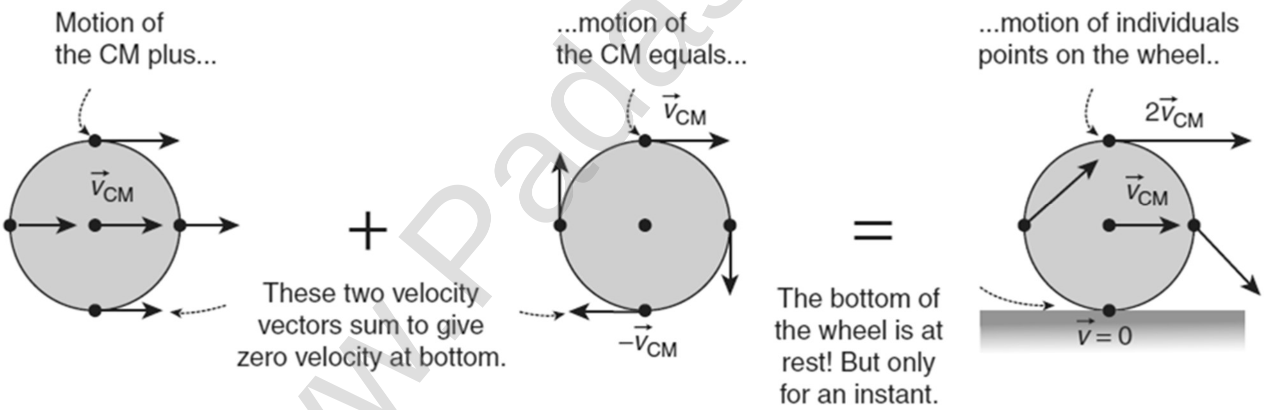
1) In pure rolling, the point of the rolling object which comes in contact with the surface is at momentary rest.

2) This is the case with every point that is on the edge of the rolling object. As the rolling proceeds, **all the points on the edge, one by one come in contact with the surface; remain at momentary rest at the time of contact and then take the path of the cycloid as already mentioned.** Hence, we can consider the pure rolling in two different ways.

   (i) The combination of **translational motion and rotational motion about thecenter of mass.** (or)

   (ii) **The momentary rotational motion about the point of contact.**

3) As the point of contact is at **momentary rest in pure rolling, its resultant velocity vis zero (v = 0). For example, at the point of contact,** v_{TRANS} is forward (to right) and v_{ROT} is backwards (to the left).



4) That implies that, **v_{TRANS} and v_{ROT} are equal in magnitude and opposite in direction ($v = v_{TRANS} - v_{ROT} = 0$).** Hence, we conclude that in pure rolling, for all the points on the edge, the magnitudes of v_{TRANS} and v_{ROT} are equal ($v_{TRANS} = v_{ROT}$).

   As $v_{TRANS} = v_{CM}$ and $v_{ROT} = R\omega$, in pure rolling we have, $v_{CM} = R\omega$

5) For the topmost point, the two velocities v_{TRANS} and v_{ROT} are equal in magnitudeand in the same direction (to the right). Thus, the resultant velocity v is the sum ofthese two velocities, $v = v_{TRANS} + v_{ROT}$. In other form, $v = 2\ v_{CM}$

Sliding:

i) Sliding is the case when $v_{CM} > R\omega$ (or $v_{TRANS} > v_{ROT}$). The translation is morethan the rotation. This kind of motion happens **when sudden break is applied in amoving vehicles, or when the vehicle enters into a slippery road.** In this case, the point of contact has more of v_{TRANS} than v_{ROT}.

ii) Hence, it has a **resultant velocity v in the forward direction**. The kinetic frictional force (f_k) opposes the relative motion. Hence, it **acts in the opposite direction of therelative velocity.**

iii) This frictional force reduces the **translational velocity and increases the rotational velocity till they become equal and the object sets on pure rolling**. Sliding is also referred as forward slipping.

Slipping:

1) Slipping is the case when $v_{CM} < R\omega$ (or $v_{TRANS} < v_{ROT}$). The rotation is morethan the translation. This kind of motion happens when we suddenly start thevehicle from rest or the vehicle is stuck in mud.

2) In this case, **the point of contact has more of v_{ROT} than v_{TRANS}. It has a resultant velocity v in the backward direction**.

3) The kinetic frictional force (fk) opposes the relative motion. Hence it acts in the opposite direction of the relative velocity.

4) This **frictional force reduces the rotational velocity and increases the translational velocity till they become equal and the object sets pure rolling**. Slipping is sometimes emphasized as backward slipping.

56. Write an expression for the kinetic energy of a body in pure rolling.

1) The total kinetic energy (KE) as the sum of kinetic energy due to translational motion (KE_{TRANS}) and kinetic energy due to rotational motion (KE_{ROT}). $KE = KE_{TRANS} + KE_{ROT}$

2) If the mass of the rolling object is M, the velocity of center of mass is v_{CM}, its moment of inertia about center of mass is I_{CM} and angular velocity is ω, then$KE = \frac{1}{2} Mv^2_{CM} + \frac{1}{2} I_{CM}\, \omega^2$

With center of mass as reference:

3) The moment of inertia (I_{CM}) of a rolling object about the center of mass is, $I_{CM} = MK^2$ and $v_{CM} = R\omega$. Here, K is radius of gyration.

$$KE = \frac{1}{2} Mv^2_{CM} + \frac{1}{2} (MK^2) \frac{v^2_{CM}}{R^2}$$

$$KE = \frac{1}{2} Mv^2_{CM} + \frac{1}{2} Mv^2_{CM} \left(\frac{K^2}{R^2}\right)$$

$$KE = \frac{1}{2} Mv^2_{CM}\left(1 + \frac{K^2}{R^2}\right)$$

With point of contact as reference:

4) We can also arrive at the same expression by taking the momentary rotationhappening with respect to the point of contact (another approach to rolling). If we take the point of contact as O, then,
$KE = \frac{1}{2} I_o\, \omega^2$

5) Here, I_o is the moment of inertia of the object about the point of contact. By parallelaxis theorem, $I_o = I_{CM} + MR^2$. Further we can write, $I_o = MK^2 + MR^2$.

With $v_{CM} = R\omega$ or $\omega = \frac{v_{CM}}{R}$

$KE = \frac{1}{2}(MK^2 + MR^2)\frac{v^2_{CM}}{R^2}$

$KE = \frac{1}{2} Mv^2_{CM}\left(1 + \frac{K^2}{R^2}\right)$

6) KE in **pure rolling can be determined by any one of the following two cases.**

(i) **The combination of translational motion and rotational motion about the center ofmass.** (or)

(ii) The **momentary rotational motion about the point of contact**.

விதைக்கின்ற நேரத்தை வீணடித்து விட்டால், அறுவடை காலத்தில் ஆனந்தம் பெற முடியாது. அதுபோலதான் கற்கும் பருவத்தை வீணடித்து விட்டால் பின்னர் காலமெல்லாம் வருந்த வேண்டும். இளமையில் நீ வியர்வை சிந்தாவிட்டால், முதுமையில் நீ கண்ணீர் சிந்த வேண்டும்.

உங்களுடைய பிற்காலம் பொற்காலம் ஆக வேண்டும் என்றால் கற்கும் காலத்தில் கவனமுடன் படியுங்கள். **படிக்கும்போது ஆர்வம் இல்லாமல் படித்தால் சோர்வும் வெறுப்பும்தான் மிஞ்சும். உங்களுடைய பெற்றோர்களும், இந்த தேசமும் ஆயிரம் கனவுகளோடு காத்திருக்கிறது.** ஆம், அக்கனவுகளை நனவாக்கும் சக்தி நீங்கள் என்பதை உணர்ந்து செயலாற்றத் தொடங்குங்கள்.

ஒரு கல்லைச் செதுக்கிச் செதுக்கி அழகிய சிலையாக்குகின்ற ஒரு சிற்பியைப் போல, உங்களுடைய அறிவு உளி கொண்டு அறியாமையை நீக்கிய பின்னர் வெற்றி என்கிற வெளிச்ச சிலையை உருவாக்குங்கள்.

UNIT – VI (GRAVITATION)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. State Kepler's three laws.

1. **Law of orbits:** Each planet moves around the Sun in an **elliptical orbit withthe Sun at one of the foci.**
2. **Law of area:**
   The radial vector (line joining the Sun to a planet) **sweeps equal areas in equal intervals of time.**
3. **Law of period:**
   The **square of the time period of revolution of a planet** around the Sun in its Elliptical orbit is **directly proportional to the cube of the semi-major axis of the ellipse.**

2. State Newton's Universal law of gravitation.

Newton's law of gravitation states that a particle of mass M_1 attracts any other particle of mass M_2 in the universe with an attractive force. The strength of **this force of attraction** was found to be **directly proportional to the product of their masses and is inversely proportional to the square of the distance between them.**

3. Will the angular momentum of a planet be conserved? Justify your answer.

Yes, Because $\vec{\tau} = \vec{r} \times \vec{F}$; $\vec{r} \times \left(\frac{GM_S M_E}{r^2}\hat{r}\right) = 0$

Since $\vec{r} = r\,\hat{r}$, $(\hat{r} \times \hat{r}) = 0$ So, $\vec{\tau} = \frac{d\vec{L}}{dt} = 0$

It implies that angular momentum is a constant vector. The angular momentum of the Earth about the Sun is constant throughout the motion.

4. Define the gravitational field. Give its unit.

The gravitational force experienced by **unit mass placed at that point.**

Unit $\vec{E}_1 = \frac{\vec{F}21}{m_2}$ in equation we get, $\vec{E} = -\frac{Gm_1}{r^2}\vec{r}$. its unit is N kg^{-1} (or) m s^{-2}

5. What is meant by superposition of gravitational field?

Consider 'n' particles of masses, m_1 ,m_2 ...$m_n$distributed in space at positions$\hat{r}_1, \hat{r}_2, \hat{r}_3$ ....etc, with respect to point P. **The total gravitational field at a point P due to all the masses is given by the vector sum of the gravitational field due to the individual masses.** This principle is known as superposition of gravitational fields.

$$\vec{E}_{total} = \vec{E}_1 + \vec{E}_2 + ...\vec{E}_n \;;\; = -\frac{Gm_1}{r_1^2}\vec{r}_1 - \frac{Gm_2}{r_2^2}\vec{r}_2 - .... \frac{Gm_n}{r_n^2}\vec{r}_n \;;\; = -\sum_{i=1}^{n}\frac{Gm_i}{r_i^2}\vec{r}_i$$

6. Define gravitational potential energy.

Gravitational potential energy associated with this conservative force field. Thegravitationalpotentialenergyisdefined**as the work done to bring the mass m_2 from infinity to a distance 'r' in the gravitational field of mass m_1. Its unit is joule.**

7. Is potential energy the property of a single object? Justify.

Potential energy is a property of a system rational than of a single object due to its physical position. Because **gravitational potential energy depends on relative position**. So, a reference level at which to set the potential energy equal to zero.

8. Define gravitational potential.

The gravitational potential at a distance r due to a mass is defined as the amount of work required to bring unit mass from infinity to the distancer.

9. What is the difference between gravitational potential and gravitational potential energy?

Gravitational potential:

The amount of work done in bringing a body of unit mass from infinity to that point without acceleration. $V = -\frac{GM}{R}$

Gravitational potential Energy:

The energy stored in the body at that point. If the position of the body **changes due to force acting on it, then change in its potential energy** is equal to the amount of work done on the body by the forces acting on it. $U = -\frac{GMm}{R}$

10. What is meant by escape speed in the case of the Earth?

The minimum speed required by an object to escape from Earth's gravitationalfield.ie. $V_e = \sqrt{2gR_E}$; $V_e = 11.2\ kms^{-1}$

11. Why is the energy of a satellite (or any other planet) negative?

The **negative sign in the total energy implies that the satellite** is bound to the Earth and it cannot escape from the Earth.

As h approaches, ∞ the **total energy tends to zero**. Its physical meaning is that the satellite is completely free from the influence of Earth's gravity and is not bound to Earth at large distances.

12. What are geostationary and polar satellites?

Geostationary satellites:

The satellites revolving the **Earth at the height of 36000km** above the **equator**, are **appear to be stationary when seen from Earth** is called geo-stationary satellites.

Polar satellites:

The satellites which revolve from **north to south of the Earth** at the height of **500 to 800km from the Earth surface** are called Polarsatellites.

13. Define weight

The weight of an object is defined as the **downward force whose magnitude W is equal to that of upward force that must be applied to the object to hold it at rest or at constant velocity relative to the earth**. The magnitude of weight of an object is denoted as, **W=N=mg.**

14. Why is there no lunar eclipse and solar eclipse every month?

Moon's orbit is tilted 5^0 with respectto Earth's orbit, only during certain periods of the year; the **Sun, Earth and Moon alignin straight line leading to either lunar eclipse** or solar eclipse depending on the alignment.

15. How will you prove that Earth itself is spinning?

The Earth's spinning motion can be proved by **observing star's position over a night. Due to Earth's spinning motion**, the stars in sky appear to move in circular motion about the pole star.

16. What is meant by state of weightlessness?

When downward acceleration of the **object is equal to the acceleration due to the gravity of the Earth**, the object appears to be weightless

17. Why do we have seasons on Earth?

The seasons in the Earth arise due to the rotation of Earth around the **Sun with 23.5° tilt. Due to this 23.5° tilt, when the northern part of Earth is farther to the Sun**, the southern part is nearer to the Sun. So when it is summer in the northern hemisphere, the southern hemisphere experience winter.

18. Water falls from the top of a hill to the ground. Why?

This is because the top of the hill is a point of **higher gravitational potential than the surface of the Earth.** i.e. **Vhill > Vground.**

19. What is the effect of rotation of the earth on the acceleration due to gravity?

The acceleration due to **gravity decreases due to rotation of the earth.** This effect is zero at poles and maximum at the equator.

20. A satellite does not need any fuel to aide around the earth. Why?

The **gravitational force between satellite and earth provides the centripetal force** required by the satellite to move in a circular orbit.

21. Why does a tide arise in the ocean?

Tides arise in the ocean due to the **force of attraction between the moon and sea water.**

22. When a man is standing in the elevator, what are forces acting on him.

1. **Gravitational force which acts downward.** If we take the vertical direction as positive y direction, the gravitational force acting on the man is $\vec{F}_G = -mg\hat{j}$
2. **The normal force exerted by floor** on the man which acts vertically upward, $\vec{N} = N\hat{j}$

23. Find the distance between Venus and Sun.

1) The **distance between Venus and Sun**. The distance between Earth and Sun is taken as **one Astronomical unit (1 AU).**
2) The trigonometric relation satisfied by this right angled triangle is $\sin\theta = \frac{r}{R}$
3) Where **R = 1 AU. r = R Sin θ = (1 AU) (Sin 46^0)**. Here sin.46^0 = 0.77. Hence Venus is at a distance of 0.77 AU from Sun.

24. Find the expression of the orbital speed of satellite revolving around the earth.

Satellite of mass M to move in a circular orbit, centripetal force must be acting on the satellite. This centripetal force is provided by the Earth's gravitational force.

$$\frac{MV^2}{(R_E+h)} = \frac{GMM_E}{(R_E+h)^2}$$

$$V^2 = \frac{GM_E}{(R_E+h)} \; ;$$

$$V = \sqrt{\frac{GM_E}{(R_E+h)}}$$

As h increases, the speed of the satellite decreases.

25. What are the points to be noted to study about gravitational field?

Case 1: If $r < r'$

Since **gravitational force is attractive, $m_2$is attracted by m_1.** Then $m_2$can move from$r'$to r without any external work. Here **work is done by the system spending its internal energy and hence the work done** is said to be negative.

Case 2: If $r > r'$

Work has to be done **against gravity to move the object from**$r'$to r. Therefore, work is done on **the body by external force and hence work done is positive.**

26. What is meant by retrograde motion of planet?

1) The planets move eastwards and reverse their motion for a while and return to eastward motion again. This is called **"retrograde motion"** of planets.
2) To explain this retrograde motion, **Ptolemy introduced the concept of "epicycle" in his geocentric model**. According to this theory, while the planet orbited the Earth, it also **underwent another circular motiontermed as "epicycle".** A combination of epicycle and circular motion around the Earth gave rise to retrograde motion of the planets with respect to Earth.

CONCEPTUAL QUESTIONS

27. In the following, what are the quantities which that are conserved?

a) Linear momentum of planet b) Angular momentum of planet

c) Total energy of planet d) Potential energy of a planet

Ans. (b & d) Angular momentum of planet, Potential energy of a Planet.

28. The work done by Sun on Earth in one year will be

a) Zero b) Non zero c) positive d) negative Ans . : Zero

29. The work done by Sun on Earth at any finite interval of time is

a) positive, negative or zero b) Strictly positive

c) Strictly negative d) It is always zero

Ans. d) it is always zero

30. If a comet suddenly hits the Moon and imparts energy which is more than the total energy of the Moon, what will happen?

If a comet hits the moon with large mass and **with large velocity may destroy the moon completely** or its impact makes the moon, go out of the orbit.

31. If the Earth's pull on the Moon suddenly disappears, what will happen to the Moon?

If the **gravitational force suddenly disappears**, moon will stop **revolving around the earth and it will move in a direction tangential to its original orbit** with a speed with which it was revolving around the earth.

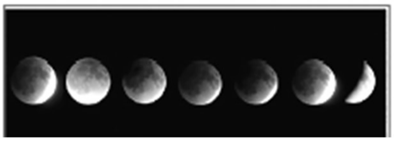
32. If the Earth has no tilt, what happens to the seasons of the Earth?

If the Earth has no tilt, there will be no seasonas like now and the duration of day and night will be equal throughout the year.

33. A student was asked a question 'why are there summer and winter for us? Hereplied as 'since Earth is orbiting in an elliptical orbit, when the Earth is veryfar away from the Sun(aphelion) there will be winter, when the Earth is nearerto the Sun(perihelion) there will be winter'. Is this answer correct? If not, whatis the correct explanation for the occurrence of summer and winter?

No, The seasons in the Earth arise due to the rotation of Earth around **the Sun with 23.5° tilt. Due to this 23.5°** tilt, when the northern part of Earth is farther to the Sun, **the southern part is nearer to the Sun.** So when it is **summer in the northern hemisphere**, the southern hemisphere experience winter.

34. The following photographs are taken from the recent lunar eclipse which occurred on January 31, 2018. Is it possible to prove that Earth is a spherefrom these photographs?



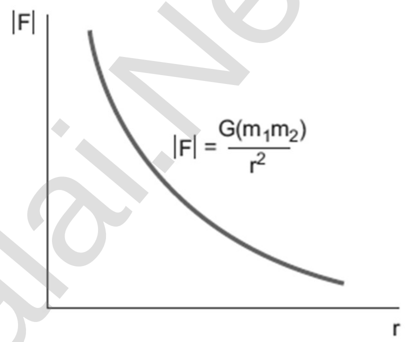
No. the moon goes around the earth in an elliptical orbit. This means its distance from us varies periodically as it goes around us.

FIVE MARKS QUESTION WITH ANSWER:

35. Discuss the important features of the law of gravitation.

Important features of gravitational force:

1) As the **distance between two massesincreases, the strength of the force tends to decrease** because of inverse dependence on r^2. Physically it implies that **Ex. The planet Uranus experiences less gravitational force from the Sun than the Earth since Uranus is at larger distance from the Sun compared to the Earth.**



2) The **gravitational forces between two particles always constitute an action-reaction pair**. It implies that **the gravitational force exerted by the Sun on the Earth is always towards the Sun.** The reaction-force is exerted by the Earth on the Sun. The direction of this reaction force is towards Earth.

3) The **torque experienced by the Earth due to the gravitational force** of the Sun is given by $\vec{\tau} = \vec{r} \times \vec{F}$; $\vec{r} \times \left(\frac{GM_SM_E}{r^2}\hat{r}\right) = 0$

Since $\vec{r} = r\,\hat{r}$, $(\hat{r} \times \hat{r}) = 0$ So, $\vec{\tau} = \frac{d\vec{L}}{dt} = 0$

It implies that **angular momentum is a constant vector. The angular momentum of the Earth about the Sun is constant** throughout the motion.

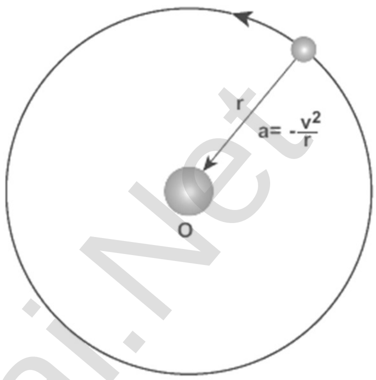
4) **Earth orbits around the Sun due to Sun's gravitational force, we assumed Earth and Sun to be point masses.** This assumption is a good approximation because **the distance between the two bodies is very much larger than their diameters.**

5) To calculate **force of attraction between a hollow sphere of mass M with uniform density and point mass m kept outside the hollow sphere**, we can replace the hollow sphere of mass M as equivalent to a point mass M located at the center of the hollow sphere.

6) If we place another object of mass 'm' inside this hollow sphere, the force experienced by this mass 'm' will be zero.

36. Explain how Newton arrived at his law of gravitation from Kepler's third law.

Newton's inverse square Law:



Newton considered the orbits of the planets as circular. For circular orbit of radius r, the centripetal acceleration towards the center is

$$a = -\frac{v^2}{r} \quad \text{------------------ 1}$$

Here v is the velocity and r, the distance of the planet from the center of the orbit. The velocity in terms of known quantities r and T, is

$$V = \frac{2\pi r}{T} \quad \text{------------------ 2}$$

Here T is the time period of revolution of the planet. Substituting this value of v in equation (1) we get,

$$a = \frac{\left(\frac{2\pi r}{T}\right)^2}{r} = -\frac{4\pi^2 r}{T^2} \quad \text{------ 3}$$

Substituting the value of 'a' from (3) in Newton's second law, F = ma, where 'm' is the mass of the planet.

$$F = \frac{4\pi mr}{T^2} \quad \text{------------------ 4}$$

From Kepler's third law, $\frac{r^3}{T^2}$ = k (Constant) --------- 5

$$\frac{r}{T^2} = \frac{k}{r^2} \quad \text{--------------- 6}$$

By substituting equation 6 in the force expression, we can arrive at the law of gravitation. $F = \frac{4\pi^2 mk}{r^2}$ ---------7

Here **negative sign implies that the force is attractive and it acts towards the center**. In equation (7), mass of the planet 'm' comes explicitly. But Newton strongly felt that according to his third law, **if Earth is attracted by the Sun, then the Sun must also be attracted by the Earth with the same magnitude of force.** So he felt that the Sun's mass (M) should also occur explicitly in the expression for force. From this insight, he equated the constant $4\pi^2 k$ to GM which turned out to be the law of gravitation.

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

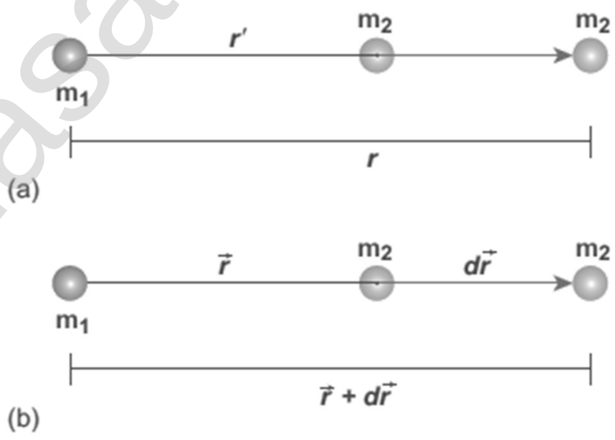
Again the negative sign in the above equation implies that the gravitational force is attractive.

37. Explain how Newton verified his law of gravitation.

1) Newton verified **his law of universal gravitation by comparing the acceleration of a terrestrial object to the acceleration of the moon.**
2) He knew that the **distance from the center of earth to the center of two spheres of known mass at either end of a light** rod suspended by a then fiber from the center of the rod.
3) He had earlier found **the small force that was needed to twist the fiber.**
4) By bringing a third sphere close to one of the suspended spheres.
5) He was **able to measure the force of gravity between the spheres** and hence gravitation.

38. Derive the expression for gravitational potential energy.

1) Two masses m_1 and m_2 are initially separated by a distance r'. Assuming m_1 to be fixed in its position, work must be done on m_2 to move the distance from r' to r as shown in Figure (a)



2) To move the mass m_2 through an infinitesimaldisplacement $d\vec{r}$from r to $\vec{r}$ + $d\vec{r}$ (shown in the Figure (b), work has to be done externally.

This infinitesimal work is given by $dW = \vec{F}_{ext} . d\vec{r}$ ------------- 1

3) The work is done against the gravitational force, therefore,

$|\vec{F}_{ext}| = |\vec{F}_G| = \frac{Gm_1m_2}{r^2}$ ---------- 2

Substituting equation (2) in (1), we get

$dW = \frac{Gm_1m_2}{r^2}\hat{r} . d\vec{r}$; $d\vec{r} = dr\,\hat{r}$

$\frac{Gm_1m_2}{r^2}\hat{r} . d\vec{r}$; $\hat{r}.\hat{r} = 1$ (Since both are unit vectors)

$dW = \frac{Gm_1m_2}{r^2} dr$

4) Thus the total work done for displacing the particle from r' to r is $W = \int_{r'}^{r} dW = \int_{r'}^{r} \frac{Gm_1m_2}{r^2} dr$

$W = -\left(\frac{Gm_1m_2}{r^2}\right)_{r'}^{r}$

$W = -\frac{Gm_1m_2}{r} + \frac{Gm_1m_2}{r'}$

W = U (r) – U (r')

Where $U(r) = \frac{Gm_1m_2}{r}$

5) This work done W gives the gravitational potential energy difference of the system of masses m_1 and m_2 when the separation between them are r and r' respectively.

39. Prove that at points near the surface of the Earth, the gravitational potentialenergy of the object is U = mgh.

1) Consider the Earth and mass system, with *r*, the distance between the mass m and the Earth's centre. Then the gravitational potential energy, $U = -\frac{GM_e m}{r}$ ---------------- 1

2) Here r = Re+h, where Re is the radius of the Earth. h is the height above the Earth's surface, $U = -G\frac{M_e m}{(R_e+h)}$ ------------- 2

If h << Re, equation (2) can be modified as

$U = -G\frac{M_e m}{R_e\left(1+\frac{h}{R_e}\right)}$; $U = -G\frac{M_e m}{R_e}\left(1+\frac{h}{R_e}\right)^{-1}$ --------- 3

3) By using Binomial expansion and neglecting the higher order terms, we get $U = -G\frac{M_e m}{R_e}\left(1-\frac{h}{R_e}\right)$ ---------- 4

We know that, for a mass m on the Earth's surface,

$G\frac{M_e m}{R_e} = mgR_e$ --------------- 5

Substituting equation (5) in (4) we get, $U = -mgR_e + mgh$

It is clear that the first term in the above expression is independent of the height h. For example, if the object is taken from h and it can be omitted. U = mgh

40. Explain in detail the idea of weightlessness using lift as an example.

i) **When the lift falls (when the lift wire cuts) with downward acceleration a = g, the person inside the elevator is in the state of weightlessness** or free fall.

ii) As they fall freely, they are **not in contact with any surface** (by neglecting air friction). The **normal force acting on the object is zero.** The **downward acceleration is equal to the acceleration due to the gravity of the Earth**. i.e (a = g). From equation N = m (g − a) we get, **a = g ∴N = m (g – g) = 0.** This is called the state of weightlessness.

41. Derive an expression for escape speed.

1) Consider an object of mass M on the surface of the Earth. **When it is thrown up with an initial speed v_i , the initial total energy of the object** is $E_i = \frac{1}{2} MV_i^2 - \frac{GMM_E}{R_E}$ --------------- 1

Where M_E, is the mass of the Earth and R_E - the radius of the Earth.

The term $-\frac{GMM_E}{R_E}$ is the potential energy of the mass M.

2) When the object reaches a height far away from Earth and hence treated as approaching infinity, **the gravitational potential energy becomes zero [U (∞) = 0] and the kinetic energy becomes zero as well**. Therefore, **the final total energy of the object becomes zero. This is for minimum energy and for minimum speed to escape**. Otherwise Kinetic energy can be non-zero.

$E_f = 0$, According to the law of energy conservation, $E_i = E_f$ -------- 2

Substituting (1) in (2) we get,

$\frac{1}{2} MV_i^2 - \frac{GMM_E}{R_E} = 0$

$\frac{1}{2} MV_i^2 = \frac{GMM_E}{R_E}$ --------------- 3

3) The escape speed, the minimum speed required by an object to escape Earth's gravitational field, hence replace, V_i with V_e. i.e,

$\frac{1}{2} MV_e^2 = \frac{GMM_E}{R_E}$

$V_e^2 = \frac{GMM_E}{R_E} \cdot \frac{2}{M}$; $V_e^2 = \frac{2GM_E}{R_E}$ ------------- 4

Using $g = \frac{GM_E}{R_e^2}$ — — — — — — — — — — — — — — — 5

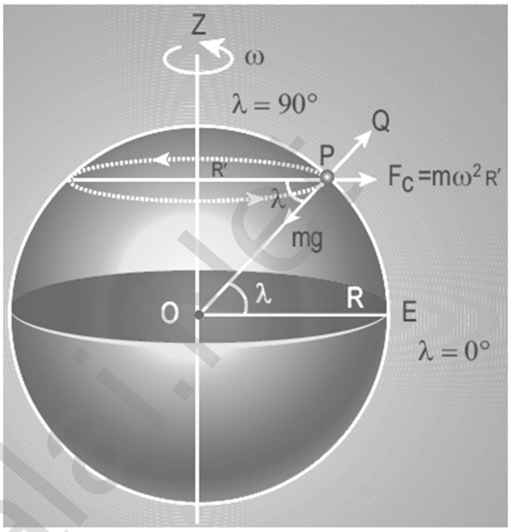
$V_e^2 = 2gR_E$; $V_e = \sqrt{2gRE}$ ------------- 6

From equation (6) the escape speed depends on two factors: **acceleration due to gravity and radius of the Earth**. It is completely independent of the mass of the object.

$Ve = \sqrt{2gR_E}$; Ve = 11.2 kms^{-1}

42. Explain the variation of g with latitude.

Variation of g with latitude:



Whenever we analyze the motion of objects in rotating frames, we must take into account the centrifugal force. **Even though we treat the Earth as an inertial frame, it is not exactly correct because the Earth spins about its own axis.** So when an object is on the surface of the Earth, it experiences a **centrifugal force that depends on the latitude of the object on Earth**. If the Earth were not spinning, the force on the object would have been mg. However, **the object experiences an additional centrifugal force due to spinning of the Earth.**

This centrifugal force is given by $m\omega^2 R'$

$\mathbf{R'} = \mathrm{R}\cos\boldsymbol{\lambda}$ ----------- 1

Where λ is the latitude. The component of centrifugal acceleration experienced by the object in the direction opposite to g is $a_c = \boldsymbol{\omega^2 R'}\cos\boldsymbol{\lambda}$

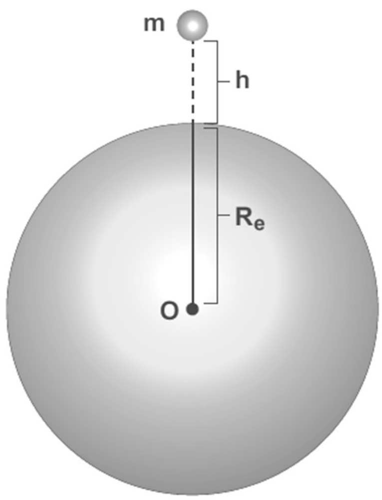
$= \boldsymbol{\omega^2 R}\cos^2\boldsymbol{\lambda}$ since $R' = R\cos\lambda$ Therefore,

$\mathbf{g'} = g - \boldsymbol{\omega^2 R}\cos^2\boldsymbol{\lambda}$ ---------- 2

From the expression (2), we can infer that at equator, $\lambda = 0$; $g' = g - \omega^2 R$. The acceleration due to gravity is minimum. At poles λ = 90; $g' = g$, it is maximum. At the equator, g' is minimum.

43. Explain the variation of g with altitude.

Variation of g with altitude:



Consider an object of mass m at a height h from the surface of the Earth. Acceleration experienced by the object due to Earth is $\mathbf{g'} = \frac{\mathbf{GM}}{(\mathbf{R_e+h})^2}$

$g' = \frac{GM}{R_e^2\left(1+\frac{h}{R_e}\right)^2}$; $g' = \frac{GM}{R_e^2}\left(1+\frac{h}{R_e}\right)^{-2}$

If h <<R_e .We can use Binomial expansion. Taking the terms upto first order

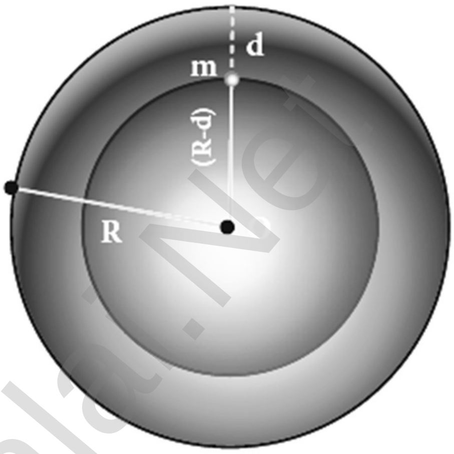
$g' = \frac{GM}{R_e^2}\left(1-2\frac{h}{R_e}\right)$;

$\mathbf{g'} = \mathbf{g}\left(\mathbf{1-2\frac{h}{R_e}}\right)$

We find that **g'**< g. This means **that as altitude h increases the acceleration due to gravity g decreases.**

44. Explain the variation of g with depth from the Earth's surface.

Variation of g with depth:



Consider a **particle of mass m which is in a deep mine on the earth. Ex. Coal mines – in Neyveli)**. Assume the **depth of the mine as d.** To Calculate g at a depth d, consider the following points. The **part of the Earth which is above the radius (R_e – d) do not contribute to the acceleration.** The result is proved earlier and is given as $g' = \frac{GM'}{(R_e-d)^2}$ Here M is the mass of the Earth of radius (R_e – d). Assuming the density of earth ρ to be constant,

$\rho = \frac{M'}{V'}$; $\frac{M'}{V'} = \frac{M}{V}$ and $M' = \frac{M}{V}V'$

$M' = \left(\frac{M}{\frac{4}{3}\pi R_e^3}\right)\left(\frac{4}{3}\pi(R_e-d)^3\right)$;

$M' = \frac{M}{R_e^3}(R_e - d)^3$

$g' = G\frac{M}{R_e^3}(R_e - d)^3 \cdot \frac{1}{(R_e-d)^2}$;

$g' = GM\frac{R_e\left(1-\frac{d}{R_e}\right)}{R_e^3}$

$g' = GM\frac{\left(1-\frac{d}{R_e}\right)}{R_e^2}$ thus $g' = g\left(1-\frac{d}{R_e}\right)$. Here also **g′<g** .

As depth increases, g′ decreases.

45. Derive the time period of satellite orbiting the Earth.

Time period of the satellite:

The distance covered by the satellite during one rotation in its orbit is equal to 2π (R_E +h) and time taken for it is the time period, T. Then

$$\frac{\text{Distance travelled}}{\text{Time taken}} = \frac{2\pi\,(RE+h)}{T}$$

From equation, $\sqrt{\frac{GM_E}{(R_E+h)}} = \frac{2\pi\,(RE+h)}{T}$ --------------- 1

$T = \frac{2\pi}{\sqrt{GM_E}}(R_E+h)^{\frac{3}{2}}$ ----------------- 2

Squaring both sides of the equation (2), we get $T^2 = \frac{4\pi^2}{GM_E}(R_E + h)^3$

$\frac{4\pi^2}{GM_E}$ = Constant say c, $T^2 = c\,(R_E + h)^3$ ------------- 3

Equation (3) implies that a satellite orbiting the **Earth has the same relation between time and distance as that of Kepler's law of planetary**

motion. For a satellite orbiting near the surface of the Earth, h is negligible compared to the radius of the Earth R_E . Then, $T^2 = \frac{4\pi^2}{GM_E} R_E^3$; $T^2 = \frac{4\pi^2}{\frac{GM_E}{R_E^2}}$

$T^2 = \frac{4\pi^2}{g} R_E$ Since $\frac{GM_E}{R_E^2} = g$; $T = 2\pi\sqrt{\frac{R_E}{g}}$

46. Derive an expression for energy of satellite.

Energy of an Orbiting Satellite

The total energy of a satellite orbiting the Earth at a distance h from the surface of Earth is calculated as follows; **The total energy of the satellite is the sum of its kinetic energy and the gravitational potential energy**. The **potential energy of the satellite is, U =** $\frac{GM_SM_E}{(R_E+h)}$

Here M_S - mass of the satellite, M_E- mass of the Earth,

R_E - radius of the Earth.

The Kinetic energy of the satellite is KE = ½ M_SV^2 -----------1

Here v is the orbital speed of the satellite and is equal to $v = \frac{GM_E}{(R_E+h)}$

Substituting the value of v in (1), the kinetic energy of the satellite becomes,

$$KE = \frac{1}{2}\frac{GM_SM_E}{2(R_E+h)}$$

Therefore the total energy of the satellite is $E = \frac{1}{2}\frac{GM_SM_E}{(R_E+h)} - \frac{GM_SM_E}{(R_E+h)}$

$$E = -\frac{GM_SM_E}{2(R_E+h)}$$

The negative sign in the total energy implies that the satellite is bound to the Earth and it cannot escape from the Earth.

47. Explain in detail the geostationary and polar satellites.

Geo-stationary and polar satellite

1) The satellites orbiting the Earth have different time periods corresponding to different orbital radii. Can we calculate the orbital **radius of a satellite if its time period is 24 hours is calculated below.** Kepler's third law is used to find the radius of the orbit.

$T^2 = \frac{4\pi^2}{GM_E}(R_E + h)^3$; $(R_E + h)^3 = \frac{GM_ET^2}{4\pi^2}$

$(R_E + h) = \left(\frac{GM_ET^2}{4\pi^2}\right)^{\frac{1}{3}}$

2) Substituting for the **time period (24 hrs = 86400 seconds**), mass, and **radius of the Earth, h turns out to be 36,000 km**. Such satellites are called **"geo-stationary satellites"**, since they appear to be stationary when seen from Earth.

3) Geo-stationary satellites for the purpose of telecommunication. Another type of **satellite which is placed at a distanceof 500 to 800 km** from the surface of the Earth orbits the Earth from north to south direction.

4) This type of satellite that **orbits Earth from North Pole to South Pole** is called a polar satellite. The **time period of a polar satellite is nearly 100 minutes and the satellite completes many revolutions in a day.**

5) **A Polar satellite covers a small strip of area from pole to pole during one revolution.** In the next revolution it covers a different strip of area since the Earth would have moved by a small angle. In this way polar satellites cover the entire surface area of the Earth.

48. Explain how geocentric theory is replaced by heliocentric theory using the ideaof retrograde motion of planets.

1) To explain this retrograde motion, Ptolemy introduced the concept of **"epicycle" in his geocentric model.** According to this theory, while the **planet orbited the Earth, it also underwent another circular motion termed as "epicycle".**

2) A combination of epicycle and circular motion around the Earth gave rise to **retrograde motion of the planets with respect to Earth.**

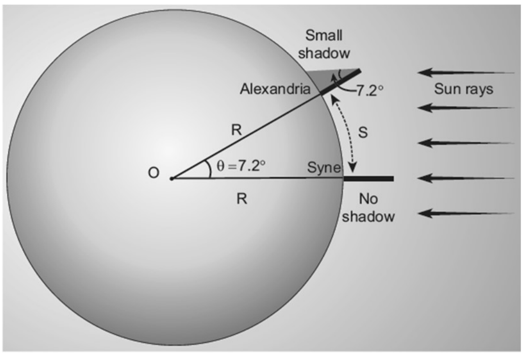
3) But Ptolemy's **model became more and more complex as every planet was found to undergo retrograde motion. In the 15th century, the Polish astronomer Copernicus proposed.**

4) The heliocentric model to explain this problem in a simpler manner. According to this model, **the Sun is at the center of the solar system and all planets orbited the Sun.**

5) The **retrograde motion of planets with respect to Earth is because of the relative motion of the planet with respect to Earth.**

49. Explain in detail the Eratosthenes method of finding the radius of Earth.

During noon time of summer solstice, the Sun's rays cast no shadow in the **city Syne which was located 500 miles away from Alexandria. At the same day and same time, he found that in Alexandria the Sun's rays made 7.2 degree with local vertical.** This difference of 7.2 degree was due to the curvature of the Earth.



The angle **7.2 degree is equivalent to $\frac{1}{8}$ radian. So, $\theta = \frac{1}{8}$ rad.**

If S is the length of the arc between the cities of Syne and Alexandria, and if R is radius of Earth, then S = R θ = 500 miles, so radius of the Earth

R = $\frac{500}{\theta}$ miles , R = 500 $\frac{miles}{\frac{1}{8}}$ R = 4000 miles.

1 mile is equal to 1.609 km. So, he measured the radius of the Earth to be equal to **R = 6436 km, which is amazingly close to the correct value of 6378 km.**

50. Describe the measurement of Earth's shadow (umbra) radius duringtotal lunar eclipse

1) It is possible to measure the radius of shadow of the Earth at the point where the Moon crosses.
2) When the Moon is inside the umbra shadow, it appears red in color. As soon as the Moon exits from the umbra shadow, it appears in crescent shape.
3) By finding the apparent radii of the Earth's umbra shadow and the Moon, the ratio of these radii can be calculated.
4) The apparent radius of Earth's umbra shadow = R_s= 13.2 cm
   The apparent radius of the Moon = R_m= 5.15 cm
   The ratio $\frac{R_S}{R_m}$ ≈2.56 .
   The radius of the Earth's umbra shadow is R_s= 2.56 x R_m.

UNIT – VII (PROPERTIES OF MATTER)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. Define stress and strain.

The **force per unit area is called as stress.** Stress, $\sigma = \frac{Force}{Area} = \frac{F}{A}$
The SI unit of **stress is N m^{-2} or Pascal (Pa)** and its dimension is **[$ML^{-1}T^{-2}$].**
The fractional change in the size of the object, in other words, strain measures the degree of deformation. Strain, e = $\frac{Change\ in\ Size}{Original\ size} = \frac{\Delta l}{l}$

2. State Hooke's law of elasticity.

Hooke's law is for a small deformation, when **the stress and strain are proportional to each other.**

3. Define Poisson's ratio.

The ratio of relative contraction (lateral strain) to relative expansion (longitudinal strain). It is denoted by the symbol μ.
Poisson s ratio, μ = **Lateral strain / Longitudinal strain**

4. Explain elasticity using intermolecular forces.

In a solid, inter-atomic forces bind two or more atoms together and the atoms occupy the positions of stable equilibrium. **When a deforming force is applied on a body, its atoms are pulled apart or pushed closer.** When the deforming force is removed, **inter-atomic forces of attraction or repulsion restore the atoms to their equilibrium positions. If a body regains its original shape and size after the removal of deforming force**, it is said to be elastic and the property is called elasticity.

5. Which one of these is more elastic, steel or rubber? Why?

Steel is **more elastic than rubber because the steel has higher young's modulus than rubber**. That's why, **if equal stress is applied on both steel and rubber, the steel produces less strain.**

6. A spring balance shows wrong readings after using for a long time. Why?

When the spring balances have been used for a long time, they **develop elastic fatigue in them and therefore the reading shown by such balances will be wrong.**

7. What is the effect of temperature on elasticity?

If the temperature of the substance increases, its elasticity decreases.

8. Write down the expression for the elastic potential energy of a stretched wire.

Consider a wire whose un-stretch length is L and area of cross section is A. Let a force produce an extension *l* and further assume that the elastic limit of the wire has not been exceeded and there is no loss in energy. Then, the work done by the force F is equal to the energy gained by the wire.

The work done in stretching the wire by d*l*, dW = F dl

The total work done in stretching the wire from 0 to l is

$$W = \int_0^l F\,dl \text{ ---------------1}$$

From Young's modulus of elasticity, $Y = \frac{F}{A} \times \frac{L}{l} \Rightarrow F = \frac{Y\,Al}{L}$ -------- 2

Substituting equation (2) in equation (1), we get

$$W = \int_0^l \frac{Y\,Al}{L}\,dl = \frac{Y\,Al^2}{L.2} = ½ .F\,l$$

$$W = \int \frac{Y\,Al'}{L}\,dl' = \frac{YA}{L}\frac{l'^2}{2}\Big|_0^l = \frac{YA}{L}\frac{l^2}{2} = \frac{1}{2}\left(\frac{YAl}{L}\right)l = \frac{1}{2}F\,l$$

$$W = \frac{1}{2}F\,l \text{ = Elastic potential energy.}$$

9. State Pascal's law in fluids.

If the **pressure in a liquid is changed at a particular point**, the change is transmitted to the entire liquid without being diminished in magnitude.

10. State Archimedes principle.

It states that when a **body is partially or wholly immersed in a fluid**, it experiences an **upward thrust equal to the weight of the fluid displaced** by it and its up-thrust acts through the centre of gravity of the liquiddisplaced.

11. What do you mean by up-thrust or buoyancy?

The **upward force exerted by a fluid that opposes the weight of an immersed object in a fluid** is called up-thrust or buoyant force and the phenomenon is called buoyancy.

12. State the law of floatation.

The law of floatation states **that a body will float in a liquid if the weight of the liquid displaced by the immersed part of the body equals the weight of the body.**

13. Define coefficient of viscosity of a liquid.

The coefficient of viscosity is defined as **the force of viscosity acting between two layers per unit area** and unit velocity gradient of the liquid. Its unit is **Nsm^{-2} and dimension is $[ML^{-1}T^{-1}]$.**

14. Distinguish between streamlined flow and turbulent flow.

Streamlined flow:

When a liquid flows such that each particle of the liquid passing through a point moves along the same path with the same velocity as its predecessor then the flow of liquid is said to be a streamlined flow.

The velocity of the particle at any point is constant. It is also referred to as steady or laminar flow.

The actual path taken by the particle of the moving fluid is called a streamline, which is a curve, the tangent to which at any point gives the direction of the flow of the fluid at that point.

Turbulent flow:

When the speed of the moving fluid exceeds the critical speed, $v_c$the motion becomes turbulent.

The velocity changes both in magnitude and direction from particle to particle.

The path taken by the particles in turbulent flow becomes erratic and whirlpool-like circles called eddy current or eddies.

15. What is Reynold's number? Give its significance.

Reynold's number(R_C) is **a dimensionless number, which is used to find out the nature of flow of the liquid. $R_C = \frac{\rho v D}{\eta}$**

Where, ρ- density of the liquid, v –The velocity of flow of liquid.

D- Diameter of the pipe, η - The coefficient of viscosity of the fluid.

16. Define terminal velocity.

The **maximum constant velocity acquired by a body while falling freely through a viscous medium** is called the terminal velocity.

17. Write down the expression for the Stoke's force and explain the symbolsinvolved in it.

Viscous force F acting on a spherical body of **radius r depends directly on**

i) radius (r) of the sphere

ii) velocity (v) of the sphere and

iii) coefficient of viscosity η of the liquid $F = 6\pi\eta r v$

18. State Bernoulli's theorem.

According to Bernoulli's theorem, **the sum of pressure energy, kinetic energy, and potential energy per unit mass of an incompressible, non-viscous fluid in a streamlined flow remains a constant.**

19. What are the energies possessed by a liquid? Write down their equations.

A liquid in a steady flow can possess three kinds of energy. They are (1) Kinetic energy, (2) Potential energy, and (3) Pressure energy, respectively.

KE = ½ mv^2 ----------- 1

PE = mgh -------------2 F x d = w = PV = pressure energy -------------3

20. Two streamlines cannot cross each other. Why?

No two streamlines can cross each other. If they doso, the **particles of the liquid at the point of intersection will have two different directions for their flow**, which will destroy the steady nature of the liquid flow.

21. Define surface tension of a liquid. Mention its S.I unit and dimension.

The surface tension of a liquid is defined as the energy per unit area of the surface of a liquid. (or) **The surface tension of a liquid is defined as the force of tension acting perpendicularly on both sides of an imaginary line of unit length drawn on the free surface of the liquid.**

Its unit is N m^{-1} and dimension is [MT^{-2}]

22. How is surface tension related to surface energy?

Consider a **rectangular frame of wire ABCD in a soap solution**. Let AB be the movable wire. Suppose the frame is dipped in soap solution, soap film is formed which pulls **the wire AB inwards due to surface tension**. Let F be the force due to surface tension, then F = (2T)l

Here, 2 is introduced because **it has two free surfaces**. Suppose AB is moved by **a small distance Δx to new a position A'B'.** Since the area increases, some work has to be done against the inward force due to surface tension.

Work Done = Force x distance = (2T) $l(\Delta x)$

Increases in area of the film ΔA = (2 l) (Δx) = $2l\Delta x$

Therefore, Surface energy = $\frac{\text{Work Done}}{\text{Increase in Surface area}}$

$= \frac{2Tl\Delta x}{2l\Delta x} = T$

Hence, the surface energy per unit area of a surface is numerically equal to the surface tension.

23. Define angle of contact for a given pair of solid and liquid.

The **angle between the tangent to the liquid surface at the point of contact and the solid surface** is known as the angle of contact.

24. Distinguish between cohesive and adhesive forces.

The force between the like molecules which holds the liquid together is called '**cohesive force**'.

When the liquid is in contact with a solid, the molecules of the these solid and liquid will experience an attractive force which is called '**adhesive force'.**

25. What are the factors affecting the surface tension of a liquid?

(1) **The presence of any contamination or impurities**considerably affects the **force of surface tension depending upon the degree of contamination.**

(2) **The presence of dissolved substances**can also **affect the value of surface tension**. For example, **a highly soluble substance like sodium chloride (NaCl) when dissolved in water (H_2O) increases the surface tension of water.** But the sparingly soluble substance **like phenol** or **soap solution when mixed in water decreases the surface tension of water.**

(3) **Electrification**affects the surface tension. **When a liquid is electrified, surface tension decreases. Since external force acts on the liquid surface due to electrification, area of the liquid surface increases** which acts against the contraction phenomenon of the surface tension. Hence, it decreases.

(4) **Temperature**plays a **very crucial role in altering the surface tension of a liquid.** Obviously, the surface tension decreases linearly with the rise of temperature.

26. What happens to the pressure inside a soap bubble when air is blown into it?

Pressure is greater inside the small build.

27. What do you mean by capillarity or capillary action?

The **rise or fall of a liquid in a narrow tube** is called capillarity or capillary action.

28. A drop of oil placed on the surface of water spreads out. But a drop of water place on oil contracts to a spherical shape. Why?

A **drop of oil placed on the surface of water spreads** because the force of **adhesion between water and oil molecules dominates the cohesive force** of oil molecules.

On the other hand, **cohesive force of water molecules dominates the adhesive force between water and oil molecules**. So **drop of water on oil contracts to a sphericalshape.**

29. State the principle and usage of Venturimeter.

Bernoulli's theorem is the **principle of Venturimeter**.

Venturimeter is **used to measure the rate of flow or flow speed of the incompressible fluid flowing through apipe.**

30. What are the applications of surface tension?

1) **Oil pouring on the water** reduces surface tension. So that the **floating mosquitos' eggs drown and killed.**
2) Finely adjusted surface tension of the liquid makes droplets of desired size, which **helps in desktop printing, automobile painting and decorativeitems.**
3) **Specks of dirt are removed** from the cloth when it is washed in detergents added hot water, which has low surfacetension.
4) **A fabric can be made waterproof, by adding suitable waterproof material (wax) to the fabric.** This increases the angle of contact due tosurface tension.

31. What physical quantity actually do we check by pressing the tyre after pumping?

After pumping the tyre, we actually check the compressibility of air by pressing the tyre. For smooth riding, reartyre should have less compressibility than the front.

32. Give some examples for surface tension.

Clinging of painting brush hairs, when taken out ofwater.
Needle float on thewater, Camphorboat.

33. How do water bug sand water striders walkon the surface ofwater?

When the water bugs or water striders are on the surface of the water, its Weight is balanced by the surface tension of the water. Hence, they can easily walk onit.

34. Whataretheapplicationsofviscosity?

1) Viscosity of liquids helps in choosing **the lubricants for various machinery parts. Low viscous lubricants** are used in light machinery parts and high viscous lubricants are used in heavy machineryparts.
2) As **high viscous liquids damp the motion**; they are used **in hydraulic brakes as brakeoil.**
3) **Blood circulation** through arteries and veins depends upon the viscosity offluids.
4) Viscosity is used in **Millikan's oil-drop method** tofind the **charge of an electron.**

35. Explain the Stoke's law application in raindrop falling.

According to Stoke's law, **terminal velocity is directly proportional to square of radius of the spherical body.** So that smaller raindrops having less terminal velocity float as cloud in air. When they gather as bigger drops get higher terminal velocity and start falling.

36. Define Young's modulus. Give its unit.

Young's modulus is defined as **the ratio of tensile or compressive stress to the tensile or compressive strain. Its unit is N m^{-2} or pascal.**

37. What are the applications of elasticity?

Elasticity is used in **structural engineering in which bridges and buildings are designed** such away that it can withstand load of flowing traffic, the force of winds and even its own weight.

The material of high Young's modulus is **used inconstructing beams.**

38. Define Pressure.Give its unit and dimension.

The pressure is defined as **the force acting per unit area. Its unit is Nm^{-2} or pascal and dimension is $[ML^{-1}T^{-2}]$.**

39. What is elasticity? Giveexamples.

Elasticity is the **property of a body in which it regains its original shape andsize after the removal of deforming force.**

Ex: Rubber, metals, steel ropes.

40. What is plasticity? Give anexample.

Plasticity is the **property of a body in which it does not regains its original shape and size after the removal of deforming force. Ex: Glass.**

CONCEPTUAL QUESTIONS

41. Why coffee runs up into a sugar lump (a small cube of sugar) when one cornerof the sugar lump is held in the liquid?

The coffee runs up into the pores of sugar lump due **to capillary action of the liquid.**

42. Why two holes are made to empty an oil tin?

When oil comes out from a hole of an oil tin, **pressure inside it decreased than the atmosphere.** Therefore, the surrounding air rushup in to the same hole prevents the oil to come out. Hence **two holes are made to empty the oiltin.**

43. We can cut vegetables easily with a sharp knife as compared to a blunt knife. Why?

Since the stress produced on **the vegetables by the sharp knife is higher than the blunt knife, vegetables can be cut easily with the sharp knife.**

44. Why the passengers are advised to remove the ink from their pens while goingup in an aero-plane?

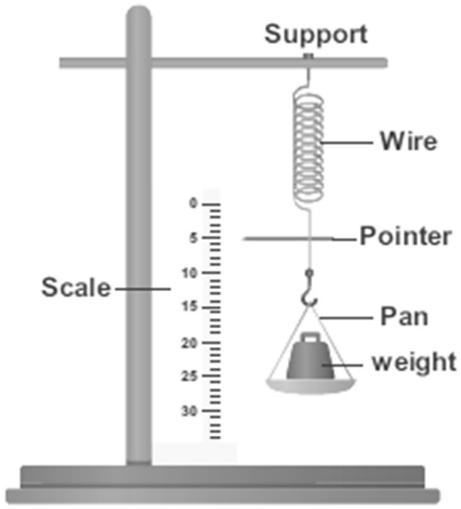
When an aero-plane ascends, **the atmospheric pressure is decreased.** Hence, the ink from the pen will leak out. So that, the passengers are advised **to remove the ink from their pens while going up in theaero-plane.**

45. We use straw to suck soft drinks, why?

When we suck the soft drinks through the straw, **the pressure inside the straw becomes less than the atmospheric pressure**. Due to the difference in pressure, the soft drink rises in the straw and we are able to enjoy it conveniently.

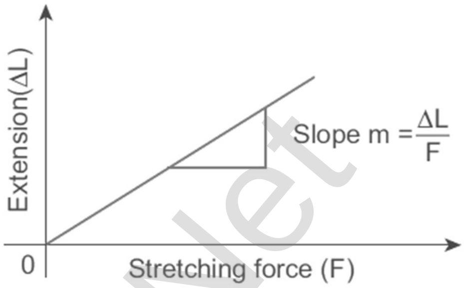
FIVE MARKS QUESTION WITH ANSWER

46. State Hooke's law and verify it with the help of an experiment.



1) Hooke's law is for a small deformation, when the stress and strain are proportional to each other.
2) It can be verified in a simple way by stretching a thin straight wire (stretches like spring) of length L and uniform cross-sectional area A suspended from a fixed-point O.
3) A pan and a pointer are attached at the free end of the wire as shown in Figure (a).
4) The extension produced on the wire is measured using a vernier scale arrangement. The experiment shows that for a given load, the corresponding stretching force is F and the elongation produced on the wire is ΔL.
5) It is directly proportional to the original length L and inversely proportional to the area of cross section A. A graph is plotted using F on the X- axis and ΔL on the Y- axis.

6) This graph is a straight line passing through the origin as shown in Figure (b).



Therefore, ΔL = (slope)F

Multiplying and dividing by volume,

V = A L,

F (slope) = $\frac{AL}{AL}\Delta L$

Rearranging, we get, $\frac{F}{A} = \left[\frac{L}{A(slope)}\right]\frac{\Delta L}{L}$

Therefore, , $\frac{F}{A}\,\alpha\left[\frac{\Delta L}{L}\right]$

Comparing with stress equation and strain equation, we get $\sigma\alpha\varepsilon$

i.e., the stress is proportional to the strain in the elastic limit.

47. Explain the different types of modulus of elasticity.

There are three types of elastic modulus.

(a) Young's modulus, (b) Rigidity modulus (or Shear modulus)

(c) Bulk modulus

Young's modulus:

When a wire is stretched or compressed, **then the ratio between tensile stress (or compressive stress) and tensile strain (or compressive strain) is defined as Young's modulus.**

$= \frac{\text{Tensile stress or compressive stress}}{\text{Tensile starin or compressive strain}}$ $Y = \frac{\sigma_t}{\varepsilon_t}$ or $Y = \frac{\sigma_c}{\varepsilon_c}$

The unit for Young modulus has the **same unit of stress because, strain has no unit. So, S.I. unit of Young modulus is N m^{-2}or pascal.**

Bulk modulus:

Bulk modulus is defined as **the ratio of volume stress to the volume strain.**

Bulk modulus, K = $\frac{\text{Normal (Perpendicular)stress or pressure}}{\text{Volume strain}}$

The normal stress or pressure is $\sigma_n = \frac{F_n}{\Delta A} = \Delta p$

The volume strain is $\varepsilon_v = \frac{\Delta V}{V}$

Therefore, Bulk modulus is K = $-\frac{\sigma_n}{\varepsilon_v} = -\frac{\Delta p}{\frac{\Delta V}{V}}$

The **negative sign in the equation means that when pressure is applied on the body, its volume decreases**. Further, the equation implies that a material can be easily compressed if it has a small value of bulk modulus.

The rigidity modulus or shear modulus:

The rigidity modulus is defined **as Rigidity modulus or Shear modulus,**

$$\eta_R = \frac{\text{Shearing stress}}{\text{Angle of shear or shearing strain}}$$

The shearing stress is $\sigma_s = \frac{\text{Trangential force}}{\text{Area over which it is applied}} = \frac{F_t}{\Delta A}$

The angle of shear or shearing strain $\varepsilon_s = \frac{x}{h} = \theta$

Therefore, Rigidity modulus is $\eta = \frac{\sigma_s}{\varepsilon_s} = \frac{\frac{F_t}{\Delta A}}{\frac{x}{h}} = \frac{\frac{F_t}{\Delta A}}{\theta}$

Further, the equationimplies, that **a material can be easily twisted if it has small value of rigidity modulus**. For example, **consider a wire, when it is twisted through an angle θ, a restoring torque is developed**, that is

$$\tau \propto \theta$$

This means that for a larger torque, wire will twist by a larger amount (angle of shear θ is large). Since, **rigidity modulus is inversely proportional to angle of shear, the modulus of rigidity is small.**

48. Derive an expression for the elastic energy stored per unit volume of a wire.

When a body is stretched, work is done against the restoring force (internal force). This **work done is stored in the body in the form of elastic energy. Consider a wire whose un-stretch length is L and area of cross section is A.** Let a force produce an extension *l* and further assume that the elastic limit of the wire has not been exceeded and there is no loss in energy. Then, the work done by the force F is equal to the energy gained by the wire.

The work done in stretching the wire by d*l*, dW = F dl

The total work done in stretching the wire from 0 to l is

$$W = \int_0^l F\,dl \text{ -----------------1}$$

From Young's modulus of elasticity, $Y = \frac{F}{A} \times \frac{L}{l} \Rightarrow F = \frac{Y\,Al}{L}$ --------- 2

Substituting equation (2) in equation (1), we get

$$W = \int_0^l \frac{Y\,Al}{L} dl = \frac{Y\,Al^2}{L.2} = \tfrac{1}{2}.Fl$$

$$W = \int \frac{Y\,Al'}{L} dl' = \frac{YA}{L}\frac{l'^2}{2}\Big|_0^l = \frac{YA}{L}\frac{l^2}{2} = \frac{1}{2}\left(\frac{YAl}{L}\right) l = \frac{1}{2} Fl$$

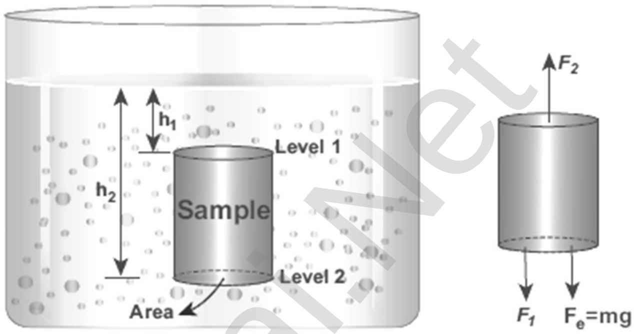
W = $\frac{1}{2}$ F*l* = Elastic potential energy.

Energy per unit volume is called energy density,

$$u = \frac{\text{Elastic potential energy}}{\text{Volume}} = \frac{\frac{1}{2}Fl}{AL} \frac{1}{2}\frac{F}{A}\frac{l}{L} = \frac{1}{2}(\text{Stress x Strain})$$

49. Derive an equation for the total pressure at a depth 'h' below the liquidsurface.

Consider a **water sample of cross-sectional area in the form of a cylinder. Let $h_1$and $h_2$be the depths from the air-water interface to level 1 and level 2 of the cylinder**, respectively as shown in Figure.



Let F1 be the force acting downwards on level 1 and F_2be the force acting upwards on level 2, such that, **$F_1 = P_1A$ and $F_2 = P_2A$.Let us assume the mass of the sample to be mand under equilibrium condition, the total upward force (F_2) is balanced by the total downward force (F_1+ mg),** in other words, the gravitational force will act downward which is being exactly balanced by the difference between the force. $F_2 - F_1$

$$F_2 - F_1 = mg = F_G$$

Where *m* is the mass of the water available in the sample element. Let ρ be the density of the water then, the mass of water available in the sample element is **$m = \rho V = \rho A (h_2 - h_1)$ $V = A (h_2 - h_1)$**

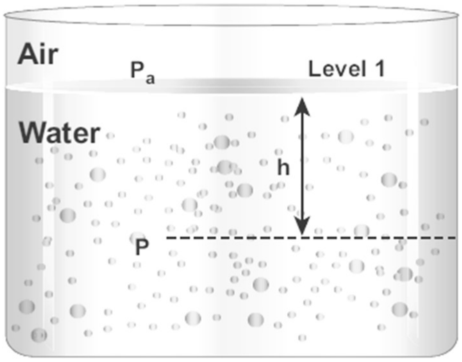
Hence, gravitational force, **$F_G = \rho A (h_2 - h_1) g$**

On substituting the value of W in equation

$$F_2 = F_1 + m g \Rightarrow P_2A = P_1A + \rho A(h_2 - h_1)g$$

Cancelling out A on both sides, $P_2 = P_1 + \rho(h_2 - h_1)g$

If we choose the level 1 at the surface of the liquid (i.e., **air-water interface) and the level 2 at a depth 'h' below the surface (as shown in Figure (b), then the value of h1 becomes zero ($h_1 = 0$)** and in turn P1 assumes the value of atmospheric pressure (say Pa). In addition, the pressure (P_2) at a depth becomes P. Substituting these values in equation, we get **$P = P_a + \rho gh$**



Which means, the pressure at a depth h is greater than the pressure on the surface of the liquid, where Pa is the **atmospheric pressure which is equal to 1.013×10^5Pa**. If the atmospheric pressure is neglected or ignored, then $P = \rho gh$

50. State and prove Pascal's law in fluids.

Hydraulic lift which is **used to lift a heavy load with a small force**. It is a **force multiplier.** It consists of two cylinders A and B connected to each other by a horizontal pipe, filled with a liquid (Figure). They are fitted with **frictionless pistons of cross sectional areas $A_1$and A_2(A_2> A_1). Suppose a downward force F is applied on the smaller piston**, the pressure of the liquid under this piston increases to P$\left(\text{where}, P = \frac{F_1}{A_1}\right)$. But according to Pascal's law, this increased pressure P is transmitted undiminished in all directions. So a pressure is exerted on piston B. Upward force on piston B is

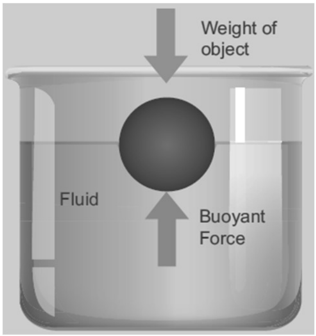
$$F_2 = P x A_2 = \frac{F_1}{A_1} x A_2 \Rightarrow F_2 = \frac{A_2}{A_1} x F_1$$

Therefore by **changing the force on the smaller piston A, the force on the piston B has been increased by the factor** $\frac{A_2}{A_1}$ and this factor is called the mechanical advantage of the lift.

51. State and prove Archimedes principle.

It states that when a **body is partially or wholly immersed in a fluid**, it experiences an upward thrust equal to **the weight of the fluid displaced by it and its up-thrust acts through the centre of gravity of the liquiddisplaced.**

Up-thrust or buoyant force = weight of liquid displaced.



52. Derive the expression for the terminal velocity of a sphere moving in a high viscous fluid using stokes force.

Expression for terminal velocity:

Consider a sphere of radius *r* which falls freely through a highly viscous liquid of coefficient of viscosity η. Let the density of the material of the sphere be ρ and the density of the fluid be σ.

Gravitational force acting on the sphere, F_G = mg = $\frac{4}{3}\pi r^3 \rho g$

(Downward force)

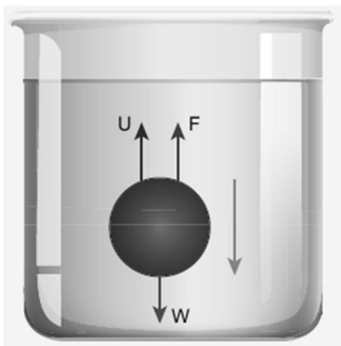
Up thrust, U = $\frac{4}{3}\pi r^3 \sigma g$ (upward force)

Viscous force F = $6\pi\eta r v_t$

At terminal velocity v_t, downward force = upward force

F_G – U = F ⇒ $\frac{4}{3}\pi r^3 \rho g - = \frac{4}{3}\pi r^3 \sigma g$ = $6\pi\eta r v_t$

$V_t = \frac{2}{9} x \frac{r^2(\rho-\sigma)}{\eta} g \Rightarrow V_t \propto r^2$



Here, it should be noted that the terminal speed of the sphere is directly proportional to the square of its radius. If σ is greater than ρ, then the term (ρ - σ) becomes negative leading to a negative terminal velocity.

53. Derive Poiseuille's formula for the volume of a liquid flowing per second through a pipe under streamlined flow.

Consider a liquid flowing steadily through a horizontal capillary tube. Let v = $\left(\frac{V}{t}\right)$be the volume of the liquid flowing out per second through a **capillary tube. It depends on (1) coefficient of viscosity (η) of the liquid, (2) radius ofthe tube (r), and (3) the pressure gradient**$\left(\frac{P}{l}\right)$. Then, v $\alpha \eta^a r^b \left(\frac{P}{l}\right)^c$;

v = $k\eta^a r^b \left(\frac{P}{l}\right)^c$ where, kis a dimensionless constant. Therefore,

[v] = $\frac{\text{Volume}}{\text{time}}$ = [L^3T^{-1}], $\left[\frac{dP}{dx}\right] = \frac{\text{Pressure}}{\text{distance}}$ = [$ML^{-2}T^{-2}$],

[η] = [$ML^{-1}T^{-1}$] and [r] = [L]

Substituting in equation, So, equating the powers of M, L, and T on both sides, we get a + c = 0, −a + b −2c =3, and −a −2c = −1

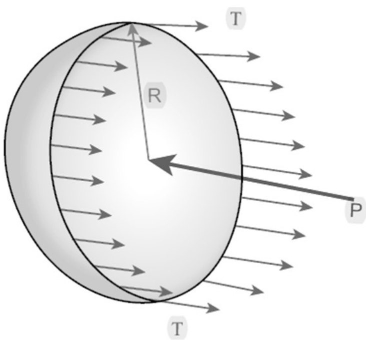
We have three unknowns *a*, *b*, and *c.* We have three equations, on solving, we get a = −1, b = 4, and c = 1

Therefore, equation becomes, v= k$\eta^{-1} r^4 \left(\frac{P}{l}\right)^1$

Experimentally, the value of *k* is shown to be $\frac{\pi}{8}$, we have v = $\frac{\pi r^4 P}{8\eta l}$

54. Obtain an expression for the excess of pressure inside a i) liquid drop ii) liquid bubble iii) air bubble.

i) Excess of pressure inside air bubble in a liquid.

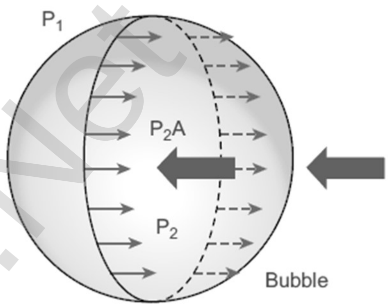


Consider an air bubble of radius R inside a liquid having surface tension T as shown in Figure (a). Let $P_1$and P_2be the pressures outside and inside the air bubble, respectively. Now, the excess pressure inside the air bubble is

ΔP = P_1− P_2. To find the excess pressure inside the air bubble, let us consider the forces acting on the air bubble.

ii) Excess pressure inside a soap bubble.

Consider a soap bubble of radius *R* and the surface tension of the soap bubble be Tas shown in Figure. **A soap bubble has two liquid surfaces in contact with air, one inside the bubble and other** outside the bubble. Therefore, the force on the soap bubble due to surface tension is **2×2πRT.** The various forces acting on the soap bubble are,



i) **Force due to surface tension F_T = 4πRT towards right**

ii) Force due to **outside pressure F_{P1}= $P_1πR^2$towards right**

iii) Force due to **inside pressure F_{P2}= $P_2πR^2$towards left**

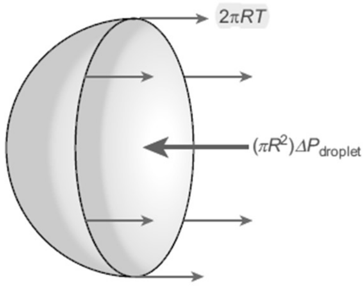
As the bubble is in equilibrium, $F_{P2}=F_T + F_{P1}$

$$P_2\pi R^2 = 4\pi RT + P_1\pi R^2 \Rightarrow (P_2 - P_1)\pi R^2 = 4\pi RT$$

Excess pressure is $\Delta P = P_2 - P_1 = \frac{4T}{R}$

iii) Excess pressure inside the liquid drop

Consider a liquid drop of radius R and the surface tension of the liquid is T as shown in Figure. The various forces acting on the liquid drop are,



i) Force due to **surface tension F_T = 2πRT towards right**

ii) Force due to **outside pressure F_{P1}= $P_1πR^2$towards right**

iii) Force due to inside pressure F_{P2}= $P_2πR^2$towards left

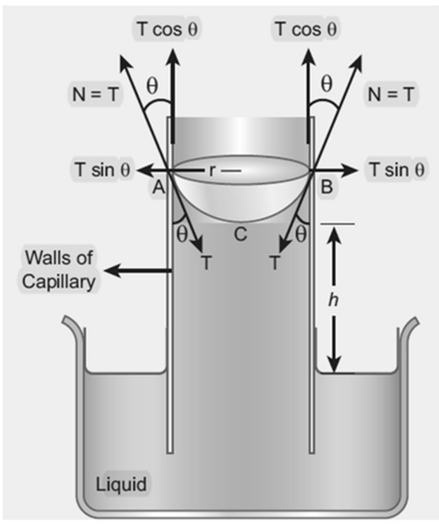
As the liquid drop is in equilibrium, $F_{P2}=F_T + F_{P1}$

$$P_2\pi R^2 = 2\pi RT + P_1\pi R^2 \Rightarrow (P_2 - P_1)\pi R^2 = 2\pi RT$$

Excess pressure is $\Delta P = P_2 - P_1 = \frac{2T}{R}$

55. What is capillarity? Obtain an expression for the surface tension of a liquid by capillary rise method.

Consider a capillary tube which is held vertically in a beaker containing water; **the water rises in the capillary tube to a height hdue to surface tension.**



The surface tension force F_T, acts along the tangent at the point of contact downwards and its reaction force upwards. Surface tension T, is resolved into **two components i) Horizontal component Tsinθ and ii) Vertical componentTcosθ acting upwards**, all along the whole circumference of the meniscus.

Total upward force = (Tcosθ) (2πr) = 2πrTcosθ

Where θ is the angle of contact, *r* is the radius of the tube. Let ρ be the density of water and *h* be the height to which the liquid rises inside the tube.

$$\text{Then,}\begin{pmatrix}\text{the volume of}\\ \text{liquid column in}\\ \text{the tube, V}\end{pmatrix}=\begin{pmatrix}\text{Volume of the liquid}\\ \text{column of radius r}\\ \text{height h}\end{pmatrix}+\begin{pmatrix}\text{Volume of liquid of}\\ \text{radius r and height}\\ \text{r} - \text{Volume of the}\\ \text{hemisphere of radius r}\end{pmatrix}$$

$$V = \pi r^2 h + \left(\pi r^2 x\, r - \frac{2}{3}\pi r^3\right) \Rightarrow \pi r^2 h + \frac{1}{3}\pi r^3$$

The upward force supports the weight of the liquid column above the free surface, therefore,

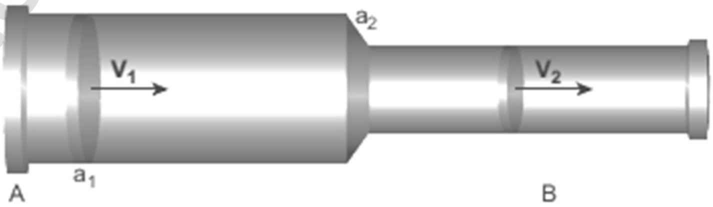
$$2\pi r T \cos\theta = \pi r^2\left(h + \frac{1}{3}r\right)\rho g \Rightarrow T = \frac{r\left(h+\frac{1}{3}r\right)\rho g}{2\cos\theta}$$

If the capillary is a very fine tube of radius (i.e., radius is very small) then $\frac{r}{3}$ can be neglected when it is compared to the height h. Therefore,

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

56. Obtain an equation of continuity for a flow of fluid on the basis of conservationof mass.

Consider a pipe AB of varying cross sectional area $a_1$and $a_2$such that$a_1 > a_2$. A non-viscous and incompressible liquid flows steadily through the pipe, with velocities $v_1$and $v_2$in area $a_1$and a_2, respectively as shown in Figure.



Let $m_1$be the mass of fluid flowing through section *A* in time Δt,

$$\mathbf{m_1 = (a_1 v_1 \Delta t)\,\rho}$$

Let $m_2$be the mass of fluid flowing through section *B* in time Δ*t*,

$$\mathbf{m_2 = (a_2 v_2 \Delta t)\,\rho}$$

For an **incompressible liquid, mass is conserved $m_1 = m_2$**

$$a_1 v_1\,\Delta t\,\rho = a_2 v_2 \Delta t\,\rho$$

$$\mathbf{a_1 v_1 = a_2 v_2 \Rightarrow a\,v = constant}$$

which is called **the equation of continuity and it is a statement of conservation of mass in the flow of fluids.**

In general, a v = constant, which means that the volume flux or flow rate remains constant throughout the pipe. In other words, the smaller the cross section, greater will be the velocity of the fluid.

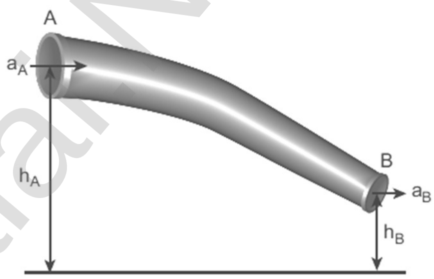
57. State and prove Bernoulli's theorem for a flow of incompressible, non-viscous, and streamlined flow of fluid.

Bernoulli's theorem:

According to Bernoulli's theorem, **the sum of pressure energy, kinetic energy, and potential energy per unit mass of an incompressible, non-viscous fluid in a streamlined flow remains a constant.**

$\frac{P}{\rho} + \frac{1}{2}v^2 + gh =$ **Constant**, this is known as Bernoulli's equation.

Proof:



Let us consider a flow of liquid through a pipe AB as shown in Figure. Let Vbe the volume of the liquid when it enters Ain a time *t* which is equal to the volume of the liquid leaving *B* in the same time. Let a_A, $v_A$and $P_A$be the area of cross section of the tube, velocity of the liquid and pressure exerted by the liquid at *A* respectively.

Let the **force exerted by the liquid at Ais $F_A = P_A a_A$**

Distance travelled by the liquid in time t is $d = v_A t$

Therefore, the work done is $W = F_A d = P_A a_A v_A t$

But $a_A v_A t = a_A d = V$, volume of the liquid entering at A.

Thus, the **work done is the pressure energy (at A), $W = F_A d = P_A V$**

Pressure energy per unit volume at A = $\frac{\text{Pressure energy}}{\text{Volume}} = \frac{P_A V}{V} = P_A$

Pressure energy per unit mass at A = $\frac{\text{Pressure energy}}{\text{Mass}} = \frac{P_A V}{m} = \frac{P_A}{\frac{m}{V}} = \frac{P_A}{\rho}$

Since m is the mass of the liquid entering at A in a given time, therefore, pressure energy of the liquid at A is $E_{PA} = P_A V = P_A V \times \left(\frac{m}{m}\right) = m\frac{P_A}{\rho}$

Potential energy of the liquid at A, $P_{EA} = mg\,h_A$,

Due to the flow of liquid, the **kinetic energy of the liquid at A, $KE_A = ½\, mV_A^2$**

Therefore, the total energy due to the flow of liquid at A,

$$E_A = EP_A + KE_A + PE_A\ ;\ \mathbf{E_A = m\frac{P_A}{\rho} + ½\, mV_A^2 + mgh_A}$$

Similarly, let a_B, v_B, and $P_B$be the area of cross section of the tube, velocity of the liquid, and pressure exerted by the liquid at B. Calculating the total energy at E_B, we get $\mathbf{E_B = m\frac{P_B}{\rho} + ½\, mV_B^2 + mgh_B}$

From the **law of conservation of energy, $E_A = E_B$**

$$E_A = m\frac{P_A}{\rho} + ½\, mV_A^2 + mgh_A = E_B = m\frac{P_B}{\rho} + ½\, mV_B^2 + mgh_B$$

$$\mathbf{\frac{P_A}{\rho} + ½\, V_A^2 + gh_A = \frac{P_B}{\rho} + ½\, V_B^2 + gh_B = constant}$$

Thus, the above equation can be written as $\frac{P}{\rho g} + \frac{1}{2}\frac{v^2}{g} + h =$ **constant**

58. Describe the construction and working of venturimeter and obtain an equationfor the volume of liquid flowing per second through a wider entry of the tube.

Venturimeter:

This device is used **to measure the rate of flow (or say flow speed) of the incompressible fluid flowing through a pipe**. It works on the principle of Bernoulli's theorem.

Let P_1be the pressure of the fluid at the wider region of the tube A. Let us assume that the fluid of density 'ρ' flows from the pipe with speed 'v_1' and into the narrow region, its speed increases to 'v_2'. According **to the Bernoulli's equation, this increase in speed is accompanied by a decrease in the fluid pressure P_2at the narrow region of the tube B.** Therefore, the **pressure difference between the tubes A and B is noted by measuring the height difference ($\Delta P = P_1 - P_2$) between the surfaces of the manometer liquid.**

From the equation of continuity, we can say that

$Av_1 = a\,v_2$which means that $V_2 = \frac{A}{a} v_1$

Using Bernoulli's equation, $P_1 + \rho\frac{v1^2}{2} = P_2 + \rho\frac{v2^2}{2} = P_2 + \rho\frac{1}{2}\left(\frac{A}{a}v_1\right)^2$

From the above equation, the pressure difference,

$\Delta P = P_1 - P_2 = \rho\frac{V1^2}{2}\left(\frac{A^2 - a^2}{a^2}\right)$

Thus, the speed of flow of fluid at the wide end of the tube A

$v_1^2 = \frac{2(\Delta P)a^2}{\rho(A^2 - a^2)} \Rightarrow V_1 = \sqrt{\frac{2(\Delta P)a^2}{\rho(A^2 - a^2)}}$

The volume of the liquid flowing out per second is

$AV_1 = \sqrt{\frac{2(\Delta P)a^2}{\rho(A^2 - a^2)}}$

$= aA\sqrt{\frac{2(\Delta P)}{\rho(A^2 - a^2)}}$

59. Write any two applications of Bernoulli's theorem.

(a) Blowing off roofs during wind storm:

1) In olden days, **the roofs of the huts or houses were designed with a slope**. One important scientific reason is that as per the Bernoulli's principle, **it will be safeguarded except roof during storm or cyclone.**
2) **During cyclonic condition, the roof is blown off without damaging the other parts of the house.**
3) In accordance with the **Bernoulli's principle, the high wind blowing over the roof creates a low-pressure P_1.**
4) The pressure under the roof $P_2$is greater. Therefore, this **pressure difference ($P_2 - P_1$) creates an up thrust and the roof is blown off.**

(b) Aerofoil lift:

1) The wings of an airplane (aerofoil) are so designed that its **upper surface is more curved than the lower surface and the front edge** is **broader than the real edge.**
2) As the aircraft moves, the **air moves faster above the aerofoil than at the bottom.**
3) According to Bernoulli's Principle, **the pressure of air below is greater than above, which creates an up-thrust called the dynamic lift to the aircraft.**

60. Write the applications of elasticity.

1) The elastic behavior is one such property which especially decides the **structural design of the columns and beams of a building.**
2) As far as the **structural engineering is concerned**, the amount of stress that the **design could withstand is a primary safety factor**.
3) A bridge has to be designed in such a way that it should have the **capacity to withstand the load of the flowing traffic, the force of winds,** and even its own weight.
4) The elastic behavior or in other **words the bending of beams is a major** concern over **the stability of the buildings or bridges.**
5) To reduce the bending of a beam for a given load, one should **use the material with a higher Young's modulus of elasticity (Y).**
6) The Young's modulus of steel is **greater than aluminium or copper. Iron comes next to steel.**
7) This is the reason why steel is mostly preferred in **the design of heavy duty machines and iron rods in the construction of buildings**.

UNIT – VIII (HEAT AND THERMODYNAMICS)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. 'An object contains more heat'- is it a right statement? If not why?

Heat is not a quantity. **Heat is energy in transit which flows from higher temperature object to lower temperature object.** Once the heating process is stopped we cannot use the word heat. When we use the word 'heat', it is the **energy in transit but not energy stored in the body.** An Object has more heat is wrong, instead object is hot will be appropriate.

2. Obtain an ideal gas law from Boyle's and Charles' law.

1) Acceleration to Boyle's law P $\alpha \frac{1}{V}$
2) Acceleration to Charle's law V α T. By combining these two equations Wehave PV = CT. Here C is a positive constant.
3) So we can write the constant C as k times the number of particles N. Here k is the **Boltzmann constant ($1.381\times10^{-23}JK^{-1}$)** and it is found to be a **universal constant**. So the **ideal gas law** can be stated as follows **PV = NkT**

3. Define one mole.

One mole of any substance is**the amount of that substance whichcontains Avogadro number (N_A) of particles (such as atoms or molecules**).

4. Define specific heat capacity and give its unit.

Specific heat capacity of a substance is defined as **the amount of heat energy required to raise the temperature of 1kg of a substance by 1 Kelvin or 1°C**

$\Delta Q = ms\,\Delta T$; Therefore, s = $\frac{1}{m}\frac{\Delta Q}{\Delta T}$

Where, s – Specific heat capacity of a substance and its value depends only on the nature of the substance not amount of substance.

ΔQ - Amount of heat energy ; ΔT - Change in temperature ;

m – Mass of the substance; **The SI unit for specific heat capacity is $Jkg^{-1}K^{-1}$**

5. Define molar specific heat capacity.

Molar specific heat capacity is defined as **heat energy required to increase the temperature of one mole of substance by 1K or 1°C.** C = $\frac{1}{\mu}\frac{\Delta Q}{\Delta T}$

Here C is known as molar specific heat capacity of a substance and μ is number of moles in the substance.

The **SI unit for molar specific heat capacity is J mol^{-1} K^{-1}**

6. **What is a thermal expansion?**

Thermal expansion is**the tendency of matter to change in shape, area, and volume due to a change in temperature.**

All three states of matter (solid, liquid and gas) expand when heated. When **a solid is heated, its atoms vibrate withhigher amplitude** about their fixed points. The relative change in the size of solids is small.

7. **Give the expressions for linear, area and volume thermal expansions.**

Linear Expansion:

$\alpha_L = \frac{\Delta L}{L\Delta T}$; Where, αL = coefficient of linear expansion.

ΔL = Change in length; L = Original length; ΔT = Change in temperature.

Area Expansion:

$\alpha_A = \frac{\Delta A}{A\Delta T}$; Where, αA = coefficient of area expansion.

ΔA = Change in area; A = Original area; ΔT = Change in temperature

Volume Expansion:

$\alpha_V = \frac{\Delta V}{V\Delta T}$Where, αV = coefficient of volume expansion;

ΔV = Change in volume; V = Original volume; ΔT = Change in temperature. Unit of coefficient of linear, area and volumetric expansion of solids is$^\circ C^{-1}$ or K^{-1}

8. **Define latent heat capacity. Give its unit.**

Latent heat capacity of a substance is defined **as the amount of heat energy required to change the state of a unit mass of the material.**

$Q = m \times L ; L = \frac{Q}{m}$

Where L = Latent heat capacity of the substance; Q = Amount of heat m = mass of the substance. The SI unit for Latent heat capacity is J kg^{-1}.

9. **State Stefan-Boltzmann law.**

Stefan Boltzmann law states that, **the total amount of heat radiated per second per unit area of a black body is directly proportional to the fourth power of its absolute temperature.**

$E \propto T^4$ or $E = \sigma T^4$; Where, **σ is known as Stefan's constant**. Its value is 5.67×10^{-8} Wm^{-2} k^{-4}

10. What is Wien's law?

Wien's law states that, **the wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the black body.** $\lambda_m \, \alpha \, \frac{1}{T}$ or $\lambda_m = \frac{b}{T}$. Where, **b is known as Wien's constant. Its value is 2.898× 10^{-3} m K**

11. Define thermal conductivity. Give its unit.

The **quantity of heat transferred through a unit length of a material in a direction normal to unit surface area due to a unit temperature difference under steady state conditions** is known as thermal conductivity of a material.

$\frac{Q}{L} = \frac{KA\Delta T}{L}$; Where, K is known as the coefficient of thermal conductivity.

The SI unit **of thermal conductivity is J s^{-1} m^{-1} K^{-1} or W m^{-1} K^{-1}.**

12. What is a black body?

A black body is an object **that absorbs all electromagnetic radiations. It is a perfect absorber and radiator of energy with no reflecting power.**

13. What is a thermodynamic system? Give examples.

Thermodynamic system:

A thermodynamic system is a finite part of the universe. It is a collection of **large number of particles** (atoms and molecules) specified by certain parameters called pressure (P), Volume (V) and Temperature (T). The remaining part of the universe is called surrounding. Both are separated by a boundary.

Examples: A thermodynamic system can be liquid, solid, gas and radiation. Bucket of water, Air molecules in the room, Human body, Fish in the sea.

14. What are the different types of thermodynamic systems?

Open system can **exchange both matter and energy** with the environment.

Closed systemexchange energy, but not matter with the environment.

Isolated system can **exchange neither energy nor matter** with the environment.

15. What is meant by 'thermal equilibrium'?

Two systems are said to be in **thermal equilibrium with each other if they are at the same temperature, which will not change with time**.

16. What is mean by state variable? Give example.

In thermodynamics, the state of a thermodynamic system is **represented by a set of variables called thermodynamic variables.**

Examples: Pressure, temperature, volume and internal energy etc.

The values of these **variables completely describe the equilibrium state of a thermodynamic system**.

17. What are intensive and extensive variables? Give examples.

Extensive variabledepends on the size or mass of the system.

Example: Volume, total mass, entropy, internal energy, heat capacity etc.

Intensive variablesdo not depend on the size or mass of the system.

Example: Temperature, pressure, specific heat capacity, density etc.

18. What is an equation of state? Give an example.

Equation of state:

The equation which connects the state variables in a specific manner is called equation of state. **A thermodynamic equilibrium is completely specified by these state variables by the equation of state**. If the system is not in thermodynamic equilibrium, then **these equations cannot specify the state of the system.**

Example of equation of state called vander Waals equation. Real gases obey this equation at thermodynamic equilibrium. The air molecules in the room truly obey vander Waals equation of state. But at room temperature with low density we can approximate it into an ideal gas.

19. State Zeroth law of thermodynamics.

The zeroth law of thermodynamics states that**if two systems, A and B, are in thermal equilibrium with a third system, C, then A and B are in thermal equilibrium with each other.**

20. Define the internal energy of the system.

The internal energy of a thermodynamic system is **the sum of kinetic and potential energies of all the molecules of the system with respect to the center of mass of the system.**

The energy due to molecular motion including translational, rotational and vibrational motion is called internal kinetic energy (E_K) The energy due to molecular interaction is called internal potential energy (E_P).

Example: Bond energy. $U = E_K + E_P$

21. Are internal energy and heat energy the same? Explain.

No, but they are related. If heat energy is added to substance, its **internal energy will increase**. Internal energy is a means are of the amount of kinetic and potential energy possessed by particles in a substation.

Heat energy concerns only transfer of internal energy from the hotter to a colder body.

22. Define one calorie.

The amount of heat required at a pressure of standard atmosphere to **raise the temperature of 1g of water 1^{0}C.**

23. Did joule converted mechanical energy to heat energy? Explain.

1) Yes, in his experiment, **two masses were attached with a rope and a paddle wheel. When these masses fall through a distance h due to gravity, both the masses lose potential energy equal to 2mgh.**
2) When the masses fall, **the paddle wheel turns. Due to the turning of wheel inside water**, frictional force comes in between the water and the paddle wheel.
3) This causes a **rise in temperature of the water**. This implies that gravitational potential energy is converted to internal energy of water.
4) The **temperature of water increases due to the work done by the masses**. In fact, Joule was able to show that the mechanical work has the same effect as giving heat.

24. State the first law of thermodynamics.

Change in internal energy (ΔU) of the system is **equal to heat supplied to the system (Q) minus the work done by the system (W) on the surroundings.**

25. Can we measure the temperature of the object by touching it?

1) No, when you **stand bare feet with one foot on the carpet and the other on the tiled floor, your foot on tiled floor feels cooler than the foot on the carpet** even though both the tiled floor and carpet are at the same room temperature.
2) It is because the **tiled floor transfers the heat energy to your skin at higher rate than the carpet.** So the skin is not measuring the actual temperature of the object; instead it measures the rate of heat energy transfer.
3) But if we place a **thermometer on the tiled floor or carpet it will show the same temperature.**

26. Give the sign convention for Q and W.

System gains heat	-	Q is positive
System loses heat	-	Q is negative
Work done on the system	-	W is negative
Work done by the system	-	W is positive

27. Define the quasi-static process.

A quasi-static process is an **infinitely slow process in which the system changes its variables (P,V,T)** so slowly such that it remains in **thermal,mechanical and chemical equilibrium with its surroundings throughout**. By this infinite slow variation, the system is always almost close to equilibrium state.

28. Give the expression for work done by the gas.

In general the work done by the gas by **increasing the volume from V_i to V_f is given by W =** $\int_{V_f}^{V_i} PdV$

29. What is PV diagram?

PV diagram is a **graph between pressure P and volume V of the system.** The P-V diagram is **used to calculate the amount of work done by the gas during expansion** or on the gas during compression.

30. Explain why the specific heat capacity at constant pressure is greater than the specific heat capacity at constant volume.

Because when heat is added at constant pressure the substance, expands and work. i.e. **more amount of energy has to be supplied to a constant pressure to increase the system's temperature by the same amount.** Some of this energy is lost due to expansion work done by the system.

31. Give the equation of state for an isothermal process.

The equation of state for **isothermal process is given by PV = Constant**

32. Give an expression for work done in an isothermal process.

$$W = \mu RT \text{ in } \left(\frac{V_f}{V_i}\right)$$

33. Express the change in internal energy in terms of molar specific heat capacity.

If Q is the heat supplied to mole of a gas at constant volume and if the temperature changes by an amount ΔT , we have **Q = $\mu C_v \Delta T$** -------------*1*

By applying the first law of thermodynamics for this constant volume process (W=0, since dV=0), we have **Q = ΔU –** *0* -----------*2*

By comparing the equations (1) and (2), $\Delta U = \mu C_v \Delta T$ or $C_v = \frac{1}{\mu}\frac{\Delta U}{\Delta T}$

If the limit ΔTgoes to zero, we can write $C_v = \frac{1}{\mu}\frac{dU}{dT}$

Since the temperature and internal energy are state variables, the above relation holds true for any process.

34. Apply first law for (a) an isothermal (b) adiabatic (c) isobaric processes.

Isothermal: Q = W ; Q – Heat ; W – Wire

Adiabatic: ΔU = W Change internal Energy; **Isobaric:**ΔU = Q – PΔU

35. Give the equation of state for an adiabatic process.

The equation of state for an adiabatic process is given by **PV^{γ} = Constant.**Here γ is called adiabatic exponent $\left(\gamma = \frac{C_p}{C_v}\right)$ which depends on the nature of the gas. **The equation implies that if the gas goes from an equilibrium state (P_i, V_i) to another equilibrium state (P_f ,V_f) adiabatically then it satisfies the relation.**

36. Give an equation state for an isochoric process.

The equation of state for an **isochoric process** is given by P= $\left(\frac{\mu R}{V}\right)$T,

Where, $\left(\frac{\mu R}{V}\right)$ = Constant

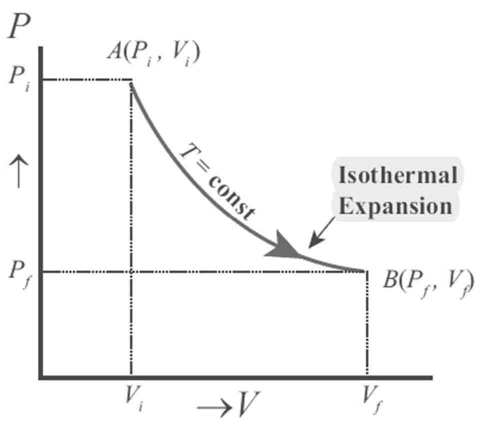
37. If the piston of a container is pushed fast inward. Will the ideal gas equationbe valid in the intermediate stage? If not, why?

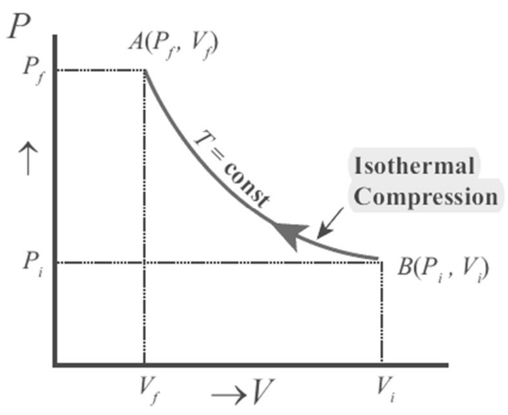
Decrease in volume leading to increase in temperature work is done on the gas. Ideal gas equation PV = RT. When piston be pushed further the parameters V and Rare taken as constant. The equation becomes

P = kT. i.e P α T

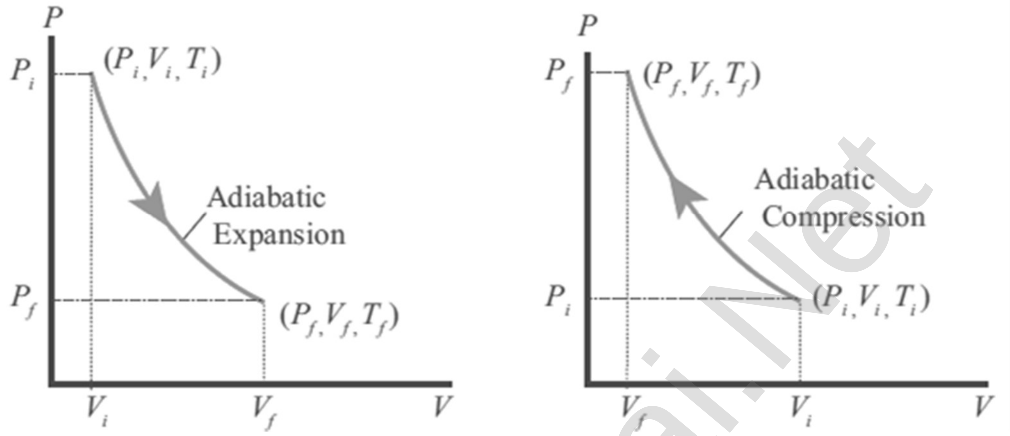
38. Draw the PV diagram for ;

a. Isothermal process

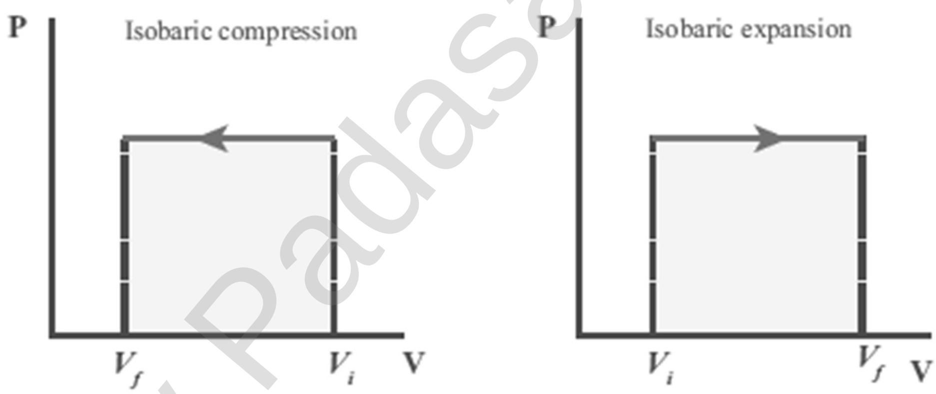




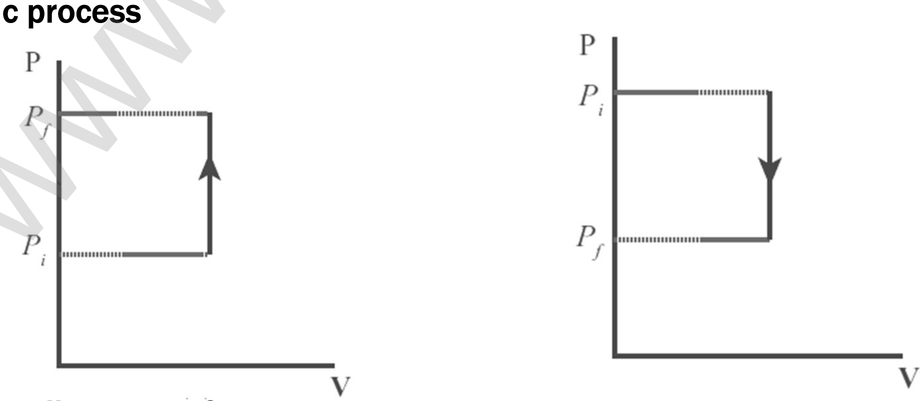
b. Adiabatic process



c. isobaric process



d. Isochoric process



39. **What is a cyclic process?**

This is a thermodynamic process in which the thermodynamic system returns **to its initial state after undergoing a series of changes**. Since **the system comes back to the initial state, the change in the internal energy iszero.** In cyclic process, **heat can flow in to system and heat flow out of the system.**

40. What is meant by reversible and irreversible processes?

Reversible process: A thermodynamic process can be considered **reversible only if it possible to retrace the path in the opposite direction in sucha way that the system and surroundings pass through the same states** as in the initial, direct process. Example: **A quasi–static isothermal expansion of gas, slow compression and expansion of a spring.**

Irreversible process: All natural processes are irreversible. Irreversible process cannot be plotted in a PV diagram, because these processes cannothave unique values of pressure, temperature at every stage of the process.

41. State Clausius form of the second law of thermodynamics

"Heat always flows from hotter object to colder object spontaneously". This is known as the **Clausius form of second law of thermodynamics.**

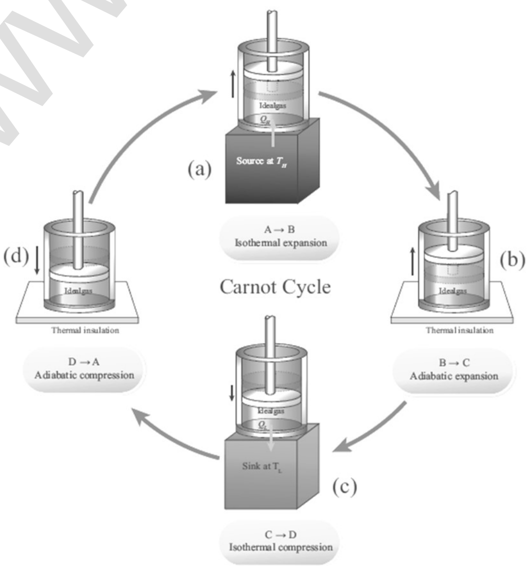
42. State Kelvin-Planck statement of second law of thermodynamics.

Kelvin-Planck statement: It is impossible to **construct a heat engine that operates in a cycle, whose sole effect is to convert the heat completely into work.** This implies that **no heat engine in the universe can have 100% efficiency.**

43. Define heat engine.

Heat engine is **a device which takes heat as input and converts this heat in to work by undergoing a cyclic process.**

44. What are processes involves in a Carnot engine?



45. Can the given heat energy be completely converted to work in a cyclic process? If not, when can, the heat can completely have converted to work?

1) No, In a cyclic process, **the complete heat energy is not completely converted to work.** The whole heat cannot be converted into work, as it will violate second law of thermodynamics.
2) In an Isothermal process **the whole heat can be converted into work. For an isothermal process dQ = dT**, which shows that whole heat can be converted into work.

46. State the second law of thermodynamics in terms of entropy.

"For all the processes that occur in nature (irreversible process), **the entropy always increases**. For reversible process entropy will not change". Entropy determines the direction in which natural process should occur.

47. Why does heat flow from a hot object to a cold object?

Because entropy increases when heat flows from hot object to cold object.

48. Define the coefficient of performance.

COP is a **measure of the efficiency of a refrigerator. It is defined as the ratio of heat extracted from the cold body (sink) to the external work done by the compressor W. COP = $\beta = \frac{Q_L}{W}$**

49. Can water be boiled without heating?

Yes, at low pressure, **the water boils fast at low temperature below the room temperature, when the pressure is made low**, the water starts boiling without supplying any heat.

50. As air is a bad conductor of heat, why do we not feel warm without clothes?

This is conductor when we are without clothes air carries **away heat from our body due to convection and hence we feel cold.**

51. Why is it hotter at the same distance over the top of a fire than in front of it?

At a point in front of fire, heat is received due to the process of radiation only, while at a point above the fire, **heat reaches both due to radiation and convection.**

52. Define Triple point.

Triple point the triple point of a substance is **the temperature andpressure at which the three phases (gas, liquid and solid)** of that substance coexist in thermodynamic equilibrium. The **triple point of water is at 273.1 K**

53. Write the applications of thermal conversion.

1) **Boiling water in a cooking pot is an example of convection**. Water at the bottom of the pot receives more heat. Due to heating, **the water expands and the density of water decreases at the bottom.**
2) Due to this decrease in density, molecules rise to the top. At the same time the molecules at the **top receive less heat and become denser and come to the bottom of the pot.**
3) This process goes on continuously. **The back and forth movement of molecules is called convection current.**
4) To keep the room warm, we use room heater. **The air molecules near the heater will heat up and expand.**
5) As they expand, the density of **air molecules will decrease and rise up while the higher density cold air will come down**. This circulation of air molecules are called convection current.

54. Write the main features of Prevost theory?

1) Every object emits heat radiations at all finite temperatures (except 0 K) as well as it absorbs radiations from the surroundings. For example, **if you touch someone, they might feel your skin as either hot or cold.**
2) A body at high temperature radiates more heat to the surroundings than it receives from it. Similarly, **a body at a lower temperature receives more heat from the surroundings than it loses to it.**
3) Prevost applied the idea of **'thermal equilibrium'** to radiation. He suggested that **all bodies radiate energy but hot bodies radiate more heat than the cooler bodies**. At one point of time the rate of exchange of heat from both the bodies will become the same. Now the bodies are said to be in 'thermal equilibrium. Only at absolute zero temperature a body will stop emitting.

55. Draw and explain the distribution of radiation intensity.

1) It implies that if temperature of **the body increases, maximal intensity wavelength (λm) shifts towards lower wavelength (higher frequency) of electromagnetic spectrum.**
2) The peak of the **wavelengths is inversely proportional to temperature**. The curve is known as '**black body radiation curve**'.

FIVE MARKS QUESTION WITH ANSWER:

56. Explain the meaning of heat and work with suitable examples.

Meaning of work:

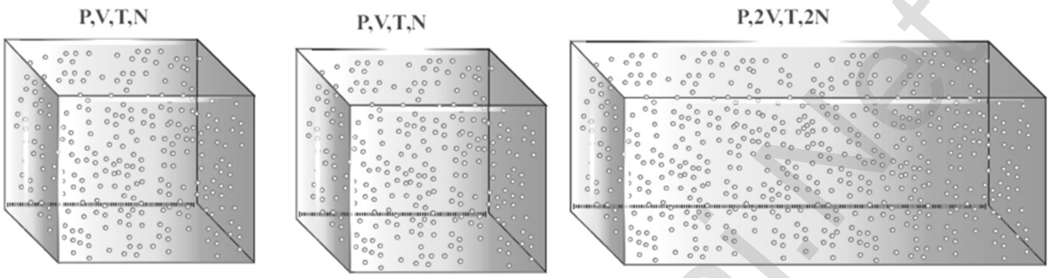
1) When you rub your hands against each other the temperature of the hands increases. You have done some **work on your hands by rubbing. The temperature of the hands increases due to this work.** Now if you place your hands on the chin, the temperature of the chin increases.
2) This is because the **hands are at higher temperature than the chin. In the above example, the temperature of hands is increased due to work and temperature of the chin is increased due to heat transfer from the hands to the chin.**
3) By doing work on the system, **the temperature in the system will increase and sometimes may not. Like heat, work is also not a quantity and through the work energy is transferred to the system.** So we cannot use the word 'the object contains more work' or 'less work'.
4) Either **the system can transfer energy to the surrounding by doing work on surrounding or the surrounding may transfer energy to the system by doing work on the system.** For the transfer of energy from one body to another body through the process of work, they need not be at different temperatures.

57. Discuss the ideal gas laws.

Boyle's law, Charles' law and ideal gas law:

1) For a given gas at low pressure (density) **kept in a container of volume V, experiments revealed the following information.**
   When the gas is kept at constant temperature, the pressure of the gas is inversely proportional to the volume.
   $P \ \alpha \frac{1}{V}$ It was discovered by Robert Boyle (1627-1691) and is known as Boyle's law.
2) When the gas is kept at constant pressure, the volume of **the gas is directly proportional to absolute temperature. V α T.** It was discovered by Jacques Charles (1743-1823) and is known as Charles' law.
   By combining these two equations we have PV = CT. Here C is a positive constant.
3) C is proportional to the number of particles in the gas container by considering the following argument.
4) If we take **two containers of same type of gas with same volume V, same pressure P and same temperature T, then the gas in each container obeys the above equation. PV = CT.**

5) If the two containers of gas is considered as a single system, then the **pressure and temperature of this combined system will be same but volume will be twice and number of particles will also be double** as shown in figure.



Two Separate systems Single system

For this combined system, V becomes 2V, so C should also double to match with the ideal gas equation $\frac{P(2V)}{T} = 2C$.

6) It implies that C must depend on the number of particles in the gas and also should have the dimension of $\left[\frac{PV}{T}\right] = JK^{-1}$.

7) we can write the constant C as k times the number of particles N. Here k is the **Boltzmann constant ($1.381\times10^{-23}JK^{-1}$)** and it is found to be a universal constant. So the ideal gas law can be stated as follows
$PV = NkT$

58. Explain in detail the thermal expansion.

1) Thermal expansion is the tendency of matter to change in shape, area, and volume due to a change in temperature.

2) All three states of matter (solid, liquid and gas) expand when heated. **When a solid is heated, its atoms vibrate with higher amplitude about their fixed points.** The relative change in the size of solids is small. **Railway tracks are given small gaps so that in the summer, the tracks expand and do not buckle.** Railroad tracks and bridges have expansion joints to allow them to expand and contract freely with temperature changes.

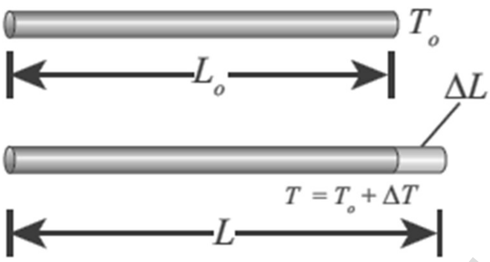
3) **Liquids**, have less intermolecular forces than solids and hence they expand more than solids. This is the **principle behind the mercury thermometers.**

4) In the case of **gas molecules, the intermolecular forces are almost negligible and hence they expand much more than solids. For example, in hot air balloons when gas particles get heated, they expand and take up more space.**

5) The **increase in dimension of a body due to the increase in its temperature is called thermal expansion.**

6) The expansion in length is called **linear expansion.** Similarly, the expansion in area is termed as **area expansion**and the expansion in volume is termed as **volume expansion.**

Linear Expansion:



In solids, for a small change in temperature ΔT, the fractional change in length $\left(\frac{\Delta L}{L}\right)$ is directly proportional to ΔT. $\frac{\Delta L}{L} = \alpha_L \Delta T$

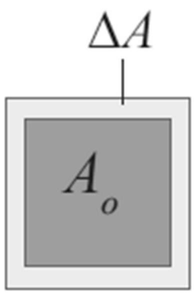
Therefore, $\alpha_L = \frac{\Delta L}{L\,\Delta T}$; Where, αL = coefficient of linear expansion.

ΔL = Change in length; L = Original length;

ΔT = Change in temperature.

Area Expansion:

For a small change in temperature ΔT the fractional change in area $\left(\frac{\Delta A}{A}\right)$ of a substance is directly proportional to ΔT and it can be written as $\frac{\Delta A}{A} = \alpha_A \Delta T$



Therefore,

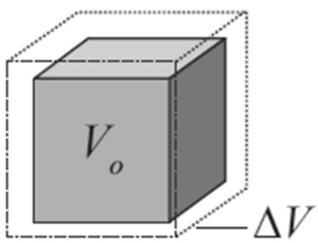
$\alpha_A = \frac{\Delta A}{A\,\Delta T}$; Where, αA = coefficient of area expansion.

ΔA = Change in area; A = Original area;

ΔT = Change in temperature

Volume Expansion:

For a small change in temperature ΔT the fractional change in volume$\left(\frac{\Delta V}{V}\right)$of a substance is directly proportional to ΔT.



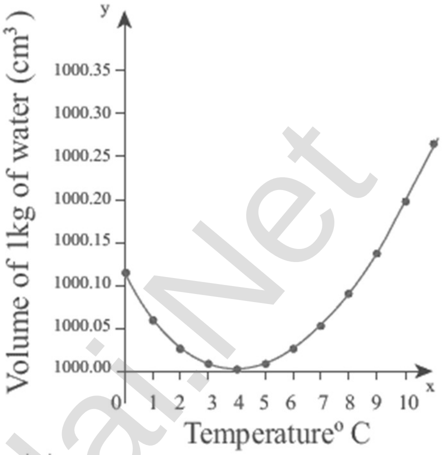
$\frac{\Delta V}{V} = \alpha_V \Delta T$, Therefore, $\alpha_V = \frac{\Delta V}{V\,\Delta T}$

Where, αV = coefficient of volume expansion;

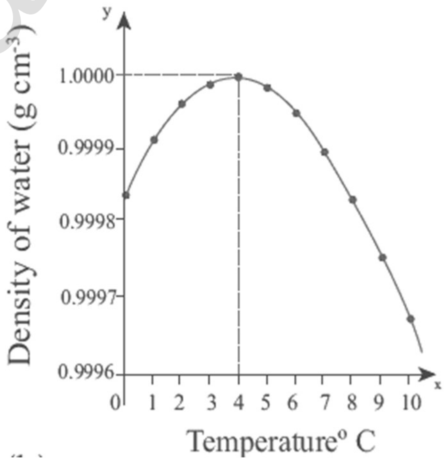
ΔV = Change in volume; V = Original volume; ΔT = Change in temperature. Unit of coefficient of linear, area and volumetric expansion of solids is $^\circ C^{-1}$ or K^{-1}

59. Describe the anomalous expansion of water. How is it helpful in our lives?

Anomalous expansion of water:



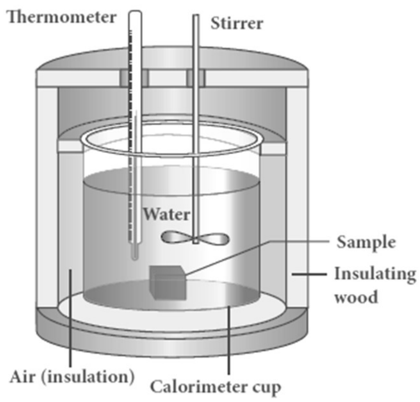
1) Liquids expand on heating and contract on cooling at moderate temperatures. But water exhibits an anomalous behavior. **It contracts on heating between 0˚C and 4˚C.**
2) The volume of the given amount of water decreases as it is **cooled from room temperature, until it reach 4˚C .**
3) Below 4˚C the **volume increases and so the density decreases**. This means that the water has **a maximum density at 4˚C. This behavior of water is called anomalous expansion of water**.



4) In cold countries during the winter season, **the surface of the lakes will be at lower temperature than the bottom.**
5) Since the solid water (ice) **has lower density than its liquidform, below 4°C, the frozen water will be on the top surface**above the liquid water (ice floats).
6) This is due to the anomalous expansion of water. As the **water in lakes and ponds freeze only at the top the species** living in the lakes will be safe at the bottom.

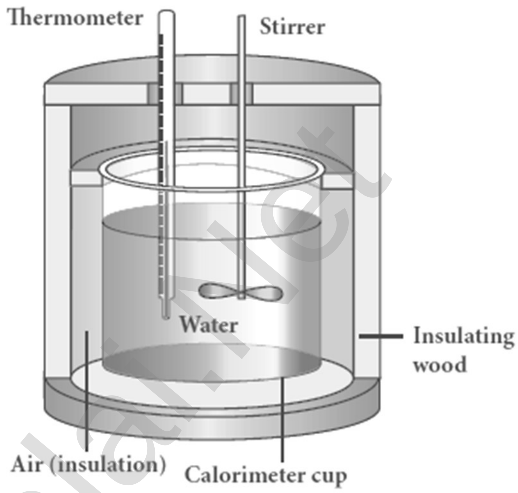
60. Explain Calorimetry and derive an expression for final temperature when twothermodynamic systems are mixed.

Calorimetry:



1) Calorimetry means **the measurement of the amount of heat released or absorbed by thermodynamic system during the heating process.** When a body at higher temperature is brought in contact with **another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the cold body.** No heat is allowed to escape to the surroundings. It can be mathematically expressed as $Q_{gain} = -Q_{lost}$; $Q_{gain} + Q_{lost} = 0$

2) Heat gained or lost is measured with a calorimeter. Usually the calorimeter is an insulated container of water as shown in Figure.



3) A sample **is heated at high temperature (T_1) and immersed into water at room temperature (T_2) in the calorimeter.** After some time both sample and water reach a final equilibrium temperature T_f. Since **the calorimeter is insulated, heat given by the hot sample is equal to heat gained by the water.** It is shown in the Figure.

$Q_{gain} = -Q_{lost}$

Note the sign convention. The heat lost is denoted by negative sign and heat gained is denoted as positive.

From the definition of specific heat capacity

$$Q_{gain} = m_2s_2(T_f - T_2)\ ;\ Q_{lost} = m_1s_1(T_f - T_1)$$

Here s_1 and s_2 specific heat capacity of hot sample and water respectively. So we can write

$$m_2s_2(T_f - T_2) = -m_1s_1(T_f - T_1)$$

$$\mathbf{m_2s_2T_f - m_2s_2T_2 = -m_1s_1T_f + m_1s_1T_1}$$

$$m_2s_2T_f + m_1s_1T_f = m_2s_2T_2 + m_1s_1T_1$$

The final temperature $T_f = \dfrac{m_1S_1T_1 + m_2S_2T_2}{m_1S_1 + m_2S_2}$

61. Discuss various modes of heat transfer.

Conduction:

Conduction is the process of **direct transfer of heat through matter due to temperature difference.** When two objects are in **direct contact with one another, heat will be transferred from the hotter object to the colder one. Thermal conductivity depends on the nature of the material.**

Convection:

Convection is the process in which **heat transfer is by actual movement of molecules in fluids such as liquids and gases.** In convection, **molecules move freely from one place to another.**

Radiation:

Radiation is a form of **energy transfer from one body to another by electromagnetic waves.** Radiation which requires **no medium to transfer energy from one object to another.**

Example: 1. Solar energy from the Sun. 2. Radiation from room heater.

62. Explain in detail Newton's law of cooling.

Newton's law of cooling:

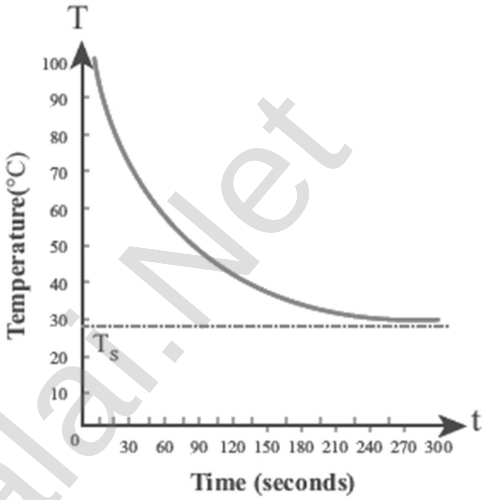
1) Newton's law of cooling states that the **rate of loss of heat of a body is directly proportional to the difference in the temperature between that body and its surroundings.**

$\frac{dQ}{dt} \alpha - (T - T_s)$ ------------ 1

2) The **negative sign indicates that the quantity of heat lost by liquid goes on decreasing with time.** Where,

T = Temperature of the object

T_s = Temperature of the surrounding.



From the graph in Figure, it is clear that **the rate of cooling is high initially and decreases with falling temperature.**

3) Let us consider an object of mass m and specific heat capacity s at temperature T. Let Ts **be the temperature of the surroundings.** If the temperature falls by a small amount dT in time dt, then the amount of heat lost is, dQ = msdT -------------- 2

4) Dividing both sides of equation (2) by $\frac{dQ}{dt} = \frac{msdT}{dt}$ ------------3

From Newton's law of cooling $\frac{dQ}{dt} \alpha - (T - T_S)$

$\frac{dQ}{dt} = - a (T - T_S)$ --------- 4

Where a is some positive constant. From equation (2) and (4)

$- a (T - T_S) = ms \frac{dT}{dt}$

$\frac{dT}{(T - TS)} = - \frac{a}{ms} dt$ ------------------- 5

Integrating equation (5) on both sides,

$\int_0^\infty \frac{dT}{(T - TS)} = - \int_0^t \frac{a}{ms} dt$

In $(T - T_S) = \frac{a}{ms} t + b_1$

Where b_1 is the constant of integration. taking exponential both sides, we get,

$T = T_S + b_2 e^{-\frac{a}{ms}t}$. Here $b_2 = e^{b1}$ = Constant

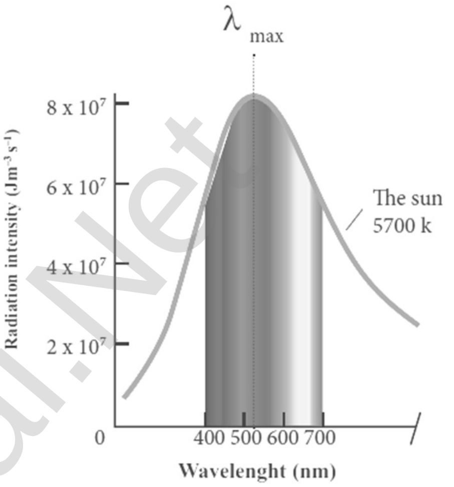
63. Explain Wien's law and why our eyes are sensitive only to visible rays?

1) Wien's law states that, **the wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the black body.**

$\lambda_m \; \alpha \; \frac{1}{T}$ or $\lambda_m = \frac{b}{T}$ --------1

Where, b is known as Wien's constant.

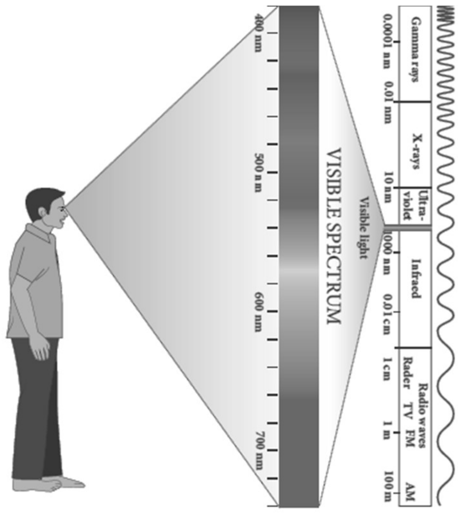
Its value is 2.898× 10^{-3} m K



2) The **Sun is approximately taken as a black body.** Since any object above 0 K will emit radiation, Sun also emits radiation. Its surface temperature is about 5700 K. By substituting this value in the equation (1).

$\lambda_m = \frac{\mathbf{b}}{\mathbf{T}} = \frac{\mathbf{2.898 \times 10^{-8}}}{\mathbf{5700}} \approx 508\text{nm}$

3) It is the wavelength at which **maximum intensity is 508 nm.** Since the Sun's temperature is around 5700K, **the spectrum of radiations emitted by Sun lie between 400 nm to 700 nm**which is the visible part of the spectrum.



4) The humans evolved under the Sun by receiving its radiations. **The human eye is sensitive only in the visible not in infrared or X-ray ranges in the spectrum.**

5) Suppose if humans had evolved in a planet near the star Sirius (9940K), then they would have had the ability to see the Ultraviolet rays!

64. Discuss the

a. Thermal equilibrium **b. Mechanical equilibrium**

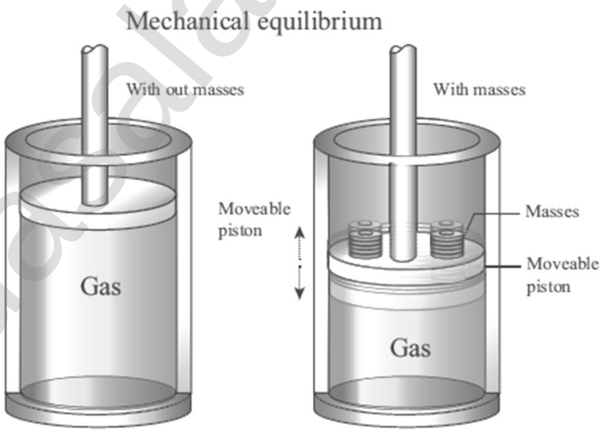
c. Chemical equilibrium **d. Thermodynamic equilibrium.**

a. Thermal equilibrium:

Two systems are said to be in **thermal equilibrium with each other if they are at the same temperature, which will not change with time.**

b. Mechanical equilibrium:

Consider a gas container with piston as shown in Figure. When some mass is placed on the piston, it will **move downward due to downward gravitational force and after certain humps and jumps the piston will come to rest at a new position**. When the downward gravitational force given by the **piston is balanced by the upward force exerted by the gas, the system is said to be in mechanical equilibrium**. A system is said to be in mechanical equilibrium if no unbalanced force acts on the thermodynamic system or on the surrounding by thermodynamic system.



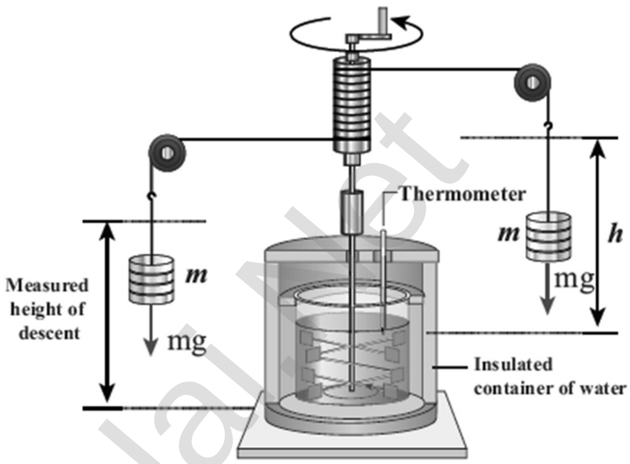
c. Chemical equilibrium:

If there is **no net chemical reaction between two thermodynamic** systems in contact with each other then it is said to be in chemical equilibrium.

d. Thermodynamic equilibrium:

If two systems are set to be in thermodynamic equilibrium, then the **systems are at thermal, mechanical and chemical equilibrium with each other**. In a state of thermodynamic equilibrium, the macroscopic variables such as pressure, volume and temperature will have fixed values and do not change with time.

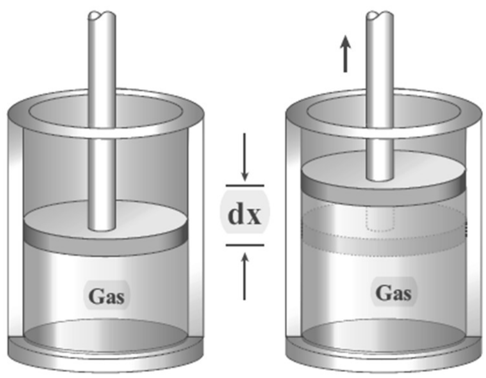
65. Explain Joule's Experiment of the mechanical equivalent of heat.



1) Joule showed that **mechanical energy can be converted into internal energy**and vice versa. In his experiment, two masses were attached with a rope and a paddle wheel.
2) When these masses fall through a distance h due to gravity, **both the masses lose potential energy equal to 2mgh.**
3) When the masses fall, **the paddle wheel turns. Due to the turning of wheel inside water, frictional force comes in between the water and the paddle wheel.**
4) This causes a rise in temperature of the water. This implies that **gravitational potential energy is converted to internal energy of water.**
5) The temperature of water increases due to the work done by the masses. In fact, **Joule was able to show that the mechanical work has the same effect as giving heat.**
6) He found that to raise 1 g of an object by 1°C, 4.186 J of energy is required. In earlier days the heat was measured in calorie. **1 cal = 4.186 J.** This is called Joule's mechanical equivalent of heat.

66. Derive the expression for the work done in a volume change in a thermodynamic system.

Work done in volume changes



1) Consider a gas contained in the **cylinder fitted with a movable piston**. Suppose the gas is expanded quasi-**statically by pushing the piston by a small distance dx.**
2) Since the expansion occurs quasi-statically the pressure, **temperature and internal energy will have unique values at every instant**. The small work done by the gas on the piston. dW = Fdx ----------- 1
3) The force exerted by the gas on the piston F = PA. Here A is area of the piston and P is pressure exerted by the gas on the piston.
Equation (1) can be rewritten as dW = PA dx ---------- 2

4) But Adx = dV= change in volume during this expansion process.
So the small work done by the gas during the expansion is given by
dW = PdV

5) Note here that is**positive since the volume is increased**. Here, is positive. In general the work done by the gas by increasing the volume from $V_i$to V_f is given by W = $\int_{V_i}^{V_f} PdV$ ---------- 4
Suppose if the **work is done on the system, then $V_i>V_f$. Then, W is negative.**

6) Note here the pressure P is inside the integral in equation (4). It implies that while **the system is doing work, the pressure need not be constant.**

7) To evaluate the integration we need to first express the pressure as a function of volume and temperature using the equation of state.

67. Derive Mayer's relation for an ideal gas.

Meyer's relation

1) Consider μ mole of an ideal gas in a container with volume V, pressure P and temperature T.

2) When **the gas is heated at constant volume the temperature increases by dT. As no work is done by the gas, the heat that flows into the system will increase only the internal energy**. Let the change in internal energy be dU.
If Cv is the molar specific heat capacity at constant volume,
$dU = \mu C_v dT$ ----------- 1

3) Suppose the gas is heated at constant pressure so that the temperature increases by dT. If 'Q' is the heat supplied in this process and 'dV' the change in volume of the gas. **$Q = \mu C_p dT$** ---------- 2

4) If W is the work done by the gas in this process, then
W = PdV -----------3
But from the first law of thermodynamics, **Q = dU + W** --------4
Substituting equations (1), (2) and (3) in (4), we get,
$\mu C_p dT = \mu C_v dT + PdV$ ----------5

5) For mole of ideal gas, the equation of state is given by
$PV = \mu RT \Rightarrow PdV+VdP = \mu RdT$ --------- 6
Since the pressure is constant, **dP=0**
$\therefore C_p dT = C_v dT + RdT$
$\therefore C_P= C_v+R$ (or) $C_p- C_v= R$ ---------- 7
This relation is called Meyer's relation

68. Explain in detail the isothermal process.

Isothermal process

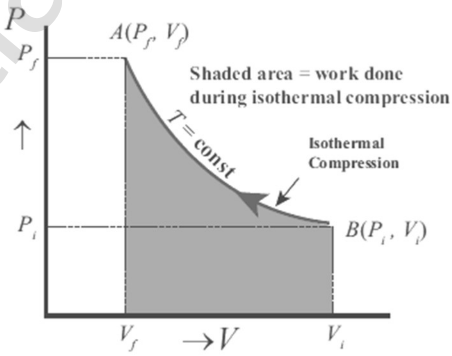
1) It is a process in which **the temperature remains constant but the pressure and volume of a thermodynamic system will change**. The ideal gas equation isPV= μRT, Here, T is constant for this process
So the equation of state for isothermal process is given by

PV = constant----- 1

2) This implies that if the gas goes from one equilibrium state (P_1,V_1) to another equilibrium state (P_2,V_2) the following relation holds for this process $P_1V_1 = P_2V_2$ -------2

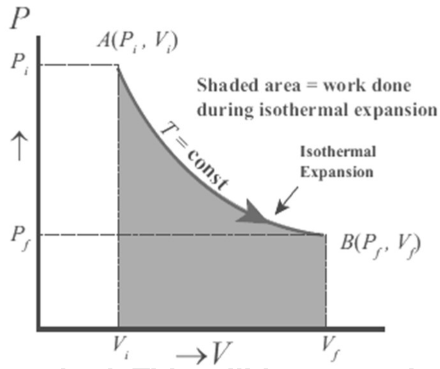
3) Since PV = constant, P is inversely proportional to P $\alpha \frac{1}{V}$.

This implies that **PV graph is a hyperbola. The pressure-volume graph for constant temperature is also called isotherm. PV diagram for quasi-static isothermal expansion and quasi-static isothermal compression.**



4) We know that for an ideal gas the internal energy is a function of temperature only. For an isothermal process since temperature is constant, the **internal energy is also constant.**

This implies that dU or ΔU = 0.For an isothermal process, **the first law of thermodynamics** can be written as follows, Q = W ----------- 3



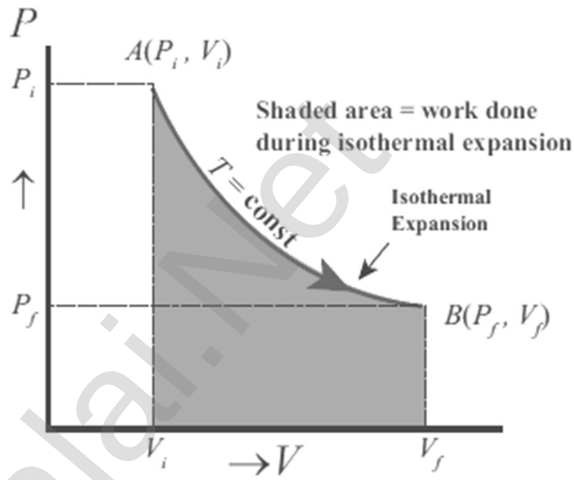
5) From equation (3), we infer that the heat **supplied to a gas is used to do only external work.**

6) The isothermal compression takes place when the **piston of the cylinder is pushed. This will increase the internal energy which will flow out of the system through thermal contact.**

69. Derive the work done in an isothermal process

Work done in an isothermal process:

1) Consider an ideal gas which is allowed to expand quasi-statically at constant temperature from initial state (P_i,V_i) to the final state (P_f, V_f). We can calculate the work done by the gas during this process. From equation the work done by the gas,



$W = \int_{V_i}^{V_f} PdV$ ------------- 1

2) As the process occurs quasi-statically, at every stage the gas is at equilibrium with the surroundings. Since it is in equilibrium at every stage the ideal gas law is valid. Writing pressure in terms of volume and temperature,

$P = \frac{\mu RT}{V}$------------------2

Substituting equation (2) in (1) we get,

$W = \int_{V_i}^{V_f} \frac{\mu RT}{V} dV$; $W = \mu RT \int_{V_i}^{V_f} \frac{dV}{V}$ ------------- 3

In equation (3), we take μRTout of the integral, since it is constant throughout the isothermal process.

By performing the integration in equation (3),

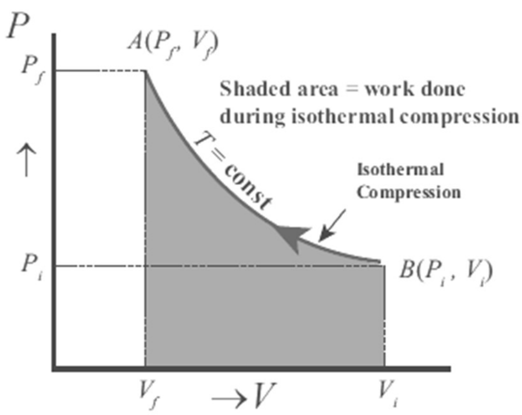
we get $W = \mu RT \ln\left(\frac{V_f}{V_i}\right)$ -------------- 4

3) Since we have an isothermal expansion, $\frac{V_f}{V_i} > 1$, So $\ln\left(\frac{V_f}{V_i}\right) > 0$.

As a result, the work done by the gas during an isothermal expansion is positive.

The above result in equation (4) is true for isothermal compression also.

But in an isothermal compression $\frac{V_f}{V_i} < 1$, So $\ln\left(\frac{V_f}{V_i}\right) < 0$. As a result, the work done on the gas in an isothermal compression is negative.



4) In the **PV diagram the work done during the isothermal expansion is equal to the area under the graph.** Similarly, for an isothermal compression, **the area under the PV graph is equal to the work done on the gas which turns out to be the area with a negative sign.**

70. Explain in detail an adiabatic process.

Adiabatic process:

1) This is a process in which **no heat flows into or out of the system (Q=0). But the gas can expand by spending its internal energy or gas can be compressed through some external work.** So the pressure, volume and temperature of the system may change in an adiabatic process.

2) The equation of state for an adiabatic process is given by

PV^{γ} = Constant-------------1

Here γ is called adiabatic exponent $\left(\gamma = \frac{C_p}{C_v}\right)$ which depends on the nature of the gas.

3) The equation (1) implies that if the gas goes from an equilibrium state (P_i,V_i) to another equilibrium state (P_f ,V_f) adiabatically then it satisfies the relation

$P_iV_i^{\gamma} = P_fV_f^{\gamma}$ ------------ 2

4) The**PV diagram of an adiabatic expansion and adiabatic compression process.** The PV diagram for an adiabatic process is also called **adiabat.**

5) Note that the PV diagram for isothermal and adiabatic processes look similar. But **actually the adiabatic curve is steeper than isothermal curve.**

6) To rewrite the equation (1) in terms of T and V. From ideal gas equation, the pressure P = $\frac{\mu RT}{V}$. Substituting this equation in the equation (1), we have $\frac{\mu RT}{V}V^{\gamma}$ = Constant or $\frac{T}{V}V^{\gamma} = \frac{Constant}{\mu R}$

7) Note here that is another constant. So it can be written as

$TV^{\gamma-1}$ = Constant -----------3

The equation (3) implies that if the gas goes from an initial equilibrium state (T_i,V_i) to final equilibrium state (T_f, V_f) adiabatically then it satisfies the **relation$T_iV_i^{\gamma-1} = T_fV_f^{\gamma-1}$** -------------- 4

The equation of state for adiabatic process can also be written in terms of T and P as $T^{\gamma}P^{1-\gamma}$ = constant.

71. Derive the work done in an adiabatic process

Work done in an adiabatic process:

1) Consider μ moles of an ideal gas enclosed in a cylinder having perfectly non conducting walls and base. **A frictionless and insulating piston of cross sectional area A is fitted in the cylinder**. Let W be the work done when the system goes from the initial state (P_i,V_i,T_i) to the final state (P_f,V_f,T_f) adiabatically. W = $\int_{V_i}^{V_f} PdV$ -------------- 1

2) By assuming that the adiabatic process occurs quasi-statically, at every stage the ideal gas law is valid. Under this condition, the adiabatic equation of state is PV^γ = constant (or) P = $\frac{Constant}{V^\gamma}$ can be substituted in theequation (1), we get $W_{adia} = \int_{V_i}^{V_f} \frac{Constant}{V^\gamma} dV$

$$= \text{Constant} \int_{V_i}^{V_f} V^{\gamma} dV$$

$$= \text{Constant} \left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_{V_i}^{V_f}$$

$$= \frac{\text{Constant}}{1-\gamma}\left[\frac{\text{Constant}}{V_f^{\gamma-1}} - \frac{\text{Constant}}{V_i^{\gamma-1}}\right]$$

But, $P_iV_i^\gamma = P_fV_f^\gamma$ = constant.

$$W_{adia} = \frac{1}{1-\gamma}\left[\frac{P_fV_f^\gamma}{V_f^{\gamma-1}} - \frac{P_iV_i^\gamma}{V_i^{\gamma-1}}\right]$$

$W_{adia} = \frac{1}{1-\gamma}[P_fV_f - P_iV_i]$ -------- 2

From ideal gas law, $P_fV_f = \mu RT_f$ and $P_iV_i = \mu RT_i$

Substituting in equation (2), we get, $W_{adia} = \frac{\mu R}{\gamma-1}[T_i - T_f]$

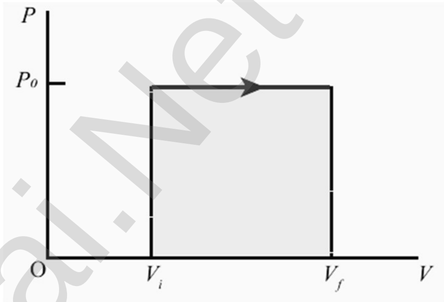
3) In adiabatic expansion, work is done by the gas. i.e., W_{adia} is positive. As $T_i > T_f$,the gas cools during adiabatic expansion. In adiabatic compression, work is done on the gas. i.e., W_{adia} is negative. As $T_i < T_f$, the temperature of the gas increases during adiabatic compression.

72. Explain the isobaric process and derive the work done in this process

Isobaric process:

1) This is a thermodynamic process that occurs at constant pressure. Even though pressure is constant in this process, temperature, volume and internal energy are not constant. From the ideal gas equation, we have

$V = \left(\frac{\mu R}{P}\right)T$ ---------1 Here $\frac{\mu R}{P}$ = Constant



2) In an isobaric process the temperature is directly proportional to volume. $V \propto T$ (Isobaric process) ---- (2)

This implies that for a isobaric process, the V-T graph is a straight line passing through the origin.

3) If a gas goes from a state (V_i,T_i) to (V_f,T_f) at constant pressure, then the system satisfies the following equation $\frac{T_f}{V_f} = \frac{T_i}{V_i}$

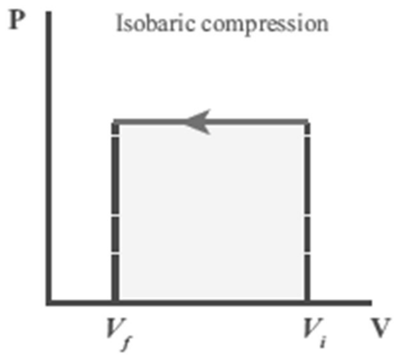
The work done in an isobaric process:

Work done by the gas W = $\int_{V_i}^{V_f} PdV$

In an isobaric process, the pressure is constant, so P comes out of the integral,

$W = P\int_{V_i}^{V_f} dV$ W = P [V_f – V_i] = PΔV ----------3

4) Where ΔV denotes change in the volume. If ΔV is negative, W is also negative. This implies that the work is done on the gas. If ΔV is positive, W is also positive, implying that work is done by the gas.



5) The equation (3) can also be rewritten using the **ideal gas equation.**

From ideal gas equation PV = μRT and

$V = \frac{\mu RT}{P}$ Substituting this in equation (3) we

get, $W = \mu R T_f\left(1 - \frac{T_i}{T_f}\right)$

6) In the PV diagram, **area under the isobaric curve is equal to the work done in isobaric process.** The shaded area in the following Figure is equal to the work done by the gas.

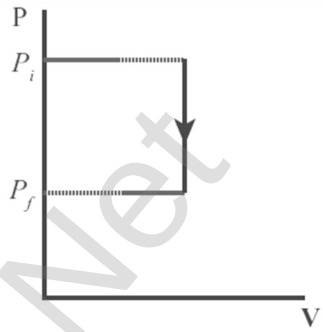
7) The first law of thermodynamics for isobaric process is given by

ΔU = Q - PΔV

73. Explain in detail the isochoric process.

Isochoric process:

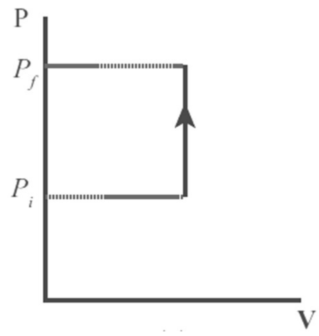
1) This is a thermodynamic process in which the volume of the system is kept constant. But pressure, **temperature and internal energy continue to be variables**. The pressure - volume graph for an isochoric process is a vertical line parallel to pressure axis.



2) The equation of state for an isochoric process is given by $P = \left(\frac{\mu R}{V}\right)$

Where, $\left(\frac{\mu R}{V}\right)$ = Constant

It that the pressure is **directly proportional to temperature. This implies that the P-T graph for an isochoric process is a straight line passing through origin.** If a gas goes from state (P_i,T_i) to (P_f,T_f) at constant volume, then the system satisfies the following equation $\frac{P_i}{T_i} = \frac{P_f}{T_f}$



For an isochoric process, ΔV=0 and W=0. Then the first law becomes ΔU = Q

3) Implying that **the heat supplied is used to increase only the internal energy.** As a result, the temperature increases and pressure also increases.

4) Suppose a **system loses heat to the surroundings through conducting walls by keeping the volume constant**, then its **internal energy decreases.** As a result, the **temperature decreases; the pressure also decreases.**

74. What are the limitations of the first law of thermodynamics?

Limitations of first law of thermodynamics

The first law of **thermodynamics explains well the inter convertibility of heat and work.** But it does **not indicate the direction of change.**

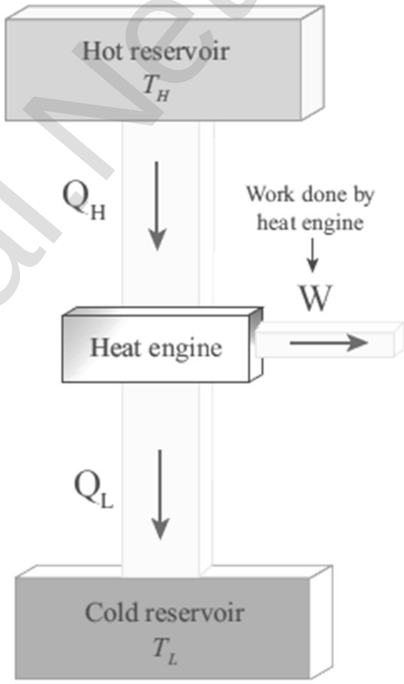
For example,

a. When a hot object is in contact with a cold object, **heat always flows from the hot object to cold object but not in the reverse direction.** According to first law, it is possible for the energy to flow from hot object to cold object or from cold object to hot object. But in nature **the direction of heat flow is always from higher temperature to lower temperature.**

b. When brakes are applied, a car stops due to friction and the work done against friction is converted into heat. But this **heat is not reconverted to the kinetic energy of the car. So the first law is not sufficient to explain many of natural phenomena.**

75. Explain the heat engine and obtain its efficiency.

Heat engine is a device which takes **heat as input and converts this heat in to work by undergoing a cyclic process.**



A heat engine has three parts:

(a) Hot reservoir (b) Working substance

(c) Cold reservoir

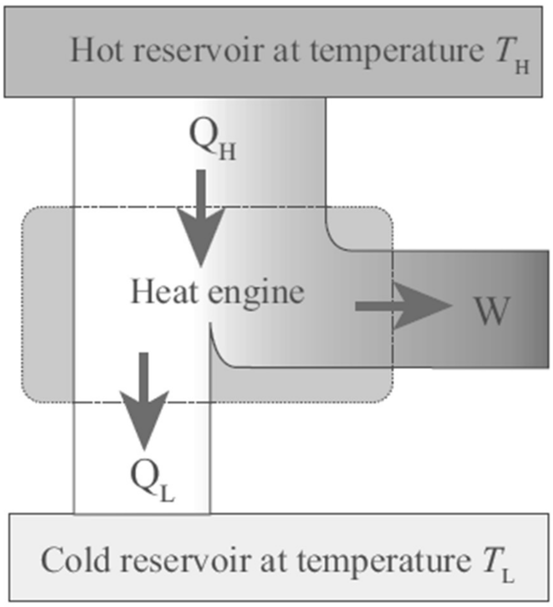
A Schematic diagram for heat engine is given below in the figure

1) **Hot reservoir (or) Source:**
It supplies heat to the engine. It is always maintained at a high temperature T_H

2) **Working substance:** It is a substance like gas or water, which converts the heat supplied into work.

i) A simple example of a heat engine is a steam engine. **In olden days' steam engines were used to drive trains.** The working substance in these is water which absorbs heat from the burning of coal.

ii) The heat converts the water into steam. This steam is does work by rotating the wheels of the train, thus making the train move.



3) Cold reservoir (or) Sink: The heat engine ejects some amount of heat (Q_L) **in to cold reservoir after it doing work.** It is always maintained at a low temperature T_L.
For example, in the automobile engine, the cold reservoir is the surroundings at room temperature. The automobile ejects heat to these surroundings through a silencer.

4) The **heat engine works in a cyclic process.** After a cyclic process it returns to the same state. Since the heat engine returns to the same state after it ejects heat, **the change in the internal energy of the heat engine is zero.**

5) The efficiency of the heat engine is defined as the ratio of the work done (output) to the heat absorbed (input) in one cyclic process. Let the working substance absorb heat Q_H units from the source and reject Q_L units to the sink after doing work W units

We can write **Input heat = Work done + ejected heat**

$$Q_H = W + Q_L$$
$$W = Q_H - Q_L$$

Then the efficiency of heat engine $\eta = \frac{\text{Output}}{\text{Input}} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

6) Note here that Q_H, Q_L and W all are taken as positive, a sign convention followed in this expression.

Since $Q_L < Q_H$, **the efficiency (η) always less than 1. This implies that heat absorbed is not completely converted into work.** The second law of thermodynamics placed fundamental restrictions on converting heat completely into work.

76. Explain in detail Carnot heat engine.

A reversible **heat engine operating in a cycle between two temperatures in a particular way is called a Carnot Engine**. The Carnot engine has four parts which are given below.

1) **Source:** It is the source of heat maintained at constant high temperature TH. Any amount of heat can be extracted from it, without changing its temperature.
2) **Sink:** It is a cold body maintained at a constant low temperature TL. It can absorb any amount of heat.
3) Insulating stand: It is made of perfectly non-conducting material. Heat is not conducted through this stand.
4) **Working substance:** It is an ideal gas enclosed in a cylinder with perfectly non-conducting walls and perfectly conducting bottom. A non-conducting and frictionless piston is fitted in it.

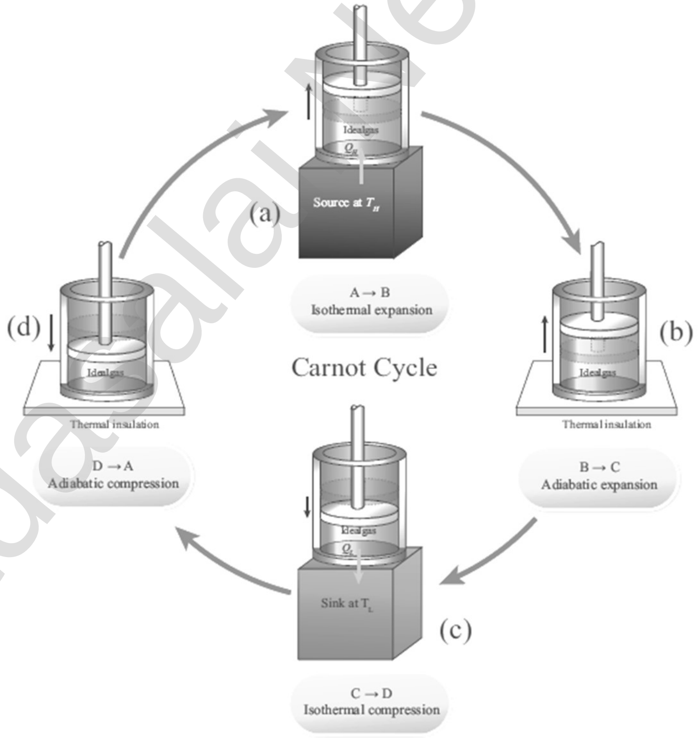
Carnot's cycle:

i) The **working substance is subjected to four successive reversible processes forming** what is called Carnot's cycle.

ii) Let the initial pressure, volume of the working substance be P_1,V_1.

Step A to B: Quasi-static isothermal expansion from (P_1,V_1,T_H) to (P_2,V_2,T_H):

5) The cylinder is placed on the source. **The heat (Q_H) flows from source to the working substance (ideal gas) through the bottom of the cylinder.** Since the process is isothermal, the internal energy of the working substance will not change. The input heat increases the volume of the gas. The piston is allowed to move out very slowly (quasi-statically).



6) W_1 is the work done by the gas in expanding from volume V_1 to volume V_2 with a decrease of pressure from P_1 to P_2. This is represented by the P-V diagram along the path AB.

7) Then the work done by the gas (working substance) is given by

$$\therefore Q_H = W_{A\to B} = \int_{V_1}^{V_2} PdV$$

Since the process occurs quasi-statically, the gas is in equilibrium with the source till it reaches the final state. The work done in the isothermal expansion is given by the equation.

Step B to C: Quasi-static adiabatic expansion from (P_2,V_2,T_H) to (P_3,V_3,T_L)

1) The cylinder is placed on the insulating stand and the piston is allowed to move out. **As the gas expands adiabatically from volume V_2 to volume V_3 the pressure falls from P_2 to P_3.**

2) The temperature falls to T_L. This adiabatic expansion is represented by curve BC in the P-V diagram. This adiabatic process also occurs quasi-statically and implying that this process is reversible and the ideal gas is in equilibrium throughout the process. The work done by the gas in an adiabatic expansion is given by,

$$W_{B\to C} = \int_{V_2}^{V_3} PdV = \frac{\mu R}{\gamma - 1}[T_H - T_L] = \text{Area under the curve BC}$$

Step C ⟶ D: Quasi-static isothermal compression from (P_3,V_3,T_L) to (P_4,V_4,T_L):

1) The cylinder is placed on the sink and the gas is isothermally compressed until the pressure and volume become P_4 and V_4 respectively. This is represented by the curve CD in the PV diagram. Let $W_{C\to D}$ be the work done on the gas. According to first law of thermodynamics

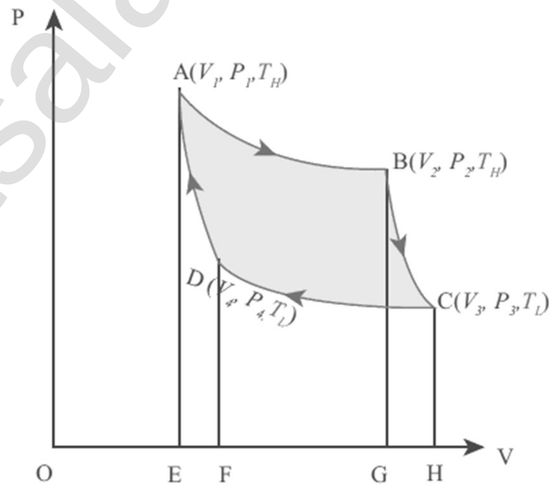
$W_{C\to D}= \int_{V_3}^{V_4} PdV = \mu RT_L \ln = \frac{V_4}{V_3} = - \mu RT_L \ln = \frac{V_3}{V_4}$

= – Area under the curve CD

Here $V_3$is greater than V_4. So the work done is negative, implying work is done on the gas.

Step D⟶A: Quasi-static adiabatic compression from (P_4,V_4,T_L) to (P_1,V_1,T_H):

1) The cylinder is placed on the insulating stand again and the gas is compressed adiabatically till it attains the initial pressure P_1, volume $V_1$and temperature T_H. This is shown by the curve DA in the P-V diagram.



$W_{D\to A}= \int_{V_4}^{V_1} PdV= \frac{\mu R}{\gamma-1}[T_L - T_H]$ = Area under the curve DA

2) In the adiabatic compression also work is done on the gas so it is negative. Let 'W' be the net work done by the working substance in one cycle

∴W=Work done by the gas – work done on the gas

= $W_{A\to B} + W_{B\to C} - W_{C\to D} - W_{D\to A}$ since $W_{B\to C} = W_{D\to A}$

= $W_{A\to B} - W_{C\to D}$

The net work done by the Carnot engine in one cycle

$W=W_{A\to B} - W_{C\to D}$ --------------1

Equation (1) shows that the **net work done by the working substance in one cycle is equal to the area (enclosed by ABCD) of the P-V diagram.**

3) It is **very important to note that after one cycle the working substance returns to the initial temperature T_H.** This implies that the change in internal energy of the working substance after one cycle is zero.

77. Derive the expression for Carnot engine efficiency.

Efficiency of a Carnot engine:

Efficiency is defined as **the ratio of work done by the working substance in one cycle to the amount of heat extracted from the source.**

$\eta = \frac{\text{Work done}}{\text{Heat extracted}} = \frac{W}{Q_H}$ --------- 1

From the first law of thermodynamics, $W = Q_H - Q_L$

$\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$ ------------ 2

Applying isothermal conditions, we get,

$Q_H = \mu RT_H \ln \frac{V_2}{V_4}$; $Q_L = \mu RT_L \ln \frac{V_3}{V_4}$ ----------- 3

Here we omit the negative sign. Since we are interested in only the amount of heat (Q_L) ejected into the sink, we have, $\frac{Q_L}{Q_H} = \frac{T_L \ln \frac{V_3}{V_4}}{T_H \ln \frac{V_2}{V_1}}$ ---------4

By applying adiabatic conditions, we get, $T_H V_2^{\gamma-1} = T_L V_3^{\gamma-1}$

By dividing the above two equations, we get, $T_H V_1^{\gamma-1} = T_L V_4^{\gamma-1}$

By dividing the above two equations, we get, $\left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$

Which implies that, $\frac{V_2}{V_1} = \frac{V_3}{V_4}$ -------------5

Substituting equation (5) in (4), we get, $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$

The efficiency η - 1 $-\frac{T_L}{T_H}$

Note: T_L and T_H should be expressed in Kelvin scale.

78. Explain the second law of thermodynamics in terms of entropy.

Entropy and second law of thermodynamics:

1) We have seen in the equation that **the quantity $\frac{Q_H}{T_H}$. Is equal to $\frac{Q_L}{T_L}$ the quantity $\frac{Q}{T}$ is called entropy.**It is a very important thermodynamic property of a system.

2) It is also a **state variable. $\frac{Q_H}{T_H}$ is the entropy received by the Carnot enginefrom hot reservoir and $\frac{Q_L}{T_L}$ is entropy given out by the Carnot engine to the cold reservoir.** For reversible engines (Carnot Engine) both entropies should be same, so that the change in entropy of the Carnot engine in one cycle is zero. But for all practical engines like diesel and petrol engines which are not reversible engines, they satisfy the relation $\frac{Q_L}{T_L} > \frac{Q_H}{T_H}$.

3) In fact we can reformulate the second law of thermodynamics as follows **"For all the processes that occur in nature (irreversible process), the entropy always increases. For reversible process entropy will not change".** Entropy determines the direction in which natural process should occur.

4) Because **entropy increases when heat flows from hot object to cold object. If heat were to flow from a cold to a hot object, entropy will decrease** leading to violation of second law thermodynamics.

5) **Entropy is also called 'measure of disorder'.** All natural process occurs such that the disorder should always increases.

6) Consider a **bottle with a gas inside. When the gas molecules are inside the bottle it has less disorder.** Once it spreads into the entire room it leads to more disorder.

7) In other words when **the gas is inside the bottle the entropy is less and once the gas spreads into entire room, the entropy increases. From the second law of thermodynamics, entropy always increases.**

8) If the air molecules go back in to the bottle, **the entropy should decrease, which is not allowed by the second law of thermodynamics.**

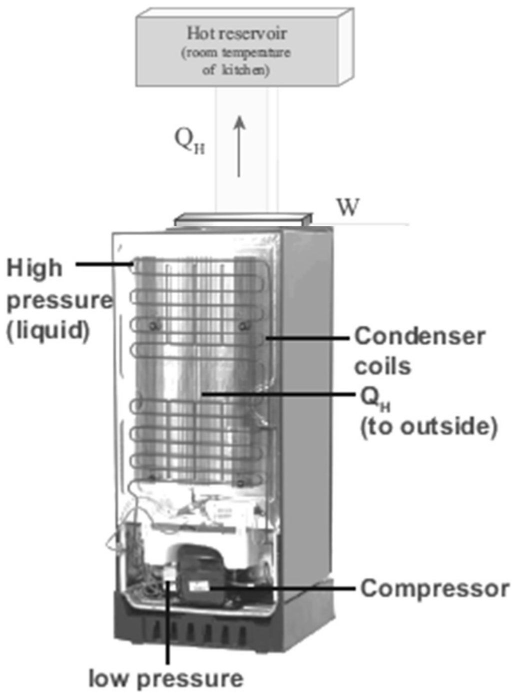
9) The same explanation applies to a drop of **ink diffusing into water. Once the drop of ink spreads, its entropy is increased. The diffused ink can never become a drop again.** So the natural processes occur in such a way that entropy should increase for all irreversible process.

79. Explain in detail the working of a refrigerator.

Refrigerator:

A refrigerator is a **Carnot's engine working in the reverse order.**

Working Principle:



The working substance (gas) absorbs a quantity of heat Q_L from the cold body (sink) at a lower temperature T_L. **A certain amount of work W is done on the working substance by the compressor and a quantity of heat Q_H is rejected to the hot body (source) ie, the atmosphere at T_H.** When you stand beneath of refrigerator, you can feel warmth air. From the first law of thermodynamics,

we have $Q_L + W = Q_H$

As a result, the cold reservoir (refrigerator) further cools down and the surroundings (kitchen or atmosphere) gets hotter.

UNIT – IX (KINETIC THEORY OF GASES)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. **What is the microscopic origin of pressure?**

With the help **of kinetic theory of gases, the pressure is linked to the velocity of molecules.** P = $\frac{1}{3}\frac{N}{V}$ mV^{-2} m – mass of a molecule;

N - Avogadro Number; V – Volume; V^{-2} – Avogadro velocity molecules.

2. **What is the microscopic origin of temperature?**

Average Kinetic Energy / Molecule : KE = ε = $\frac{3}{2}$ NkT

3. **Why moon has no atmosphere?**

The escape speed of gases on **the surface of Moon is much less than the root mean square speeds of gases due to low gravity. Due to this all the gases escape from the surface of the Moon.**

4. **Write the expression for rms speed, average speed and most probable speed ofa gas molecule.**

$V_{rms} = \sqrt{\frac{3RT}{M}}$; V_{ave} $\overline{V} = \sqrt{\frac{8RT}{\pi M}}$; $V_{mp} = \sqrt{\frac{2RT}{M}}$

5. **What is the relation between the average kinetic energy and pressure?**

The internal energy of the gas is given by U = $\frac{3}{2}$ NkT

The above equation can also be written as U = $\frac{3}{2}$ PV Since PV = NkT

$$P = \frac{2}{3}\frac{U}{V} = \frac{2}{3}u \quad \text{---------------1}$$

From the equation (1), we can state that the pressure of the gas is equal to two thirds of internal energy per unit volume or internal energy density. u = $\frac{U}{V}$

Writing pressure in terms of mean kinetic energy density using equation.

$$P = \frac{1}{3}nm\overline{v^2} = \frac{1}{3}\rho\overline{v^2} \quad \text{-------------2}$$

where ρ = nm = mass density (Note n is number density)

Multiply and divide R.H.S of equation (2) by 2, we get P = $\frac{2}{3}\left(\frac{\rho}{2}\overline{v^2}\right)$

$$P = \frac{2}{3}\overline{KE} \quad \text{--------------------3}$$

From the equation (3), pressure is equal to 2/3 of mean kinetic energy per unit volume.

6. Define the term degrees of freedom.

The minimum number of independent coordinates needed to specify **the position and configuration of a thermo-dynamical system in space** is called the degree of freedom of the system.

7. State the law of equipartition of energy.

According to kinetic theory, the average kinetic energy of system of **molecules in thermal equilibrium at temperature T is uniformly distributed to all degrees of freedom** (x or y orfreedom will get ½ kT of energy. This is called law of equipartition of energy.

8. Define mean free path and write down its expression.

Average distance travelled **by the molecule between collisions is called mean free path (λ).** We can calculate the mean free path based on kinetic theory.

9. Deduce Charles' law based on kinetic theory.

Charles' law: From the equation $P = \frac{2}{3}\frac{U}{V} = \frac{2}{3}u$ we get $PV = \frac{2}{3}U$

For a fixed pressure, the volume of **the gas is proportional to internal energy of the gas or average kinetic energy of the gas and the average kinetic energy is directly proportional to absolute temperature.**

It implies that V α T or $\frac{V}{T}$ = Constant.

10. Deduce Boyle's law based on kinetic theory.

Boyle's law: From the equation $P = \frac{2}{3}\frac{U}{V} = \frac{2}{3}u$ we get $PV = \frac{2}{3}U$

But the internal energy of an ideal gas is equal to N times the average kinetic energy (∈) of each molecule. U = N∈

For a fixed temperature, the average translational kinetic energy ∈ will remain constant. It implies that $PV = \frac{2}{3}N\epsilon$ Thus PV = constant

Therefore, pressure of a given **gas is inversely proportional to its volume provided the temperature remains constant. This is Boyle's law.**

11. Deduce Avogadro's law based on kinetic theory.

This law states that at constant temperature and pressure, equal volumes of all gases contain the same number of molecules. For two different gases at the same temperature and pressure, according to kinetic theory of gases,

From equation $P = \frac{1}{3}\frac{N_1}{V}m_1\overline{v_1^2} = \frac{1}{3}\frac{N_2}{V}m_2\overline{v_2^2}$ ------------ 1

Where $\overline{v_1^2}$ and $\overline{v_2^2}$ are the mean square speed for two gases and N_1 and N_2 are the number of gas molecules in two different gases.

At the same temperature, average kinetic energy per molecule is the same for two gases. $\frac{1}{2}m_1\overline{v_1^2} = \frac{1}{2}m_2\overline{v_2^2}$ ------------------- 2

Dividing the equation (1) by (2) we get $N_1 = N_2$

This is Avogadro's law. It is sometimes referred to as Avogadro's hypothesis or Avogadro's Principle.

12. List the factors affecting the mean free path.

1) Mean free path **increases with increasing temperature. As the temperature increases, the average speed of each molecule will increase.** It is the reasonwhy the smell of hot sizzling food reaches several meter away than smell of cold food.
2) Mean free **path increases with decreasing pressure of the gas and diameter of the gas molecules.**

13. What is the reason for Brownian motion?

According to kinetic theory, any particle suspended in a liquid or gas is continuously bombarded from **all the directions so that the mean free path is almost negligible. This leads to the motion of the particles in a random** and zig–zag manner.

14. What are the factors which affect Brownian motion?

1) Brownian motion **increases with increasing temperature.**
2) Brownian **motion decreases with bigger particle size, high viscosity and density of the liquid (or) gas.**

15. What is meant by rms speed of the molecules of a gas? Is rms speed same asthe average speed?

The rms speed of the molecule of a gas is defined as **the square root of the mean of the square of speeds of all molecules.**

No, rms speed is **different from the average speed.** $V_{rms} = \sqrt{\frac{V_1^2+V_2^2+V_3^2}{3}}$

$\overline{V}$ = Average speed = $\frac{V_1+V_2+V_3}{3}$

16. Why No hydrogen in Earth's atmosphere?

As the **root mean square speed of hydrogen is much greater than that of nitrogen, it easily escapes from the earth's atmosphere**. In fact, the presence of nonreactive nitrogen instead of highly combustible hydrogen deters many disastrous consequences.

17. Mention the different ways of increasing the number of molecular collisionsper unit time in a gas.

The numbers of collisions per unit time can **be increased by increasing the temperature of the gas, increasing the number of molecules**, and **decreasing the volume of the gas.**

18. On which factors does the average kinetic energy of gas molecular depend?

The average kinetic energy of a gas molecular **depends only on the absolute temperature of the gas and is directly proportional to it.**

19. When a gas is heated, its temperature increases. Explain it on the basis ofkinetic temperature of gases.

When a gas is heated, **the rms velocity of its molecule increases**. As $V_{rms}\ \sqrt{T}$. So the temperature of the gas increases.

20. What is an ideal gas? (or) What is perfect gas?

An **ideal gas is that gas which obeys the gas laws.** i.e. Charle's law, Boyle's law etc, at all **values of temperature and pressure.** Molecules of such a gas should be free from intermolecular attraction.

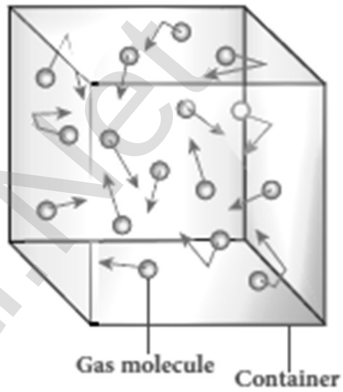
FIVE MARKS QUESTION WITH ANSWER

21. Write down the postulates of kinetic theory of gases.

1) All the molecules of a gas **are identical, elastic spheres**.
2) The molecules of different gases are different.
3) The number of molecules in a gas is **very large and the average** separation between them is larger than size of the gas molecules.
4) The molecules of a gas are in **a state of continuous random motion.**
5) The molecules collide with one another and also with the walls of the container.
6) These **collisions are perfectly elastic so that there is no loss of kinetic energy during collisions.**
7) Between two successive collisions, **a molecule moves with uniform velocity.**
8) The molecules do not exert any force of attraction or repulsion on each other except during collision. **The molecules do not possess any potential energy and the energy is wholly kinetic.**
9) The collisions are instantaneous. The time spent by a molecule in eachcollision is very small compared to the time elapsed between two consecutive collisions.
10) These **molecules obey Newton's laws of motion even though they move randomly.**

22. Derive the expression of pressure exerted by the gas on the walls of thecontainer.

1) Consider a monatomic gas of N molecules each having a mass m inside a cubical container of side *l* as shown in the Figure (a).

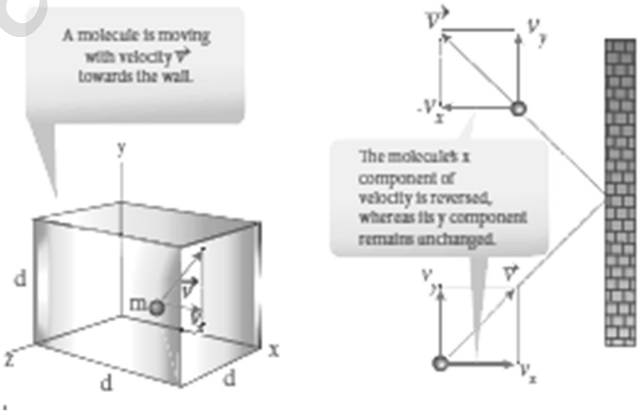


2) The **molecules of the gas are in random motion. They collide with each other and also with the walls of the container**. As the collisions are elastic in nature, there is no loss of energy, but a change in momentum occurs.

3) **The molecules of the gas exert pressure on the walls of the container due to collision on it. During each collision, the molecules impart certain momentum to the wall**. Due to transfer of momentum, the walls experience a continuous force.

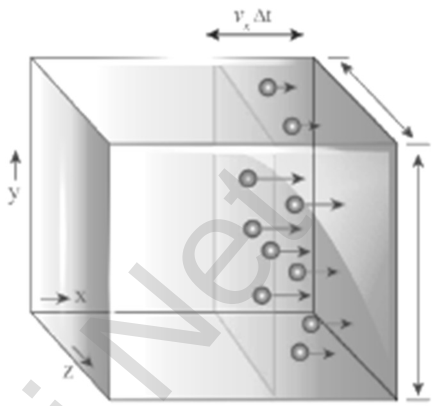
4) The force experienced per unit area of the walls of the container determines the pressure exerted by the gas. It is essential to determine the total momentum transferred by the molecules in a short interval of time.

5) A molecule of mass m moving with a velocity $\vec{v}$having components (v_x, v_y, v_z) hits the right side wall. Since we have assumed that the collision is elastic, the particle rebounds with same speed and its x-component is reversed. This is shown in the Figure (b). The components of velocity of the molecule after collision are ($-v_x$, v_y, v_z).



The x-component of momentum of the molecule before collision = mv_x

The x-component of momentum of the molecule after collision = $-mv_x$



6) The change in momentum of the molecule in x direction =Final momentum – initial momentum = $-mv_x - mv_x = -2mv_x$

According to law of conservation of linear momentum, the change in momentum of the wall = $2mv_x$

7) The number of molecules hitting the right side wall in a small interval of time Δt is calculated as follows. The molecules within the distance of $v_x\Delta t$ from the right side wall and moving towards the right will hit the wall in the time interval Δt. This is shown in the Figure. The number of molecules that will hit the right side wall in a time interval Δt is equal to the product of volume ($Av_x\Delta t$) and number density of the molecules (n). Here A is area of the wall and n is number of molecules per unit volume $\left(\frac{N}{V}\right)$. We have assumed that the number density is the same throughout the cube.

8) Not all the n molecules will move to the right, therefore on an average only half of the n molecules move to the right and the other half moves towards left side. The number of molecules that hit the right side wall in a time interval Δt = $\frac{n}{2}Av_x\Delta t$ ------------------- 1

In the same interval of time Δt, the total momentum transferred by the molecules $\Delta p = \frac{n}{2}Av_x\Delta t \times 2mv_x = Av_x^2\, nm\Delta t$ ----------2

9) From Newton's second law, the change in momentum in a small interval of time gives rise to force. The force exerted by the molecules on the wall (in magnitude) $F = \frac{\Delta P}{\Delta t} = nm\, Av_x^2$ ------------- 3

Pressure, P = force divided by the area of the wall.

$P = \frac{F}{A} = nmv_x^2$ ----------------- 4

Since all the molecules are moving completely in random manner, they do not have same speed. So we can replace the term $v_x^2$by the average $\overline{v_x^2}$in equation. $P = nm\,\overline{v_x^2}$ -------------- 5

10) Since the gas is assumed to move in random direction, it has no preferred direction of motion (the effect of gravity on the molecules is neglected). It implies that the molecule has same average speed in all thethree direction. So, $\overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2}$.

The meansquare speed is written as $\overline{v^2} = \overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2}$

$\overline{v_x^2} = \frac{1}{3}\overline{v^2}$

Using this in equation (5), we get, $\overline{v_x^2} = \frac{1}{3}\text{nm}\overline{v^2}$ or

$P = \frac{1}{3}\frac{N}{V}m\overline{v^2}$ as $\left[n = \frac{N}{V}\right]$

23. Explain in detail the kinetic interpretation of temperature.

1) To understand the microscopic origin of temperature in the same way,

Rewrite the equation $P = nm\overline{v_x^2}$

$P = \frac{1}{3}\frac{N}{V}m\overline{v^2}$; $PV = \frac{1}{3}Nm\overline{v^2}$ -------------1

Comparing the equation (1) with ideal gas equation PV=NkT,

$NkT = \frac{1}{3}Nm\overline{v^2}$;

$KT = \frac{1}{3}m\overline{v^2}$ --------------2

Multiply the above equation by 3/2 on both sides,

$\frac{3}{2}KT = \frac{1}{2}m\overline{v^2}$ ------------------- 3

R.H.S of the equation (3) is called average kinetic energy of a single molecule($\overline{KE}$). Th e average kinetic energy per molecule

$\overline{KE} = \epsilon = \frac{3}{2}KT$ ----------- 4

2) Equation (3) implies that **the temperature of a gas is a measure of the average translational kinetic energy per molecule of the gas. Equation 4 is a very important result from kinetic theory of gas.** We can infer the following from this equation.

3) The average kinetic energy of the molecule is **directly proportional to absolute temperature of the gas. The equation (3) gives the connectionbetween the macroscopic world** (temperature) to microscopic world (motion of molecules).

4) The **average kinetic energy of each molecule depends only on temperature of the gas not on mass of the molecule.** In other words, if the temperature of an ideal gas is measured using thermometer, the **average kinetic energy of each molecule can be calculated without seeing the molecule through naked eye.**

5) By multiplying **the total number of gas molecules with average kinetic energy of each molecule, the internal energy of the gas is obtained.**

Internal energy of ideal gas $U = N\left(\frac{1}{2}m\overline{v^2}\right)$

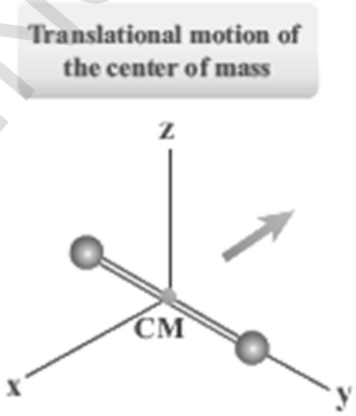
By using equation (3) $U = \frac{3}{2}NKT$ ---------- 5

From equation (5), we understand that the internal energy of an ideal gas depends only on absolute temperature and is independent of pressure and volume.

24. Describe the total degrees of freedom for mono-atomic molecule, diatomic molecule and tri-atomic molecule.

Mono-atomic molecule: A mono-atomic molecule by virtue of its nature has only three translational degrees of freedom. Therefore, f = 3

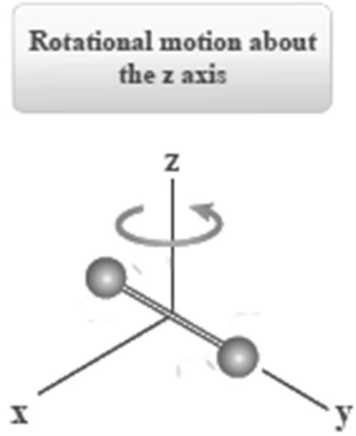
Example: Helium, Neon, Argon

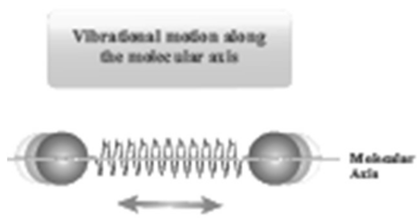


Diatomic molecule: There are two cases.

1) **At Normal Temperature A molecule of a diatomic gas consists of two atoms bound to each other by a force of attraction. Physically the molecule can be regarded** as a system of two point masses fixed at the ends of a mass less elastic spring. The center of mass lies in the center of the diatomic molecule. So, **the motion of the center of mass requires three translational degrees of freedom** (figure a). In addition, the diatomic molecule can rotate about three mutually perpendicular axes (figure b). But the moment of inertia about its own axis of rotation is negligible (about y axis in the figure). Therefore, **it has only two rotational degrees of freedom (one rotation is about Z axis and another rotation** is about Y axis). Therefore, totally there are five degrees of freedom.

f= 5





2) **At High Temperature at a very high temperature such as 5000 K, the diatomic molecules possess additional two degrees of freedom due to vibrational**motion [one due to kinetic energy of vibration and the other is due to potential energy] (Figure c). So totally there are seven degrees of freedom.

f = 7. Examples: Hydrogen, Nitrogen, Oxygen.

3) **Tri-atomic molecules**There are two cases.

Linear tri-atomic molecule in this type, two atoms lie on either side of the central atom as shown in the Figure. **Linear tri-atomic molecule has three translational degrees of freedom.**

It has two rotational degrees of freedom because it is similar to diatomic molecule except there is an additional atom at the center. At normal temperature, linear tri-atomic molecule will have five degrees of freedom. **At high temperature it has two additional vibrational degrees of freedom. So a linear tri-atomic molecule has seven degrees of freedom. Example: Carbon dioxide**

Non-linear tri-atomic molecule in this case, the three atoms lie at the vertices of a triangle as shown in the Figure. **It has three translational degrees of freedom and three rotational degrees of freedom about three mutually orthogonal axes.** The total degrees of freedom, f = 6

Example: **Water, Sulphurdioxide.**

25. Derive the ratio of two specific heat capacities of mono-atomic, diatomic and Tri-atomic molecules.

Application of law of equipartition energy in specific heat of a gas:

Meyer's relation $C_P - C_V = R$ connects the two specific heats for one mole of an ideal gas. Equipartition law of energy is used to calculate the value of $C_P - C_V$ and the ratio between them $\gamma = \frac{C_P}{C_V}$. Here γ is called adiabatic exponent.

i) **Monatomic molecule:**

Average kinetic energy of a molecule = $\left[\frac{3}{2}\mathbf{kT}\right]$

Total energy of a mole of gas $\frac{3}{2}kT \times N_A$; $= \frac{3}{2}RT$

For one mole, the molar specific heat at constant volume

$$C_V = \frac{dU}{dT} = \frac{d}{dT}\left[\frac{3}{2}RT\right]$$

$$C_V = \left[\frac{3}{2}R\right] ; C_P = C_V + R$$

$$= \frac{3}{2}R + R = \frac{5}{2}R$$

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$;

$$= \frac{\frac{5}{2}R}{\frac{3}{2}R} = \frac{5}{3}\ \boldsymbol{\gamma} = 1.67$$

ii) **Diatomic molecule:**

Average kinetic energy of a diatomic molecule at low temperature $= \frac{5}{2}kT$

Total energy of one mole of gas $= \frac{5}{2}kT \times N_A$; $= \frac{5}{2}RT$

(Here, the total energy is purely kinetic) For one mole Specific heat at constant volume. $C_V = \frac{dU}{dT}$; $= \left[\frac{5}{2}RT\right]$; $C_V = \frac{5}{2}R$

But, $C_P = C_V + R$

$= \frac{5}{2}R + R = \frac{7}{2}R$

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$; $= \frac{\frac{7}{2}R}{\frac{5}{2}R} = \frac{7}{5}$ **γ =1.40**

Energy of a diatomic molecule at high temperature is equal to $\frac{7}{2}$RT

$C_V = \frac{dU}{dT}$; $= \left[\frac{7}{2}RT\right]$; $C_V = \frac{7}{2}R$

But, $C_P = C_V + R$

$= \frac{7}{2}R + R = \frac{9}{2}R$

Note that the C_V and C_P are **higher for diatomic molecules than the mono atomic molecules.** It implies that to increase the temperature ofdiatomic gas molecules by 1°C it requires more heat energy than mono-atomic molecules.

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$;

$= \frac{\frac{9}{2}R}{\frac{7}{2}R} = \frac{9}{7}$ **γ =1.28**

iii) **Tri-atomic molecule:**

a) Linear molecule:

Energy of one mole $= \frac{7}{2}kT \times N_A$; $= \frac{7}{2}RT$

$C_V = \frac{dU}{dT}$; $= \frac{d}{dT}\left[\frac{7}{2}RT\right]$; $C_V = \frac{7}{2}R$

But, $C_P = C_V + R$

$= \frac{7}{2}R + R = \frac{9}{2}R$

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$; $= \frac{\frac{9}{2}R}{\frac{7}{2}R} = \frac{9}{7}$ **γ =1.28**

b) Non-linear molecule:

Energy of a mole $= \frac{6}{2}kT \times N_A$; $= \frac{6}{2}RT = 3RT$

$C_V = \frac{dU}{dT}$; = 3R ;

But, $C_P = C_V + R$;= 3R + R = 4R

The ratio of specific heats, $\gamma = \frac{C_P}{C_V} = \frac{4R}{3R} = \frac{4}{3}$ **γ = 1.33**

Note that according to kinetic theory model of gases the **specific heat capacity at constant volume and constant pressure are independent of temperature.** But in reality it is not sure. The specific heat capacity varies with the temperature.

26. Explain in detail the Maxwell Boltzmann distribution function.

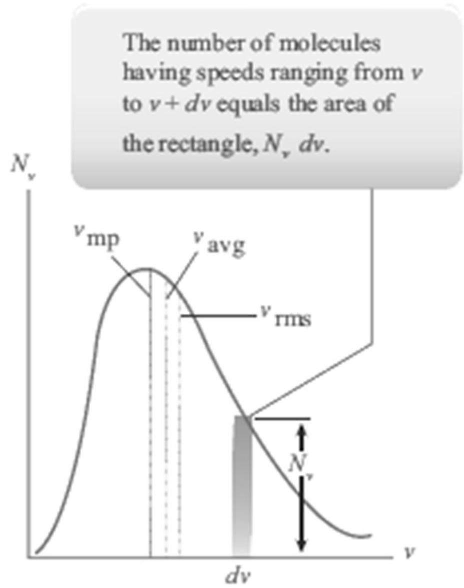
1) The air molecules are **moving in random directions. The speed of each molecule is not the same even though macroscopic parameters** like temperature and pressure are fixed.

2) Each molecule **collides with every other molecule and they exchange their speed. Section we calculated the rms speed of each molecule and not the speed of each molecule** which is rather difficult.

3) In this scenario we can find the number of gas molecules that move with the speed of **5 m s^{-1}to 10 m s^{-1}or 10 m s^{-1}to 15 m s^{-1}etc.**

4) In general our interest is to find how many gas molecules have the range of speed from v to v + dv. This is given by Maxwell's speed distribution function. $N_V = 4_pN\left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2\frac{mv^2}{e^{2kT}}$

The above expression is graphically shown as follows



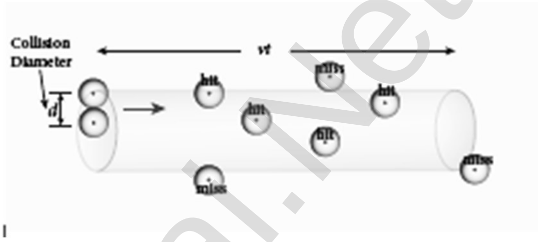
5) for a given temperature **the number of molecules having lower speed increases parabolically but decreases exponentially after reaching most probable speed.** The rms speed, average speed and most probable speed are indicated in the Figure. It can be **seen that the rms speed is greatest among the three.**

6) The area under the graph will give the total number of gas molecules in the system. Figure shows **the speed distribution graph for two different temperatures. As temperature increases, the peak of the curve is shifted to the right. It implies that the average speed of each molecule will increase.** But thearea under each graph is same since it represents the total number of gas molecules.

27. Derive the expression for mean free path of the gas.

Expression for mean free path

1) We know from postulates of **kinetic theory that the molecules of a gas are in random motion and they collide with each other**. Between two successive collisions, a molecule moves along a straight path with uniform velocity.



2) This path is called mean free path. Consider a system of molecules each with diameter d. Let n be the number of molecules per unit volume. Assume that **only one molecule is in motion and all others** are at rest as shown in the Figure.

3) If a molecule moves with average speed v in a time t, the distance travelled is vt. In this **time t, consider the molecule to move in an imaginary cylinder of volume $\pi d^2 vt$.**

4) It collides with **any molecule whose center is within this cylinder. Therefore, the number of collisions is equal to the number of molecules in the volume of the imaginary cylinder**. It is equal to $\pi d^2 vtn$. The total path length divided by the number of collisions in time t is the mean free path.

Mean free path = $\frac{\text{Distance travelled}}{\text{Number of collisions}}$; $\lambda = \frac{vt}{n\pi d^2 vt} = \frac{1}{n\pi d^2}$ ------------- 1

5) Though we have assumed that **only one molecule is moving at a time and other molecules are at rest, in actual practice all the molecules are in random motion.** So the average relative speed of one molecule with respect to other molecules has to be taken into account. After some detailed calculations (you will learn in higher classes) the correct expression for mean free path. $\lambda = \frac{1}{\sqrt{2}n\pi d^2}$---------------- 2

6) The equation (1) implies that**the mean free path is inversely proportional to number density. When the number density increases the molecular collisions increases**so it decreases the distance travelled by the molecule before collisions.

Case1: Rearranging the equation (2) using 'm' (mass of the molecule)

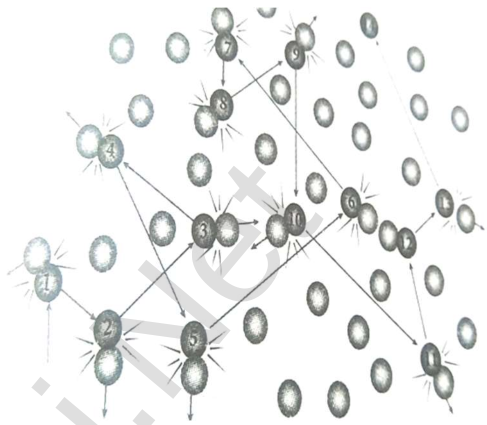
$\lambda = \frac{m}{\sqrt{2}\pi d^2 mn}$ But mn=mass per unit volume = ρ (density of the gas)

$\lambda = \frac{m}{\sqrt{2}\pi d^2 \rho}$ Also we know that PV = NkT

$P = \frac{N}{V}kT = nkT$; $n = \frac{P}{kT}$

Substituting $n = \frac{P}{kT}$ in equation (2), we get $\lambda = \frac{kT}{\sqrt{2}\pi d^2 P}$

28. Describe the Brownian motion.



1) Brownian motion is due **to the bombardment of suspended particles by molecules of the surrounding fluid.**
2) According to kinetic theory, **any particle suspended in a liquid or gas is continuously bombarded from all the directions so that the mean free path is almost negligible.** This leads to the motion of the particles in a random and zig-zag manner

Factors affecting Brownian motion:

1) Brownian motion **increases with increasing temperature.**
2) Brownian motion **decreases with bigger particle size, high viscosity and density of the liquid (or) gas.**

பிறந்த நாளுக்கு என்ன வேண்டும் என நாடு கேட்டபோது, புத்தகங்கள் வேண்டும் எனச் சற்றும் தயக்கமின்றி **லெனின்** கூறிடக் குவிந்த புத்தகங்கள் பல லட்சமாம். இன்று மாஸ்கோ லெனின் நூலகம்தான் உலகிலேயே மிகப்பெரிய நூலகமாம்.

தனிமைத் தீவில் தள்ளப்பட்டால் என்ன செய்வீர்கள்? என்று கேட்கப்பட்டபோது புத்தகங்களுடன் மகிழ்ச்சியாக வாழ்ந்து விட்டு வருவேன் என்று பதிலளித்தாராம் **நேரு**.

எங்கே தங்க விரும்புகிறீர்கள் என்று லண்டன் தோழர்கள் கேட்டபோது, எந்த விடுதி நூலகத்திற்கு அருகில் உள்ளது எனக் கேட்டாராம் **டாக்டர் அம்பேத்கர்**.

மனிதனின் மிகப்பெரிய கண்டுபிடிப்பு எது என்று வினவப்பட்டபோது சற்றும் யோசிக்காமல் புத்தகம் எனப் பதிலளித்தாராம் **ஆல்பர்ட் ஐன்ஸ்டீன்**.

UNIT – X (OSCILLATIONS)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. What is meant by periodic and non-periodic motion? Give any two examples, foreach motion.

1) **Periodic motion**Any motion which **repeats itself in a fixed time interval** is known as periodic motion.
Examples: Hands in pendulum clock, swing of a cradle, the revolution of the Earth around the Sun, waxing and waning of Moon, etc.

2) **Non-Periodic Motion**Any motion which **does not repeat itself after aregular interval of time** is known as non-periodic motion.
Example: Occurrence of Earth quake, eruption of volcano, etc.

2. What is meant by force constant of a spring?

The displacement of the particle is measured **in terms of linear displacement $\vec{r}$. The restoring force is $\vec{F} = -k\vec{r}$**, where kis a spring constant or force constant.

1) Oscillations of a loaded spring2) Vibrations of a turning force

3. Define time period of simple harmonic motion.

The time period is defined **as the time taken by a particle to complete one oscillation. It is usually denoted by T.** For one complete revolution, the time taken is t = T, therefore, $\omega T = 2\pi \Rightarrow T = \frac{2\pi}{\omega}$

4. Define frequency of simple harmonic motion.

The **number of oscillations produced by the particle per second** is called frequency. It is denoted by f. **SI unit for frequency is s^{-1} or hertz**
(In symbol, Hz).

Angular frequency is related to time period by $f = \frac{1}{T}$

The number of cycles (or revolutions) per second is called angular frequency.

It is usually denoted by the Greek small letter 'omega', ω.

Angular frequency and frequency are related by $\omega = 2\pi f$

SI unit for angular frequency is rad s^{-1}.

5. What is an epoch?

The displacement time t = 0 s (initial time), the phase $\varphi = \varphi_0$ is called **epoch.** (initial phase) where $\varphi_0$is called the angle of epoch.

6. **Write short notes on two springs connected in series.**

Consider only **two springs whose spring constant are k_1 and k_2 and which can be attached to a mass m**. The results thus obtained can be generalized for any number of springs in series.

7. **Write short notes on two springs connected in parallel.**

Consider only **two springs of spring constants k_1 and k_2 attached to a mass m. The results can be generalized**to any number of springs in parallel.

8. **Write down the time period of simple pendulum.**

The angular frequency of this oscillator (natural frequency of this system) is $\omega^2 = \frac{g}{l} \Rightarrow \omega = \sqrt{\frac{g}{l}}$ in $rads^{-1}$

The frequency of oscillations is $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$ in Hz, and time period of oscillations is $T = 2\pi\sqrt{\frac{l}{g}}$

9. **State the laws of simple pendulum?**

Law of length: For a given value of acceleration due to gravity, the time period of a simple pendulum is **directly proportional to the square root of length of the pendulum. T $\alpha\sqrt{l}$**

Law of acceleration: For a fixed length, the time period of a simple pendulum is **inversely proportional to square root of acceleration due to gravity. T $\alpha\frac{1}{\sqrt{g}}$**

10. **Write down the equation of time period for linear harmonic oscillator.**

From Newton's second law, we can write the equation for the particle executing simple harmonic motion $m\frac{d^2x}{dt^2} = -kx$;

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x$$

Comparing the equation with simple harmonic motion equation,

we get, $\omega = \sqrt{\frac{k}{m}}$ rad s^{-1}

Natural **frequency of the oscillator**is $f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ **Hertz.**

and the **time period of the oscillation** is $T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}}$ **second.**

11. What is meant by free oscillation?

When the oscillator is **allowed to oscillate by displacing its position from equilibrium position, it oscillates with a frequency which is equal to the natural frequency of the oscillator.** Such an oscillation or vibration is known as free oscillation or free vibration.

12. Explain damped oscillation. Give an example.

1) Due to the presence of friction and air drag, **the amplitude of oscillation decreases as time progresses.** It implies that the oscillation is not sustained and the energy of the SHM decreases gradually indicating the loss of energy.

2) **The energy lost is absorbed by the surrounding medium. This type of oscillatory motion** is known as damped oscillation.

Examples (i) The oscillations of a pendulum (including air friction) or pendulum oscillating inside an oil filled container. (ii) Electromagnetic oscillations in a tank circuit. (iii) Oscillations in a dead beat and ballistic galvanometers.

13. Define forced oscillation. Give an example.

In this type of vibration, **the body executing vibration initially vibrates with its natural frequency and due to the presence of external periodic force, the body later vibrates with the frequency of the applied periodic force**. Such vibrations are known as forced vibrations. **Example:** Sound boards of stringed instruments.

14. What is meant by maintained oscillation? Give an example.

While playing in swing, **the oscillations will stop after a few cycles, this is due to damping. To avoid damping we have to supply a push to sustain oscillations. By supplying energy from an external source**, the amplitude of the oscillation can be made constant. Such vibrations are known as maintained vibrations.

Example: The vibration of a tuning fork getting energy from a battery or from external power supply.

15. Explain resonance. Give an example.

The frequency of external periodic force (or driving force) matches with the **natural frequency of the vibrating body (driven). As a result, the oscillating body begins to vibrate such that its amplitude increases** at each step and ultimately it has a large amplitude. Such a phenomenon is known as resonance and the corresponding vibrations are known as resonance vibrations.

Example: The breaking of glass due to sound.

16. Define oscillatory or vibratory motion.

When an object or a particle moves back and forth repeatedly for some duration of time its motion is said to be oscillatory (or vibratory).

Examples: our heart beat, swinging motion of the wings of an insect, grandfather's clock (pendulum clock), etc.

17. State five characteristics of SHM.

Displacement: The distance travelled by the vibrating particle at any instant of time t from its mean position is known as displacement.

Velocity: The rate of change of displacement of the particle is velocity.

Acceleration: The rate of change of velocity of the particle is acceleration.

Amplitude: The maximum displacement on either side of mean position.

Time Period: The time taken by the particle executing SHM to complete one vibration.

18. Will a pendulum clock loss or gain time when taken to the top of a mountain?

On the top of the mountain, **the value of g is less than that on the surface of the earth the decreases in the value of g increases** the time period of the pendulum on the top of the mountain. So the pendulum clock loses time.

19. Why are army troops not allowed to march in steps while crossing the bridge?

Army troops are not allowed to march in **steps because it is quite likely that the frequency of the footsteps may match with the natural frequency of thebridge and due to resonance the bridge**may pick up large amplitude and break.

20. How can earthquakes cause disaster sometimes?

The resonance may cause **disaster during the earthquake, if the frequency of oscillation present within the earth per chance coincides** with natural frequency of some building, which may start vibrating with large amplitude due to resonance and may get damaged.

21. Every simple harmonic motion is periodic motion but every periodic motion need not be simple harmonic motion. Do you agree? Give example.

Yes, every periodic motion need not be simple harmonic motion. The motion of the earth round the sun is a period motion, but not simple harmonic motion as the back and forth motion is not taking place.

22. Glass windows may be broken by a far-away explosion. Explain why?

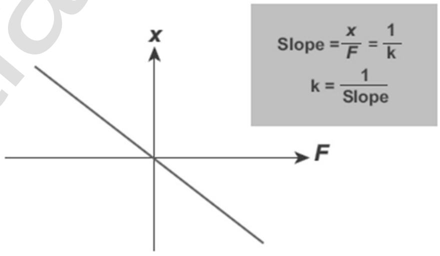
A large amplitude in all directions. As these sound waves strike the glass windows, they set them into forced oscillations.

Since glass is brittle, so the glass windows break as soon as they start oscillating due to forced oscillations.

FIVE MARKS QUESTION WITH ANSWER

23. What is meant by simple harmonic oscillation? Give examples and explain whyevery simple harmonic motion is a periodic motion whereas the converse neednot be true.

1) Simple harmonic motion is a special type of **oscillatory motion in which the acceleration or force on the particle is directly proportional to its displacement from a fixed point and is always directed** towards that fixed point.



2) In one dimensional case, let x be the displacement of the particle and a_x be the **acceleration of the particle, then $a_x \propto$; $a_x = -\, b\, x$**

where b is a constant which measures acceleration per unit displacement and dimensionally it is equal to T^{-2}. By multiplying by mass of the particle on both sides of equation and from **Newton's second law, the force is $F_x = -\, kx$**

where kis a force constant which is defined as force per unit length.

3) The **negative sign indicates that displacement and force (or acceleration) are in opposite directions.**

4) This means that when **the displacement of the particle is taken towards right of equilibrium position** (x takes positive value), the force (or acceleration) will point towards equilibrium (towards left) and similarly, when **the displacement of the particle is taken towards left of equilibrium position (x takes negative value),** the force (or acceleration) will point towards equilibrium (towards right).

5) This type of force is known as **restoring force**because it always directs the particle executing simple harmonic motion to restore to its original (equilibrium or mean) position. **This force (restoring force) is central and attractive whose center of attraction is the equilibrium position**.

6) In order to represent in two or three dimensions, we can write using vector notation $\vec{F} = -\, k\vec{r}$, where $\vec{r}$is the displacement of the particle from the chosen origin. Note that the force and displacement have a linear relationship.

7) This means that **the exponent of force $\vec{F}$ and the exponent of displacement $\vec{r}$ are unity.** The sketch between cause (magnitude of force $|\vec{F}|$) **and effect (magnitude of displacement $|\vec{r}|$) is a straight line passing through second and fourth quadrant**

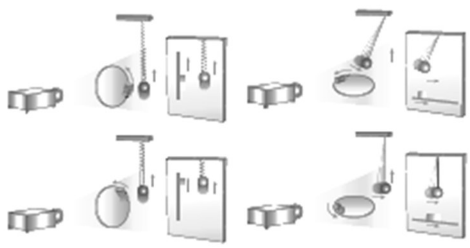
By measuring slope $\frac{1}{k}$, one can find the numerical value of force constant k.

24. Describe Simple Harmonic Motion as a projection of uniform circular motion.

1) Consider a particle of mass m moving with uniform speed v along the **circumference of a circle whose radius is r in anti-clockwise direction.** Let us assume that the origin of the coordinate system coincides with the center O of the circle.

2) If ω is **the angular velocity of the particle and θ the angular displacement of the particle at any instant of time t, then θ = ωt.** By projecting the uniform circular motion on its diameter gives a simple harmonic motion.

3) This means that we can **associate map (or a relationship) between uniform circular (or revolution) motion to vibratory motion.** Conversely, any vibratory motion or revolution can be mapped to uniform circular motion. In other words, these two motions are similar in nature.



4) Let us first **project the position of a particle moving on a circle, on to its vertical diameter or on to a line parallel to vertical diameter.** Similarly, we can do it for horizontal axis or a line parallel to horizontal axis.

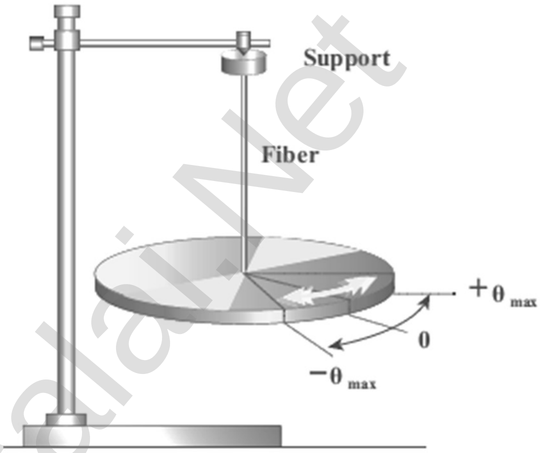
5) As a specific example, **consider a spring mass system (or oscillation of pendulum). When the spring moves up and down (or pendulum moves to and fro), the motion of the mass or bob is mapped to points** on the circular motion.

6) Thus, if a **particle undergoes uniform circular motion then the projection of the particle on the diameter of the circle** (or on a line parallel to the diameter) traces straight-line motion which is simple harmonic in nature.

7) The circle is known as reference circle of the simple harmonic motion. The **simple harmonic motion can also be defined as the motion of the projection of a particle on any diameter of a circle of reference.**

25. What is meant by angular harmonic oscillation? Compute the time period of angular harmonic oscillation.

1) **When a body is allowed to rotate freely about a given axis then the oscillation** is known as the angular oscillation. The point at which the resultant **torque acting on the body is taken to be zero is called mean position.**



2) If the body is displaced from the mean position, then the resultant torque acts such that it is **proportional to the angular displacement and this torque has a tendency to bring the body towards the mean position.** Let $\vec{\theta}$ be the angular displacement of the body and the resultant torque $\vec{\tau}$ acting on the body is $\vec{\tau} \propto \vec{\theta}$ ------------ 1

$\vec{\tau} = -k\vec{\theta}$ ------------ 2

k is the restoring torsion constant, which is torque per unit angular displacement. If *I* is the moment of inertia of the body and $\vec{\alpha}$ is the angular acceleration then $\vec{\tau} = I\vec{\alpha} = -k\vec{\theta}$.

But $\vec{\alpha} = \frac{d^2\vec{\theta}}{dt^2}$ and therefore, $\vec{\alpha} = \frac{d^2\vec{\theta}}{dt^2} = \frac{k}{I}\vec{\theta}$ ------------ 3

3) This differential equation resembles simple harmonic differential equation.So, comparing equation with simple harmonic motion given in equation, we have $\omega = \sqrt{\frac{k}{I}}$ rad s^{-1} ---------- 4

The frequency of the angular harmonic motion is $f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{I}}$ Hz...5

and the time period of the oscillation is $T = \frac{1}{f} = 2\pi\sqrt{\frac{I}{k}}$ second.

26. Write down the difference between simple harmonic motion and angularsimple harmonic motion.

S. No.	Simple Harmonic Motion	Angular Harmonic Motion
1	The displacement of the particle is measured in terms of linear displacement $\vec{r}$	The displacement of the particle is measured in terms of angular displacement $\vec{\theta}$
2	Acceleration of the particle is $\vec{a} = -\omega^2\vec{r}$	Angular Acceleration of the particle is $\vec{\alpha} = -\omega^2\vec{\theta}$
3	Force , $\vec{F}$= m$\vec{a}$ where m is called mass of the particle.	Torque, $\vec{\tau}$ = I$\vec{\alpha}$ where I is called moment of inertia of a body.
4	The restoring force $\vec{F}$= – k$\vec{r}$ where k is restoring force constant	The restoring torque $\vec{\tau}$= – k$\vec{\theta}$ where k is restoring torsion constant. Note: k pronounced "kappa"
5	Angular frequency ω = $\sqrt{\frac{k}{m}}$rad^{-1}	Angular frequency ω = $\sqrt{\frac{k}{I}}$rad^{-1}

27. Discuss the simple pendulum in detail.

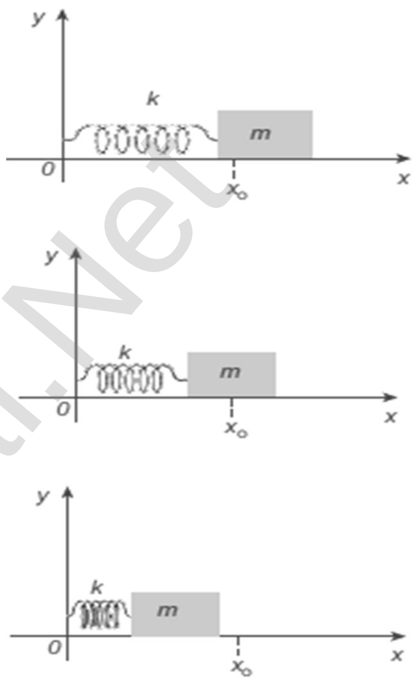
1) **A pendulum is a mechanical system which exhibits periodic motion. It has a bob with mass m suspended by a long string** (assumed to be mass less and inextensible string) and the other end is fixed on a stand.

2) **When a pendulum is displaced through a small displacement from its equilibrium position and released**, the bob of the pendulum executes to and fro motion. Let l be the length of the pendulum which is taken as the distance between the point of suspension and the centre of gravity of the bob.

3) Two forces act on the bob of the pendulum at any displaced position.
(i) The gravitational force acting on the body ($\vec{F}$=–m$\vec{g}$) which acts vertically downwards. (ii) The tension in the string $\vec{F}$which acts along the string to the point of suspension.

4) Resolving the gravitational force into its components:
a. **Normal component:** The component along the string but in opposition to the direction of tension, **F_{as}= mg cosθ.**
b. **Tangential component:** The component perpendicular to the string i.e., along tangential direction of arc of swing, **F_{ps}= mg sinθ.**

28. Explain the horizontal oscillations of a spring.



1) Consider a system containing a block of mass m attached to a mass less spring with stiffness constant or force constant or spring constant k placed on a smooth horizontal surface (frictionless surface) as shown in Figure.

2) **Let x_0 be the equilibrium position or mean position of mass m when it is left undisturbed.** Suppose the mass is displaced through a small displacement x towards right from its equilibrium position and then released, it will oscillate back and forth about its mean position x_0.

3) **Let F be the restoring force (due to stretching of the spring) which is proportional to the amount of displacement of block.** For one dimensional motion, mathematically, we have $F \alpha\, x$; $F = -\, kx$

4) **Where negative sign implies that the restoring force will always act opposite to the direction of the displacement.** Notice that, the restoring force is linear with the displacement.

5) This is not always true; in case if we apply **a very large stretching force, then the amplitude of oscillations becomes very large (which means, force is proportional to displacement containing higher** powers of x) and therefore, the oscillation of the system is not linear and hence, it is called non-linear oscillation.

6) We restrict ourselves only to linear oscillations throughout our discussions, which means Hooke's law is valid (force and displacement have a linear relationship).

From Newton's second law, we can write the equation for the particle executing simple harmonic motion $m\frac{d^2x}{dt^2} = -\,kx$; $\frac{d^2x}{dt^2} = -\,\frac{k}{m}x$ -----------1

Comparing the equation (1) with simple harmonic motion equation, we get $\omega^2 = \frac{k}{m}$. Which means the angular frequency or natural frequency of the oscillator is $\omega = \sqrt{\frac{k}{m}}$ rsd s^{-1} ----------- 2

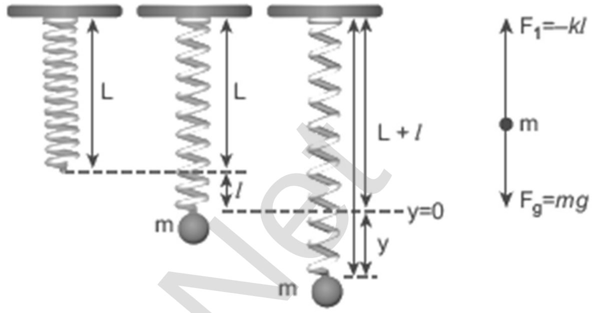
Natural frequency of the oscillator is $f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ Hertz -------- 3

and the time period of the oscillation is $T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}}$ second -------- 4

Notice that **in simple harmonic motion, the time period of oscillation is independent of amplitude.** This is valid only if the amplitude of oscillation is small.

29. Describe the vertical oscillations of a spring.

1) **Consider a mass less spring with stiffness constant or force constant k attached to a ceiling** as shown in Figure. Let the length of the spring before loading mass m be L. If the block of mass m is attached to the other end of spring, then the spring elongates by a length l.



2) **Let F_1 be the restoring force due to stretching of spring. Due to mass m, the gravitational force acts vertically downward.** We can draw free-body diagram for this system as shown in Figure. When the system is under equilibrium,

$F_1 + mg = 0$ -------------- 1

3) But the spring elongates by small displacement l,

therefore, $F_1 \propto \boldsymbol{l} \Rightarrow F_1 = -k\,\boldsymbol{l}$ ---------- 2

Substituting equation (2) in equation (1), we get $-k\,l + mg = 0$

$mg = kl$ or $\frac{m}{k} = \frac{l}{g}$ ---------- 3

4) Suppose we apply a very small external force on the mass such that the mass further displaces downward by a displacement y, then it will oscillate up and down. Now, the restoring force due to this stretching of spring (total extension of spring is $y + l$) is

$F_2 \propto (y + \boldsymbol{l})$ $F_2 = -k(y + \boldsymbol{l}) = -ky - k\boldsymbol{l}$ -----4

Since, the mass moves up and down with acceleration $\frac{d^2y}{dt^2}$, by drawing the free body diagram for this case, we get $-ky - k\boldsymbol{l} + mg = m\frac{d^2y}{dt^2}$ ----- 5

The net force acting on the mass due to this stretching is $F = F_2 + mg$

$F = -ky - k\boldsymbol{l} + mg$ ----------- 6

5) The gravitational force opposes the restoring force. Substituting equation (3) in equation (6), we get $F = -ky - k\boldsymbol{l} + k\boldsymbol{l} = -ky$

Applying Newton's law, we get $m\frac{d^2y}{dt^2} = -ky$; $m\frac{d^2y}{dt^2} = -\frac{k}{m}y$ ----------- 7

6) The above equation is in the form of simple harmonic differential equation. Therefore, we get the time period as $T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}}$ second

The time period can be rewritten using equation (3)

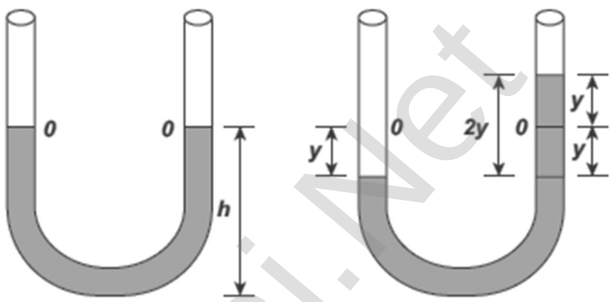
$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{l}{g}}$ second

The acceleration due to gravity g can be computed from the formula

$g = 4\pi^2\left(\frac{l}{T^2}\right) ms^{-1}$

30. Write short notes on the oscillations of liquid column in U-tube.

1) **Consider a U-shaped glass tube which consists of two open arms with uniform cross-sectional area A. Let us pour a non-viscous uniform incompressible liquid of density** ρ in the U-shaped tube to a height h as shown in the Figure.



2) If the liquid and tube are not disturbed then the liquid surface will be in equilibrium position O. **It means the pressure as measured at any point on the liquid is the same and also at the surface on the arm** (edge of the tube on either side), which balances with the atmospheric pressure.

3) **Due to this the level of liquid in each arm will be the same. By blowing air one can provide sufficient force in one arm**, and the liquid gets disturbed from equilibrium position O, which means, the pressure at blown arm is higher than the other arm.

4) This creates difference in pressure which will cause the liquid to oscillate for a very short duration of time about the mean or equilibrium position and finally comes to rest.

Time period of the oscillation is T = $2\pi\sqrt{\frac{l}{g}}$ second

31. Discuss in detail the energy in simple harmonic motion.

a. Expression for Potential Energy

1) **For the simple harmonic motion, the force and the displacement are related** by Hooke's law $\vec{F} = -k\vec{r}$

2) Since force is a vector quantity, **in three dimensions it has three components.** Further, the force in the above equation is a conservative force field; such a force can be derived from a scalar function which has only one component. In one dimensional case

$F = -kx$ ---------------(1)

The work done by the conservative force field is independent of path. The potential energy U can be calculated from the following expression.

$F = \frac{dU}{dx}$ ------------ 2

Comparing (1) and (2), we get $-\frac{dU}{dx} = -kx$; $dU = kxdx$

3) This work done by the force F during a small displacement dx stores as potential energy $U(x) = \int_0^x kx'\,dx = \frac{1}{2}(x')^2\Big|_0^x = \frac{1}{2}kx^2$ ------ 3

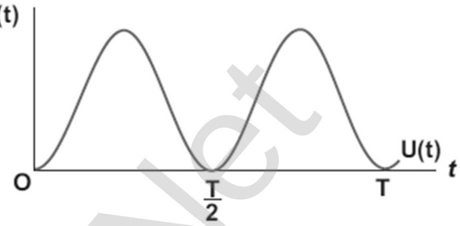
From equation $\omega = \sqrt{\frac{k}{m}}$, we can substitute the value of force constant

$k = m\omega^2$ in equation (3), $U(x) = m\,\omega^2 x^2$

4) where ω is the natural frequency of the oscillating system. For the particle executing simple harmonic motion from equation $x = A \sin \omega t$

$U(t) = \frac{1}{2} m\omega^2 A^2 \sin^2\omega t$ ------------4

This variation of U is shown below.



b. Expression for Kinetic Energy

Kinetic energy $KE = \frac{1}{2} m v_x^2 = \frac{1}{2} m \left(\frac{dx}{dt}\right)^2$

Since the particle is executing simple harmonic motion, from equation

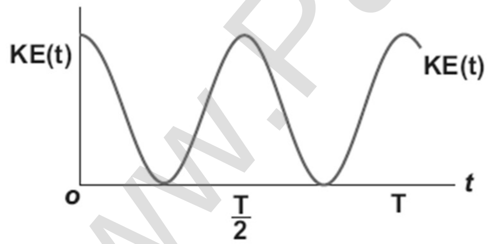
$y = A \sin \omega t$; $x = A \sin \omega t$ Therefore, velocity is $v_x = \frac{dx}{dt}$ A ωcosωt

$= a\omega\sqrt{1 - \left(\frac{x}{A}\right)^2}$; $v_x = \omega\sqrt{A^2 - x^2}$ ------------ 5

Hence, $KE = \frac{1}{2} m v_x^2 = \frac{1}{2} m\omega^2 (A^2 - x^2)$ ------------ 6

$KE = \frac{1}{2} m\omega^2 A^2 \cos^2\omega t$ ------------ 7

This variation with time is shown below.



c. Expression for Total Energy

Total energy is the sum of kinetic energy and potential energy

$E = KE + U$ ------------8 ; $E = \frac{1}{2} m\,\omega^2 (A^2 - x^2) + \frac{1}{2} m\,\omega^2 x^2$

Hence, cancelling x^2 term, $E = \frac{1}{2} m\,\omega^2 A^2$ = Constant ---------9

Alternatively, from equation (4) and equation (7),

we get the total energy as $E = \frac{1}{2} m\omega^2 A^2 \sin^2\omega t + \frac{1}{2} m\omega^2 A^2 \cos^2\omega t$

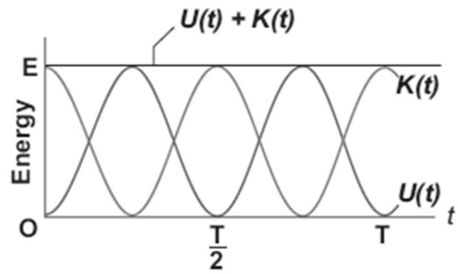
$E = \frac{1}{2} m\omega^2 A^2 (\sin^2\omega t + \cos^2\omega t)$

From trigonometry identity,

$(\sin^2\omega t + \cos^2\omega t) = 1$

$E = \frac{1}{2} m\omega^2 A^2$ = Constant.

which gives the law of conservation of total energy. This is depicted in Figure.

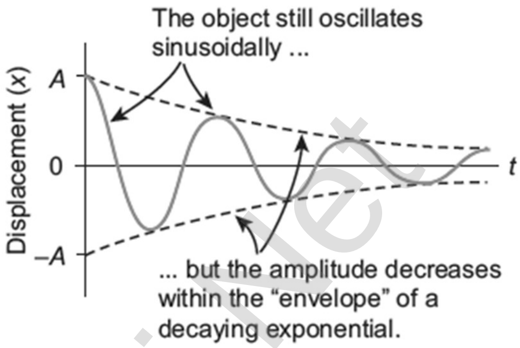


Thus the amplitude of simple harmonic oscillator, can be expressed in terms of total energy. $A = \sqrt{\frac{2E}{m\omega^2}} = \sqrt{\frac{2E}{k}}$

32. Explain in detail the four different types of oscillations.

Damped oscillations:

1) **During the oscillation of a simple pendulum, we have assumed that the amplitude of the oscillation** is constant and also the total energy of the oscillator is constant. But in reality, in a medium, due to the presence of friction and air drag, the amplitude of oscillation decreases as time progresses.



2) It implies **that the oscillation is not sustained and the energy of the SHM decreases gradually indicating the loss of energy. The energy lost is absorbed by the surrounding medium**. This type of oscillatory motion is known as damped oscillation.

3) In other words, if an oscillator moves in **a resistive medium, its amplitude goes on decreasing and the energy of the oscillator is used to do work against the resistive medium.**

4) The motion of the oscillator is said to be damped and in this case, the **resistive force (or damping force) is proportional to the velocity of the oscillator.**

Examples (i) The oscillations of a pendulum (including air friction) or pendulum oscillating inside an oil filled container. (ii) Electromagnetic oscillations in a tank circuit. (iii) Oscillations in a dead beat and ballistic galvanometers.

Maintained oscillations:

1) **While playing in swing**, the oscillations will stop after a few cycles, this is due to damping. **To avoid damping we have to supply a push to sustain oscillations.**

2) **By supplying energy from an external source, the amplitude of the oscillation can be made constant**. Such vibrations are known as maintained vibrations.

Example: The vibration of a tuning fork getting energy from a battery or from external power supply.

Forced oscillations:

1) Any oscillator driven by **an external periodic agency to overcome the damping is known as forced oscillator or driven oscillator.**

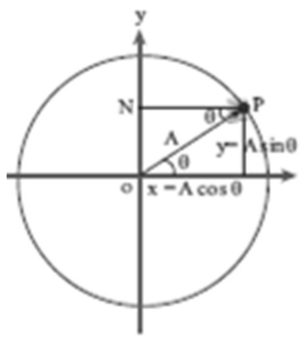
2) In this type of vibration, **the body executing vibration initially vibrates with its natural frequency and due to the presence of external periodic**

force, the body later vibrates with the frequency of the applied periodic force. Such vibrations are known as forced vibrations.
Example: Sound boards of stringed instruments.

Resonance:

1) It is a special case of **forced vibrations where the frequency of external periodic force (or driving force) matches with the natural frequency** of the vibrating body (driven).
2) As a **result the oscillating body begins to vibrate such that its amplitude increases at each step and ultimately it has a large amplitude.** Such a phenomenon is known as resonance and the corresponding vibrations are known as resonance vibrations.
Example: The breaking of glass due to sound.

33. Show that the projection of uniform circular motion on a diameter is SHM.

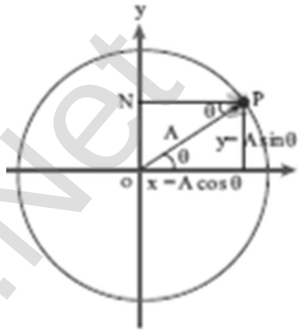


1) **Consider a particle of mass m moving with uniform speed v along the circumference of a circle whose radius is r in anti-clockwise** direction as shown in Figure. Let us assume that the origin of the coordinate system coincides with the center O of the circle.
2) **If ω is the angular velocity of the particle and θ the angular displacement** of the particle at any instant of time t, then $\theta = \omega t$.
3) By projecting the uniform circular motion on its diameter gives a simple harmonic motion. This means that we **can associate a map (or a relationship) between uniform circular (or revolution)** motion to vibratory motion.
4) Conversely, any vibratory motion or revolution can be mapped to uniform circular motion. In other words, these two motions are similar in nature.

34. Explain briefly about the graphical representation of Displacement, VelocityandAcceleration in SHM.

Displacement:

1) **The distance travelled by the vibrating particle at any instant of time t from its mean position is known as displacement.** Let P be the position of the particle on a circle of radius A at some instant of time t as shown in Figure. Then its displacement y at that instant of time t can be derived as follows



In ΔOPN Sin $\boldsymbol{\theta} = \frac{ON}{OP} \Rightarrow$ ON = OP Sin $\boldsymbol{\theta}$

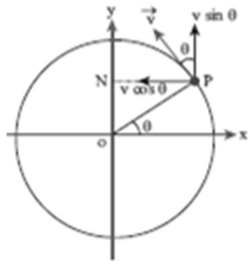
But θ = ωt, ON = y and OP = A

y = A sin ωt -------------1

2) The displacement y takes maximum value (which is equal to A) when sin ωt = 1. This maximum displacement from the mean position is known as amplitude (A) of the vibrating particle. For simple harmonic motion, the amplitude is constant. But, in general, for any motion other than simple harmonic, the amplitude need not be constant, it may vary with time.

Velocity:

1) The rate of change of displacement is velocity. Taking derivative of equation (1) with respect to time, we get



v = $\frac{dy}{dt} = \frac{d}{dt}$(A sin ωt)

For circular motion (of constant radius), amplitude A is a constant and further, for uniform circular motion, angular velocity ω is a constant. Therefore, v = $\frac{dy}{dt}$ = (A ωcos ωt) -----------2

Using trigonometry identity, $\sin^2 \omega t + con^2 \omega t = 1$

⇒cos ωt = $\sqrt{1 - Sin^2\omega t}$, we get, v = Aω$\sqrt{1 - Sin^2\omega t}$

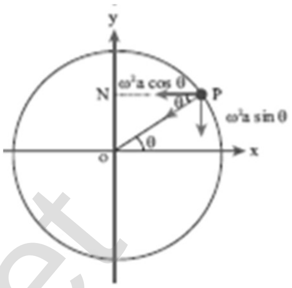
From equation(1) sin ωt = $\frac{y}{A}$; v = Aω$\sqrt{1 - \left(\frac{y}{A}\right)^2}$

v = ω$\sqrt{A^2 - y^2}$ -----------3

2) From equation (3), when the displacement y = 0, the velocityv = ωA (maximum) and for the maximum displacement y = A, the velocity v= 0 (minimum).

3) As displacement increases from zero to maximum, the velocity decreases from maximum to zero. This is repeated.

Since velocity is a vector quantity, equation (2) can also be deduced by resolving in to components.



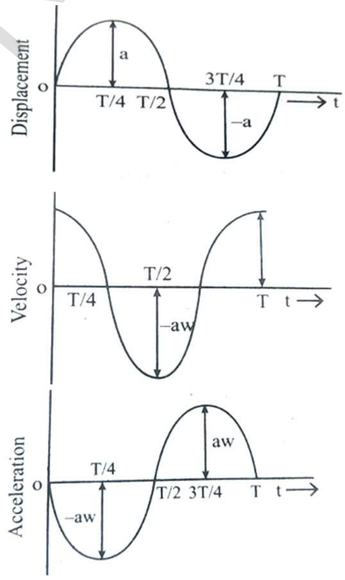
Acceleration:

The rate of change of velocity is acceleration.

$a = \frac{dv}{dt} = \frac{d}{dt}(A\,\omega\cos\omega t)$; $a = -\omega^2 A\sin\omega t = -\omega^2 y$ ---------4

$a = \frac{d^2y}{dt^2} = -\omega^2 y$ ------------5

The mean position (y = 0), velocity of the particle is maximum but the acceleration of the particle is zero. At the extreme position (y = ±A), the velocity of the particle is zero but the acceleration is maximum $\pm A\omega^2$ acting in the opposite direction.

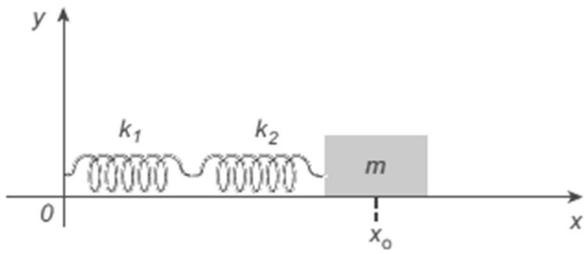


Time	ωt	Displacement (y = A sin ωt)	Velocity (v= A ωcos ωt)	Acceleration ($a = -\omega^2 A\sin\omega t$)
t=0	0	0	Aω	0
$t=\frac{T}{4}$	$\frac{\pi}{2}$	+ A	0	$-A\omega^2$
$t=\frac{T}{2}$	π	0	− Aω	0
$t=\frac{3T}{4}$	$\frac{3\pi}{2}$	− A	0	$A\omega^2$
t = T	2π	0	Aω	0

35. Explain the effective spring constant in series connection and parallel connection

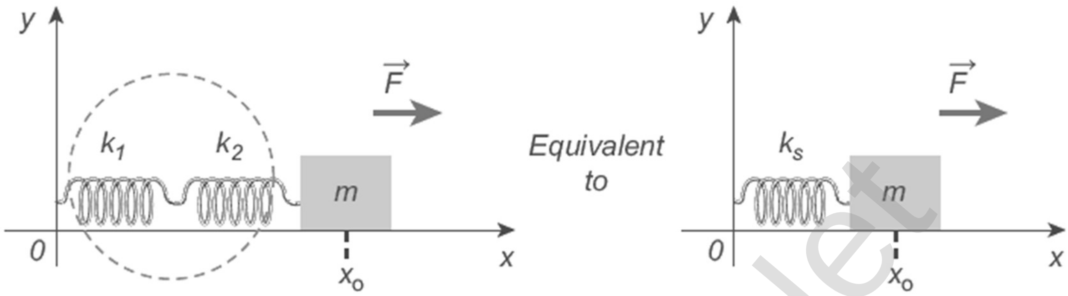
a) Springs connected in series

1) **When two or more springs are connected in series, all the springs in series with an equivalent spring (effective spring)** whose net effect is the same as if all the springs are in series connection.



2) Given the **value of individual spring constants k_1, k_2, k_3,... (known quantity), we can establish a mathematical relationship to find out an effective (or equivalent) spring constant k_s(unknown quantity).** For simplicity, let us consider only two springs whose spring constant are k_1 and k_2 and which can be attached to a mass m as shown in Figure.

3) The results thus obtained can be generalized for any number of springs in series. Let F be the applied force towards right as shown in Figure.

4) 

Since the spring constants for different spring are different and the connection points between them is not rigidly fixed, the strings can stretch in different lengths.

5) Let x_1 and x_2 be the elongation of springs from their equilibrium position (un-stretched position) due to the applied force F. Then, the net displacement of the mass point is $x = x_1 + x_2$ ----------1

From Hooke's law, the net force

$F = -k_s(x_1+x_2) \Rightarrow x_1 + x_2 = -\frac{F}{k_s}$ ----------2

For springs in series connection

$-k_1x_1 = -k_2x_2 = F$

$x_1 = -\frac{F}{k_1}$ and $x_2 = -\frac{F}{k_2}$ ----------3

Therefore, substituting equation (3) inequation (2), the effective spring constant can be calculated as $-\frac{F}{k_1} - \frac{F}{k_2} = \frac{F}{k_s}$

$\frac{1}{k_s} = \frac{1}{k_1} + \frac{1}{k_2}$ or $k_s = \frac{k_1k_2}{k_1+k_2}$ Nm^{-1} ------------ 4

Suppose we have n springs connected in series, the effective spring constant in series is $\frac{1}{k_s} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + ... + \frac{1}{k_n} = \sum_{i=1}^{n}\frac{1}{k_i}$ ---------5

If all spring constants are identical i.e., $k_1 = k_2 = ... = k_n = k$

then $\frac{1}{k_s} = \frac{n}{k} \Rightarrow k_s = \frac{k}{n}$ ---------- 6

6) This means that the effective spring constant. reduces by the factor n. Hence, for springs in series connection, the effective spring constant is lesser than the individual spring constants.

7) From equation (3), we have, $k_1x_1 = k_2x_2$Then the ratio of compressed distance or elongated distance $x_1$and $x_2$is $\frac{x_2}{x_1} = \frac{k_1}{k_2}$ -----------7

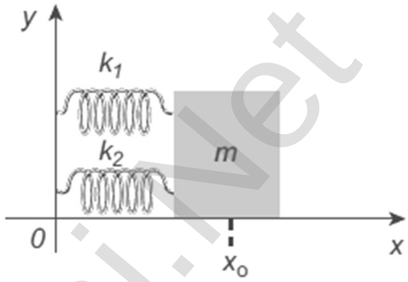
The elastic potential energy stored in first and second springs are

$v_1 = \frac{1}{2}k_1x_1^2$ and $v_2 = \frac{1}{2}k_2x_2^2$ respectively.

Then, their ratio is $\frac{v_1}{v_2} = \frac{\frac{1}{2}k_1x_1^2}{\frac{1}{2}k_2x_2^2}$ ----------- 8

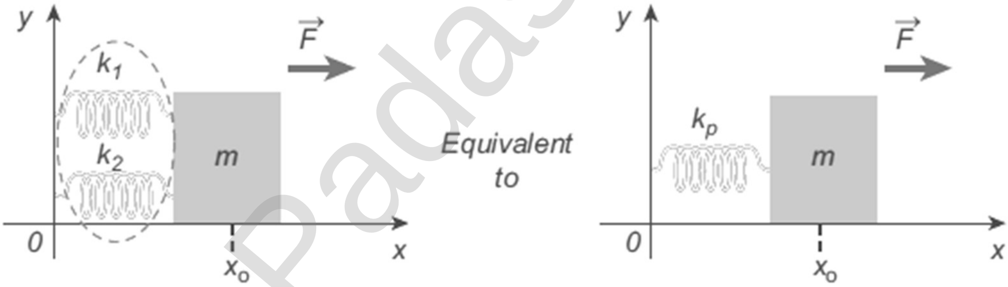
b) Springs connected in parallel

1) **When two or more springs are connected in parallel, we can replace, all these springs with an equivalent spring (effective spring) whose net effect is same as if all the springs are in parallel connection.**



2) Given the values of individual spring constants to be $k_1, k_2, k_3, \ldots$ (known quantities), we can establish a mathematical relationship to find out an effective (or equivalent) spring constant k_p(unknown quantity).

3) For simplicity, let us consider only two springs of spring constants k_1 and k_2 attached to a mass m as shown in Figure. The results can be generalized to any number of springs in parallel.



4) Let the force F be applied towards right as shown in Figure. In this case, both the springs elongate or compress by the same amount of displacement. Therefore, net force for the displacement of mass m is

$F = -k_p x$ ------------ 1

where k_p is called effective spring constant.

5) Let the first spring be elongated by a displacement x due to force F_1 and second spring be elongated by the same displacement x due to force F_2, then the net force $F = -k_1 x - k_2 x$ ------------ 2

Equating equations (2) and (1), we get

$$k_p = k_1 + k_2 \quad \text{------------------- 3}$$

Generalizing, for n springs connected in parallel, $k_p = \sum_{i=1}^{n} k_i$ --------- 4

If all spring constants are identical i.e., $k_1 = k_2 = \ldots = k_n = k$

then $k_p = nk$ ------------ 5.

6) This implies **that the effective spring constant increases by a factor n.** Hence, for the springs in parallel connection, the effective spring constant is greater than individual spring constant.

UNIT – XI (WAVES)

TWO MARKS AND THREE MARKS QUESTION WITH ANSWER:

1. **What is meant by waves?**

The **disturbance which carries energy and momentum from one point in space to another point in space without the transfer of the medium** is known as a wave.

2. **Write down the types of waves.**

a) Mechanical wave:

Waves which require a medium for propagation are known as mechanical waves.

Examples: sound waves, ripples formed on the surface of water, etc.

b) Non mechanical wave:

Waves which do not require any medium for propagation are known as non-mechanical waves. **Example:** light

Further, waves can be classified into two types

a. Transverse waves b. Longitudinal waves

3. **What are transverse waves? Give one example.**

In transverse wave motion, the constituents of the medium oscillate or vibrate about their mean positions in a direction perpendicular to the direction of propagation (direction of energy transfer) of waves.

Example: light (electromagnetic waves)

4. **What are longitudinal waves? Give one example.**

In **longitudinal wave motion, the constituent of the medium oscillate or vibrate about their mean positions in a direction parallel** to the direction of propagation (direction of energy transfer) of waves.

Example: Sound waves travelling in air.

5. **Define wavelength.**

For **transverse waves, the distance between two neighbouring crests or troughs** is known as the wavelength.

For **longitudinal waves, the distance between two neighbouring compressions or rarefactions** is known as the wavelength.

The **SI unit of wavelength is meter.**

6. Write down the relation between frequency, wavelength and velocity of a wave.

Dimension of wavelength is, $[\lambda] = L$;

Frequency $f = \frac{1}{Time\ period}$,

which implies that the dimension of frequency is, $|f| = \frac{1}{|T|} = T^{-1}$

$\Rightarrow [\lambda f] = [\lambda]\,[f] = LT^{-1} = [Velocity]$

Therefore, Velocity, $\lambda f = v$

Where v is known as the wave velocity or phase velocity. This is the velocity with which the wave propagates. Wave velocity is the distance travelled by a wave in one second.

7. What is meant by interference of waves?

Interferenceis a phenomenon in which **two waves superimpose to form a resultant wave of greater, lower or the same amplitude**.

8. Explain the beat phenomenon.

When two or more waves superimpose each other with slightly different frequencies, **then a sound of periodically varying amplitude at a point is observed. This phenomenon is known as beats**. The number of amplitude maxima per second is called beat frequency. If we have two sources, then their difference in frequency gives the beat frequency.

Number of beats per second $n = |f_1 - f_2|$ per second.

9. Define intensity of sound and loudness of sound.

The **intensity of sound**is defined as "**the sound power transmitted per unit area taken normal to the propagation of the sound wave**".

The **loudness of sound**is defined as "**the degree of sensation of sound produced in the ear or the perception of sound by the listener**".

10. Explain Doppler Effect.

When the source and the observer are in relative motion with respect to each other and to the medium in which sound propagates, the frequency of the sound wave observed is different from the frequency of the source. This phenomenon is called Doppler Effect.

11. Explain red shirt and blue shift in Doppler Effect.

The **spectral lines of the star are found to shift towards red end of the** spectrum **(called as red shift)** then the **star is receding away from the Earth**. Similarly, if the spectral lines of the star are found to shift towards the blue end of the spectrum **(called as blue shift)** then the star is approaching Earth.

12. What is meant by end correction in resonance air column apparatus?

The antinodes are not exactly formed at the open end, we have to include a correction, called end correction. $L_1 + e = \frac{\lambda}{4}$ and $L_2 + e = \frac{3\lambda}{4}$

13. Sketch the function y = x + a. Explain your sketch.

i) A combination of constant and direct

ii) A fixed amount is added at regular intervals

iii) y = x + a, a suitable conclusion statement would be that,

1) Y is linear with x
2) Y varies linearly with x
3) Y is a linear function of x, y is the intercept

14. Write down the factors affecting velocity of sound in gases.

Pressure, Temperature, Density, Humidity and wind

15. What is meant by an echo? Explain.

1) An echo is a repetition of sound produced by the reflection of sound waves from a wall, **mountain or other obstructing surfaces. The speed of sound in air at 20°C is 344 ms^{-1}.** If we shout at a wall which is at 344 m away, then the sound will take 1 second to reach the wall.

2) After reflection, the sound will take one more second to reach us. Therefore, we hear the echo after two seconds. Scientists have estimated that we can hear two sounds properly if the time gap or time interval between each sound is $\left(\frac{1}{10}\right)^{th}$ of a second (persistence of hearing) i.e., 0.1 s. Then,

Velocity = $\frac{\text{Distance travelled}}{\text{Time taken}}$; = $\frac{2d}{t}$

2d = 344 x 0.1=34.1m; d = 17.2 m

The minimum distance from a sound reflecting wall to hear an echo at 20°C is 17.2 meter.

16. What is reverberation?

In a **closed room the sound is repeatedly reflected from the walls and it is even heard long after the sound source ceases to function.** The residual sound remaining in an enclosure and the phenomenon of multiple reflections of sound is called reverberation.

17. Write characteristics of wave motion.

1) For the propagation of the waves, **the medium must possess both inertia and elasticity, which decide the velocity of the wave in that medium.**
2) In a given medium, **the velocity of a wave is a constant whereas the constituent particles in that medium move with different velocities at different positions. Velocity is maximum** at their mean position and zero at extreme positions.
3) Waves **undergo reflections, refraction, interference, diffraction and Polarization.**

CONCEPTUAL QUESTIONS:

18. Why is it that transverse waves cannot be produced in a gas? Can thetransverse waves can be produced in solids and liquids?

Transverse waves travel in the form of crests and troughs and so involve change in shape. **As gas no elasticity of shape, hence transverse waves cannot be produced in it. Yes, solids and liquids have elasticity**so, transverse wave can be produced.

19. Why is the roar of our national animal different from the sound of a mosquito?

Roaring of a **national animal and tiger produces a sound of low pitch and high intensity or loudness, whereas**the buzzing of mosquito produces a sound of high pitch and low intensity or loudness.

20. A sound source and listener are both stationary and a strong wind is blowing. Is there a Doppler effect?

Yes, It does not matter whether be sound source or be transmission media are in motion.

21. In an empty room why is it that a tone sounds louder than in the room having things like furniture etc.

Sound is a form of energy. The furniture which act as obstacles absorbs most of energy. **So the intensity of sound becomes low but in empty room, due to the absence of obstacles the intensity of sound remains** mostly same but we feel it louder.

22. How do animals sense impend danger of hurricane?

Some animals are believed to **be sensitive to be low frequency sound waves emitted by hurricanes.** They can also defect the slight drops in air and water pressure that signal a storm's approach.

23. Is it possible to realize whether a vessel kept under the tap is about to fillwith water?

The frequency of the note produced by an **air column is inversely proportional to its length. As the level of water in the vessel rises, the length of the air column above it decreases.** It produces sound of decreasing frequency. i.e. the sound becomes shorter. From the **shrillness of sound, it is possible to realize whether the vessel is filled which water. V_{min} = 11.71ms^{-1}**

FIVE MARKS QUESTION WITH ANSWER

24. Discuss how ripples are formed in still water.

1) **A stone in a trough of still water, we can see a disturbance produced at the place where the stone strikes the water surface**. We find that this **disturbance spreads out (diverges out)** in the form of concentric **circles of ever increasing radii (ripples)** and strike the boundary of the trough.
2) This is because some of the kinetic energy of the stone is transmitted to the water molecules on the surface. Actually the particles of the water (medium) themselves do not move outward with the disturbance.
3) This can be observed by keeping a paper strip on the water surface. The strip moves up and down when the disturbance (wave) passes on the water surface. This shows that the water molecules only undergo vibratory motion about their mean positions.

25. Briefly explain the difference between travelling waves and standing waves.

S. No.	Progressive waves	Stationary waves
1	**Crests and troughs are formed in transverse progressive waves**, and compression and rarefaction are formed in **longitudinal progressive** waves. These waves move forward or backward in a medium i.e., they will advance in a medium with a definite velocity.	**Crests and troughs are formed in transverse stationary waves**, and compression and rarefaction are formed in **longitudinal stationary waves. These waves neither move** forward nor backward in a medium i.e., they will not advance in a medium.
2	All the particles in the medium vibrate such that the **amplitude of the vibration for all particles is same.**	Except at nodes, all other particles of the medium vibrate such that amplitude of **vibration is different for different particles.** The amplitude is minimum or zero at nodes and maximum at anti-nodes.
3	These wave **carry energy while propagating.**	These waves **do not transport energy.**

26. Show that the velocity of a travelling wave produced in a string is v = $\sqrt{\frac{T}{\mu}}$

1) Consider an elemental segment in the string as shown in the Figure. **Let A and B be two points on the string at an instant of time. Let dl and dmbe the length and mass of the elemental string**, respectively.

By definition, linear mass density, μ is $\mu = \frac{dm}{dl}$ -------- 1

$dm = \mu dl$ ---------- 2

2) The elemental string **AB has a curvature which looks like an arc of a circle with centre at O, radius R and the arc subtending an angle θ** at the origin O as shown in Figure. The angle θ can be written in terms of arc length and radius as $\theta=\frac{dl}{R}$. The centripetal acceleration supplied by the tension in the string is $a_{cp} = \frac{v^2}{R}$ -------------- 3

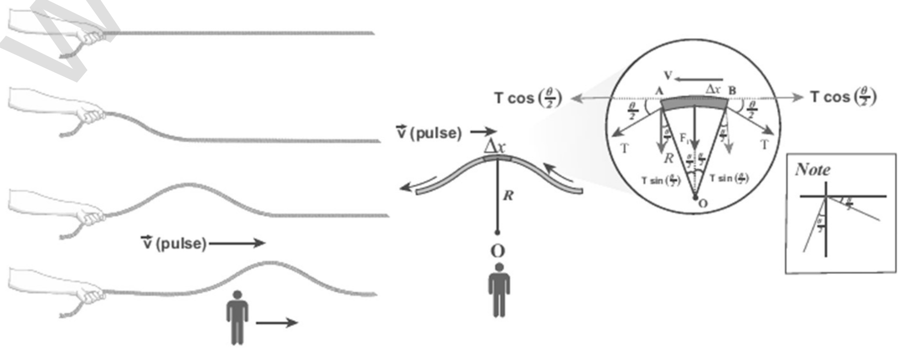
3) Then, **centripetal force can be obtained when mass of the string (dm) is included in equation** (3)

$F_{cp} = \frac{(dm)v^2}{R}$ --------------- 4

4) The centripetal force experienced by elemental string can be calculated by substituting equation (2) in equation (4) we get,

$\frac{(dm)v^2}{R} = \frac{\mu v^2 dl}{R}$ ------------ 5

5) The **tension T acts along the tangent of the elemental segment of the string at A and B. Since the arc length is very small, variation in the tension force can be ignored.** We can resolve T into horizontal component T $\cos\left(\frac{\theta}{2}\right)$and vertical component T$\sin\left(\frac{\theta}{2}\right)$.



6) The **horizontal components at A and B are equal in magnitude but opposite in direction; therefore, they cancel each other. Since the elemental arc length AB is taken to be very small,** the vertical components at A and B appears to acts vertical towards the centre of the arc and hence, they add up. The net radial force $F_r$is

$F_r = 2T \sin\left(\frac{\theta}{2}\right)$ ---------6

7) Since the amplitude of **the wave is very small when it is compared with the length of the string, the sine of small angle is approximated as** $\sin\left(\frac{\theta}{2}\right) \approx \frac{\theta}{2}$. Hence, equation (6) can be written as

$F_r = 2T \times \frac{\theta}{2} = T\,\theta$ --------7

8) But $\theta = \frac{dl}{R}$, therefore substituting in equation (7),

we get $F_r = T\frac{dl}{R}$ -----------8

Applying Newton's second law **to the elemental string in the radial direction, under equilibrium, the radial component of the force is equal to the centripetal force.** Hence equating equation (5) and equation (8), we have

$T\frac{dl}{R} = \mu v^2 \frac{dl}{R}$ $v = \sqrt{\frac{T}{\mu}}$ measured in ms^{-1} ---------9

27. Describe Newton's formula for velocity of sound waves in air and also discussthe Laplace's correction.

1) Newton assumed that when sound propagates in air, the formation of **compression and rarefaction takes place in a very slow manner** so that the process is isothermal in nature.

2) That is, the **heat produced during compression (pressure increases, volume decreases), and heat lost during rarefaction (pressure decreases, volume increases)** occur over a period of time such that the temperature of the medium remains constant. Therefore, by treating the air molecules to form an ideal gas, the changes in pressure and volume obey Boyle's law,

PV = Constant ------------ 1

3) Differentiating equation (1), we get $PdV + VdP = 0$ or

$P = -V\frac{dP}{dV} = B_T$-------- 2

where, BT is an isothermal bulk modulus of air. Substituting equation (2) in equation $V = \sqrt{\frac{B}{\rho}}$ the speed of sound in air is

$V_T = \sqrt{\frac{B_T}{\rho}} = \sqrt{\frac{P}{\rho}}$ -------------3

Since P is the pressure of air whose value at NTP (Normal Temperature and Pressure) is 76 cm of mercury, we have

$\mathbf{P = (0.76 \times 13.6 \times 10^3 \times 9.8)\ Nm^{-2}}$

$\rho = 1.293\ kg\ m^{-3}$. here ρ is density of air

Then the speed of sound in air at Normal Temperature and

Pressure (NTP) is $V_T = \sqrt{\frac{0.76 \times 13.6 \times 10^3 \times 9.8}{1.293}}$ **= 279.80 ms^{-1} ≈ 280 ms^{-1}**

(theoretical value)

But the speed of sound in air at 0°C is experimentally observed as **332ms^{-1} which is close upto 16% more than theoretical value**

(Percentage error is $\frac{(332-2\quad)}{332}$ x 100% = 15.6%) This error is not small.

Laplace's correction:

1) Laplace assumed that when the sound propagates through a medium, the particles oscillate very rapidly such that the **compression and rarefaction occur very fast.** Hence the exchange of heat produced due to compression and cooling effect due to rarefaction do not take place, because, air (medium) is a bad conductor of heat.

2) Since, temperature is no longer considered as a constant here, **sound propagation is an adiabatic process. By adiabatic considerations, the gas obeys Poisson's law** (not Boyle's law as Newton assumed), which is

$P\boldsymbol{v}^{\gamma}$ = Constant ---------- 4

Where, $\gamma = \frac{C_P}{C_V}$, which is the ratio between specific heat at constant pressure and specific heat at constant volume. Differentiating equation (4) on both the sides, we get

$\boldsymbol{v}^{\gamma}$ dP + P($\boldsymbol{\gamma V \gamma^{-1} dV}$) = 0 or $\boldsymbol{\gamma^{P}}$= $-V\frac{dP}{dV}$ B_A -----------5

where, BA is the adiabatic bulk modulus of air. Now, substituting equation (5) in equation $V = \sqrt{\frac{B}{\rho}}$ the speed of sound in air is

$V_A = \sqrt{\frac{B_T}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma} V_T$ ------------6

V_A = 331ms^{-1}

28. Write short notes on reflection of sound waves from plane and curvedsurfaces.

1) **Sound also reflects from a harder flat surface;** this is called as **specular reflection.**

2) Specular reflection is **observed only when the wavelength of the source is smaller than dimensions of the reflecting surface, as well as smaller than surface irregularities.**

3) **When the sound waves hit the plane wall, they bounce off in a manner similar to that of light.** Suppose a loudspeaker is kept at an angle with respect to a wall (plane surface), then the waves coming from the source (assumed to be a point source) can be treated as spherical wave fronts (say, compressions moving like a spherical wave front).

4) Therefore, **the reflected wave front on the plane surface is also spherical, such that its centre of curvature (which lies on the other** side of plane surface) can be treated as the image of the sound source (virtual or imaginary loud speaker) which can be assumed to be at a position behind the plane surface.

Reflection of sound through the curved surface:

1) The behaviour of sound is different when it is reflected from **different surfaces-convex or concave or plane**. The sound **reflected from a convex surface is spread out and** so it is easily attenuated and weakened. Whereas, if it is reflected from the concave surface it will converge at a point and this can be easily amplified.

2) The parabolic reflector (curved reflector) **which is used to focus the sound precisely to a point is used in designing the parabolicmics** which are known as high directional microphones.

3) We know that **any surface (smooth or rough) can absorb sound. For example, the sound produced in a big hall or auditorium or theatre is absorbed by the walls, ceilings, floor, seats etc.**

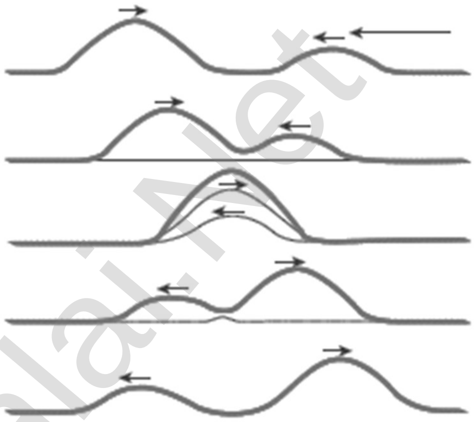
29. Briefly explain the concept of superposition principle.

1) **When a jerk is given to a stretched string which is tied at one end, a wave pulse is produced and the pulse travels along the string.** Suppose two persons holding the stretched string on either side give a jerk simultaneously, then these two wave pulses move towards each other, meet at some point and move away from each other with their original identity.

2) Their behaviour is very different only at the **crossing/meeting points; this behaviour depends on whether the two pulses have the same or different shape** as figure.

3) When the **pulses have the same shape, at the crossing, the total displacement is the algebraic sum of their individual displacements** and hence its net amplitude is higher than the amplitudes of the individual pulses.

4) Whereas, if the **two pulses have same amplitude but shapes are 180° out of phase at the crossing point, the net amplitude vanishes at that point and the pulses will recover their identities after crossing.**



5) **Only waves can possess such a peculiar property and it is called superposition of waves.** This means that the principle of superposition explains the net behaviour of the waves when they overlap.

6) Generalizing to any number of waves i.e, **if two are more waves in a medium move simultaneously, when they overlap**, their total displacement is the vector sum of the individual displacements.

7) To understand mathematically, let us consider two functions which characterize the displacement of the waves, for example,
$y_1 = A_1 \sin(kx - \omega t)$ and $y_2 = A_2 \cos(kx - \omega t)$

8) Since, both y_1 and y_2 satisfy the wave equation (solutions of wave equation) then their **algebraic sum $y = y_1 + y_2$** also satisfies the wave equation.

9) This means, the displacements are additive. **Suppose we multiply y_1 and y_2 with some constant then their amplitude is scaled by that constant Further**, if C_1 and C_2 are used to multiply the displacements y_1 and y_2, respectively, then, their net displacement y is
$y = C_1 y_1 + C_2 y_2$

10) This can be generalized to any number of waves. In the case of n such waves in more than one dimension the displacements are written using vector notation. Here, the net displacement $\vec{y}$ is $\vec{y} = \sum_{i=1}^{n} C_i \vec{y}_i$
The principle of superposition can explain the following:
(a) Space (or spatial) Interference (also known as Interference)
(b) Time (or Temporal) Interference (also known as Beats)
(c) Concept of stationary waves.

11) Waves that **obey principle of superposition are called linear waves (amplitude is much smaller than their wavelengths). In general, if the amplitude of the wave is not small then they are called non-linear waves.** These violate the linear superposition principle, e.g. laser. In this chapter, we will focus our attention only on linear waves.

30. Explain how the interference of waves is formed.

1) Consider two harmonic waves having identical frequencies, constant phase difference φ and same wave form (can be treated as coherent source), but having amplitudes A_1 and A_2, then

$y_1 = A_1 \sin(kx - \omega t)$ ---------------------1

$y_2 = A_2 \sin(kx - \omega t + \varphi)$ ----------------- 2

Suppose they move simultaneously in a particular direction, then interference occurs (i.e., overlap of these two waves),

$y = y_1 + y_2$ -----------3

2) Therefore, substituting equation (1) and equation (2) in equation (3), we get $y = A_1 \sin(kx - \omega t) + A_2 \sin(kx - \omega t + \varphi)$

Using trigonometric identity $\sin(\alpha+\beta) = (\sin\alpha \cos\beta + \cos\alpha \sin\beta)$, we get

$y = A_1 \sin(kx - \omega t) + A_2[\sin(kx - \omega t)\cos\varphi + \cos(kx - \omega t)\sin\varphi]$

$y = \sin(kx - \omega t)(A_1 + A_2\cos\varphi) + A_2\sin\varphi \cos(kx - \omega t)$ --------------4

Let us re-define

$A\cos\theta = (A_1 + A_2\cos\varphi)$ -------------- 5

and $A\sin\theta = A_2\sin\varphi$ ------------------6

then equation (4) can be rewritten as

$y = A\sin(kx-\omega t)\cos\theta + A\cos(kx-\omega t)\sin\theta$

$y = A(\sin(kx-\omega t)\cos\theta + \sin\theta\cos(kx-\omega t))$

$y = A\sin(kx-\omega t + \theta)$ ------------7

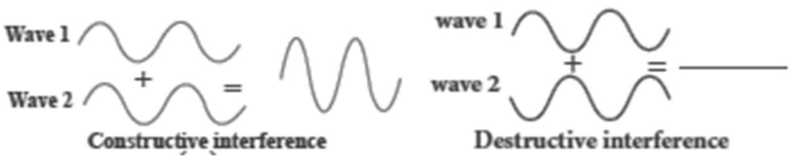
By squaring and adding equation (5) and equation (6), we get

$A^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\varphi$ -------------8

Since, intensity is square of the amplitude ($I = A^2$),

we have $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\varphi$ -------------9

This means the resultant intensity at any point depends on the phase difference at that point.



a) For constructive interference:

1) **When crests of one wave overlap with crests of another wave, their amplitudes will add up and we get constructive interference**. The resultant wave has a larger amplitude than the individual waves as shown in Figure.

2) The constructive interference at a point occurs if there is maximum intensity at that point, which means that $\cos\varphi = +1$

$\Rightarrow \varphi = 0, 2\pi, 4\pi, \ldots = 2n\pi$, where $n = 0,1,2,\ldots$

3) This is the **phase difference in which two waves overlap to give constructive interference**. Therefore, for this resultant wave,

$I_{maximum} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2 = (A_1 + A_2)^2$

Hence, **the resultant amplitude A = $A_1 + A_2$**

b) For destructive interference:

1) When the trough of one wave overlaps with the crest of another wave, their amplitudes "cancel" each other and we get destructive interference as shown in Figure. **The resultant amplitude is nearly zero.**

2) The destructive interference occurs if there is **minimum intensity at that point, which means $\cos\varphi = -1 \Rightarrow \varphi = \pi, 3\pi, 5\pi, \ldots = (2n-1)\pi$,** where n = 0,1,2,.... i.e. This is the phase difference in which two waves overlap to give destructive interference.

3) Therefore, $I_{minimum} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2 = (A_1 - A_2)^2$

Hence, the resultant amplitude $A = A_1 - A_2$

31. Describe the formation of beats.

Formation of beats: When two or more waves superimpose each other with slightly different frequencies, then a sound of periodically varying amplitude at a point is observed. This phenomenon is known as beats. The number of amplitude maxima per second is called beat frequency. If we have two sources, then their difference in frequency gives the beat frequency. Number of beats per second $n = |f_1 - f_2|$ per second

32. What are stationary waves? Explain the formation of stationary waves and alsowrite down the characteristics of stationary waves.

1) When the wave hits the rigid boundary it bounces back to the original medium and can interfere with the original waves. A pattern is formed, which are known as standing waves or stationary waves.

2) Consider two harmonic progressive waves (formed by strings) that have the same amplitude and same velocity but move in opposite directions. Then the displacement of the first wave (incident wave) is

$y_1 = A\sin(kx - \omega t)$ (waves move toward right) ---------------1

and the displacement of the second wave (reflected wave) is

$y_2 = A\sin(kx + \omega t)$ (waves move toward left) -------------2

both will interfere with each other by the principle of superposition, the net displacement is $y = y_1 + y_2$ ---------------3

Substituting equation (1) and equation (2) in equation (3), we get

$y = A\sin(kx - \omega t) + A\sin(kx + \omega t)$ -------------4

Using trigonometric identity, we rewrite equation (4) as

$y(x, t) = 2A\cos(\omega t)\sin(kx)$ ---------- 5

3) This represents a stationary wave or standing wave, which means that this **wave does not move either forward or backward, whereas progressive or travelling waves will move forward or backward.**

4) Further, the displacement of the particle in equation (5) can be written in more compact form, $y(x, t) = A'\cos(\omega t)$ where, $A' = 2A\sin(kx)$, implying that the particular element of the string executes simple harmonic motion with amplitude equals to A'.

5) The maximum of this amplitude occurs at positions for which $\sin(kx) = 1$

$\Rightarrow kx = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, ... m\pi$

where m takes half integer or half integral values. The position of maximum amplitude is known as antinodes.

Characteristics of stationary waves:

1) Stationary waves are characterized by the confinement of a wave **disturbance between two rigid boundaries.** This means, the wave does not move forward or backward in a medium (does not advance), it remains steady at its place. Therefore, they are called "stationary waves or standing waves".

2) Certain **points in the region in which the wave exists have maximum amplitude, called as anti-nodes and at certain** points the amplitude is minimum or zero, called as nodes.

3) The distance between **two consecutive nodes (or) anti-nodes is** $\frac{\lambda}{2}$

4) The distance between a **node and its neighbouring anti-node is** $\frac{\lambda}{4}$

5) The transfer of energy along the **standing wave is zero**

33. Discuss the law of transverse vibrations in stretched strings.

i) The law of length:

For a given wire with **tension T (which is fixed) and mass per unit length μ (fixed) the frequency varies inversely with the vibrating length.**

Therefore, $f \alpha \frac{1}{l} \Rightarrow f = \frac{C}{l} \Rightarrow l \times f = C$, where C is a constant.

ii) The law of tension:

For a given **vibrating length** l**(fixed) and mass per unit length μ (fixed) the frequency varies directly with the square root of the tension T,** $f \alpha \sqrt{T}$

$\Rightarrow f = A\sqrt{T}$ where A is a constant

iii) The law of mass:

For a given vibrating length l(fixed) and tension T(fixed) the frequency varies inversely with the square root of the mass per unit length μ,

$f \alpha \frac{1}{\sqrt{\mu}} \Rightarrow f = \frac{B}{\sqrt{\mu}}$, where B is a constant.

34. Explain the concepts of fundamental frequency, harmonics and overtones in detail.

1) Keep the **rigid boundaries at x = 0 and x = L and produce a standing wave by wiggling the string (as in plucking strings in a guitar). Standing waves with a specific wavelength are produced**. Since, the amplitude must vanish at the boundaries, therefore, the displacement at the boundary y(x = 0, t) = 0 and y(x = L, t) = 0 -----------1

Since the nodes formed are at a distance $\frac{\lambda_n}{2}$ apart, we have $n\left[\frac{\lambda_n}{2}\right]$=L

2) where n is an integer, L is the **length between the two boundaries and λ_n is the specific wavelength that satisfy the specified boundary** conditions. Hence, $\lambda_n = \left(\frac{2L}{n}\right)$ --------------2

3) Therefore, **not all wavelengths are allowed. The (allowed) wavelengths should fit with the specified boundary conditions**, i.e., for n = 1, the first mode of vibration has specific wavelength λ_1= 2L. Similarly, for n = 2, the second mode of vibration has specific wavelength $\lambda_2 = \left(\frac{2L}{2}\right)$ = L

For n = 3, the third mode of vibration has specific wavelength $\lambda_3 = \left(\frac{2L}{3}\right)$ and so on. The frequency of each mode of vibration (called natural frequency) can be calculated. $f_n = \frac{v}{\lambda_n} = n\left(\frac{v}{2L}\right)$ -----------3

4) The lowest natural frequency is called the fundamental frequency.

$f_1 = \frac{v}{\lambda_1} = \left(\frac{v}{2L}\right)$ -----------4

The second natural frequency is called the first over tone.

$f_2 = 2\left(\frac{v}{2L}\right) = \frac{1}{L}\sqrt{\frac{T}{\mu}}$

The third natural frequency is called the second over tone.

$f_3 = 3\left(\frac{v}{2L}\right) = 3\left(\frac{1}{2L}\sqrt{\frac{T}{\mu}}\right)$ and so on. Therefore, the nth natural frequency can be computed **as integral (or integer) multiple of fundamental frequency, i.e., $f_n = nf_1$, where n is an integer** ----------- 5

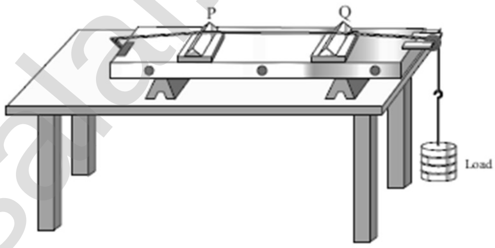
5) If natural frequencies are written as **integral multiple of fundamental frequencies, then the frequencies are called harmonics**. Thus, the first harmonic is **$f_1 = f_1$ (the fundamental frequency is called first harmonic), the second harmonic is $f_2 = 2f_1$, the third harmonic is $f_3 = 3f_1$ etc.**

35. What is a sonometer? Give its construction and working. Explain how to determine the frequency of tuning fork using sonometer.

1) Sono means *sound* related, and **sonometer implies sound-related measurements. It is a device for demonstrating the relationship between the frequency of the sound produced** in the transverse standing wave in a string, and the tension, length and mass per unit length of the string.

2) Therefore, using this device, we can determine the following quantities:
a) the frequency of the tuning fork or frequency of alternating current
b) the tension in the string
c) the unknown hanging mass

Construction:



3) The sonometer is made up of a **hollow box which is one-meter-long with a uniform metallic thin string attached** to it. One end of the string is connected to a hook and the other end is connected to a weight hanger through a pulley as shown in Figure.

4) Since only one string is used, it is also known as monochord. The weights are **added to the free end of the wire to increase the tension of the wire.**

5) Two adjustable **wooden knives are put over the board, and their positions are adjusted to change the vibrating length** of the stretched wire.

Working:

6) A transverse stationary or standing wave is produced and hence, at the knife edges P and Q, nodes are formed. In between the knife edges, anti-nodes are formed.

If the length of the vibrating element is l then $l = \frac{\lambda}{2} \Rightarrow \lambda = 2l$

7) Let f be the frequency of the vibrating element, Tthe tension of in the string and μthe mass per unit length of the string. Then using equation

$v = \sqrt{\frac{T}{\mu}}$, we get $f = \frac{v}{\lambda} = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ in Hz -----------1

8) Let ρbe the density of the material of the string and dbe the diameter of the string. Then the mass per unit length μ,

μ= Area × density = $\pi r^2\rho = \frac{\pi\rho d^2}{4}$; $f = \frac{v}{\lambda} = \frac{1}{2l}\sqrt{\frac{T}{\frac{\pi\rho d^2}{4}}}$ $f = \frac{1}{ld}\sqrt{\frac{T}{\pi\rho}}$

36. Write short notes on intensity and loudness.

Intensity of sound:

1) **When a sound wave is emitted by a source, the energy is carried to all possible surrounding points.** The average sound energy emitted or transmitted per unit time or per second is called sound power.
2) Therefore, **the intensity of sound is defined as "the sound power transmitted per unit area taken normal to the propagation of the sound wave".**
3) For a particular source (fixed source), **the sound intensity is inversely proportional to the square of the distance from the source.**

$I = \frac{\text{power of the source}}{4\pi r^2} \Rightarrow I \alpha \frac{1}{r^2}$

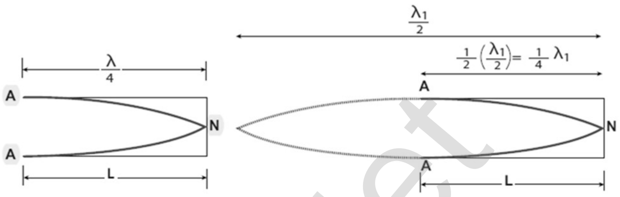
This is known as inverse square law of sound intensity.

Loudness of sound:

1) Two sounds with same intensities need not have the same loudness. For example, the **sound heard during the explosion of balloons in a silent closed room is very loud when compared to the same explosion happening in a noisy market.**
2) Though the intensity of the sound is the same, the loudness is not. If the intensity of sound is increased, then loudness also increases. But additionally, **not only does intensity matter, the internal and subjective experience of "how loud a sound** is" i.e., the sensitivity of the listener also matters here.
3) This is often called loudness. That is, **loudness depends on both intensity of sound waves and sensitivity of the ear (It is purely observer dependent quantity which varies from person to person)** whereas the intensity of sound does not depend on the observer.
4) The loudness of sound is defined as "**the degree of sensation of sound produced in the ear or the perception of sound by the listener".**

37. Explain how overtones are produced in a
(a) Closed organ pipe (b) Open organ pipe

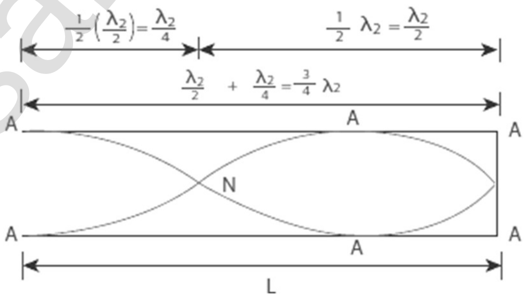
a) Closed organ pipes:



1) It is a pipe with one end closed and the other end open. If one end of a pipe is closed, the wave reflected at this closed end is 180° out of phase with the incoming wave.

2) Thus there is **no displacement of the particles at the closed end. Therefore, nodes are formed at the closed end and anti-nodes are formed at open end.**

3) Consider the simplest mode of vibration of the air column called the fundamental mode. **Anti-node is formed at the open end and node at closed end**. From the Figure, let L be the length of the tube and the wavelength of the wave produced. For the fundamental mode of vibration, we have,



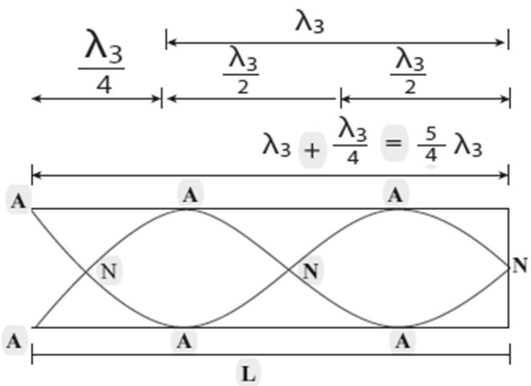
$L = \frac{\lambda_1}{4}$ or $\lambda_1 = 4L$; The frequency of the note emitted is

$f_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$ **which is called the fundamental note.**

4) The frequencies higher than fundamental frequency can be produced by blowing air strongly at open end. Such frequencies are called overtones.

The Figure 2 shows the second mode of vibration having two nodes and two anti-nodes. $4L = 3\lambda_2$ $L = \frac{3\lambda_2}{4}$ or $\lambda_2 = \frac{4L}{3}$

The frequency of this $f_2 = \frac{v}{\lambda_2} = \frac{3v}{4L} = 3f_1$



is called **first over tone**, since here, the frequency is **three times the fundamental frequency** it is called **third harmonic**.

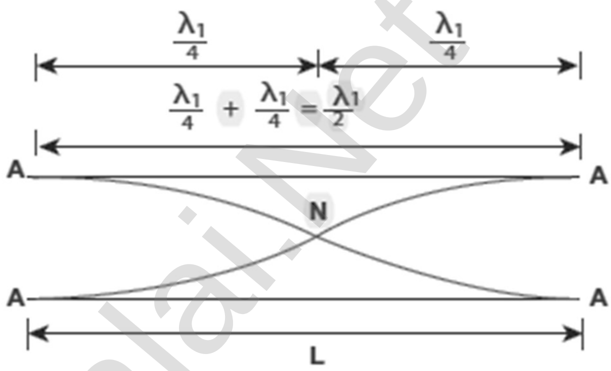
5) The Figure 3 shows third mode of vibration having three nodes and three anti-nodes. $4L = 5\lambda_3$ $L = \frac{5\lambda_3}{4}$ or $\lambda_3 = \frac{4L}{5}$

The frequency of this $f_3 = \frac{v}{\lambda_3} = \frac{5v}{4L} = 5f_1$ is called **second over tone**, and since **n = 5** here, this is called **fifth harmonic**.

6) Hence, the closed organ pipe has only odd harmonics and frequency of the nth harmonic is f_n= **(2n+1)f_1. Therefore, the frequencies of harmonics are in the ratio f_1: f_2: f_3: f_4:...= 1 : 3 : 5 : 7 : ...**

b) Open organ pipe:

1) **It is a pipe with both the ends open. At both open ends, anti-nodes are formed. Let us consider the simplest mode of vibration of the air column called fundamental mode. Since anti-nodes are formed at the open end,** a node is formed at the mid-point of the pipe.



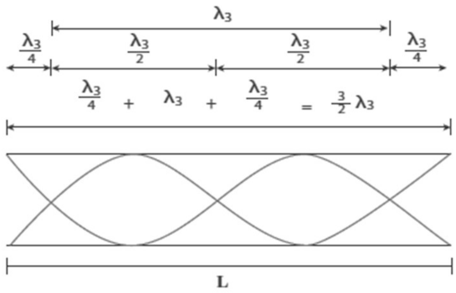
2) From Figure, if L be the length of the tube, the wavelength of the wave produced is given by

$L = \frac{\lambda_1}{2}$ or $\lambda_1 = 2L$

The frequency of the note emitted is $f_1 = \frac{v}{\lambda_1} = \frac{v}{2L}$

which is called the fundamental note.

3) The **frequencies higher than fundamental frequency can be produced by blowing** air strongly at one of the open ends. Such frequencies are called overtones.

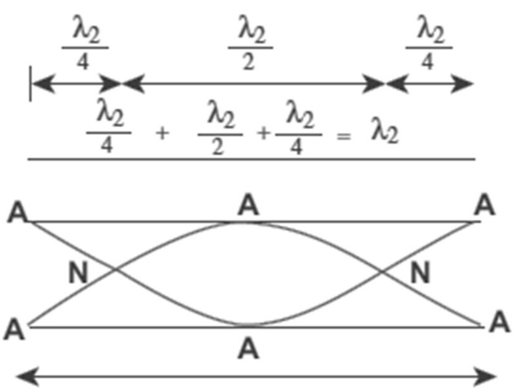


4) The Figure shows the second mode of vibration in open pipes. It has two nodes and three anti-nodes, and therefore, **L =$\lambda_2$or λ_2= L .The frequency $f_2 = \frac{v}{\lambda_2} = \frac{v}{L}$** $= 2 \times \frac{v}{2L}$ = 2$f_1$is called **first over tone**. Since n = 2 here, it is called the **second harmonic.**

5) The Figure shows the third mode of vibration having three nodes and four anti-nodes $L = \frac{3}{2}\lambda_3$ or $\lambda_3 = \frac{2L}{3}$;

$f_3 = \frac{v}{\lambda_3} = \frac{3v}{2L} = 3 \times \frac{v}{2L} = 3f_1$

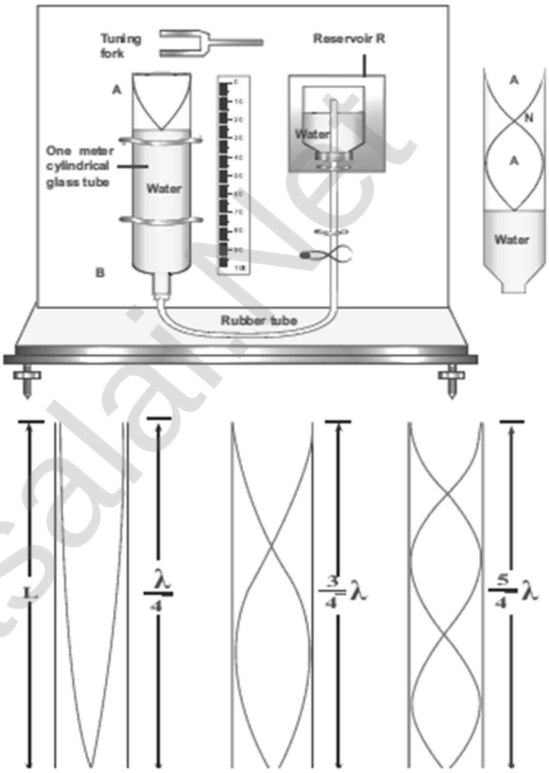
is called second over tone. Since **n = 3** here, it is called the **third harmonic**.



6) Hence, the open organ pipe has all the harmonics and frequency of n[th]harmonic is fn = nf1. Therefore, **the frequencies of harmonics are in the ratiof_1: f_2: f_3: f_4:...= 1 : 2 : 3 : 4: ....**

38. How will you determine the velocity of sound using resonance air columnapparatus?

1) The resonance air column apparatus is **one of the simplest techniques to measure the speed of sound in air at room temperature.**



2) It consists of a cylindrical glass tube of **one-meter length whose one end A is open and another end B is connected to the water reservoir R through a rubber tube** as shown in Figure. This cylindrical glass tube is mounted on a vertical stand with a scale attached to it.

3) The **tube is partially filled with water and the water level can be adjusted by raising or lowering the water in the reservoir R.** The surface of the water will act as a closed end and other as the open end.

4) Therefore, it **behaves like a closed organ pipe, forming nodes at the surface of water and antinodes at the closed end.**

5) When a **vibrating tuning fork is brought near the open end of the tube, longitudinal waves are formed inside the air column**. These waves move downward as shown in Figure, and reach the surfaces of water and get reflected and produce standing waves.

6) The **length of the air column is varied by changing the water level until a loud sound is produced in the air column. At this particular length the frequency of waves in the air column resonates with the frequency of the tuning fork (natural frequency of the tuning fork).**

7) At resonance, the frequency of sound waves produced is equal to the frequency of the tuning fork. This will occur only when the length of air column is proportional to $\left(\frac{1}{4}\right)^{th}$ of the wavelength of the sound waves produced. Let the **first resonance occur at length**L_1, then $\frac{1}{4}\lambda = L_1$

8) But since the antinodes are not exactly formed at the open end, we have to include a correction, called end correction e, by assuming that the antinode is formed at some **small distance above the open end. Including this end correction, the first resonance** is$\frac{1}{4}\lambda = L_1 + e$

9) Now the length of the air column is increased to get the second resonance. Let L_2 be the length at which **the second resonance occurs.**

Again taking end correction into account, $\frac{3}{4}\lambda = L_2 + e$

In order to avoid end correction,

let us take the difference of equation $\frac{1}{4}\lambda = L$,

and equation $f_1 : f_2 : f_3 : f_4 : ... = 1 : 2 : 3 : 4 : ...$

$$\frac{3}{4}\lambda - \frac{1}{4}\lambda = (L_2 + e - L_1 + e)$$

$$\Rightarrow \frac{1}{2}\lambda = L_2 - L_1 = \Delta L \Rightarrow \lambda = 2\,\Delta L$$

39. What is meant by Doppler effect? Discuss the following cases

(1) Source in motion and Observer at rest

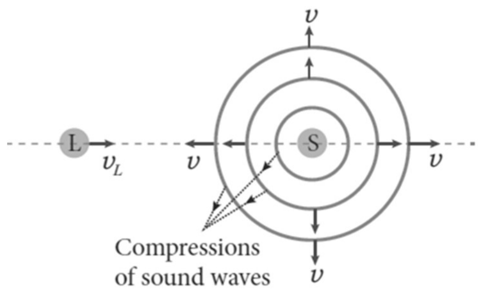
(a) Source moves towards observer (b) Source moves away from the observer

Doppler effect:

Whenever there is a relative motion between the source of sound and the listener, the frequency of the sound observed by the listener is different from the frequency produced by the source.

i) Observed frequency: Stationary source and Moving listener:

1) Consider a point source S of sound at rest with respect to the medium (air) in which it is kept. **The medium is assumed to be uniform and is also at rest. The source emits sound waves of frequency f and wavelength λ.**



2) **Sound waves travel with the same speed v in all directions radially away from the source in the form of spherical waves.** The compressions (or wave fronts) of sound waves are represented by concentric circles in the Figure. The distance between two successive compressions is equal to its wavelength λ and the frequency of the wave is given by $f = \frac{v}{\lambda}$ --------- 1

3) **When the listener L is stationary, there is no relative motion between the source and the listener.** Since v and λ remain unchanged, the frequency of sound observed by the listener is the same as the source frequency f.

4) Now the **listener moves directly toward the stationary source figure. If v_L is the speed of the listener, then the relative speed of sound with respect to the listener becomes** $v' = v + v_L$. Since the wavelength remains unchanged (because the source is stationary), the frequency

of sound observed by the listener is changed and the observed frequency f^I is given by $f' = \frac{v'}{\lambda} = \frac{v+v_L}{\lambda}$

Using the equation 1, $f' = \left(\frac{v+v_L}{v}\right) f$ -------- 2

(listener moving toward the source)

5) Thus, **the observed frequency is greater than the source frequency when the listener moves toward the stationary source**. If the listener is moving away from the stationary source, the observed frequencycan be obtained from equation 2 by taking negative value for v_L. It is given by $f' = \left(\frac{v+(-v_L)}{v}\right) f$;

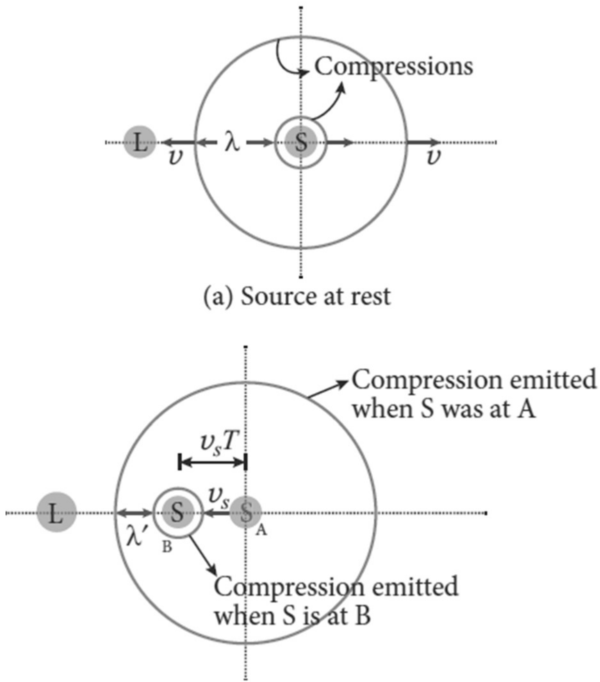
$f' = \left(\frac{v-v_L}{v}\right) f$ ------------- 3

(listener moving away from the source)

Thus, the observed frequency is less than the source frequency when the listener is moving away from the stationary source.

ii) Observed frequency: Moving source and stationary listener:

1) Assume that both the source S and the listener L are at rest as shown in Figure. Two successive compressions arealso shown and are represented by two concentric circles. The second compression has just been emitted and is still near the source. The distance between two successive compressions is the wavelength $\lambda$of the sound. Since f**is the frequency of the source, then the time between emissions** of compressions is T= $\frac{1}{f} = \frac{\lambda}{v}$



(a) Source at rest

(b) Source moving

2) Now the **listener is stationary and the source moves directly toward the listener.** Let the speed of the source be v_s which is less than the speed of sound v.

3) In a time T,**the first compression travels a distance v T = λ and the source moves a distance v_sT**. As a result, **the distance between twosuccessive compressions is decreased from λ to $\lambda' = \lambda - v_sT$.** Therefore, the wavelength observed by the listener is given by

$$\lambda' = \lambda - v_s T = \lambda - \left(\frac{v_s}{f}\right)$$

The observed frequency is then given by $f' = \frac{v}{\lambda'} = \frac{v}{\lambda - \left(\frac{v_s}{f}\right)}$

$$= \frac{v}{\left(\frac{v_s}{f}\right) - \left(\frac{v_s}{f}\right)} ; f' = \left(\frac{v}{v - v_s}\right) f \text{------------}4$$

(source moving away from the listener)

4) Thus, **whenever the source moves toward the stationary listener, the observed frequency is greater than the source frequency**. If the source is moving away from the stationary listener, the observed frequency can be obtained from equation 3 by taking negative value for v_s. It is given by $f' = \left(\frac{v}{v-(-v_s)}\right) f$; $f' = \left(\frac{v}{v+v_s}\right) f$____________ 4

(source moving away from the listener)

Thus, the observed frequency is less than the source frequency when the source is moving away from the stationary listener.

iii) Observed frequency: Both source and listener moving:

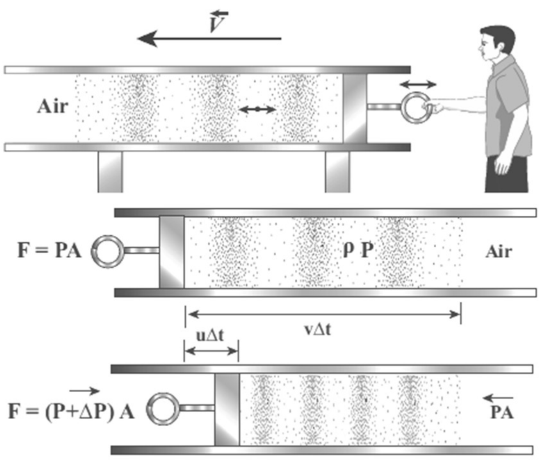
When both source and listener are moving, the observed frequency is obtained by combining equations 2and 4.

$$f' = \left(\frac{v + v_L}{v - v_s}\right) f$$

v_s and v_L take positive values if the source or the listener moves toward the other. Likewise, **they are negative when the source or the listener moves away from the other.**

40. Write the expression for the velocity of longitudinal waves in an elasticmedium.

1) **Consider an elastic medium (here we assume air) having a fixed mass contained in a long tube (cylinder) whose cross sectional area is A and maintained under a pressure P.** One can generate longitudinal waves in the fluid either by displacing the fluid using a piston or by keeping a vibrating tuning fork at one end of the tube.



2) Let us **assume that the direction of propagation of waves coincides with the axis of the cylinder. Let ρ be the density of**

the fluid which is initially at rest. At t = 0, the piston at left end of the tube is set in motion toward the right with a speed u.

3) Let u be the velocity of the piston and v be the velocity of the elastic wave. **In time interval Δt, the distance moved by the piston Δd = u Δt. Now, the distance moved by the elastic disturbance is Δ*x* = vΔt.** Let Δm be the mass of the air that has attained a velocity v in a time Δt .
Therefore, $\Delta m = \rho A \Delta x = \rho A (v \Delta t)$

4) Then, the momentum imparted due to motion of piston with velocity u is $\Delta p = [\rho A (v \Delta t)]u$
But the change in momentum is impulse.
The net impulse is $I = (\Delta P\ A)\Delta t$ Or $(\Delta P\ A)\Delta t = [\rho A (v \Delta t)]u$
$\Delta P = \rho v u$ -------------1

5) When the sound waves passes through air, the small volume element (ΔV) of the air undergoes regular compressions and rarefactions. So, the change in pressure can also be written as $\Delta P = B \frac{\Delta V}{V}$
where, V is original volume and B is known as bulk modulus of the elastic medium.
But $V = A \Delta x = A v \Delta t$ and $\Delta V = A \Delta d = A u \Delta t$
Therefore,$\Delta P = B \frac{Au\ \Delta t}{Av\ \Delta t} = B \frac{u}{v}$ ------------- 2
Comparing equation (1) and equation (2),
we get $\rho v u = B \frac{u}{v}$ or $v^2 = \frac{B}{\rho} \Rightarrow v = \sqrt{\frac{B}{\rho}}$ --------3
In general, the velocity of a longitudinal wave in elastic medium is $v = \sqrt{\frac{E}{\rho}}$, where E is the modulus of elasticity of the medium.

Cases: For a solid:

i) One-dimension rod (1D)
$v = \sqrt{\frac{Y}{\rho}}$, ----------4 where Y is the Young's modulus of the material of the rod and ρ is the density of the rod. The 1D rod will have only Young's modulus.

ii) Three-dimension rod (3D)
The speed of longitudinal wave in a solid is $v = \sqrt{\frac{4+\frac{3}{4}\eta}{\rho}}$ --------5
where η is the modulus of rigidity, K is the bulk modulus and ρ is the density of the rod.

Cases: For liquids:v = $\sqrt{\frac{K}{\rho}}$, ------- 6 where, K is the bulk modulus and ρ is the density of the rod.

41. Discuss the effect of pressure, temperature, density, humidity and wind.

a) Effect of pressure:

1) For a fixed temperature, when the pressure varies, correspondingly density also varies such that the ratio $\left(\frac{P}{\rho}\right)$becomes constant. This means that **the speed of sound is independent of pressure for a fixed temperature.**

2) If the **temperature remains same at the top and the bottom of a mountain then the speed of sound will remain same at these two points.** But, in practice, the temperatures are not same at top and bottom of a mountain; hence, the speed of sound is different at different points.

b) Effect of temperature:

Since v ∝T,

1) The **speed of sound varies directly to the square root of temperature in kelvin.** Let v_0 be the speed of sound at temperature at 0° C or 273 K and vbe the speed of sound at any arbitrary temperature T (in kelvin),

then $\frac{v}{v_0} = \sqrt{\frac{T}{273}} = \sqrt{\frac{273+t}{273}}$

v= $v_0\sqrt{\mathbf{1} + \frac{t}{\mathbf{273}}} \cong v_0\left(\mathbf{1} + \frac{t}{\mathbf{546}}\right)$ (using binomial expansion)

Since v_0 = 331m s^{-1} at 0^0C, v at any temperature in t^0C is

v = (331 + 0.60t) ms^{-1}

2) Thus the **speed of sound in air increases by 0.61 ms^{-1} per degree Celsius rise in temperature.** Note that when the temperature is increased, the **molecules will vibrate faster due to gain in thermal energy and hence, speed of sound increases.**

c) Effect of density:

1) Let us **consider two gases with different densities having same temperature and pressure.** Then the speed of sound in the two gases are$v_1 = \sqrt{\frac{\gamma_1 P}{\rho_1}}$ ---------1 and $v_2 = \sqrt{\frac{\gamma_2 P}{\rho_2}}$ ---------2

Taking ratio of equation (1) and equation (2), we get $\frac{v_1}{v_2} = \frac{\sqrt{\frac{\gamma_1 P}{\rho_1}}}{\sqrt{\frac{\gamma_2 P}{\rho_2}}} = \sqrt{\frac{\gamma_1 \rho_2}{\gamma_2 \rho_1}}$

For gases having same value of $\gamma, \frac{v_1}{v_2} = \sqrt{\frac{\rho_2}{\rho_1}}$ ---------- 3

Thus the velocity of sound in a **gas is inversely proportional to the square root of the density of the gas.**

d) Effect of moisture (humidity):

1) We know that density of moist air is 0.625 of that of dry air, which means the presence of moisture in air (increase in humidity) decreases its density. Therefore, speed of sound increases with rise in humidity.

From equation v = $\sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma^c T}$

v = $\sqrt{\frac{\gamma P}{\rho}}$ Let ρ_1, v_1 and ρ_2, v_2 be the density and speeds of sound in dry air and moist air, respectively. Then $\frac{v_1}{v_2} = \frac{\sqrt{\frac{\gamma_1 P}{\rho_1}}}{\sqrt{\frac{\gamma_2 P}{\rho_2}}} = \sqrt{\frac{\rho_2}{\rho_1}}$ if $\gamma_1 = \gamma_2$

Since P is the total atmospheric pressure, it can be shown that

$$\frac{\rho_2}{\rho_1} = \frac{P}{P_1 + 0.625 P_2}$$

e) Effect of wind:

The speed of sound is also **affected by blowing of wind**. In the direction **along the wind blowing, the speed of sound increases whereas in the direction opposite to wind blowing, the speed of sound decreases.**

42. Write the applications of reflection of sound waves:

a) Stethoscope: It works on the principle of multiple reflections.

It consists of three main parts: i) Chest piece (ii) Ear piece (iii) Rubber tube

i) Chest piece:

It consists of a small disc-shaped resonator (diaphragm) which is very sensitive to sound and amplifies the sound it detects.

ii) Ear piece:

It is made up of metal tubes which are used to hear sounds detected by the chest piece.

iii) Rubber tube:

This tube connects both chest piece and ear piece. It is used to **transmit the sound signal detected by the diaphragm, to the ear piece. The sound of heart beats (or lungs) or any sound produced by internal organs can be detected**, and it reaches the ear piece through this tube by multiple reflections.

b) Echo:

1) An echo is **a repetition of sound produced by the reflection of sound waves from a wall, mountain or other obstructing surfaces. The speed of sound in air at 20°C is 344 m s^{-1}.** If we shout at a wall which is at 344 m away, then the sound will take 1 second to reach the wall.

2) After reflection**, the sound will take one more second to reach us. Therefore, we hear the echo after two seconds.** Scientists have estimated that we can hear two sounds properly if the time gap or time interval between each sound is $\left(\frac{1}{10}\right)^{th}$ of a second (persistence of hearing) i.e., 0.1 s. Then,

Velocity = $\frac{\text{Distance travelled}}{\text{Time taken}}$; = $\frac{2d}{t}$

2d = 344 x 0.1=34.1m; d = 17.2 m

The minimum distance from a sound reflecting wall to hear an echo at 20°C is 17.2 meter.

c) SONAR:

SOund NAvigation and Ranging. Sonar systems make use of **reflections of sound waves in water to locate the position or motion of an object.** Similarly, dolphins and bats use the sonar principle to find their way in the darkness.

d) Reverberation:

In a closed room the sound is repeatedly **reflected from the walls and it is even heard long after the sound source ceases to function.** The residual sound remaining in an enclosure and the phenomenon of multiple reflections of sound is called reverberation.

The **duration for which the sound persists is called reverberation time. It should be noted that the reverberation time greatly affects the quality of sound heard in a hall.** Therefore, halls are constructed with some optimum reverberation time.

43. Write characteristics of progressive waves:

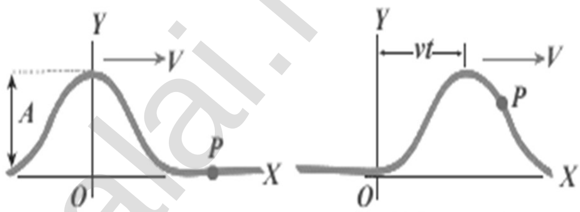
1) Particles in the medium **vibrate about their mean positions with** the sameamplitude.
2) The phase **of every particle ranges from 0 to 2π.**
3) No particle remains at rest permanently. During wave propagation, particlescome to the rest position only twice at the extreme points.
4) Transverse progressive waves are characterized by **crests and troughs whereas longitudinal progressive waves are characterized by compressions andrarefactions.**
5) When the **particles pass through the mean position they always move withthe same maximum velocity.**

6) The displacement, velocity and acceleration of particles separated fromeach other by $n\lambda$ are the same. where n is an integer, and λ is the wavelength.

44. Derive the equation of a plane progressive wave.

1) A jerk on a stretched string at time t = 0 s. Let us assume that the wave pulse created during this disturbance moves along positive x direction with constant speed v as shown in Figure.

2) We can represent the shape of the wave pulse, mathematically as $y = y(x, 0) = f(x)$ at time t = 0s. Assume that the shape of the wave pulse remains the same during the propagation. After some timet, the pulse moving towards the right and any point on it can be represented by x' (read it as x prime) as shown in Figure. Then, $y(x, t) = f(x') = f(x - vt)$



(a) Pulse at t = 0 (b) Pulse at time t

3) Similarly, **if the wave pulse moves towards left with constant speed v, then $y = f(x + vt)$. Both waves $y = f(x + vt)$ and $y = f(x - vt)$** will satisfy the following one **dimensional differential equation known as the wave equation** $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$.

4) where the symbol ∂ represent partial derivative. Not all the solutions satisfying this differential equation can represent waves, because any physical acceptable wave must take finite values for all values of x and t.

5) But if the function represents a wave then it must satisfy the differential equation. Since, in one dimension (one independent variable), the partial derivative with respect to x is the same as total derivative in coordinate x, we write $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$.

45. Explain the Graphical representation of the wave.

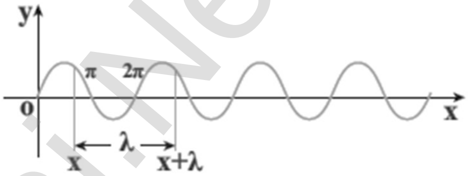
Let us graphically represent the two forms of the wave variation

a) Space (or Spatial) variation graph

b) Time (or Temporal) variation graph

a) Space variation graph:

1) By keeping the time fixed, the change in displacement with respect to x is plotted. Let us consider a sinusoidal graph, y = A sin(k x) as shown in the Figure, where k is a constant. Since the wavelength λ denotes the distance between any two points in the same state of motion, the displacement y is the same at both the ends.



y = xand y = x + λ, i.e.,

y = A sin(kx) = A sin(k(x+ λ))

= A sin(kx+ k λ) ------------------- 1

The sine function is a periodic function with period 2π. Hence,

y = A sin(kx+ 2π) = A sin(kx) ----------------- 2

Comparing equation (1) and equation (2), we get

kx+ k λ = kx+ 2π , This implies K = $\frac{2\pi}{\lambda}$rad m^{-1}---------------3

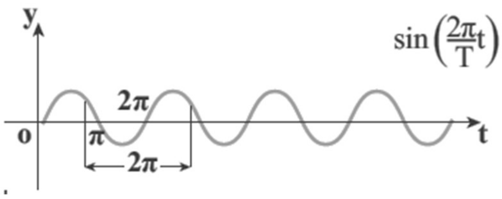
where k is called wave number. This measures how many wavelengths are present in 2π radians.

The spatial periodicity of the wave is $\lambda = \frac{2\pi}{k}$ in m

Then, At t = 0 s y(x, 0) = y(x+ λ, 0) and At any time t, y(x, t) = y(x+ λ, t)

b) Time variation graph:

1) By **keeping the position fixed, the change in displacement with respect to time is plotted**. Let us consider a sinusoidal graph, y =A sin(ωt) as shown in the Figure, where ω is angular frequency of the wave which measures how quickly wave oscillates in time or number of cycles per second.



2) The **temporal periodicity or time period**is $T = \frac{2\pi}{\omega} \Rightarrow \omega = \frac{2\pi}{T}$

The angular frequency is related to frequency f by the expression ω = 2 πf, where the frequency f is defined as the number of oscillations made by the medium particle per second.

3) **Since inverse of frequency is time period, we have, T = $\frac{1}{f}$ in seconds This is the time taken by a medium particle to complete one oscillation.** Hence, we can define the speed of a wave (wave speed, v) as the distance traversed by the **wave per second** v = $\frac{\lambda}{T}$ = λf in ms^{-1}

46. Derive the relation between intensity and loudness.

1) According to Weber-Fechner's law, **"loudness (L) is proportional to the logarithm of the actual intensity (I) measured with an accurate non-human instrument". This means that L ∝lnI , L = klnI**where k is a constant, which depends on the unit of measurement.

2) The **difference between two loudness, L_1 and L_0 measures the relative loudness between two precisely measured intensities and is called as sound intensity level.**

3) Sound intensity level is $\Delta L = L_1 - L_0 = k\ln I_1 - k\ln I_0 = k\ln\left[\frac{I_1}{I_0}\right]$ if k = 1, then **sound intensity level is measured in bel**, in honour of Alexander Graham Bell. Therefore, $\Delta L = \ln\left[\frac{I_1}{I_0}\right]$bel

4) However, this is practically a bigger unit, so we use a convenient smaller unit, called decibel. Thus, **decibel = $\frac{1}{10}$bel ,**

5) Therefore, by multiplying and dividing by 10,

we get $\Delta L = 10\left(\ln\left[\frac{I_1}{I_0}\right]\right)\frac{1}{10}$bel ; $\Delta L = 10\ln\left[\frac{I_1}{I_0}\right]$decibel with k = 10

For practical purposes, we use logarithm to base 10 instead of natural logarithm, $\Delta L = 10\log_{10}\left[\frac{I_1}{I_0}\right]$decibel.

UNIT – I (NATURE OF PHYSICAL WORLD AND MEASUREMENT)

1. From a point on the ground, the top of a tree is seen to have an angle ofelevation 60⁰. The distance between the tree and a point is 50 m. Calculatethe height of the tree?

Solution

$\theta = 60^0$, The distance between the tree and a point x = 50 m,
Height of the tree (h)=?

For triangulation method $\tan\theta = \frac{h}{x}$

$h = x\tan\theta$; $= 50 \times \tan 60^0$; $= 50 \times 1.732$
h= 86.6 m; The height of the tree is 86.6 m.

2. A RADAR signal is beamed towards a planet and its echo is received 7minutes later. If the distance between the planet and the Earth is6.3×10^{10} m. Calculate the speed of the signal?

Solution

The distance of the planet from the Earth
$d = 6.3 \times 10^{10}$ m
Time t = 7 minutes = 7×60 s.
the speed of signal V=?

The speed of signal $V = \frac{2d}{t} = \frac{2x6.3x10^{10}}{7x60}$;
$V = 3x10^8\ ms^{-1}$

No.	Log
12.6	1.1004
420	2.6232
(−)	$\bar{2}.4772$
Antilog	3.000×10^8

3. Two resistances $R_1 = (100 \pm 3)\ \Omega$, $R_2 = (150 \pm 2)\ \Omega$, are connected in series.What is their equivalent resistance?

Solution

$R_1 = 100 \pm 3\ \Omega$, $R_2 = 150 \pm 2\Omega$
Equivalent resistance R =?
Equivalent resistance $R = R_1+R_2$
$= (100 \pm 3) + (150 \pm 2)$; $= (100 + 150) \pm (3 + 2)$
$R = (250 \pm 5)\ \Omega$

4. The temperatures of two bodies measured by a thermometer are $t_1 = (20 + 0.5)°C$, $t_2 = (50 \pm 0.5)°C$. Calculate the temperature difference andthe error therein.

Solution

$t_1 = (20 \pm 0.5)°C$ $t_2 = (50 \pm 0.5)°C$ ‘ temperature difference t=?
$t = t_2 - t_1$; $= (50 \pm 0.5) - (20 \pm 0.5)°C$
$= (50 - 20) \pm (0.5+0.5)$; $t = (30 \pm 1)°C$

5. The voltage across a wire is (100 ± 5)V and the current passing through it is (10±0.2) A. Find the resistance of the wire.

Solution

Resistance is given by Ohm's law R = $\frac{V}{I}$; = $\frac{100}{10}$; R = 10Ω

$\frac{\Delta R}{R} = \left(\frac{\Delta V}{V} + \frac{\Delta I}{I}\right)$; $\Delta R = \left(\frac{\Delta V}{V} + \frac{\Delta I}{I}\right)R$

$= \left(\frac{5}{100} + \frac{0.2}{10}\right)10$; =(0.05 + 0.02)10 ; = 0.07 x 10 = 0.7

The resistance R = (10 ± 0.7) Ω

6. A physical quantity x is given by $x = \frac{a^2b^3}{c\sqrt{d}}$.If the percentage errors ofmeasurement in a, b, c and d are 4%, 2%, 3% and 1% respectively, thencalculate the percentage error in the calculation of x.

Solution

Given $x = \frac{a^2b^3}{c\sqrt{d}}$;

The percentage error in $x$is given by

$\frac{\Delta x}{x}$ x 100 = 2 $\frac{\Delta a}{a}$ x 100 + 3 $\frac{\Delta b}{b}$ x 100 + $\frac{\Delta c}{c}$ x 100 + $\frac{1}{2}\frac{\Delta d}{d}$ x 100

= (2 × 4%) + (3 × 2%) + (1 × 3%) + (½ ×1%); = 8% +6%+3% +0.5%

The percentage error is x = 17.5%

7. State the number of significant figures in the following

i) 600800 - Four ii) 400 - One iii) 0.007 - One iv) 5213.0 - Five v) 2.65 × 10^{24}m - Three
vi) 0.0006032– Four

8. Round off the following numbers as indicated

i) 18.35 up to 3 digits	:	18.4
ii) 19.45 up to 3 digits	:	19.4
iii) 101.55 × 10^6 up to 4 digits	:	101.6 x 106
iv) 248337 up to digits 3 digits	:	248000
v) 12.653 up to 3 digits	:	12.7

9. Convert 76 cm of mercury pressure into Nm^{-2} using the method ofdimensions.

Solution

In cgs system 76 cm of mercury pressure = 76 × 13.6 × 980 dyne cm^{-2}

The dimensional formula of pressure P is $[ML^{-1}T^{-2}]$

$$P_1[M_1^aL_1^bT_1^c] = P_2[M_2^aL_2^bT_2^c] \; ; \; P_2 = P_1\left[\frac{M_1}{M_2}\right]^a \left[\frac{L_1}{L_2}\right]^b \left[\frac{T_1}{T_2}\right]^c$$

M_1 = 1g, M_2 = 1kg; L_1 = 1 cm, L_2 = 1m; T_1 = 1 s, T_2 = 1s

As a =1, b= -1, and c = -2

$$\text{Then } P_2 = 76 \times 13.6 \times 980 \left[\frac{1g}{1kg}\right]^1 \left[\frac{1cm}{1m}\right]^{-1} \left[\frac{1s}{1s}\right]^{-2}$$

$$= 76 \times 13.6 \times 980 \left[\frac{10^{-3}kg}{1kg}\right]^1 \left[\frac{10^{-2}m}{1m}\right]^{-1} \left[\frac{1s}{1s}\right]^{-2}$$

$= 76 \times 13.6 \times 980 \times [10^{-3}] \times 10^2$;$P_2 = 1.01 \times 10^5\ Nm^{-2}$

10. If the value of universal gravitational constant in SI is $6.6\times10^{-11}\ Nm^2\ kg^{-2}$, thenfind its value in CGS System?

Solution

Let G_{SI} be the gravitational constant in the SI system and G_{cgs} in the cgs system. Then$G_{SI} = 6.6 \times 10^{-11} Nm^2\ kg^{-2}$

G_{cgs} =?

$$n_2 = n_1\left[\frac{M_1}{M_2}\right]^a \left[\frac{L_1}{L_2}\right]^b \left[\frac{T_1}{T_2}\right]^c \; ; \; G_{cgs} = G_{SI}\left[\frac{M_1}{M_2}\right]^a \left[\frac{L_1}{L_2}\right]^b \left[\frac{T_1}{T_2}\right]^c$$

M_1 = 1 kg, L_1 = 1m, T_1 = 1s ; M_2 = 1 g, L_2 = 1 cm, T_2 = 1s

The dimensional formula for G is $M^{-1}L^3T^{-2}$;a = -1, b = 3 and c = -2

$$G_{cgs} = 6.6 \times 10^{-11}\left[\frac{1kg}{1g}\right]^{-1} \left[\frac{1m}{1cm}\right]^3 \left[\frac{1s}{1s}\right]^{-2}$$

$$= 6.6 \times 10^{-11}\left[\frac{1kg}{10^{-3}kg}\right]^{-1} \left[\frac{1m}{10^{-2}m}\right]^3 \left[\frac{1s}{1s}\right]^{-2}$$

$= 6.6 \times 10^{-11} \times 10^{-3} \times 10^6 \times 1$;$G_{cgs} = 6.6 \times 10^{-8} dynecm^2g^{-2}$

11. Check the correctness of the equation ½ mv^2 = mgh using dimensionalanalysis method.

Solution

Dimensional formula for ½ $mv^2 = [M][LT^{-1}]^2 = [ML^2T^{-2}]$

Dimensional formula for mgh= $[M][LT^{-2}][L]=[ML^2T^{-2}]$

$[ML^2T^{-2}] = [ML^2T^{-2}]$

Both sides are dimensionally the same, hence the equations ½ mv^2 = mgh is dimensionally correct.

12. Obtain an expression for the time period T of a simple pendulum. The timeperiod T depends on (i) mass 'm' of the bob (ii) length 'l' of the pendulum and(iii) acceleration due to gravity g at the place where the pendulum is suspended. (Constant k = 2π)

Solution

T∝ $m^a l^b g^c$; T = k $m^a l^b g^c$

Here k is the dimensionless constant. Rewriting the above equation withdimensions

$[T^1] = [M^a]\ [L^b]\ [LT^{-2}]^c$ $[M^0L^0T^1] = [M^a\ L^{b+c}\ T^{-2c}]$

Comparing the powers of M, L and T on both sides, a=0, b+c=0, -2c=1

Solving for a,b and c a = 0, b = 1/2, and c = −1/2

From the above equation T = k. $m^0 l^{1/2} g^{1/2}$

T = k $\left(\frac{l}{g}\right)^{1/2}$; k $\sqrt{l/g}$;

Experimentally k = 2π,

hence T = 2π$\sqrt{l/g}$

EXERCISE PROBLEM

13. In a submarine equipped with sonar, the time delay between the generationof a pulse and its echo after reflection from an enemy submarine is observedto be 80 s. If the speed of sound in water is 1460 ms^{-1}. What is the distanceof enemy submarine?

Solution

t = 80s , v = 1460 ms^{-1}, D = ?

D = $\frac{v\,t}{2} = \frac{1460 \times 80}{2}$; = 1460 x 40 ; 58400m

D = 58.4km

14. The radius of the circle is 3.12 m. Calculate the area of the circle with regardto significant figures.

Solution

r = 31.2 m ; A = ?

A = πr^2 ; = 3.14 x 3.12 x 3.12 ; = 30.57m^2

A = 30.6 m^2(*rounding off with significant figure3*)

15. Assuming that the frequency γ of a vibrating string may depend upon.
(i) applied force (F)
(ii) length (l)
(iii) mass per unit length (m), prove that $\gamma \propto \frac{1}{l}\sqrt{\frac{F}{m}}$ using dimensional analysis.

Solution

$\gamma \propto F^a l^b m^c$ .... 1 (or) $\gamma = k\, F^a l^b \left(\frac{M}{l}\right)^c$

Dimension of v = $[T^{-1}]$; Dimension of l = [L]
Dimension of F = $[MLT^{-2}]$; Dimension of m = $[ML^{-1}]$
Put these dimensional formula in equation 1
$[T^{-1}] \propto [MLT^{-2}]^a\,[L]^b\,[ML^{-1}]^c$
$[M^0L^0T^{-1}] \propto \left[M^{a+c}\,L^{a+b-c}\,T^{-2a}\right]$
Compare the powers of M, L and T on both sides, we get,
a + c =0 ; a+b – c ; – 2a = –1
$a = \frac{1}{2}$, b = –1, $c = -\frac{1}{2}$
Put the values of a, b and c in equation 1

$\gamma \propto F^{\frac{1}{2}}\, l^{-1}\, m^{\frac{1}{2}}$; $\gamma \propto \frac{F^{\frac{1}{2}}}{l\; m^{\frac{1}{2}}}$; $= \frac{1}{l}\left[\frac{F}{m}\right]^{\frac{1}{2}}$

$\gamma \propto \frac{1}{l}\sqrt{\frac{F}{m}}$

16. Jupiter is at a distance of 824.7 million km from the Earth. Its angulardiameter is measured to be 35.72″. Calculate the diameter of Jupiter

Solution

X = 824.7 million km = $824.7 \times 10^6 \times 10^3$ m
θ = 35.72" = $35.72 \times 4.85 \times 10^{-6}$ rad; b = ?
$x = \frac{b}{\theta}$; $b = x\theta$;
= $824.7 \times 10^9 \times 35.72 \times 4.85 \times 10^{-6}$
= $1.428 \times 10^5 \times 10^3$m ; **b = 1.428×10^5km**

UNIT – II (KINEMATICS)

17. Two vectors $\vec{A}$ and $\vec{B}$ of magnitude 5 units and 7 units respectively make anangle 60^0 with each other.Find the magnitude of the resultant vector and itsdirection with respect to the vector $\vec{A}$

Solution

The magnitude of the resultant vector $\vec{R}$is given by

$R = |\vec{R}| = \sqrt{5^2 + 7^2 + 2x5x7\cos 60^0}$; $= \sqrt{25 + 49 + \frac{70x1}{2}}$;

$\mathbf{R} = \sqrt{\mathbf{109}}$ units

The angle α between $\vec{R}$and $\vec{A}$is given by $\tan\alpha = \frac{B\ Sin\ \theta}{A+B\ Cos\theta}$

$= \frac{7\ x\ \sin 60^0}{5+7\ \cos 60^0}$; $= \frac{7\ x\ \sqrt{3}}{10+7}$ $= \frac{7\ x\ \sqrt{3}}{17}$; ≅0.713 ; α ≅35^0

18. Two vectors $\vec{A}$ and $\vec{B}$ of magnitude 5 units and 7 units make an angle 60^0 witheach other . Find the magnitude of the difference vector $\vec{A} - \vec{B}$and itsdirection with respect to the vector $\vec{A}$

Solution

The magnitude of the difference vector $\vec{A} - \vec{B}$is given by

$|\vec{A} - \vec{B}| = \sqrt{5^2 + 7^2 - 2x5x7\cos 60^0}$; $= \sqrt{25 + 49 - 35}$;

$= \sqrt{\mathbf{39}}$ units

The angle that between $\vec{A} - \vec{B}$ makes the vector $\vec{A}$ given by

$\tan\alpha = \frac{B\ Sin\ \theta}{A-B\ Cos}$

$= \frac{7\ x\ \sin 60^0}{5-7\ \cos 60^0}$; $= \frac{7\ x\ \sqrt{3}}{10-7}$ $= \frac{7}{\sqrt{3}}$; =4.041 ; $\alpha = \tan^{-1}(4.041)$; α ≅ 76^0

19. Two vectors $\vec{A}$and $\vec{B}$are given in the component form as $\vec{A} = 5\vec{i} + 7\vec{j} - 4\vec{k}$and $\vec{B} = 6\vec{i} + 3\vec{j} + 2\vec{k}$. Find $\vec{A} + \vec{B}$, $\vec{B} + \vec{A}$, $\vec{A} - \vec{B}$, $\vec{B} - \vec{A}$.

Solution

$\vec{A} + \vec{B} = (5\vec{i} + 7\vec{j} - 4\vec{k}) + (6\vec{i} + 3\vec{j} + 2\vec{k})$; $= \mathbf{11\vec{i} + 10\vec{j} - 2\vec{k}}$.

$\vec{B} + \vec{A} = (6\vec{i} + 3\vec{j} + 2\vec{k}) + (5\vec{i} + 7\vec{j} - 4\vec{k})$; $= \mathbf{11\vec{i} + 10\vec{j} - 2\vec{k}}$.

$\vec{A} - \vec{B} = (5\vec{i} + 7\vec{j} - 4\vec{k}) - (6\vec{i} + 3\vec{j} + 2\vec{k})$; $= \mathbf{-\vec{i} + 4\vec{j} - 6\vec{k}}$.

$\vec{B} - \vec{A} = (6\vec{i} + 3\vec{j} + 2\vec{k}) - (5\vec{i} + 7\vec{j} - 4\vec{k})$; $= \mathbf{\vec{i} - 4\vec{j} + 6\vec{k}}$.

Note that the vectors$\vec{A} + \vec{B}$ and $\vec{B} + \vec{A}$are same and the vectors$\vec{A} - \vec{B}$ and$\vec{B} - \vec{A}$are opposite to each other.

20. Given the vector $\vec{A} = 2\vec{i} + 3\vec{j}$, what is $3\vec{A}$?

Solution

$3\vec{A} = 3(2\vec{i} + 3\vec{j}) = 6\vec{i} + 9\vec{j}$. The vector $3\vec{A}$ is given as in the same direction as vector $\vec{A}$

21. **Given two vectors $\vec{A} = 2\vec{i} + 4\vec{j} + 5\vec{k}$ and $\vec{B} = \vec{i} + 3\vec{j} + 6\vec{k}$. Find the product $\vec{A} \cdot \vec{B}$, and the magnitudes of $\vec{A}$ and $\vec{B}$. What is the angle between them?**

Solution

$\vec{A} \cdot \vec{B}$ = 2+12+30 = 44

Magnitude A = $\sqrt{4+16+25}$; = $\sqrt{45}$units

Magnitude B = $\sqrt{1+9+36}$; = $\sqrt{46}$ units

The angle between the two vectors is given by

$\theta = \cos^{-1}\left(\frac{A.B}{AB}\right)$;

= $\cos^{-1}\left(\frac{44}{\sqrt{45 \times 46}}\right)$; = $\cos^{-1}\left(\frac{44}{45.49}\right)$; = $\cos^{-1}(0.967)$ ∴ $\theta \cong 15^0$

No.	Log
44	1.6435
½ x 2070	1.6580
(−)	$\bar{1}$.9855
Antilog	9.672×10^{-1}

22. **Check whether the following vectors are orthogonal.**
i) $\vec{A} = 2\vec{i} + 3\vec{j}$ and $\vec{B} = 4\vec{i} - 5\vec{j}$ ii) $\vec{C} = 5\vec{i} + 2\vec{j}$ and $\vec{D} = 2\vec{i} - 5\vec{j}$

Solution

$\vec{A}.\vec{B}$ = 8 -15 = -7≠0 . Here $\vec{A}$ and $\vec{B}$ are *not orthogonal to each other*.

$\vec{C}.\vec{D}$ = 10 -10 = 0 . Here $\vec{C}$ and $\vec{D}$ are *orthogonal to each other*.

23. **Two vectors are given as $\vec{r} = 2\vec{i} + 3\vec{j} + 5\vec{k}$ and $\vec{F} = 3\vec{i} - 2\vec{j} + 4\vec{k}$. Find theresultant vector $\vec{\tau} = \vec{r} \times \vec{F}$**

Solution

$$\vec{\tau} = \vec{r} \times \vec{F} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 2 & 3 & 5 \\ 3 & -2 & 4 \end{vmatrix}$$

= $(12-(-10))\hat{\imath} + (15-8)\hat{\jmath} + (-4-9)\hat{k}$; $\vec{\tau} = 22\hat{\imath} + 7\hat{\jmath} - 13\hat{k}$

24. **Assume your school is located 2 km away from your home. In the morning youare going to school and in the evening you come back home. In this entire tripwhat is the distance travelled and the displacement covered?**

Solution

The displacement covered is zero. It is because your initial and final positions are the same. But the distance travelled is 4 km.

25. **An athlete covers 3 rounds on a circular track of radius 50 m. Calculate thetotal distance and displacement travelled by him.**

Solution

The total distance the athlete covered =3x circumference of track

Distance = 3 × 2π ×50 m ; = 300π m(or)

Distance ≈ 300 x 3.14 ≈ 942 m

The *displacement is zero*, since the athlete reaches the same point A after three rounds from where he started.

26. The position vector of a particle is given $\vec{r} = 2t\vec{i} + 3t^2\vec{j} - 5\vec{k}$.
a) Calculate the velocity and speed of the particle at any instant *t*
b) Calculate the velocity and speed of the particle at time *t* = 2 s

Solution

The velocity $\bar{\bar{v}} = \frac{d\bar{r}}{dt} = 2\vec{i} + 6t\vec{j}$;
The speed $v(t) = \sqrt{2^2 + (6t)^2}$ ms^{-1}
The velocity of the particle at *t* = 2 s ;
$\vec{v}(2sec) = 2\vec{i} + 12\vec{j}$
The speed of the particle at *t* = 2 s ;
$v(2s) = \sqrt{2^2 + 12^2} = \sqrt{4 + 144}$
$= \sqrt{148}$; ≈ 12.16 ms^{-1}

No.	Log
½ x 148	½ x 2.1703 1.0851
Antilog	1.216×10^1

27. The velocity of three particles A, B, C are given below. Which particle travels atthe greatest speed?

$$\bar{v}_A = 3\vec{i} - 5\vec{j} + 2\vec{k}\ ;\ \bar{v}_B = \vec{i} + 2\vec{j} + 3\vec{k}\ ;\ \bar{v}_C = 5\vec{i} + 3\vec{j} + 4\vec{k}$$

Solution

Speed of A = $|\bar{v}_A| = \sqrt{(3)^2 + (-5)^2 + (2)^2}$; $= \sqrt{9 + 25 + 4}$; ; $= \sqrt{38}$ ms^{-1}
Speed of B = $|\bar{v}_B| = \sqrt{(1)^2 + (2)^2 + (3)^2}$; $= \sqrt{1 + 4 + 9}$; ; $= \sqrt{14}$ ms^{-1}
Speed of C = $|\bar{v}_C| = \sqrt{(5)^2 + (3)^2 + (4)^2}$; $= \sqrt{25 + 9 + 16}$; ; $= \sqrt{50}$ ms^{-1}
The particle C has the greatest speed $\sqrt{50} > \sqrt{38} > \sqrt{14}$

28. Consider two masses of 10 g and 1 kg moving with the same speed 10ms^{-1}. Calculate the magnitude of the momentum.

Solution

p = mv
For the mass of 10 g, m = 0.01 kg;p = 0.01 × 10 = 0.1 kg ms^{-1}
For the mass of 1 kg;p = 1 × 10 = 10 kg ms^{-1}
Thus even though both the masses have the same speed, the momentum of the heavier mass is 100 times greater than that of the lighter mass.

29. A particle moves along the x-axis in such a way that its coordinates x varies with time 't' according to the equation x = 2 – 5t + 6t². What is the initial velocity of the particle?

Solution

Velocity , $v = \frac{dx}{dt}$; $\frac{d}{dt}(2 - 5t + 6t^2)$ (or) v = –5 + 12t
For initial velocity, t =0 ;Initial velocity = –5ms^{-1}

The negative sign implies that at t = 0 the velocity of the particle is along negative x direction.

Average speed = total path length / total time period

30. Suppose two trains A and B are moving with uniform velocities along parallel tracks but in opposite directions. Let the velocity of train A be 40 km h^{-1} due east and that of train B be 40 kmh^{-1} due west. Calculate the relative velocities of the trains

Solution

Relative velocity of A with respect to B V_{AB} = 80 km h^{-1} due east Thus to a passenger in train B, the train A will appear to move east with a velocity of 80 km h^{-1}

The relative velocity of B with respect to A, V_{BA}= 80 km h^{-1}due west
To a passenger in train A, the train B will appear to move westwards with a velocity of 80 kmh^{-1}

31. Consider two trains A and B moving along parallel tracks with the same velocity in the same direction. Let the velocity of each train be 50 km h-1 due east. Calculate the relative velocities of the trains.

Solution

Relative velocity of B with respect to A, $v_{BA} = v_B - v_A$
= 50 km h^{-1} + (−50) km h^{-1} ; = 0 km h^{-1}
Similarly, relative velocity of A withrespect to B i.e., v_{AB} is also zero.
Thus each train will appear to be at restwith respect to the other.

32. How long will a boy sitting near the window of a train travelling at 36 km h^{-1} see a train passing by in the opposite direction with a speed of 18 km h^{-1}. The length of the slow-moving train is 90 m.

Solution

The relative velocity of the slow-moving train with respect to the boy is
= (36 + 18) km h^{-1} = 54 km h^{-1} = 54 $\times\frac{5}{18}$ ms^{-1} = 15 ms^{-1}
Since the boy will watch the full length of the other train, to find the time taken towatch the full train: $15 = \frac{90}{t}$ or $t= \frac{90}{15}$; t = 6s

33. A swimmer's speed in the direction of flow of a river is 12 km h^{-1}. Against the direction of flow of the river the swimmer's speed is 6 km h^{-1}. Calculate the swimmer's speed in still water and the velocity of the river flow.

Solution

Let v_s and v_r, represent the velocities ofthe swimmer and river respectively withrespect to ground.
$v_s + v_r = 12$ (1) and $v_s - v_r = 6$ (2)
Adding the both equations (1) and (2)
$2v_s = 12 + 6 = 18$ km h^{-1}or vs = 9 km h^{-1}
From Equation (1),
$9 + v_r = 12$ or$v_r = 3$ km h^{-1}
When the river flow and swimmer movein the same direction, the net velocity ofswimmer is 12 km h^{-1}.

34. An iron ball and a feather are both falling from a height of 10 m.
a) What are the time taken by the iron ball and feather to reach the ground?
b) What are the velocities of iron ball and feather when they reach the ground? (Ignore air resistance and take g = 10 m s^{-2})

Solution

Since kinematic equations are independent of mass of the object.
The time taken by both iron ball and feather to reach the ground are the same. This is given by T = $\sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 10}{10}} = \sqrt{2}s \approx 1.414s$

Thus, both feather and iron ball reachground at the same time.

$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 10} = \sqrt{200}$ $ms^{-1} \approx 14.14 ms^{-1}$

35. A train was moving at the rate of 54 km h^{-1} when brakes were applied. It came to rest within a distance of 225 m. Calculate the retardation produced in the train.

Solution

The final velocity of the particle v = 0

The initial velocity of the particle u = 54 x $\frac{5}{18}$ ms^{-1} = 15 ms^{-1} ; s = 225 m

Retardation is always against the velocity of the particle.

$v^2 = u^2 - 2aS$; $0 = (15)^2 - 2a(225)$; 450 a = 225

a = $\frac{225}{450}$ ms^{-2} ; =0.5 ms^{-2} ; Retardation = =0.5 ms^{-2}

36. In the cricket game, a batsman strikes the ball such that it moves with the speed 30 m s^{-1} at an angle 30^0 with the horizontal. The boundary line of the cricket ground is located at a distance of 75 m from the batsman? Will the ball go for a six? (Neglect the air resistance and takeacceleration due to gravityg = 10 m s^{-2}).

Solution

The motion of the cricket ball in air is essentially a projectile motion. As we have already seen, the range (horizontal distance) of the projectile motion is given by

R = $\frac{u^2 \sin 2\theta}{g}$; The initial speed u= 30m s^{-1}

The projection angle θ = 30^0

The horizontal distance travelled by the cricket ball

No.	Log
45	1.6532
1.732	0.2385
(–)	1.8917
Antilog	7.793 x 10^1

R = $\frac{(30)^2 \times \sin 60^0}{10} = \frac{900 \times \frac{\sqrt{3}}{2}}{10}$; **R= 77.94 m**

This distance is greater than the distanceof the boundary line. Hence the ball willcross this line and go for a six.

37. A particle moves in a circle of radius 10 m. Its linear speed is given by v= 3t where t is in second and v is in m s^{-1}.
(a) Find the centripetal and tangential acceleration at t = 2 s.
(b) Calculate the angle between the resultant acceleration and the radius vector

Solution

The linear speed at t = 2 s; v = 3t ; **v= 6ms^{-1}**

The centripetal acceleration at t = 2 s is $a_c = \frac{v^2}{r}$; $= \frac{6^2}{10}$; a_c = **3.6ms^{-2}**

The tangential acceleration is $a_t = \frac{dv}{dt}$; a_t **= 3ms^{-1}**

The angle between the radius vector with resultant acceleration is given by $\tan\theta = \frac{a_t}{a_c}$; $= \frac{3}{3.6}$; $\tan\theta = 0.833$

$\theta = \tan^{-1}(0.833) = 0.69$ radian

In terms of degree $\theta = 0.69 \times 57.27^0 \approx 40^0$

38. A particle is in circular motion with an acceleration α = 0.2 $rads^{-2}$.
(a) What is the angular displacement made by the particle after 5 s?
(b) What is the angular velocity at t = 5 s?. Assume the initial angular velocity is zero.

Solution

Since the initial angular velocity is zero$(\omega_0 = 0)$

The angular displacement made by the particle is given by

$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$; $= \frac{1}{2} \times 2 \times 10^{-1} \times 25$; $\theta = 2.5$ rad

In terms of degree $\theta = 2.5 \times 57.27^0 \approx 143^0$

EXERCISE PROBLEM

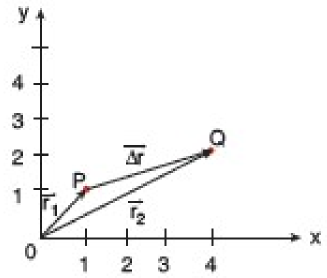
39. The position vectors particle has length 1m and makes 30^0 with the *x*-axis. What are the lengths of the x and y components of the position vector?

Solution

l = 1m , $\theta = 30^0$; Length of x – component $l_x = l\cos\theta = 1 \times \cos 30^0 = \frac{\sqrt{3}}{2}$

Length of y – component $l_y = l\sin\theta = 1 \times \sin 30^0 = \frac{1}{2} = 0.5$

40. A particle has its position moved from $\vec{r_1} = 3\hat{\imath} + 4\hat{\jmath}$ to $\vec{r_2} = \hat{\imath} + 2\hat{\jmath}$ Calculatethe displacement vector $(\Delta\vec{r})$and draw the $\vec{r_1}, \vec{r_2}$ and $\Delta\vec{r}$vector in a twodimensional Cartesian coordinate system.



$\Delta\vec{r} = \vec{r_2} - \vec{r_1}$; ; $= (\hat{\imath} + 2\hat{\jmath}) - (3\hat{\imath} + 4\hat{\jmath})$; $= \hat{\imath} + 2\hat{\jmath} - 3\hat{\imath} - 4\hat{\jmath}$

$\Delta\vec{r} = -2\hat{\imath} - 2\hat{\jmath}$

41 Calculate the average velocity of the particle whose position vector changes from $\vec{r_1} = 5\hat{\imath} + 6\hat{\jmath}$ to $\vec{r_2} = \widehat{2\imath} + 3\hat{\jmath}$ in a time 5 second.

Solution

The average velocity $\vec{v}_{avg} = \frac{\Delta\vec{r}}{\Delta t} = \frac{\vec{r}_2 - \vec{r}_1}{t}$; $= \frac{(\widehat{2\imath}+3\hat{\jmath})-(5\hat{\imath}+6\hat{\jmath})}{5}$

$= \frac{2\hat{\imath}+3\hat{\jmath}-5\hat{\imath}-6\hat{\jmath}}{5}$; $= \frac{-3\hat{\imath}-3\hat{\jmath}}{5}$; $\vec{v}_{avg} = -\frac{3}{5}(\hat{\imath}+\hat{\jmath})$

42. Convert the vector $\hat{r} = 3\hat{\imath} + 2\hat{\jmath}$ into a unit vector.

Solution

The magnitude of the vector $\hat{r} = 3\hat{\imath} + 2\hat{\jmath}$

$|\hat{r}| = \sqrt{3^2 + 2^2} = \sqrt{9+4} = \sqrt{13}$; $\hat{r} = \frac{\vec{r}}{|\vec{r}|} = \frac{3\hat{\imath}+2\hat{\jmath}}{\sqrt{13}}$

43. What are the resultants of the vector product of two given vectors given by $\vec{A} = 4\hat{\imath} - 2\hat{\jmath} + \hat{k}$ and $\vec{B} = 5\hat{\imath} + 3\hat{\jmath} - 4\hat{k}$

Solution

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 4 & -2 & 1 \\ 5 & 3 & -4 \end{vmatrix}$$

$= (8 - 3)\hat{\imath} + (5+16)\hat{\jmath} + (12 + 10)\hat{k}$;

$\vec{A} \times \vec{B} = 5\hat{\imath} + 21\hat{\jmath} + 22\hat{k}$

44. An object at an angle such that the horizontal range is 4 times of the maximum height. What is the angle of projection of the object?

Solution

Horizontal Range $R = \frac{u^2\sin 2\theta}{g}$; maximum height $h_{max} = \frac{u^2\sin^2\theta}{2g}$;

$R = 4h_{max}$; $\frac{u^2\sin 2\theta}{g} = 4\text{x}\,\frac{u^2\sin^2\theta}{2g}$

$\frac{u^2 2\sin\theta\cos\theta}{g} = 4\text{x}\,\frac{u^2\sin^2\theta}{2g}$; $\cos\theta = \sin\theta$; $\frac{\sin\theta}{\cos\theta} = 1$; $\tan\theta = 1$

$\boldsymbol{\theta = \tan^{-1}(1) = 45^0}$

45. Calculate the area of the triangle for which two of its sides are given by the vectors $\vec{A} = 5\hat{\imath} - 3\hat{\jmath}$ and $\vec{B} = 4\hat{\imath} + 6\hat{\jmath}$

Solution

$\Delta = \frac{1}{2}|\vec{A} \times \vec{B}|$ ----------1

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 5 & -3 & 0 \\ 4 & 6 & 0 \end{vmatrix}$$

$= (0 - 0)\hat{\imath} + (0 - 0)\hat{\jmath} + (30 + 12)\hat{k}$; $|\vec{A} \times \vec{B}| = 42\hat{k}$

$|\vec{A} \times \vec{B}| = 42$ put this in equation 1 $\Delta = \frac{1}{2} \times 42$; $\boldsymbol{\Delta} = 21\text{m}^2$

46. If Earth completes one revolution in 24 hours, what is the angulardisplacement made by Earth in one hour. Express your answer in both radianand degree.

Solution

Angular displacement for one complete revolution (i.e.) for 24 hours = 360^0

Hence, angular displacement for one hour, $\theta = \frac{360^0}{24}$; $=15^0$ or

$\theta = \frac{\pi}{180^0} x\ 15^0$; $= \frac{\pi}{12}$ rad [$180^0 = \pi$ rad]

47. A object is thrown with initial speed $5ms^{-1}$ with an angle of projection 30^0. What is the height and range reached by theparticle?

No.	Log
25	1.3979
78.4	1.8943
(−)	$\bar{1}$.5036
Antilog	3.188×10^{-1}

Solution

i) maximum height of the projectile, $h_{max} = \frac{u^2 \sin^2\theta}{2g}$

$h_{max} = \frac{5^2 \sin 30^0 \sin 30^0}{2 \times 9.8}$; $= \frac{25 \times \left[\frac{1}{2}\right] \times \left[\frac{1}{2}\right]}{2 \times 9.8}$; $= \frac{25}{8 \times 9.8}$; $= \frac{25}{78.4}$; $h_{max} = 0.3188m$

No.	Log
43.3	1.6365
19.6	1.2922
(−)	0.3443
Antilog	2.209×10^0

ii) Horizontal Range R = $\frac{u^2 \sin 2\theta}{g}$; $= \frac{u^2 2 \sin\theta \cos\theta}{g}$; $= \frac{5^2 \times 2 \sin 30^0 \cos 30^0}{9.8}$

$= \frac{25 \times 2 \left[\frac{1}{2}\right] \times \left[\frac{\sqrt{3}}{2}\right]}{9.8}$; $= \frac{25 \times 1.732}{2 \times 9.8} = \frac{43.300}{19.6}$; R = 2.21m

48. A foot-ball player hits the ball with speed 20 ms^{-1} with angle 30^0 with respectto horizontal direction. The goal post is at distance of 40 m from him. Find outwhether ball reaches the goal post?

Solution

Here the reaches ball is considering as a projectile. Its range

Horizontal Range R = $\frac{u^2 \sin 2\theta}{g}$; $= \frac{u^2 2 \sin\theta \cos\theta}{g}$; $= \frac{20^2 \times 2 \sin 30^0 \cos 30^0}{9.8}$

$= \frac{400 \times 2 \left[\frac{1}{2}\right] \times \left[\frac{\sqrt{3}}{2}\right]}{9.8}$; $= \frac{400 \times 1.732}{2 \times 9.8} = \frac{692.800}{19.6}$; R = 35.35m

Thus the range of the reaches ball is 35.35 m. But the goal post is at a distance of 40 m from him. So ball will not reach the goal post.

49. If an object is thrown horizontally with an initial speed 10 m $s^{-1}$from the top of a building of height 100 m. what is the horizontal distancecovered by the particle?

Solution

Horizontal range of the object projected horizontally,

$R = u\sqrt{\frac{2h}{g}}$; $= 10\sqrt{\frac{2 \times 100}{9.8}} = 10\sqrt{\frac{200}{9.8}}$; $= \sqrt{\frac{200 \times 100}{9.8}}$; $= \sqrt{\frac{20000}{9.8}}$;

= 45.18m ≅ 45m

50. An object is executing uniform circular motion with an angular speed of $\frac{\pi}{12}$ radian per second. At t = 0 the object starts at an angle θ = 0. What is theangular displacement of the particle after 4 s?

Solution

$\omega = \frac{\theta}{t}$ or $\theta = \omega t$; $\theta = \frac{\pi}{12} \text{x } 4$; $= \frac{\pi}{3}$ rad ; $= 60^0$

51. The Moon is orbiting the Earth approximately once in 27 days, what is theangle transverse by the Moon per day?

Solution

Angle traversed by the Moon for one complete rotation
(i.e.) for 27days = 360⁰ =$2\pi\ rad$
Angle traversed by the Moon for one day,

$\theta = \frac{2\pi}{27}$; $= \frac{2 \text{ x } 3.14}{27}$; $= \frac{6.28}{27}$

$\boldsymbol{\theta}$ =0.2362 rad = 13.33⁰ [1 rad = 57.27⁰]

No.	Log
6.28	0.7980
27	1.4314
(−)	$\bar{1}$.3666
Antilog	2.326×10^{-1}

52. An object of mass m has angular acceleration α= 0.2rads⁻¹ . What is the angular displacement covered by the object after 3 second? (Assume that theobject started with angle zero with zero angular velocity).

Solution

From equation for uniform circular motion, $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ [$\omega_0 = 0$]

$\theta = 0 + \frac{1}{2} \text{x } 0.2 \text{ x } 3^2$; $\theta = \frac{1}{2} \text{x } 0.2 \text{ x } 9$; = 0.1 x 9

$\boldsymbol{\theta = 0.9}$ rad ≅ 51⁰ [1 rad = 57.27⁰]

நான் வாசிக்காத எந்த ஒரு புத்தகத்தைப் பிறர் எனக்குத் தருகிறானோ அவனே எனக்கு நல்ல நண்பன் என்கிற ஆபிரகாம் லிங்கன். இந்தப் புத்தகம் உங்களது தேர்விலும் வெற்றி பெற படிக்கற்களாக அமைந்தால் அது எனக்குக் கிடைத்த வெற்றி.

"உலகில் பிறந்த ஒவ்வொருவரும், மற்றவர்
செய்ய முடியாத ஒன்றைச் செய்து முடிக்கும்
தனிச்சிறப்பு மிக்க ஆற்றலைப்
பெற்றிருக்கிறார்கள். அந்தச்செயல் எது எனக்
கண்டு கொள்ளுங்கள். அதை மட்டுமே
வளர்த்துக் கொண்டு வந்தால், உங்கள்
வழியில் நீங்களும் சாதனை படைத்து
வெற்றி காண இயலும்."

UNIT – III (LAWS OF MOTION)

53. A book of mass m is at rest on the table. (1) What are the forces acting on thebook? (2) What are the forces exerted by the book? (3) Draw the free bodydiagram for the book.

Solution

(1) There are two forces acting on the book.

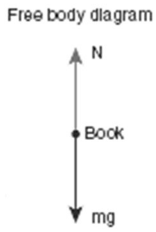
(i) Gravitational force (mg) acting downwards on the book

(ii) Normal contact force (N) exerted by the surface of the table on the book. It acts upwards as shown in the figure.

(2) **According to Newton's third law, there are two reaction forces exerted by the book.**

(i) The book exerts an equal and opposite force (mg) on the Earth which acts upwards.

(ii) The book exerts a force which is equal and opposite to normal force on the surface of the table (N) acting downwards.



54. If two objects of masses 2.5 kg and 100 kg experience the sameforce 5 N, what is the acceleration experienced by each of them?

Solution

For the object of mass 2.5 kg, the acceleration is a $=\frac{F}{m} = \frac{5}{2.5}$; = 2ms^{-2}

For the object of mass 100 kg, the acceleration is a $= \frac{F}{m} = \frac{5}{100}$; = 0.05ms^{-2}

55. The position vector of a particle is given by $\vec{r} = 3t\vec{i} + 5t^2\vec{j} + 7\vec{k}$. Find thedirection in which the particle experiences net force?

Solution

Velocity of the particle, $\vec{v} = \frac{d\vec{r}}{dt} = \frac{d}{dt}(3t)\vec{i} + \frac{d}{dt}(5t^2)\vec{j} + \frac{d}{dt}(7)\vec{k}$

$\frac{d\vec{r}}{dt} = 3\vec{i} + 10t\vec{j}$; Acceleration of the particle $\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2} = 10\vec{j}$

Here, the particle has acceleration only along positive y direction. According to Newton's second law, net force must also act along positive y direction. In addition, the particle has constant velocity in positive x direction and no velocity in z direction. Hence, there are no net force along x or z direction.

56. A person rides a bike with a constant velocity $\vec{v}$with respect to ground andanother biker accelerates with acceleration $\vec{a}$ with respect to ground. Who canapply Newton's second law with respect to a stationary observer on theground?

Solution

Second biker cannot apply Newton's second law, because he is moving with acceleration $\vec{a}$with respect to Earth (he is not in inertial frame). But the first biker can apply Newton's second law because he is moving at constant velocity with respect to Earth (he is in inertial frame).

57. A particle of mass 2 kg experiences two forces, $\vec{F}_1 = 5\vec{\imath} + 8\vec{\jmath} + 7\vec{k}$ and ,$\vec{F}_2 = 3\vec{\imath} - 4\vec{\jmath} + 3\vec{k}$. What is the acceleration of the particle?

Solution

$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2$. Acceleration is $\vec{a} = \frac{\vec{F}_{net}}{m}$

$\vec{F}_{net} = (5+3)\vec{\imath} + (8-4)\vec{\jmath} + (7+3)\vec{k}$; $\vec{F}_{net} = 8\vec{\imath} + 4\vec{\jmath} + 10\vec{k}$

$\vec{a} = \left(\frac{8}{2}\right)\vec{\imath} + \left(\frac{4}{2}\right)\vec{\jmath} + \left(\frac{10}{2}\right)\vec{k}$; $\vec{\mathbf{a}} = \mathbf{4\vec{\imath} + 2\vec{\jmath} + 5\vec{k}}$

58. An object of mass 10 kg moving with a speed of 15 ms^{-1} hits the wall andcomes to rest within a) 0.03 second b) 10 second. Calculate the impulse and average force acting on the object in both thecases.

Solution

Initial momentum of the object P_i = 10x15 = 150 $kgms^{-1}$

final momentum of the object P_f = 0 ; Δp = 150 – 0 = 150 $kgms^{-1}$

(a) Impulse J = Δp = 150 Ns ; (b) Impulse J = Δp = 150 Ns

(a) Average force $F_{avg} = \frac{\Delta p}{\Delta t} = \frac{150}{0.03}$; = 5000N ;

(b) Average force $F_{avg} = \frac{\Delta p}{\Delta t} = \frac{150}{10}$; = 15N

impulse is the same in both cases, but the average force is different.

59. Consider an object of mass 2 kg resting on the floor. The coefficient of staticfriction between the object and the floor is μ_s =0.8. What force must beapplied on the object to move it?

Solution

Since the object is at rest, the gravitational force experienced by an object is balanced by normal force exerted by floor.

N = mg

The maximum static frictional force$f_s^{max} = \mu_s N = \mu_s mg$

f_s^{max}= 0.8 x 2 x 9.8 = 15.68N

Therefore, to move the object the external force should be greater than maximum static friction F_{ext}> 15.68 N

60. Consider an object of mass 50 kg at rest on the floor. A Force of 5 N is appliedon the object but it does not move. What is the frictional force that acts on theobject?

Solution

When the object is at rest, the external force and the static frictional force are equal and opposite.

The magnitudes of these two forces are equal, $f_s = F_{ext}$

Therefore, the static frictional force acting on the object is fs = 5N

The direction of this frictional force is opposite to the direction of F_{ext}.

61. If a stone of mass 0.25 kg tied to a string executes uniform circular motionwith a speed of 2 ms^{-1} of radius 3 m, what is the magnitude of tensional forceacting on the stone?

Solution : $F_{cp} = \frac{mv^2}{r}$; $\frac{\frac{1}{4} x (2)^2}{3}$ = 0.333N

62. Consider a circular leveled road of radius 10 m having coefficient of static friction 0.81. Three cars (A, B and C) are travelling with speed 7 m s^{-1}, 8 m s^{-1} and 10 ms^{-1} respectively. Which car will skid when it moves in the circular level road? (g =10 m s^{-2})

Solution

From the safe turn condition, the speed of the vehicle (v) must be less than or equal $\sqrt{\mu_s rg}$; $v \leq \sqrt{\mu_s rg}$; $\sqrt{\mu_s rg} = \sqrt{0.81 \text{ x } 10 \text{ x } 10}$ = 9 ms^{-1}

For car C, $\sqrt{\mu_s rg}$ is less than v

The speed of car A, B and C are 7 ms^{-1}, 8 ms^{-1} and 10 ms^{-1} respectively. The cars A and B will have safe turns. But the car C has speed 10 ms^{-1} while it turns which exceeds the safe turning speed. Hence, the car C will skid.

63. Consider a circular road of radius 20 meter banked at an angle of 15 degrees. With what speed a car has to move on the turn so that it will have safe turn?

Solution

$v = \sqrt{(rg \tan\theta)} = \sqrt{20 \text{ x } 9.8 \text{ x } \tan 15^0}$

$= \sqrt{20 \text{ x } 9.8 \text{ x } 0.26}$ = 7.1 ms^{-1}

The safe speed for the car on this road is
7.1 ms^{-1}

64. Calculate the centrifugal force experienced by a man of 60 kg standing atChennai? (Given: Latitude of Chennai is 13^0)

Solution

The centrifugal force is given by $F_c = m\omega^2 R\cos\theta$

The angular velocity of Earth = $\frac{2\pi}{T}$,

where T is time period of the Earth (24 hours)

$\omega = \frac{2\pi}{24 \text{ x } 60 \text{ x } 60} = \frac{2\pi}{86400}$ = 7.268 x 10^{-5} radsec^{-1}

The radius of the Earth R = 6400 Km = 6400 × 10^3 m

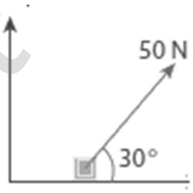
Latitude of Chennai is 13^0

F_{cf} = 60 x $(7.268 \text{ x } 10^{-5})^2$ x 6400 x 10^3 x cos (13^0)

F_{cf} = 1.9678 NA 60 kg man experiences centrifugal force of approximately 2 Newton. But due to Earth's gravity aman of 60 kg experiences aforce=mg=60×9.8=588N.
This force is very much larger than the centrifugal force.

EXERCISE PROBLEM

65. A force of 50N act on the object of mass 20 kg. shown in the figure. Calculate the acceleration of the object in x and y directions.



Solution

From Newton's second law; F=ma

Hence the acceleration ; a = $\frac{F}{m} = \frac{50}{20}$; = 2.5 ms^{-2}

The acceleration in x-axis; a_x = acos θ; = 2.5 x $\cos 30^0$; = 2.5 x $\frac{\sqrt{3}}{2}$

= 1.25 x 1.732; a_x = 1.165 ms^{-2}

The acceleration in y-axis; a_y = asin θ; = 2.5 x $\sin 30^0$; = 2.5x$\frac{1}{2}$;

a_y= 1.25 ms^{-2}

66. A spider of mass 50 g is hanging on a string of a cob web. What is the tensionin the string?

Solution

Here two forces acting on the spider.

(1) Downward gravitational force (mg) (2) Upward tension (T)

Hence, $\boldsymbol{T} = \boldsymbol{mg}$;= 50 x 10^{-3}x 9.8 =490 X 10^{-3};T = 0.49 N

67. A bob attached to the string oscillates back and forth. Resolve the forcesacting on the bob in to components. What is the acceleration experience bythe bob at an angle θ.

Solution

In the arc path, the restoring force acting along the tangential direction gives the tangential acceleration. Hence from Newton's second law,

$F_{\text{res force}} = mg \sin\theta$; $ma_T = mg\sin\theta \therefore \boldsymbol{a_T = g\sin\theta}$

The tension acting along the string gives centripetal acceleration. Hence form Newton's second law, $T - mg\cos\theta = ma_{cp}$

$$a_{cp} = \frac{T - mg\cos\theta}{m}$$

68. Calculate the acceleration of the bicycle of mass 25 kgas shown in Figures 1 and 2.

Solution

Apply Newton's second law in figure (1)

$500 - 400 = ma$

$a = \frac{F}{m}$; $= \frac{500-400}{25} = \frac{100}{25}$; $a = 4 ms^{-2}$

Apply Newton's second law in figure (2)

$400 - 400 = ma$

$a = \frac{F}{m}$; $= \frac{400-400}{25} = \frac{0}{25}$; $a = 0 ms^{-2}$

69. A stone of mass 2 kg is attached to a string of length 1 meter. The string can withstand maximum tension 200 N. What is the maximum speed that stone can have during the whirling motion?

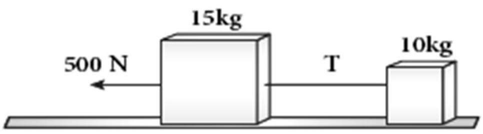
Solution

During whirling motion of the stone, the tension acting along the string provides necessary centripetal force.

If tension becomes maximum, then the centripetal force also be maximum. Hence $T_{max} = (F_{cp})_{max} = \frac{mv_{max}^2}{r}$; $v_{max}^2 = \frac{T_{max}\, r}{m}$;

$= \frac{200 \times 1}{2}$; $= 100$; $v_{max} = 10\ ms^{-1}$

70. Two bodies of masses 15 kg and 10 kg areconnected with light string kept on a smoothsurface. A horizontal force F=500 N is applied toa 15 kg as shown in the figure. Calculate thetension acting in the string.



Solution

Here motion is along horizontal direction only.

Consider the motion of mass m1; $F - T = m_1 a$ (or) $500 - T = 15\, a$

(or) T = 500 – 15 a – – – – (1)

Consider the motion of mass m_2; $T = m_2 a = 10\, a$ – – – – (2)

From equation (1) and (2)

$500 - 15\, a = 10\, a$;

$25\, a = 500$; $\boldsymbol{a} = \frac{500}{25}$; $= \mathbf{20} ms^{-2}$

Put this in equation (2), we get $T = \mathbf{10}a = \mathbf{10} \times \mathbf{20} = \mathbf{200} N$

71. People often say "For every action there is an equivalent opposite reaction".Here they meant 'action of a human'. Is it correct to apply Newton's third lawto human actions? What is mean by 'action' in Newton third law? Give yourarguments based on Newton's laws.

Ans: Newton's third law is applicable to only human's actions which involves physical force. Third law is not applicable to human's psychological actions or thoughts.

72. A car takes a turn with velocity 50 ms-1 on the circular road of radius ofcurvature 10 m. calculate the centrifugal force experienced by a person ofmass 60kg inside the car?

Solution

Centrifugal force is given by, $F_{cf} = \frac{mv^2}{r}$; $= \frac{60 \text{ x } 50 \text{ x } 50}{10}$; = 6 x 2500

F_{cf} =15000 N

73. A long stick rests on the surface. A person standing 10 m away from the stick.With what minimum speed an object of mass 0.5 kg should he thrown so thatit hits the stick. (Assume the coefficient of kinetic friction is 0.7).

Solution

When the stone moves towards the stick, it experiences kinetic friction.

According to Newton's second law,

$f_k = -ma; \mu_k N = -ma$; $\mu_k mg = -ma$; $a = -\mu_k g$

From equations of motion, $v^2 = u^2 + 2as$

When the stone hits the stick, it comes to rest. So

$v = 0$; $0 = u^2 + 2as$; $u^2 = -2as$;

$u^2 = -2(-\mu_k g)\, s$; $u^2 = 2\mu_k gs$

$u = \sqrt{2\mu_k gs}$; $= \sqrt{2 \text{ x } 0.7 \text{ x } 9.8 \text{ x } 10}$;

$= \sqrt{137.2}$; u = 11.71ms^{-1}

No.	Log
137.2	2.137 x ½ 1.0687
Antilog	1.171 x 10^1

UNIT – IV (WORK, ENERGY AND POWER)

74. A box is pulled with a force of 25 N to produce a displacement of 15 m. If the angle between the force and displacement is 30⁰, find the work done by the force.

Solution

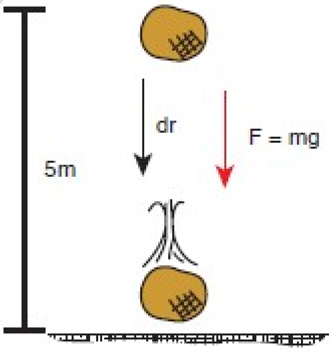
Force, F = 25 N; Displacement, dr = 15 m;
Angle between F and dr, θ = 30^0
Work done, W = Fdr cosθ ; W = 25 x 15 x cos30^0
= 25 x 15 x $\frac{\sqrt{3}}{2}$; W = 324.76 J

No.	Log
12.5	1.0969
15	1.1761
1.732	0.2385
(+)	2.5115
Antilog	3.247×10^2

75. An object of mass 2 kg falls from a height of 5 m to the ground. What is the work done by the gravitational force on the object? (Neglect air resistance; Take g = 10 m s^{-2})

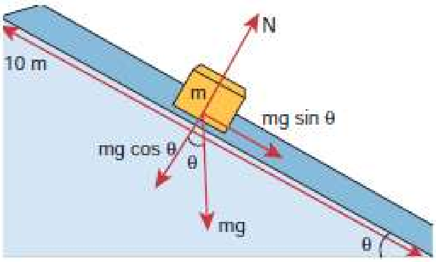
Solution

Work done, W = $\int_{r_i}^{r_f} F.dr$; W = (F cos θ) $\int_{r_i}^{r_f} dr$ = (mg cos θ) (r_f – r_i)



Hence, the angle between them is θ = 0^0;
cos0^0= 1 and the displacement, (r_f – r_i)= 5m
W = mg (r_f – r_i) ; W = 2 x 10 x 5 ;
W = 100J
The work done by the gravitational force on the object is positive.

76. An object of mass m=1 kg is sliding from top to bottom in the frictionless inclined plane of inclination angle θ = 30^0 and the length of inclined plane is 10 m as shown in the figure. Calculate the work done by gravitational force and normal force on the object. Assume acceleration due to gravity, g = 10 m s^{-2}



Solution

W = F dr = (mg sinθ) (dr)
(dr = Length of the inclined place)
W = 1 x 10 x sin (30^0) x 10
W = 100 x $\frac{1}{2}$; **W = 50 J**

The component mg cosθand the normal force N are perpendicular to the direction of motion of the object, so they do not perform any work.

77. If an object of mass 2 kg is thrown up from the ground reaches a height of 5 m and falls back to the Earth (neglect the air resistance). Calculate
(a) The work done by gravity when the object reaches 5 m height
(b) The work done by gravity when the object comes back to Earth
(c) Total work done by gravity both in upward and downward motion and mention the physical significance of the result.

Solution

(a) The work done by gravitational force in the upward motion.

dr = 5 m and F = mg

W_{up} = Fdr cos θ ; = mgdr cos180^0

W_{up} =2 x 10 x 5 x (–1) ;**W_{up} = –100 joule** [cos180^0 =–1]

(b) When the object falls back, both the gravitational force and displacement of the object are in the same direction. This implies that the angle between gravitational force and displacement of the object is 0^0; W_{down} = Fdr cos θ ; = Fdr cos0^0

W_{up} =2 x 10 x 5 x (1) ;**W_{up} = 100 joule** [cos0^0 =1]

(c) The total work done by gravity in the entire trip (upward and downward motion) W_{total} = W_{up} + W_{down}

= –100 joule + 100 joule ; W_{total} = 0

It implies that the gravity does not transfer any energy to the object. When the object is thrown upwards, the energy is transferred to the object by the external agency, which means that the object gains some energy.

78. A weight lifter lifts a mass of 250 kg with a force 5000 N to the height of 5 m.
(a) What is the workdone by the weight lifter?
(b) What is the workdone by the gravity?
(c) What is the net workdone on the object?

Solution

(a) When the weight lifter lifts the mass, force and displacement are in the same direction, which means that the angle between them θ = 0^0 .Therefore, the work done by the weight lifter,

$W_{weight\ lifter}$ = F_w h cos θ = F_w h(cos0^0)

= 5000 x 5 x 1 ; 25,000 joule ; **$W_{weight\ lifter}$ = 25 kJ**

(b) When the weight lifter lifts the mass, the gravity acts downwards which means that the force and displacement are in opposite direction. Therefore, the angle between them θ = 180^0

$W_{gravity}$ = F_g h cos θ ; = mgh (cos 180^0)

= 250 x 10 x 5 x (–1) ; = – 12500 joule ; **$W_{gravity}$= –12.5 kJ**

(c) The net workdone (or total work done) on the object

W_{net} = $W_{weight\ lifter}$ + $W_{gravity}$

= 25 kJ – 12.5 kJ

W_{net} = 12.5 kJ

79. **A variable force F= kx^2 acts on a particle which is initially at rest. Calculatethe work done by the force during the displacement of the particle from x= 0 m to x= 4 m. (Assume the constant k=1 N m^{-2})**

Solution

Work done, W = $\int_{x_i}^{x_f} F(x)dx = k \int_0^4 x^2 dx$; $\frac{64}{3}$ Nm

80. **Two objects of masses 2 kg and 4 kg are moving with the same momentumof 20 kg m s^{-1}.**
(a) Will they have same kinetic energy?
(b) Will they have same speed?
Solution

(a) The kinetic energy of the mass is given by KE =$\frac{P^2}{2m}$

For the object of mass 2kg, kinetic energy is $KE_1 = \frac{(20)^2}{2x2} = \frac{400}{4}$ = 100J

For the object of mass 4kg, kinetic energy is $KE_2 = \frac{(20)^2}{2x4} = \frac{400}{8}$ = 50J

the kinetic energy of **both masses is not the same.** The kinetic energy of the **heavier object has lesser kinetic energy than smaller mass.**
(b) As the momentum, p = mv, the two objects **will not have same speed.**

81. **An object of mass 2 kg is taken to a height 5 m from the ground g=10ms^{-2} .**
- **(a) Calculate the potential energy stored in the object.**
- **(b) Where does this potential energy come from?**
- **(c) What external force must act to bring the mass to that height?**
- **(d) What is the net force that acts on the object while the object is taken tothe height 'h'?**

Solution

(a) The potential energy U=mgh =2×10×5 = 100 J. Here the positive sign implies that the energy is stored on the mass.

(b) This potential energy is transferred from external agency which applies the force on the mass.

(c) The external applied force$\vec{F}_a$which takes the object to the height 5 m is$\vec{F}_a$= - $\vec{F}_g$. $\vec{F}_a = -(-mg\vec{j})$; $= mg\vec{j}$, where $\vec{j}$represents unit vector along vertical upward direction.

(d) From the definition of potential energy, the object must be moved at constant velocity. So the net force acting on the object is zero

$\vec{F}_g + \vec{F}_a$=0

82. Let the two springs A and B be such that $k_A > k_B$. On which spring will more workhave to be done if they are stretched by the same force?

Solution

$F = k_A x_A = k_B x_B$; $x_A = \frac{F}{k_A}$; $x_B = \frac{F}{k_B}$

The work done on the springs are stored as potential energy in the springs.

$U_A = \frac{1}{2} k_A x_A^2$; $U_B = \frac{1}{2} k_B x_B^2$

$\frac{U_A}{U_B} = \frac{k_A x_A^2}{k_B x_B^2} = \frac{k_A\left(\frac{F}{k_A}\right)^2}{k_B\left(\frac{F}{k_B}\right)^2}$; $= \frac{\frac{1}{k_A}}{\frac{1}{k_B}}$; $\frac{U_A}{U_B} = \frac{k_B}{k_A}$

$k_A > k_B$ implies that $U_B > U_A$. thus, more work is done on B than A.

83. Consider an object of mass 2 kg moved by an external force 20 N in a surfacehaving coefficient of kinetic friction 0.9 to a distance 10 m. What is the workdone by the external force and kinetic friction? Comment on the result.(Assume g = 10 ms^{-2})

Solution

m = 2 kg, d = 10 m, F_{ext} = 20 N, μk = 0.9. When an object is in motion on the horizontal surface, it experiences two forces.

(a) External force, F_{ext} = 20 N

(b) Kinetic friction $f_k = \mu k\, mg$ = 0.9 x (2) x 10 = 18N

The work done by the external force W_{ext} = Fd = 20 x10 = 200J

The work done by the force of kinetic friction $W_k = f_k d$= (-18)×10 = -180 J.

Here the negative sign implies that the force of kinetic friction is opposite to the direction of displacement.

The total work done on the object $W_{total} = W_{ext} + W_k$; = 200 J -180 J = 20 J .

Since the friction is a non-conservative force, out of 200 J given by the external force, the 180 J is lost and it cannot be recovered.

84. An object of mass 1 kg is falling from the height h= 10 m. Calculate

(a) The total energy of an object at h=10 m

(b) Potential energy of the object when it is at h= 4 m

(c) Kinetic energy of the object when it is at h= 4 m

(d) What will be the speed of the object when it hits the ground? (Assume g =10 ms^{-2})

Solution

(a) The gravitational force is a conservative force. So the total energy remains constant throughout the motion. At h=10 m, the total energy *E* is entirely potential energy.

E = U = mgh = 1 x 10 x 10 = 100J

(b) The potential energy of the object at h= 4 m is

U = mgh = 1 x 10 x 4 = 40J

(c) Since the total energy is constant throughout the motion, the kinetic energy at h= 4m must be KE = E – U = 100 – 40 = 60J

Alternatively, the kinetic energy could also be found from velocity of the object at 4 m. At the height 4 m, the object has fallen through a height of 6 m.

The velocity after falling 6 m is calculated from the equation of motion,

$V = \sqrt{2gh} = \sqrt{2 \times 10 \times 6} = \sqrt{120} ms^{-1}$; $v^2 = 120$

The kinetic energy is KE = ½ mv² = ½ x 1 x 120 = 60J

(d) When the object is just about to hit the ground, the total energy is completely kinetic and the potential energy, U = 0

$E = KE = \frac{1}{2} mv^2 = 100J$; $v = \sqrt{\frac{2}{m} KE} = \sqrt{\frac{2}{1} \times 100} = \sqrt{200} \approx 14.12 \ ms^{-1}$

85. Water in a bucket tied with rope is whirled around in a vertical circle of radius0.5 m. Calculate the minimum velocity at the lowest point so that the waterdoes not spill from it in the course of motion. ($g = 10 \ ms^{-2}$)

Solution

Radius of circle r = 0.5m

The required speed at the highest point $v_2 = \sqrt{gr} = \sqrt{10 \times 0.5} = \sqrt{5} \ ms^{-1}$

Thespeed at the lowest point $v_1 = \sqrt{5gr} = \sqrt{5} \times \sqrt{gr} = \sqrt{5} \times \sqrt{5} = 5 ms^{-1}$

86. Calculate the energy consumed in electrical units when a 75 W fan is used for8 hours daily for one month (30 days).

Solution

Power, P = 75 W

Time of usage, t = 8 hour × 30 days = 240 hours

Electrical energy consumed is the product of power and time of usage.

Electrical energy = power × time of usage = P × t

=75 watt x 240 hour

=18000 watt hour

=18 kilowatt hour = 18kWh

1 electrical unit = 1kWh ; Electrical energy =18 unit

87. A vehicle of mass 1250 kg is driven with an acceleration 0.2 ms⁻² along a straight level road against an external resistive force 500 N. Calculate the power delivered by the vehicle's engine if the velocity of the vehicle is 30 ms⁻¹

Solution

The vehicle's engine has to do work against resistive force and make vehicle to move with an acceleration. Therefore, power delivered by the vehicle engine is

P = (resistive force + mass x acceleration) (velocity)

$P = \vec{F}_{tot}.\vec{v}$; $= (F_{resistive} + F)\vec{v}$; $P = \vec{F}_{tot}.\vec{v}$; $= (F_{resistive} + ma)\vec{v}$

$= (500 \ N + (1250 \ kg) \times (0.2 \ ms^{-2}) (30 \ ms^{-1})$

P = 22.5kW

88. A bullet of mass 50 g is fired from below into a suspended object of mass 450 g. The object rises through a height of 1.8 m with bullet remaining inside the object. Find the speed of the bullet. Take g = 10 ms^{-2}.

Solution

m_1= 50 g = 0.05 kg; m_2= 450 g = 0.45 kg

The speed of the bullet is u_1. The second body is at rest (u_2=0). Let the common velocity of the bullet and the object after the bullet is embedded into the object is v. $\mathbf{v} = \frac{m_1u_1 + m_2u_2}{(m_1+m_2)}$; = $\frac{0.05u_1 + (0.45 \times 0)}{(0.05+0.45)}$; = $\frac{0.05}{0.50}u_1$

The combined velocity is the initial velocity for the vertical upward motion of the combined bullet and the object. From second equation of motion,

$\mathbf{v} = \sqrt{2gh}$; $\mathbf{v} = \sqrt{2 \times 10 \times 1.8}$; $= \sqrt{36}$; v = 6 ms^{-1}

Substituting this in the above equation, the value of u_1 is $6 = \frac{0.05}{0.50}u_1$

(or) $u_1 = \frac{0.50}{0.05} \times 6$; =10 x 6 ; u_1 = 60 ms^{-1}

89. Show that the ratio of velocities of equal masses in an inelastic collision when one of the masses is stationary is $\frac{v_1}{v_2} = \frac{1-e}{1+e}$

Solution

e= $\frac{\text{Velocity of seperation (after collision)}}{\text{Velocity of approach (before collision)}}$; $= \frac{(V_2-V_1)}{(u_1-u_2)} = \frac{(V_2-V_1)}{(u_1-0)} = \frac{(V_2-V_1)}{u_1}$;

$v_2 - v_1 = eu_1$ -------1

From the law of conservation of linear momentum, $mu_1 = mv_1 + mv_2$;

$u_1 = v_1 + v_2$ ---------2

using the equation 2 for u_1 in 1, we get $v_2 - v_1 = e(v_1+v_2)$

on simplification, we get $\frac{v_1}{v_2} = \frac{1-e}{1+e}$

EXERCISE PROBLEM

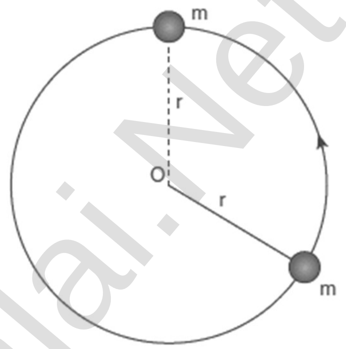
90. Calculate the work done by a force of 30 N in lifting a load of 2kg to a heightof 10m (g = 10 m s^{-2})

Solution

Work done by gravitational force: W= FS=30 x 10=**300J**

91. A bob of mass m is attached to one end of the rod of negligible mass andlength r, the other end of which is pivoted freely at a fixed centre O as shownin the figure. What initial speed must be given to the object to reach the top ofthe circle? (Hint: Use law of conservation of energy). Is this speed less orgreater than speed obtained in the theory?

Solution



At point A, Potential energy $= mg\,(0) = 0$

Kinetic energy $= \frac{1}{2} m v_A^2$

Total energy $= 0 + = \frac{1}{2} \boldsymbol{m v_A^2} = = \frac{1}{2} \boldsymbol{m v_A^2}$

At point B, Potential energy $= mgh = mg\,(2r)$

Kinetic energy$= = \frac{1}{2} m v_B^2 = = \frac{1}{2} m(0) = 0$

Total energy= mg (2r) + 0 = mg (2r)

According to the law of conservation of energy, the total energy is always constant. Hence, $\frac{1}{2} m v_A^2 = mg\,(2r)$; $v_A^2 = 4g\,r$; $\boldsymbol{v_A} = \sqrt{\mathbf{4gr}}$

This speed is less than the speed obtained in the theory, because the bob must have a speed at point A , $\boldsymbol{v_A} \geq \sqrt{\mathbf{5gr}}$ to stay in the circular path

UNIT – V (MOTION OF SYSTEM OF PARTICLES AND RIGID BODIES)

92. The position vectors of two point masses 10 kg and 5 kg are $(-3\vec{i} + 2\vec{j} + 4\vec{k})$m and $(3\vec{i} + 6\vec{j} + 5\vec{k})$m respectively. Locate the position ofcentre of mass.

Solution

$m_1 = 10$kg, $m_2 = 5$kg ; $\vec{r}_1 = (-3\vec{i} + 2\vec{j} + 4\vec{k})$m ; $\vec{r}_2 = (3\vec{i} + 6\vec{j} + 5\vec{k})$m

$\vec{r} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2}{m_1 + m_2}$; $\vec{r} = \frac{10(-3\vec{} + 2\vec{j} + 4\vec{k}) + 5(3\vec{i} + 6\vec{j} + 5\vec{k})}{10+5}$;

$= \frac{30\vec{i} + 20\vec{j} + 40\vec{k} + 15\vec{i} + 30\vec{j} + 25\vec{k}}{10+5}$; $= \frac{-15\vec{i} + 50\vec{j} + 65\vec{k}}{15}$; $= \left(-\vec{i} + \frac{10}{3}\vec{j} + \frac{13}{3}\vec{k}\right)$m

The centre of mass is located at position$\vec{r}$

93. A force of $(4\vec{i} - 3\vec{j} + 5\vec{k})$N is applied at a point whose position vector is $(7\vec{i} + 4\vec{j} - 2\vec{k})$m. find the torque of force about the origin.

Solution

$$\vec{\tau} = \vec{r} \text{x} \vec{F} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 7 & 4 & -2 \\ 4 & -3 & 5 \end{vmatrix}$$

= $(20 - 6)\hat{\imath} - (35 + 8)\hat{\jmath} + (-21 - 16)\hat{k}$;

= $(14\hat{\imath} - 43\hat{\jmath} - 37\hat{k})$ Nm

94. A cyclist while negotiating a circular path with speed 20 m s^{-1} is found to bendan angle by 30o with vertical. What is the radius of the circular path? (given, g= 10 ms^{-2})

Solution

Speed of the cyclist, v = 20 ms^{-1} ;

Angle of bending with vertical, θ = 30^0

Equation for angle of bending, $\tan\theta = \frac{v^2}{rg}$

Rewriting the above equation for radius $r = \frac{v^2}{\tan\theta g}$

$r = \frac{(20)^2}{\tan 30^0 \text{ x } 10}$; $= \frac{20 \text{ x } 20}{(\tan 30^0) \text{ x } 10}$; $= \frac{400}{\left(\frac{1}{\sqrt{3}}\right) \text{x } 10}$; $= (\sqrt{3})$ x 40 ;

= 1.732 x 40 ;r = 69.28m

95. Find the radius of gyration of a disc of mass M and radius R rotating about an axis passing through the centre of mass and perpendicular to the plane of the disc.

Solution

The moment of inertia of a disc about an axis passing through the centre of mass and perpendicular to the disc is, $I = \frac{1}{2} MR^2$

In terms of radius of gyration, $I = MK^2$; Hence $MK^2 = \frac{1}{2} MR^2$;

$K^2 = \frac{1}{2} R^2$; $K = \frac{1}{\sqrt{2}} R$ (or) $K = \frac{1}{1.414} R$ (or) **K = (0.707) R**

From the case of a rod and also a disc, we can conclude that the radius of gyration of the rigid body is always a geometrical feature like length, breadth, radius or their combinations with a positive numerical value multiplied to it.

96. Find the rotational kinetic energy of a ring of mass 9 kg and radius 3 m rotatingwith 240 rpm about an axis passing through its centre and perpendicular toits plane. (rpm is a unit of speed of rotation which means revolutions perminute)

Solution

The rotational kinetic energy is , KE = $\frac{1}{2}I\omega^2$.
The moment of Inertia of the ring is, I = MR^2
I = 9 x 3^2 ; = 9 x 9; = 81 kgm^2
The angular speed of the ring is, ω = 240 rpm ; = $\frac{240 \text{ x } 2\pi}{60}$ $rads^{-1}$
KE = $\frac{1}{2}$ x 81 x $\left(\frac{240 \text{ x } 2\pi}{60}\right)^2$. ; = $\frac{1}{2}$ x 81 x$(8\pi)^2$; KE = $\frac{1}{2}$ x 81 x 64$(\pi)^2$;
= 2592 x $(\pi)^2$; KE ≈ 25920J KE = 25.920 kJ [$(\pi)^2$ ≈ 10]

97. A rolling wheel has velocity of its centre of mass as 5 ms^{-1}. If its radius is 1.5m and angular velocity is 3 $rads^{-1}$, then check whether it is in pure rolling ornot.

Solution

Translational velocity (v_{TRANS}) or velocity of centre of mass,
v_{CM} = 5 m s^{-1}
The radius is, R = 1.5 m and the angular velocity is, ω = 3 $rads^{-1}$
Rotational velocity, v_{ROT} = Rω
v_{ROT} = 1.5×3; v_{ROT} = 4.5 ms^{-1}
As v_{CM} > Rω (or) v_{TRANS}> Rω, It is not in pure rolling, but sliding.

98. A solid sphere is undergoing pure rolling. What is the ratio of its translationalkinetic energy to rotational kinetic energy?

Solution

The expression for total kinetic energy in pure rolling is,

KE = KE_{TRANS} + KE_{ROT}

For any object the total kinetic energy KE = $\frac{1}{2}MV_{CM}^2 + \frac{1}{2}MV_{CM}^2\left(\frac{K^2}{R^2}\right)$

KE = $\frac{1}{2}MV_{CM}^2\left(1+\frac{K^2}{R^2}\right)$

then, $\frac{1}{2}MV_{CM}^2\left(1+\frac{K^2}{R^2}\right)$; = $\frac{1}{2}MV_{CM}^2 + \frac{1}{2}MV_{CM}^2\left(\frac{K^2}{R^2}\right)$

The above equation suggests that in pure rolling the ratio of total kinetic energy, translational kinetic energy and rotational kinetic energy is

given as, KE : KE_{TRANS} : KE_{ROT} ::$\left(1+\frac{K^2}{R^2}\right)$: 1 : $\left(\frac{K^2}{R^2}\right)$

Now, KE_{TRANS} : KE_{ROT} :: 1 : $\left(\frac{K^2}{R^2}\right)$; For a solid sphere ,$\frac{K^2}{R^2} = \frac{2}{5}$

Then, $KE_{TRANS}: KE_{ROT} :: 1 : \frac{2}{5}$ or $KE_{TRANS}: KE_{ROT} :: 5 : 2$

99. Four round objects namely a ring, a disc, a hollow sphere and a solid spherewith same radius R start to roll down an incline at the same time. Find outwhich object will reach the bottom first.

Solution

For all the four objects namely the ring, disc, hollow sphere and solid sphere, the radii of gyration K are R, $\sqrt{\frac{1}{2}}$ R, $\sqrt{\frac{2}{3}}$ R, $\sqrt{\frac{2}{5}}$ R With numerical values the radius of gyration K are 1R, 0.707R, 0.816R, 0.632R respectively. The expression for time taken for rolling has the radius of gyration K.

$$t = \sqrt{\frac{2h\left(1+\frac{K^2}{R^2}\right)}{g \sin^2\theta}}.$$

The one with least value of radius of gyration K will take the shortest time to reach the bottom of the inclined plane. The order of objects reaching the bottom is first, solid sphere; second, disc; third, hollow sphere and last, ring.

EXERCISE PROBLEM

100. Two particles P and Q of mass 1kg and 3 kg respectively start moving towardseach other from rest under mutual attraction. What is the velocity of theircentre of mass?

Solution

Since they are at rest initially, the velocity of centre of mass of the system is zero. (i.e.) Initially, v_{CM}=0

There is no external force and their translational motion are only due to the internal forces. It doecs not change the position of the centre of mass. So the velocity of the centre of mass v_{CM}=0

101. Find the moment of inertia of a hydrogen molecule about an axis passingthrough its centre of mass and perpendicular to the inter-atomic axis. Given: mass of hydrogen atom 1.7×10^{-27} kg and inter atomic distance is equal to 4×10^{-10}m

Solution

The moment of inertia of a hydrogen molecule about an axis passing through its centre of mass and perpendicular to the inter-atomic axis,

$I_{CM} = 2m_Hd^2 + m_Hd^2 = 2m_Hd^2$

$I_{CM} = 2 \times 1.7 \times 10^{-27} \times 2 \times 10^{10} \times 2 \times 10^{10}$

$I_{CM} = 13.6 \times 10^{-47}$

$I_{CM} = 1.36 \times 10^{-46}$kgm

UNIT – VI (GRAVITATION)

102. Calculate the value of g in the following two cases:

(a) If a mango of mass ½ kg falls from a tree from a height of 15 meters, what is the acceleration due to gravity when it begins to fall?

Solution

$g' = g\left(1 - 2\frac{h}{R_e}\right)$; $g' = 9.8\left(1 - \frac{2 \times 15}{6400 \times 10^3}\right)$; $g' = 9.8(1 - 0.469 \times 10^5)$

But 1 – 0.00000469 ≅ 1 ; Therefore **$g' = g$**

(b) Consider a satellite orbiting the Earth in a circular orbit of radius 1600km above the surface of the Earth. What is the accelerationexperienced by the satellite due to Earth's gravitational force?

Solution

$g' = g\left(1 - 2\frac{h}{R_e}\right)$; $g' = g\left(1 - \frac{2 \times 1600 \times 10^3}{6400 \times 10^3}\right)$; $g' = g\left(1 - \frac{2}{4}\right)$;

$g' = g\left(1 - \frac{1}{2}\right)$; $= \frac{g}{2}$ The above two examples show that the acceleration due to gravity is a constant near the surface of the Earth.

103. Find out the value of gin your school laboratory?

Solution

Calculate the latitude of the city or village where the school is located. The information is available in Google search. For example, the latitude of Chennai is approximately 13 degrees.$g' = g = \omega^2 R\cos^2\lambda$

Here $\omega^2 R$ = $(2 \times 3.14 / 86400)^2 \times (6400 \times 10^3) = 3.4 \times 10^{-2}$ ms^{-2}.

It is to be noted that the value of λ should be in radian and not in degree. 13 degrees is equivalent to 0.2268 rad.

$g' = 9.8 - (3.4 \times 10^{-2}) \times (\cos 0.2268)^2$; $g' = 9.7677$ ms^{-2}

104. Calculate the energy of the (i) Moon orbiting the Earth and (ii) Earth orbiting the sun.

Solution

Assuming the orbit of the Moon to be circular, the energy of Moon is given by,

$E_m = -\frac{GM_E M_m}{2R_m}$; where $M_E$is the mass of Earth 6.02×10^{24} kg; M_m is the mass of Moon 7.35×10^{22} kg; and $R_m$is the distance between the Moon and the center of the Earth 3.84×10^5km

$G = 6.67 \times 10^{-11}$ Nm^{2}kg^{-2}

$E_m = -\frac{6.67 \times 10^{-11} \times 6.02 \times 10^{24} \times 7.35 \times 10^{22}}{2 \times 3.84 \times 10^5 \times 10^3}$; $E_m = -38.42 \times 10^{-19} \times 10^{46}$

$E_m = -38.42 \times 10^{27}$Joule

The negative energy implies that the Moon is bound to the Earth.

Same method can be used to prove that the energy of the Earth is also negative.

EXERCISE PROBLEM

105. An unknown planet orbits the Sun with distance twice the semi major axisdistance of the Earth's orbit. If the Earth's time period is T_1, what is the timeperiod of this unknown planet?

Solution

$a_2 = 2a_1$. From Kepler's third law$T_1^2 \propto a_1^3$; $T_2^2 \propto a_2^3$

$\frac{T_1^2}{T_2^2} = \frac{a_1^3}{a_2^3}$; $\frac{T_1^2}{T_2^2} = \frac{a_1^3}{(2a_1)^3}$; $= \frac{a_1^3}{(8a_1)^3}$; $= \frac{1}{8}$; $T_2^2 = 8T_1^2$

$T_2 = \sqrt{8}T_1$; $= 2\sqrt{2}\ T_1$

106. Assume that you are in another solar system and provided with the set of datagiven below consisting of the planets' semi major axes and time periods. Canyou infer the relation connecting semi major axis and time period?

Planet (imaginary)	Time period(T) (in year)	Semi major axis (a) (in AU)
Kurinji	2	8
Mullai	3	18
Marutham	4	32
Neithal	5	50
Paalai	6	72

Solution

1) For Kurunji ;T = 2 years , a = 8AU = 2 x 4 = 2 $(2)^2$ = $2T^2$
2) For Mullai ;= 3 years, a = 18AU = 2 x 9 = 2 $(3)^2$ = 2 T^2
3) For Marutham ;4 years, a = 32AU = 2 x 16 = 2 $(4)^2$ = 2 T^2
4) For Neithal ;5 years, a = 50AU = 2 x 25 = 2 $(5)^2$ = 2 T^2
5) For Paalai ;6 years, a = 72AU = 2 x 36 = 2 $(6)^2$ = 2 T^2

Hence the relation connecting semi major axis and time period; $a= 2T^2$

107. If the masses and mutual distance between the two objects are doubled, whatis the change in the gravitational force between them?

Solution

By Newton's law of gravitation, $F = \frac{Gm_1m_2}{r^2}$

If $m_1 \rightarrow 2m_1$, $m_2 \rightarrow 2m_2$ and r = 2r

$= \frac{G2m_12m_2}{(2r)^2}$; $= \frac{4Gm_1m_2}{4r^2}$; $= \frac{Gm_1m_2}{r^2}$; $=$ F ; There is no change in the force.

108. If the angular momentum of a planet is given by $\vec{L}=5t^2\hat{i} - 6t\hat{j} + 3\hat{k}$. What isthe torque experienced by the planet? Will the torque be in the same directionas that of the angular momentum?

Solution Torque is given by, $\vec{\tau} = \frac{d\vec{L}}{dt} = \frac{d}{dt}(5\ t^2\hat{i} - 6t\hat{j} + 3\hat{k})$; $\vec{\tau} = 10t\hat{i} - 6\hat{j}$

Here the torque produced will be in the direction of angular momentum.

109. Suppose unknowingly you wrote the universal gravitational constant value as G' =6.67 x10^{11} .instead of the correct value G =6.67 x10^{-11}, what is the acceleration due to gravity g' for this incorrect G? According to this new acceleration due to gravity, what will be your weight W'?

Solution

The acceleration due to gravity for the value G =6.67x 10^{-11} is,

$$g = \frac{GM}{R^2};= \frac{6.67 \text{ x } 10^{-11} \text{ x M}}{R^2} \text{ ------------ } 1$$

The acceleration due to gravity for the value G' =6.67x 10^{11} is,

$$g' = \frac{G'M}{R^2};= \frac{6.67 \text{ x } 10^{11} \text{ x M}}{R^2} \text{ ----------- } 2$$

Divide (2) by (1)

$$\frac{g'}{g} = \frac{\left(\frac{G'M}{R^2}\right)}{\left(\frac{GM}{R^2}\right)};= \frac{G'}{G};= \frac{6.67 \text{ x } 10^{11}}{6.67 \text{ x } 10^{-1}};10^{22};\ g' = 10^{22}g$$

The equivalent weight is , $w' = mg' = mg10^{22};\ 10^{22}w$

110. What is the gravitational potential energy of the Earth and Sun? The Earth to Sun distance is around 150 million km. The mass of the Earth is 5.9 × 10^{24} kg and mass of the Sun is 1.9×10^{30} kg.

Solution

R_E=150 x 10^6 km →Distance between Sun and Earth
M_e=5.9 x 10^{24} kg → Mass of the Earth
M_s=1.9 x10^{30}kg→Mass of the Sun
G =6.67 x 10^{-11}Nm^{2}kg^{-2}→Gravitational constant

$$U(r) = -\frac{GM_SM_E}{R_E};= -\frac{6.67 \text{ x } 10^{-11} \text{ x } 1.9 \text{ x } 10^{30} \text{x } 5.9 \text{ x } 10^{24}}{150 \text{ x } 10^6 \text{x } 10^3}$$

$$= -\frac{6.67 \text{ x } 1.9 \text{ x } 5.9 \text{ x } 10^{43}}{150 \text{ x } 10^9};= -\frac{\mathbf{6.67 \text{ x } 1.9 \text{ x } 5.9 \text{ x } 10^{34}}}{\mathbf{150}}$$

$$U(r) = -4.985 \text{ x } 10^{-1} \text{x } 10^{34};= -49.85 \text{ x } 10^{-2} \text{x } 10^{34}$$

$\mathbf{U(r) = -49.85 \text{ x} 10^{32}}$ joule

No.	Log
6.67	0.8241
1.9	0.2788
5.9	0.7709
(+) 150	1.8738 2.1761
(−)	$\bar{1}$.6977
Antilog	4.985 x 10^{-1}

111. Earth revolves around the Sun at 30 km s^{-1}. Calculate the kinetic energy of the Earth. If the calculated the potential energy of the Earth is − 49.85 x10^{32} joule. then what is the total energy of the Earth in that case? Is the total energy positive? Give reasons.

Solution

v=30 kms^{-1}=30 x 10^3ms^{-1}
The kinetic energy of the Earth KE = ½ $M_e v^2$
KE = ½ x 5.9 x 10^{24}x 30 x 10^3x 30 x 10^3
KE = 2.95 x 10^{24}x 30 x 10^3x 30 x 10^3
KE = 2.95 x 10^{24} x 9 x10^8 ;KE = 26.55 x10^{32} Joule
Hence the total energy, E = KE + UE
= 26.55 x 10^{32} + (-49.85 x 10^{32})
E = (26.55 – 49.85) x10^{32} ;E = −23.2 x10^{32} Joule
The negative sign implies that Earth is bounded with Sun.

112. Suppose we go 200 km above and below the surface of the Earth, what are the g values at these two points? In which case, is the value of g small?

$g_{height} = g\left[1 - \frac{2h}{R}\right]$; $g_{depth} = g\left[1 - \frac{d}{R}\right]$

$g_{height} = g\left[1 - \frac{2 \times 200}{6400}\right]$; $= g\left[\frac{64-4}{64}\right]$;

$= g\left[\frac{60}{64}\right]$; $\mathbf{g_{height} = 0.94g}$

$g_{depth} = g\left[1 - \frac{200}{6400}\right]$; $= g\left[\frac{64-2}{64}\right]$;

$= g\left[\frac{62}{64}\right]$; $\mathbf{g_{height} = 0.968g}$

UNIT – VII (PROPERTIES OF MATTER)

113. A wire 10 m long has a cross-sectional area 1.25×10^{-4} m². It is subjected to a load of 5 kg. If Young's modulus of the material is 4×10^{10} Nm⁻², calculate the elongation produced in the wire. Take g = 10 ms⁻².

Solution

$\frac{F}{A} = Y \times \frac{\Delta L}{L}$; $\Delta L = \left(\frac{F}{A}\right)\left(\frac{L}{Y}\right)$; $\left(\frac{50}{1.25 \times 10^{-4}}\right)\left(\frac{10}{4 \times 10^{10}}\right)$; $=10^{-4}$ m

114. A metallic cube of side 100 cm is subjected to a uniform force acting normalto the whole surface of the cube. The pressure is 10^6 pascal. If the volumechanges by 1.5×10^{-5} m³, calculate the bulk modulus of the material.

Solution

$K = \frac{\frac{F}{A}}{\frac{\Delta V}{V}} = P\frac{V}{\Delta V}$; $K = \frac{10^6 \times 1}{1.5 \times 10^{-5}}$; $= 6.67 \times 10^{10}$ Nm^{-2}

No.	Log
10^{11}	11.0000
1.5	0.1761
(–)	10.8239
Antilog	6.666×10^{10}

115. A metal cube of side 0.20 m is subjected to a shearing forceof 4000 N. The top surface is displaced through 0.50 cm withrespect to the bottom. Calculate the shear modulus of elasticity of the metal.

Solution

Here, L = 0.20m, F=4000N, x=0.50cm ; =0.005m and Area A = L² = 0.04 m²

Therefore, $\eta_R = \left(\frac{F}{A}\right) \times \left(\frac{L}{x}\right)$; $= \left(\frac{4000}{0.04}\right) \times \left(\frac{0.20}{0.005}\right)$; $= 4 \times 10^6$ Nm^{-2}

116. A wire of length 2 m with the area of cross-section 10^{-6} m² is used to suspenda load of 980 N. Calculate i) the stress developed in the wire ii) the strain andiii) the energy stored. Given: Y=12 × 10^{10}N m^{-2}

No.	Log
980	2.9912
81.66	1.9120
(+)	4.9032
Antilog	8.002×10^4

Solution

i) Stress = $\frac{F}{A} = \frac{980}{10^{-6}}$; = 98 x 10^7 Nm^{-2}

ii) Strain = $\frac{Stress}{Y}$; $\frac{98 \times 10^7}{12 \times 10^{10}}$; =8.17 x 10^{-3}

iii) Volume = 2 x 10^{-6} m^3

Energy = ½ (Stress x Strain) x Volume

= ½ (98x10^7) x8.17x10^{-3}) x2x 10^{-6} **Energy = 8J**

117. A solid sphere has a radius of 1.5 cm and a mass of 0.038 kg. Calculate the specific gravity or relative density of the sphere.

Solution

Radius of the sphere R = 1.5 cm; mass m = 0.038 kg

Volume of the sphere V= $\frac{4}{3}\pi R^3$; = $\frac{4}{3}(3.14) \times (1.5 \times 10^{-2})^3$; 1.413 x $10^{-5}m^3$

Density $\rho = \frac{m}{V} = \frac{0.038 \text{ kg}}{1.413 \times 10^{-5} m^3}$; = 2690 kgm^{-3}

Hence, the specific gravity of the sphere = $\frac{2690}{1000}$ = 2.69

118. Two pistons of a hydraulic lift have diameters of 60 cm and 5 cm. What is theforce exerted by the larger piston when 50 N is placed on the smaller piston?

Solution

Since, the diameter of the pistons are given, we can calculate the radius of the piston r = $\frac{D}{2}$

Area of smaller piston , A_1 = $\pi\left(\frac{5}{2}\right)^2 = \pi(2.5)^2$

Area of larger piston , A_2 = $\pi\left(\frac{600}{2}\right)^2 = \pi(30)^2$

$F_2 = \frac{A_2}{A_1}$ x F_1 = (50N) x $\left(\frac{30}{2.5}\right)^2$; 7200 N

This means that with the force of 50 N, the force of 7200 N can be lifted

119. A cube of wood floating in water supports a 300 g mass at the centre of its topface. When the mass is removed, the cube rises by 3 cm. Determine thevolume of the cube.

Solution

Let each side of the cube be l. The volume occupied by 3 cm depth of cube,

V = (3cm) x l^2; $= 3l^2$cm

According to the principle of floatation, we have $V_{\rho g}$ = mg ⇒ V_ρ = m

ρ is density of water = 1000 kgm^{-3}

⇒$(3l^2 \times 10^{-2}m) \times (1000\ kgm^{-3}) = 300 \times 10^{-3}kg$

$l^2 = \frac{300 \times 10^{-3}}{3 \times 10^{-2} \times 1000} m^2; \Rightarrow l^2 = 100 \times 10^{-4}$ m²

$l = 10 \times 10^{-2}$ m = 10cm ; volume of cube V= l^3 = 1000 cm³

120. A metal plate of area 2.5×10⁻⁴ m² is placed on a 0.25×10⁻³ m thick layer ofcastor oil. If a force of 2.5 N is needed to move the plate with a velocity 3×10⁻² m s⁻¹, calculate the coefficient of viscosity of castor oil.
Given: A=2.5×10⁻⁴ m², dx = 0.25×10⁻³m, F=2.5 N and dv = 3×10⁻² ms⁻¹

Solution

$F = -\eta A \frac{dv}{dx}$; $\eta = \frac{F\,dx}{A\,dv}$; = $\frac{(2.5\ N)(0.25 \times 10^{-3} m)}{(2.5 \times 10^{-4} m^2)(3 \times 10^{-2}\ ms^{-1})}$;
= 0.083×10^3 N m⁻²s

121. Let 2.4×10⁻⁴ J of work is done to increase the area of a fi lm of soap bubblefrom 50 cm² to 100 cm². Calculate the value of surface tension of soapsolution.

Solution

A soap bubble has two free surfaces, therefore increase in surface area
$\Delta A = A_2 - A_1 = 2(100-50) \times 10^{-4} m^2 = 100 \times 10^{-4} m^2$.

Since, work done W = T x ΔA ; $T = \frac{W}{\Delta A}$; = $\frac{2.4 \times 10^{-4} J}{100 \times 10^{-4} m^2}$;
= 2.4×10^{-2} Nm⁻¹

122. If excess pressure is balanced by a column of oil (with specific gravity 0.8)4 mmhigh, where R = 2.0 cm, find the surface tension of the soap bubble.

Solution

The excess of pressure inside the soap bubble is $\Delta p = P_2 - P_1 = \frac{4T}{R}$

$\Delta p = P_2 - P_1 = \rho g h$ [$\rho g h = \frac{4T}{R}$]

Surface tension, $T = \frac{\rho g h R}{4}$; = $\frac{(800)(9.8)(4 \times 10^{-3})(2 \times 10^{-2})}{4}$;T=15.68x10⁻² Nm⁻¹

123. Water rises in a capillary tube to a height of 2.0cm. How much will the water rise through another capillary tube whose radius is one-third of the first tube?

Solution

$h \propto \frac{1}{r}$; hr = Constant

Consider two capillary tubes with radius r_1 and r_2 which on placing in a liquid, capillary rises to height h_1 and h_2, respectively. Then,

$h_1 r_1 = h_2 r_2$ = constant

$h_2 = \frac{h_1 r_1}{r_2}$; = $\frac{(2 \times 10^{-2} m) \times r}{\frac{r}{3}}$; **$h_2 = 6 \times 10^{-2}$ m**

124. Mercury has an angle of contact equal to 140⁰ with soda lime glass. A narrowtube of radius 2 mm, made of this glass is dipped in a trough containingmercury. By what amount does the mercury dip down in the tube relative tothe liquid surface outside? Surface tension of mercury T=0.456Nm^{-1}; Density of mercury ρ = 13.6×10^3 kgm^{-3}

Solution

Capillary descent, cos140 = cos(90+50) –sin50 = –0.7660

$$h = \frac{2T\cos\theta}{r\rho g} = \frac{2 \times (0.456\ Nm^{-1})(\cos 140^0)}{(2 \times 10^{-3}\ m)(13.6 \times 10^3)(9.8\ ms^{-2})} ; = \frac{2 \times 0.456 \times (-0.7660)}{2 \times 13.6 \times 9.8}$$

$$= \frac{-0.6986}{266.56} ; = -2.62 \times 10^{-3}\ m$$

where, negative sign indicates that there is fall of mercury (mercury is depressed) in glass tube.

125. In a normal adult, the average speed of the blood through the aorta (radius r= 0.8 cm) is 0.33 ms^{-1}. From the aorta, the blood goes into major arteries, which are 30 in number, each of radius 0.4 cm. Calculate the speed of the blood through the arteries.

Solution

No.	Log
1.32	0.1206
30	1.4771
(–)	$\bar{2}$.6435
Antilog	4.400 x 10-2

$$a_1v_1 = 30a_2v_2 \ ; \pi r_1^2 v_1 = 30\ \pi r_2^2 v_2 \ ; V_2 = \frac{1}{30}\left(\frac{r_1}{r_2}\right)^2 v_1$$

$$V_2 = \frac{1}{30}\left(\frac{0.8 \times 10^{-2} m}{0.4 \times 10^{-2}\ m}\right)^2 \times (0.33\ ms^{-1}) \ ; V_2 = 0.044\ ms^{-1}$$

EXERCISE PROBLEM

126. A capillary of diameter d mmis dipped in water such that the water rises to aheight of 30mm. If the radius of the capillary is made 2/3 of its previous value, then compute the height up to which water will rise in the new capillary?

Solution

Surface tension by capillary rise method is, $T = \frac{\rho r h g}{2\cos\theta}$; $h = \frac{2\,T\cos\theta}{\rho r g}$

$$h \propto \frac{1}{r} \quad \text{(or) } hr = \text{constant}$$

$$h_1 r_1 = h_2 r_2 \ ; h_2 = \frac{h_1 r_1}{r_2} ; = \frac{30 \times 10^{-3} \times r}{\left(\frac{2r}{3}\right)} ; = \frac{3 \times 30 \times 10^{-3} \times r}{2r}$$

$\boldsymbol{h_2}$ = 45 x 10^{-3} m = 45mm

127. The reading of pressure meter attached with a closed pipe is 5×10^5 N m^{-2}. Onopening the valve of the pipe, the reading of the pressure meter is4.5×10^5 Nm^{-2}. Calculate the speed of the water flowing in the pipe.

Solution

Under closed state, velocity of water; v_1=0

Under open state, velocity of water; $v_2=v$

Density of water; ρ =1000 kgm^{-3}

According to Bernoulli's theorem, for horizontal pipe

$$\frac{P_1}{\rho}+\frac{1}{2}v_1^2=\frac{P_2}{\rho}+\frac{1}{2}v_2^2\ ;\ \frac{P_1}{\rho}-\frac{P_2}{\rho}=\frac{1}{2}v_2^2-\frac{1}{2}v_1^2$$

$$\frac{P_1-P_2}{\rho}=\frac{1}{2}(v_2^2-v_1^2)\ ;\ v_2^2-v_1^2=\frac{2}{\rho}(P_1-P_2)$$

$$v^2-0=\frac{2}{1000}(5\text{ x }10^5-4.5\text{ x }10^5)\ ;\ v^2=\frac{2}{1000}(5-4.5\text{ x }10^5)$$

$$v^2=\frac{2}{1000}\text{ x }0.5\text{ x }10^5;=\frac{10^5}{10^3};=10^2\ ;\ v=10ms^{-1}$$

UNIT – VIII (HEAT AND THERMODYNAMICS)

128. When a person breaths, his lungs can hold up to 5.5 Litre of air at body temperature 37°C and atmospheric pressure (1 atm =101 kPa). This Air contains 21% oxygen. Calculate the number of oxygen molecules in the lungs.

Solution

We can treat the air inside the lungs as an ideal gas. To find the number of molecules, we can use the ideal gas law. PV = NkT

Here volume is given in the Litre. 1 Litre isvolume occupied by a cube of side 10 cm.1Litre = 10cm × 10cm × 10cm = 10^{-3} m^3

$$N=\frac{PV}{kT};=\frac{1.01\text{ x }10^5Pa\text{ x }5.5\text{ x }10^{-3}m^3}{1.38\text{ x }10^{-23}JK^{-1}\text{ x }310\text{ K}}$$; **N = 1.29×10^{23} Molecules**

Only 21% of N are oxygen. The total number of oxygen molecules

= $1.29\times10^{23}\text{ x }\frac{21}{100}$ Number of oxygen molecules = 2.7×10^{22} molecules

129. Eiffel tower is made up of iron and its height is roughly 300 m. During winterseason (January) in France the temperature is 2^0 C and in hot summer itsaverage temperature 25^0 C. Calculate the change in height of Eiffel towerbetween summer and winter. The linear thermal expansion coefficient for ironα = 10×10^{-6} per °C

Solution

$$\frac{\Delta L}{L_0}=a_L\Delta T\ ;\Delta L=a_LL_0\Delta T\ ;$$

$\Delta L=10\times10^{-6}\times300\times23$ = 0.069 m=69 mm

130. A person does 30 kJ work on 2 kg of water by stirring using a paddle wheel. While stirring, around 5 kcal of heat is released from water through its container to the surface and surroundings by thermal conduction and radiation. What is the change in internal energy of the system?

Solution

Work done on the system (by the person while stirring), W = −30 kJ = −30,000J

Heat flowing out of the system, Q = −5 kcal = −5×4184 J =−20920 J

Using First law of thermodynamics,$\Delta U = Q - W$

$\Delta U = -20{,}920\ J - (-30{,}000)\ J$

$\Delta U = -20{,}920\ J + 30{,}000\ J = 9080\ J$

Here, the heat lost is less than the work done on the system, so the change in internal energy is positive.

131. Jogging every day is good for health. Assume that when you jog a work of 500kJ is done and 230 kJ of heat is given off. What is the change in internal energyof your body?

Solution

Work done by the system (body), W = +500 kJ

Heat released from the system (body),Q = −230 kJ

The change in internal energy of a body = $\Delta U = -230\ kJ - 500\ kJ = -730\ kJ$

132. 500 g of water is heated from 30^0 C to 60^{0}C. Ignoring the slight expansion ofwater, calculate the change in internal energy of the water? (specific heat ofwater 4184 J/kg K)

Solution

When the water is heated from 30^{0}C to 60^{0}C, there is only a slight change in its volume. So we can treat this process as isochoric. In an isochoric process the work done by the system is zero. The given heat supplied is used to increase only the internal energy. $\Delta U = Q = m s_v \Delta T$

The mass of water = 500 g =0.5 kg;

The change in temperature = 30K

The heat Q = 0.5×4184×30 = 62.76 kJ

133. During a cyclic process, a heat engine absorbs 500 J of heat from a hotreservoir, does work and ejects an amount of heat 300 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine?

Solution

The efficiency of heat engine is given by$\eta = 1 - \frac{Q_L}{Q_H}$; $\eta = 1 - \frac{300}{500}$;

$= 1 - \frac{3}{5}$; $\eta = 1 - 0.6$; 0.4

The heat engine has 40% efficiency, implying that this heat engine converts only 40% of the input heat into work.

134. There are two Carnot engines A and B operating in two different temperatureregions. For Engine A, the temperatures of the two reservoirs are 150ºC and100ºC. For engine B the temperatures of the reservoirs are 350ºC and 300ºC.Which engine has lesser efficiency?

Solution

The efficiency for engine A $=1-\frac{373}{623}$;

=0.11. Engine A has 11% efficiency

No.	Log
373	2.5717
423	2.6263
(−)	$\bar{1}$.9454
Antilog	8.819×10^{-1}

The efficiency for engine

B $=1-\frac{573}{623}$; = 0.08.

Engine B has 8% efficiency

No.	Log
573	2.7582
623	2.7945
(−)	$\bar{1}$.9637
Antilog	9.198×10^{-1}

135. A refrigerator has COP of 3. How much work must be supplied to therefrigerator in order to remove 200 J of heat from its interion?

SolutionCOP = $\beta = \frac{Q_L}{W}$; $W = \frac{Q_L}{COP}$; $= \frac{200}{3}$; = 66.67J

EXERCISE PROBLEM

136. Calculate the number of moles of air is in the inflated balloon at roomtemperature The radius of the balloon is 10 cm, and pressure inside theballoon is 180 kPa.

Solution

From ideal gas equation PV = μRT or $\mu = \frac{PV}{RT}$---------1

Volume of spherical shaped balloon, $V = \frac{4}{3}\pi r^3$

$= \frac{4}{3} \times 3.14 \times (10 \times 10^{-2})^3$; 4 x 1.046 x 10^{-3} ;

V = 4.184 x 10^{-3}

From equation 1,$=\frac{180 \times 10^3 \times 4.184 \times 10^{-3}}{8.31 \times (27+273)}$;=

$\frac{180 \times 4.184}{8.31 \times 300}$;

$= \frac{180 \times 4.184}{2493}$; = 0.3021 ; **μ** ≅ 0.3 moles

No.	Log
180	2.2553
4.184	0.6216
(+) 2493	2.8769 3.3967
(−)	$\bar{1}$.4802
Antilog	3.021×10^{-1}

137. In the planet Mars, the average temperature is around -53°C and atmosphericpressure is 0.9 kPa. Calculate the number of moles of the molecules in unitvolume in the planet Mars? Is this greater than that in earth?

Solution

Number of molecules per unit volume in Mars planet is $\mu_{mars} = \frac{PV}{RT}$

$= \frac{0.9 \text{ x } 1000 \text{ x } 1}{8.31 \text{ x } (-53+273)}$; $= \frac{900}{8.31 \text{ x } 220}$; $= \frac{90}{8.31 \text{ x } 22}$; $= \frac{90}{182.82}$;

μ_{mars} = 0.4922 moles

Number of molecules per unit volume in Earth planet is $\mu_{earth} = \frac{PV}{RT}$

$= \frac{101.3 \text{ x } 1000 \text{ x } 1}{8.31 \text{ x } (27+273)}$; $= \frac{101300}{8.31 \text{ x } 300}$; $= \frac{1013}{8.31 \text{ x } 3}$; $= \frac{1013}{24.93}$;

μ_{earth} = 40.46 moles

138. A man starts bicycling in the morning at a temperature around 25⁰ C, hechecked the pressure of tire which is equal to be 500 kPa. Afternoon he foundthat the absolute pressure in the tyre is increased to 520 kPa. By assumingthe expansion of tyre is negligible, what is the temperature of tyre atafternoon?

Solution

Let this is considered as isochoric process, then P = $\left[\frac{\mu R}{V}\right] T$

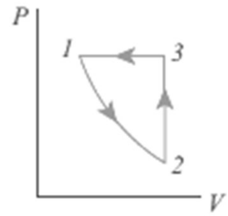
In morning ,$P_1 = \left[\frac{\mu R}{V}\right] T_1$ --------------1In afternoon ,$P_2 = \left[\frac{\mu R}{V}\right] T_2$ --------------2

Divide equation (1) by (2)

$\frac{P_1}{P_2} = \frac{T_1}{T_2}$; $T_2 = \frac{P_1}{P_2} T_1$; $T_2 = \frac{520 \text{ x } 1000}{500 \text{ x } 1000}(25+273)$; $= \frac{52}{50}$x 298

= 1.04 x 298; = 309.92 k, T_2 = 309.92 k or 36.92 ⁰c

139. Consider the following cyclic process consist of isotherm, isochoric and isobar which is given in the figure.
Draw the same cyclic process qualitatively in the V-T diagram where T is taken along x direction and V is taken along y-direction. Analyze the nature of heat exchange in each process.

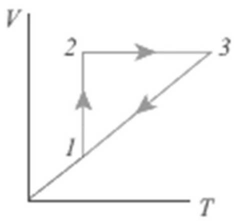


Solution

Process 1 to 2 = increase in volume. So heat must be added.

Process 2 to 3= Volume remains constant. Increase in temperature. The given heat is used to increase the internal energy.

Process 3 to 1: Pressure remains constant. Volume and Temperature are reduced. Heat flows out of the system. It is an isobaric compression where the work is done on the system.



140. For a given ideal gas 6 × 105*J* heat energy is supplied and the volume of gasis increased from 4 m3 to 6 m3 at atmospheric pressure. Calculate (a) thework done by the gas (b) change in internal energy of the gas (c) graph thisprocess in PV and TV diagram.

Solution

(a) Work done by the gas:

Work done by the gas during isobaric expansion, $W = P\,\Delta V = P\,[V_f - V_i]$;

$W = 101.3 \times 10^3 \times (6 - 4)$; $= 101300 \times (2) = 202600$ J; $W = 202.6$kJ

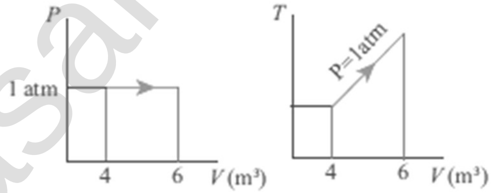
(b) Change in internal energy of the gas

From second law of thermodynamics $Q = \Delta U + W$ (or) $\Delta U = Q - W$

$= 6 \times 10^5 - 202600$; $\Delta U = 6 \times 10^5 - 2.026 \times 10^5$;

$\Delta U = (6 - 2.026) \times 10^5$;$= 3.974 \times 10^5 = 397.4 \times 10^3$ J ; $\Delta U = 397.4$kJ

(c) PV diagram and TV diagram



141. Suppose a person wants to increase the efficiency of the reversible heat engine that is operating between 100°C and 300°C. He had two ways to increase the efficiency. (a) By decreasing the cold reservoir temperature from 100°C to 50°C and keeping the hot reservoir temperature constant (b) by increasingthe temperature of the hot reservoir from 300°C to 350°C by keeping the cold reservoir temperature constant. Which is the suitable method?

Solution

Temperature of hot source; $T_H = (300+273) = 573$ K

Temperature of cold sink; $T_L = (100+273) = 373$ K

Hence efficiency of heat engine $\eta = 1 - \frac{T_L}{T_H} = \frac{T_H - T_L}{T_H}$;

$$\eta = \frac{573 - 373}{573}$$

$\boldsymbol{\eta} = \frac{200}{573}$; $= 0.\mathbf{349}$; **η**= 34.9%

No.	Log
200	2.3010
573	2.7582
(−)	$\bar{1}$.5428
Antilog	3.490×10^{-1}

In case (a) $T_H = (300 + 273) = 573$ K &

$T_L = (50 + 273) = 323$ K

$\eta = 1 - \frac{T_L}{T_H} = \frac{T_H - T_L}{T_H}$; $\eta = \frac{573-323}{573}$

$\boldsymbol{\eta} = \frac{\mathbf{250}}{\mathbf{573}}$; $= \mathbf{0.4362}$; **η** = 43.6%

No.	Log
250	2.3979
573	2.7582
(−)	$\bar{1}$.6397
Antilog	4.362×10^{-1}

In case (b) T_H = (350 + 273) = 623 K &
T_L = (100 + 273) = 373 K

$\eta = 1 - \frac{T_L}{T_H} = \frac{T_H - T_L}{T_H}$; $\eta = \frac{623-373}{623}$

$\boldsymbol{\eta} = \frac{\mathbf{250}}{\mathbf{623}}$; = $\mathbf{0.4012}$; $\boldsymbol{\eta}$ = 40.1%

No.	Log
250	2.3979
623	2.7945
(−)	$\bar{1}$.6034
Antilog	4.012×10^{-1}

142. A Carnot engine whose efficiency is 45% takes heat from a source maintainedat a temperature of 327°C. To have anengine of efficiency 60% what mustbe the intake temperature for the same exhaust (sink) temperature?

Solution

Efficiency when ,T_H = (327+ 273) = 600 K &η = 45% = 0.45

$\eta = 1 - \frac{T_L}{T_H}$; 0.45 = $1 - \frac{T_L}{600}$; $\frac{T_L}{600}$ = 1 −0.45 ; = 0.55

T_L = 0.55 x 600 = 330 K ; T_L = 330 K or 57^{0}C

Efficiency when , T_H = (57+ 273) = 330 K &η = 60% = 0.60

$\eta = 1 - \frac{T_L}{T_H}$; 0.60 = $1 - \frac{330}{T_H}$; $\frac{330}{T_H}$ = 1 −0.60 ; = 0.40

$T_H = \frac{330}{0.4} = \frac{3300}{4}$; = 825 K ; T_H = 825 K or 552^{0}C

143. An ideal refrigerator keeps its content at 0°C while the room temperature is27°C. Calculate its coefficient of performance.

Solution

Coefficient of performance (COP) of refrigerator, when
T_H = (27 + 273) = 300 K & T_L = (0 +273) = 273 K

COP = $\beta = \frac{T_L}{T_H - T_L}$; $\beta = \frac{273}{30}$; = $\frac{273}{27}$;

β =10.11

No.	Log
273	2.4362
27	1.4314
(−)	1.0048
Antilog	1.011×10^{1}

UNIT – IX (KINETIC THEORY OF GASES)

144. A football at 27°C has 0.5 mole of air molecules. Calculate the internal energyof air in the ball.

Solution

The internal energy of ideal gas = $\frac{3}{2}$ NkT

The number of air molecules is given in terms of number of moles so, rewrite the expression as U = $\frac{3}{2}\mu RT$; Nk = μR. Here μ is number of moles.

Gas constant R = 8.31 $\frac{J}{mol\ k}$; Temperature T =273+27=300K

U = $\frac{3}{2}$ x 0.5 x 8.31 x 300 = 1869.75 J.

This is approximately equivalent to the kinetic energy of a man of 57 kg running with a speed of 8 ms^{-1}.

145. Ten particles are moving at the speed of 2, 3, 4, 5, 5, 5, 6, 6, 7 and 9ms^{-1}. Calculate rms speed, average speed and most probable speed.

Solution

The average speed $\bar{v} = \frac{2+3+4+5+5+5+6+6+7+9}{10}$; = 5.2 ms^{-1}

To find the rms speed, first calculate the mean square speed

$\overline{v^2} = \frac{2^2+3^2+4^2+5^2+5^2+5^2+6^2+6^2+7^2+9^2}{10}$; = 30.6 m^2s^{-2}

$V_{max}=\sqrt{\overline{v^2}} = \sqrt{30.6}$; = 5.53 ms^{-1}

The most probable speed is 5 ms^{-1} because three of the particles have that speed.

146. Find the adiabatic exponent γ for mixture of μ_1 moles of monoatomic gas andμ_2 moles of a diatomic gas at normal temperature (27°C) .

Solution

The specific heat of one mole of a monoatomic gas $C_V = \frac{3}{2}R$

For μ_1 mole, $C_V = \frac{3}{2}\mu_1 R$, $C_P = \frac{5}{2}\mu_1 R$

The specific heat of one mole of a diatomic gas , $C_V = \frac{5}{2}R$

For μ_2 mole, $C_V = \frac{5}{2}\mu_2 R$, $C_P = \frac{7}{2}\mu_2 R$

specific heat of the mixture at constant volume$C_V = \frac{3}{2}\mu_1 R + \frac{5}{2}\mu_2 R$

The specific heat of the mixture at constant pressure

$C_P = \frac{5}{2}\mu_1 R + \frac{7}{2}\mu_2 R$

The adiabatic exponent $\gamma = \frac{C_P}{C_V} = \frac{5\mu_1 + 7\mu_2}{3\mu_1 + 5\mu_2}$

147. An oxygen molecule is travelling in air at 300 K and 1 atm, and the diameter of oxygen molecule is 1.2×10^{-10}m. Calculate the mean free path of oxygen molecule.

Solution

$$\lambda = \frac{1}{\sqrt{2}\pi n d^2}$$

We have to find the number density nBy using ideal gas law

$$n = \frac{N}{V} = \frac{P}{kT} = \frac{101.3 \times 10^3}{1.381 \times 10^{-23} \times 300}; = 2.499 \times 10^{25} \text{ molecules / m}^3$$

$$\lambda = \frac{1}{\sqrt{2} \times \pi \times 2.449 \times 10^{25} \times (1.2 \times 10^{-10})^2}$$

$$= \frac{1}{15.65 \times 10^5}; \lambda = 0.63 \times 10^{-6} \text{ m}$$

EXERCISE PROBLEM

148. A fresh air is composed of nitrogen N_2(78%) and oxygen O_2(21%). Find the rmsspeed of N_2 and O_2 at 20°C.

Solution

N_A = Avogadro Number and R = 8.314 J mol^{-1} K^{-1}

1) Nitrogen molecule (N_2)

Atomic mass of Nitrogen = 14,

Then One Nitrogen molecule = 2×14=28

Thus 28 *g* nitrogen gas contains N_A number of nitrogen molecules Hence, Molecular mass of one mole of nitrogen molecule, M = 28 g/mol = 0.028 kg/mol

RMS speed of nitrogen molecule,

$$(v_{rms}) = \sqrt{\frac{3RT}{M}}; = \sqrt{\frac{3 \times 8.314 \times (20+273)}{0.028}}$$

$$= \sqrt{\frac{3 \times 8.314 \times 293}{0.028}}; = 510.9 \text{ ms}^{-1}; (v_{rms}) = 511 \text{ ms}^{-1}$$

No.	Log
3 8.314 293	0.4771 0.9198 2.4669
(+) 0.028	3.8638 $\bar{2}$.4472
(−)	5.4166 x ½ = 2.7083
Antilog	5.109 x 10^2

2) Oxygen molecule (O_2)

Atomic mass of Oxygen = 16. Then One Oxygen molecule =2×16=32

Thus 32 *g* Oxygen contains NA number of oxygen molecules

Hence, Molecular mass of one mole of oxygen molecule M = 32 g/mol = 0.032kg/mol

RMS speed of oxygen molecule, (v_{rms})

$$= \sqrt{\frac{3RT}{M}}; = \sqrt{\frac{3 \times 8.314 \times (20+273)}{0.032}}$$

$$= \sqrt{\frac{3 \times 8.314 \times 293}{0.032}}; = 477.9 \text{ ms}^{-1}; (v_{rms}) = 478 \text{ ms}^{-1}$$

No.	Log
3 8.314 293	0.4771 0.9198 2.4669
(+) 0.032	3.8638 $\bar{2}$.5051
(−)	5.3587 x ½ = 2.6793
Antilog	4.779 x 10^2

149. If the rms speed of methane gas in the Jupiter's atmosphere is 471.8 ms⁻¹, show that the surface temperature of Jupiter is sub-zero.

Solution

$(v_{rms}) = \sqrt{\frac{3RT}{M}}$ or $v_{rms}^2 = \frac{3RT}{M}$ or $T = \frac{v_{rms}^2 M}{3R}$

$T = \frac{(471.8)^2 x\ 0.016}{3\ x\ 8.314}$; $\frac{471.8\ x\ 471.8\ x\ 0.016}{24.942}$;

T = 142.8 K ≈143 K

or T = 143 – 273 ; = – 130°C

Thus surface temperature of Jupiter planet is less than 0°C

No.	Log
471.0 471.0 0.016	2.6738 2.6738 $\bar{2}$.2041
(+) 24.942	3.5517 1.3969
(–)	2.1548
Antilog	1.428 x 10²

150. Calculate the temperature at which the rms velocity of a gas triples its valueat S.T.P. (standard temperature T_1 = 273 K)

Solution

At standard temperature and pressure (STP) ; $v_{rms\ 1} = v$ & T_1 = 273 K

At new temperature and pressure ; $v_{rms\ 2} = 3v$ & T_2 = ?

By definition, $v_{rms\ 1} = \sqrt{\frac{3RT_1}{M}}$ -----------1 ; $v_{rms\ 2} = \sqrt{\frac{3RT_2}{M}}$ -----------2

Divide equation 2 by 1

$\frac{v_{rms\ 2}}{v_{rms\ 1}} = \frac{\sqrt{\frac{3RT_2}{M}}}{\sqrt{\frac{3R\ \ 1}{M}}} = \sqrt{\frac{T_2}{T_1}}$; $\left[\frac{v_{rms\ 2}}{v_{rms\ 1}}\right]^2 = \frac{T_2}{T_1}$; $T_2 = T_1\left[\frac{v_{rms\ 2}}{v_{rms\ 1}}\right]^2$; 273 x $\left[\frac{3v}{v}\right]^2$

= 273 x 9 ; T_2 = 2557 K

151. A gas is at temperature 80°C and pressure 5×10⁻¹⁰N m⁻². What is the numberof molecules per m3 if Boltzmann's constant is 1.38×10⁻²³ J K⁻¹

Solution

Ideal gas constant PV = nkT;

$n = \frac{PV}{kT} = \frac{5\ x\ 10^{-10} x\ 1}{1.38\ x\ 10^{-23} x(80+273)}$; $= \frac{5\ x\ 10^{13}}{1.38\ x\ 353}$

n = 1.026 x 10⁻² x 10¹³; n = 1.026 x 10¹¹

152. Calculate the mean free path of air molecules at STP. The diameter of N_2 and O_2 is about 3 x 10⁻¹⁰ m.

Solution At STP P = 1.013 x 10⁵ Nm⁻² & T = 273K

By ideal gas equation, PV = NKT or $\frac{N}{V} = \frac{P}{kT}$ or $n = \frac{P}{kT}$

$n = \frac{P}{kT}$; $= \frac{1.013\ x\ 10^5}{1.38\ x\ 10^{-2}\ \ x\ 273}$; $n = \frac{1.013\ x\ 10^{28}}{1.38\ x\ 273}$;

n = 2.688 x 10⁻³ x 10²⁸

n = 2.688 x 10²⁵ molecules /m³

The mean free path $\lambda = \frac{1}{\sqrt{2}\pi n d^2}$

$\lambda = \frac{1}{3.14\ x\ (3\ x\ 10^{-10})^2 x\ 2.688\ x\ 10^{25} x\ 1.414}$; $= \frac{1}{3.14\ x\ 9\ x\ 2.688\ x\ 1.414\ x\ 10^5}$

= 9.313 x 10⁻³ x 10⁻⁵ ; λ = 9.313 x 10⁻⁸ m

153. A gas made of a mixture of 2 moles of oxygen and 4 moles of argon attemperature T. Calculate the energy of the gas in terms of RT. Neglect thevibrational modes.

Solution

Oxygen (O_2) is a di atomic molecule. Its number of degrees of freedom f = 5

Argon (Ar) is a mono atomic molecule. Its number of degrees of freedom f =3

For mono atomic molecule, total energy of μ mole of gas,

$U_1 = \mu_1 \text{ x } \frac{3}{2} N_A kT; = \mu_1 \text{ x } \frac{3}{2} RT$

For di atomic molecule, total energy of μ mole of gas,

$U_2 = \mu_2 \text{ x } \frac{5}{2} N_A kT; = \mu_2 \text{ x } \frac{5}{2} RT$

Total energy of gas mixture $U = U_1 + U_2$

$U = \mu_1 \text{ x } \frac{3}{2} RT + \mu_2 \text{ x } \frac{5}{2} RT$; $U = 4 \text{ x } \frac{3}{2} RT + 2 \text{ x } \frac{5}{2} RT$

U = 6 RT + 5 RT; U = 11RT

154. Estimate the total number of air molecules in a room of capacity 25m³ at atemperature of 27°C.

Solution

Ideal gas constant PV = NkT or $N = \frac{PV}{kT}$;

$$= \frac{1.013 \text{ x } 10^5 \text{ x } 25}{1.38 \text{ x } 10^{-23} \text{ x } (27 + 273)}$$

$$= \frac{1.013 \text{ x } 10^5 \text{ x } 25}{1.38 \text{ x } 10^{-23} \text{ x } 300} ; = \frac{1.013 \text{ x } 25 \text{ x } 10^{28}}{414}$$

$N = 6.116 \text{ x } 10^{-3} \text{ x } 10^{28}$; $N = 6.116 \text{ x } 10^{25}$ molecules

UNIT – X (OSCILLATIONS)

155. Classify the following motions as periodic and non-periodic motions?
a. Motion of Halley's comet.
b. Motion of clouds.
c. Moon revolving around the Earth.

Solution

a. Periodic motion   b. Non – periodic motion   c. Periodic motion

156. Which of the following functions of time represent periodic and non-periodic motion?a. sin ωt + cos ωt b. In ωt

Solution

a. Periodic   b. Non – periodic

157. A nurse measured the average heart beats of a patient and reported to the doctor in terms of time period as 0.8 *s*. Express the heartbeat of the patient in terms of number of beats measured per minute.

Solution

Let the number of heart beats measured be f. Since the time period is inversely proportional to the heart beat, then $f = \frac{1}{T}$; $= \frac{1}{0.8}$; **T = 1.25 s^{-1}**

One minute is 60 second, (1 second = $\frac{1}{60}$ minute ⇒ 1 s^{-1} = 60 min^{-1})

f = 1.25 s^{-1} ; f = 1.25 x 60 min^{-1} ; =75 beats per minute

158. Calculate the amplitude, angular frequency, frequency, time period and initial phase for the simple harmonic oscillation given below
a. y = 0.3 sin (40πt + 1.1) b. y = 2 cos (πt) c. y = 3 sin (2 πt – 1.5)

Solution

Simple harmonic oscillation equation is

$y = A \sin(\omega t + \varphi_0)$ (or) $y = A \cos(\omega t + \varphi_0)$

a. For the wave, **y = 0.3 sin (40πt + 1.1)**

Amplitude is A = 0.3 unit

Angular frequency ω =40π rad s^{-1}

Frequency $f = \frac{\omega}{2\pi}$; $= \frac{40\pi}{2\pi}$; f = 20 Hz

Time period $T = \frac{1}{f}$; $= \frac{1}{20}$; T = 0.05 s

Initial phase φ_0 = 1.1 rad

b. For the wave, y = **2 cos (πt)**

Amplitude is A = 2 unit

Angular frequency ω = π rad s^{-1}

Frequency $f = \frac{\omega}{2\pi}$; $= \frac{\pi}{2\pi}$; f = 0.5 Hz

Time period $T = \frac{1}{f}$; $= \frac{1}{0.5}$; T = 2s

Initial phase φ_0 = 0 rad

c. y = 3 sin (2 πt – 1.5)

Amplitude is A = 3 unit

Angular frequency ω =2π rad s^{-1}

Frequency $f = \frac{\omega}{2\pi}$; $= \frac{2\pi}{2\pi}$; f = 1 Hz

Time period $T = \frac{1}{f}$; $= \frac{1}{1}$; T = 1s

Initial phase φ_0 = 1.5 rad

159. Consider two springs whose force constants are 1 Nm^{-1} and 2 Nm^{-1} whichare connected in series. Calculate the effective spring constant (k_s) andcomment on k_s

Solution

k_1 = 1 N m^{-1}, k_2= 2 Nm^{-1} ; $k_s = \frac{k_1 k_2}{k_1+k_2}$ Nm^{-1} ; $k_s = \frac{1 \times 2}{1+2} = \frac{2}{3}$ Nm^{-1}

$k_s < k_1$ and $k_s < k_2$

Therefore, the effective spring constant is lesser than both k_1 and k_2

160. Consider two springs with force constants 1 Nm⁻¹ and 2 Nm⁻¹ connected inparallel. Calculate the effective spring constant (k_p) and comment on k_p.

Solution

$k_1 = 1 \text{ N m}^{-1}$, $k_2 = 2 \text{ Nm}^{-1}$; $k_p = k_1 + k_2 \text{ Nm}^{-1}$

$k_p = 1 + 2 = 3 \text{ Nm}^{-1}$; $k_p > k_1$ and $k_p > k_2$

Therefore, the effective spring constant is greater than both k_1 and k_2.

161. A mass m moves with a speed v on a horizontal smooth surface and collides with a nearly massless spring whose spring constant is k. If the mass stops after collision, compute the maximum compression of the spring.

Solution

When the mass collides with the spring, from the law of conservation of energy "the loss in kinetic energy of mass is gain in elastic potential energy by spring". Let x be the distance of compression of spring, then the law of conservation of energy $\frac{1}{2}\text{mv}^2$; = $\frac{1}{2}\text{k}x^2 x = v\sqrt{\frac{m}{k}}$

162. If the length of the simple pendulum is increased by 44% from its originallength, calculate the percentage increase in time period of the pendulum.

Solution

$T \propto \sqrt{l}$; T = constant $\sqrt{l}$

$\frac{T_f}{T_i} = \sqrt{\frac{1+\frac{44}{100}l}{l}}$; $\sqrt{1.44}$ = 1.2 ; Therefore, $T_f = 1.2\, T_i = T_i + 20\%\, T_i$

EXERCISE PROBLEM

163. Consider a simple pendulum of length l = 0.9 m which is properly placed on atrolley rolling down on a inclined plane which is at θ = 45° with the horizontal.Assuming that the inclined plane is frictionless, calculate the time period ofoscillation of the simple pendulum.

Solution

The effective value of acceleration due to gravity will be equal to the component of g normal to the inclined plane which is $g'=g\cos\theta$

Then the time period is given by $T = 2\pi\sqrt{\frac{l}{g'}} = 2\pi\sqrt{\frac{l}{g\cos\theta}}$

$T = 2\pi\sqrt{\frac{0.9}{9.8 \times \cos 45^0}}; = 2\pi\sqrt{\frac{0.9}{9.8 \times \frac{1}{\sqrt{2}}}}; ; = 2 \times 3.14\sqrt{\frac{0.9}{9.8 \times 0.707}}$

$T = 6.28\sqrt{\frac{0.9}{6.9286}}$; = $6.28\sqrt{0.1290}$; = 6.28 x 0.3604 ; T= 2.263s

164. A piece of wood of mass m is floating erect in a liquid whose density is ρ. If itis slightly pressed down and released, then executes simple harmonic motion.Show that its time period of oscillation is $T = 2\pi\sqrt{\frac{m}{A\,g\rho}}$

Solution

Let the wood piece of mass 'm' and area 'A' floating in liquid of density 'ρ' is pressed down by a distance 'x' and released, so that it executes SHM.

The restoring force is given by, $F = kx$(or) mg = kx (or) k = $\frac{mg}{x}$;

$= \frac{(\rho v)g}{x}$; $= \frac{(\rho Ax)g}{x}$; $= \rho Ag$

The time period of vertical oscillation is, $T = 2\pi\sqrt{\frac{m}{k}}$; $= 2\pi\sqrt{\frac{m}{A\,g\rho}}$

UNIT – XI (WAVES)

165. The average range of frequencies at which human beings can hear soundwaves varies from 20 Hz to 20 kHz. Calculate the wavelength of the soundwave in these limits. (Assume the speed of sound to be 340 ms^{-1}.

Solution

$\lambda_1 = \frac{v}{f_1} = \frac{340}{20}$; = 17 m ; $\lambda_2 = \frac{v}{f_2} = \frac{340}{20 \times 10^3}$; = 0.017m

Therefore, the audible wavelength region is from 0.017 m to 17 m when the velocity of sound in that region is 340 ms^{-1}.

166. A man saw a toy duck on a wave in an ocean. He noticed that the duck movedup and down 15 times per minute. He roughly measured the wavelength ofthe ocean wave as 1.2 m. Calculate the time taken by the toy duck for goingone time up and down and also the velocity of the ocean wave.

Solution

Given that the number of times the toy duck moves up and down is 15 times per minute. This information gives us frequency (the number of times the toy duck moves up and down)

$f = \frac{\text{15 times toy duck moves up and down}}{\text{one minute}}$

But one minute is 60 second, therefore, expressing time in terms of second.

$f = \frac{15}{60} = \frac{1}{4}$; = 0.25 Hz

The time taken by the toy duck for going one time up and down is time period which is inverse of frequency $T = \frac{1}{f} = \frac{1}{0.25}$; = 4s

The velocity of ocean wave is $v = \lambda f$ = 1.2 x 0.25 = 0.3ms^{-1}

167. Calculate the speed of sound in a steel rod whoseYoung's modulus Y = 2 × 10^{11} Nm^{-2} and ρ = 7800 kg m^{-3}.

No.	Log
10^{11} 3900	11.0000 3.5911
(−)	7.4089 x ½ 3.7044
Antilog	5.062 x 10^3

Solution

$v = \sqrt{\frac{Y}{\rho}} = \sqrt{\frac{2 \times 10^{11}}{7800}}$; $\sqrt{0.2564 \times 10^8}$;
= 0.506 x 10^4 ms^{-1} ;= 5 x 10^3 ms^{-1}

Therefore, longitudinal waves travel faster in a solid than in a liquid or a gas. Now you may understand why a shepherd checks before crossing railway track by keeping his ears on the rails to safeguard his cattle.

168. An increase in pressure of 100 kPa causes a certain volume of water todecrease by 0.005% of its original volume. (a) Calculate the bulk modulus ofwater? (b) Compute the speed of sound (compressional waves) in water?

Solution

(a) Bulk modulus B = V $\left|\frac{\Delta P}{\Delta V}\right| = \frac{100 \times 10^3}{0.005 \times 10^{-2}}$; = $\frac{100 \times 10^3}{5 \times 10^{-5}}$; = 2000Mpa, where Mpa is mega pascal

(b) Speed of sound in water is $v = \sqrt{\frac{K}{\rho}} = \sqrt{\frac{2000 \times 10^6}{1000}}$ = 1414 ms^{-1}

169. Suppose a man stands at a distance from a cliff and claps his hands. Hereceives an echo from the cliff after 4 second. Calculate the distance betweenthe man and the cliff. Assume the speed of sound to be 343 ms^{-1}.

Solution

The time taken by the sound to come back as echo is 2t = 4 ⇒t = 2 s
∴The distance is d = vt=(343 m s^{-1})(2 s) = 686 m.

170. The wavelength of two sine waves are λ_1= 1m and λ_2= 6m. Calculate the corresponding wave numbers.

Solution

$k_1 = \frac{2\pi}{1}$; k_1= 6.28 rad m^{-1} ; $k_2 = \frac{2\pi}{6}$; k_1= 1.05rad m^{-1}

171. A mobile phone tower transmits a wave signal of frequency 900MHz. Calculatethe length of the waves transmitted from the mobile phone tower.

Solution

Frequency, f = 900 MHz; = 900 x 10^6 Hz
The speed of wave is c = 3 × $10^8$$ms^{-1}$

$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{900 \times 10^6}$; = 0.33m

172. Two vibrating tuning forks produce waves whose equation is given by $y_1 = 5\sin(240\pi t)$ and $y_2 = 4\sin(244\pi t)$. Compute the number of beats persecond.

Solution

Given $y_1 = 5\sin(240\pi t)$ and $y_2 = 4\sin(244\pi t)$
Comparing with $y = A\sin(2\pi f_1 t)$, we get
$2\pi f_1 = 240\pi \Rightarrow f_1 = 120Hz$; $2\pi f_2 = 244\pi \Rightarrow f_2 = 122Hz$
The number of beats produced is $|f_1 - f_2| = |120 - 122| = |-2|$
=2 beats per sec

173. A baby cries on seeing a dog and the cry is detected at a distance of 3.0 msuch that the intensity of sound at this distance is 10^{-2} Wm^{-2}. Calculate theintensity of the baby's cry at a distance 6.0 m.

Solution

I_1 is the intensity of sound detected at a distance 3.0 m and it is given as 10^{-2} W m^{-2}.
Let I_2 be the intensity of sound detected at a distance 6.0 m. Then,
$r_1 = 3.0$ m, $r_2 = 6.0$ m and since, $I \propto \frac{1}{r^2}$
the power output does not depend on the observer and depends on the baby. Therefore, $\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$; $I_2 = I_1\frac{r_1^2}{r_2^2}$; $I_2 = 0.25 \times 10^{-2}$ Wm^{-2}

174. The sound level from a musical instrument playing is 50 dB. If three identicalmusical instruments are played together then compute the total intensity. The intensity of the sound from each instrument is 10^{-12} W m^{-2}

Solution

$\Delta L = 10\log_{10}\left[\frac{I_1}{I_0}\right] = 50$ dB ; $\log_{10}\left[\frac{I_1}{I_0}\right] = 5$ dB
$\frac{I_1}{I_0} = 10^5$; $I_1 = 10^5 I_0$; $= 10^5 \times 10^{-12}$ Wm^{-2}; $I_1 = 10^{-7}$ Wm^{-2}
Since three musical instruments are played, therefore $I_{total} = 3I_1 = 3\times10^{-7}$ Wm^{-2}

175. If a flute sounds a note with 450Hz, what are the frequencies of the second, third, and fourth harmonics of this pitch? If the clarinet sounds with a same note as 450Hz, then what are the frequencies of the lowest three harmonics produced?

Solution

For a flute which is an open pipe, we have
Second harmonics $f_2 = 2f_1 = 900$ Hz
Third harmonics $f_3 = 3f_1 = 1350$ Hz
Fourth harmonics $f_4 = 4f_1 = 1800$ Hz
For a clarinet which is a closed pipe, we have
Second harmonics $f_2 = 3f_1 = 1350$ Hz
Third harmonics $f_3 = 5f_1 = 2250$ Hz
Fourth harmonics $f_4 = 7f_1 = 3150$ Hz

176. If the third harmonics of a closed organ pipe is equal to the fundamental frequency of an open organ pipe, compute the length of the open organ pipe if the length of the closed organ pipe is 30 cm.

Solution

Let l_2 be the length of the open organ pipe, with l_1=30 cm the length of the closed organ pipe.

It is given that the third harmonic of closed organ pipe is equal to the fundamental frequency of open organ pipe.

The third harmonic of a closed organ pipe $f_2 = \frac{v}{\lambda_2} = \frac{3v}{4l_1}$; = $3f_1$

The fundamental frequency of open organ pipe is $f_1 = \frac{v}{\lambda_1} = \frac{v}{2l_2}$;

Therefore $\frac{v}{2l_2} = \frac{3v}{4l_1}$; $l_2 = \frac{2l_1}{3}$ = 20 cm

177. A frequency generator with fixed frequency of 343 Hz is allowed to vibrateabove a 1.0 m high tube. A pump is switched on to fill the water slowly in thetube. In order to get resonance, what must be the minimum height of thewater? (speed of sound in air is 343 m s^{-1})

Solution

The wavelength , $\lambda = \frac{C}{f}$; $\lambda = \frac{343 \text{ m}s^{-1}}{343 \text{ Hz}}$; = 1.0m

Let the length of the resonant columns be L_1, L_2 and L_3.

The first resonance occurs at length L_1. $L_1 = \frac{\lambda}{4} = \frac{1}{4}$ = 0.25 m

The second resonance occurs at length L_2. $L_2 = \frac{3\lambda}{4} = \frac{3}{4}$ = 0.75 m

The third resonance occurs at length L_3. $L_3 = \frac{5\lambda}{4} = \frac{5}{4}$ = 1.25 m and so on.

Since total length of the tube is 1.0 m the third and other higher resonances do not occur. Therefore, the minimum height of water H_{min} for resonance is, H_{min} = 1.0 m – 0.75 m = 0.25 m

178. A student performed an experiment to determine the speed of sound in airusing the resonance column method. The length of the air column thatresonates in the fundamental mode with a tuning fork is 0.2 m. If the lengthis varied such that the same tuning fork resonates with the first overtone at0.7 m. Calculate the end correction.

Solution

End correction e= $\frac{L_2 - 3L_1}{2}$; = $\frac{0.7 - 3\ (0.2)}{2}$; = 0.05 m

179. Consider a tuning fork which is used to produce resonance in an air column.A resonance air column is a glass tube whose length can be adjusted by avariable piston. At room temperature, the two successive resonancesobserved are at 20 cm and 85 cm of the column length. If the frequency ofthe length is 256 Hz, compute the velocity of the sound in air at roomtemperature.

Solution

Two successive length (resonance) to be L_1 = 20 cm and L_2 = 85 cm
The frequency is f = 256 Hz; v = f λ = 2f ΔL = 2f ($L_2 - L_1$)
= 2 × 256 × (85 − 20) × 10^{-2} m s^{-1}; v = 332.8 m s^{-1}

180. A sound of frequency 1500 Hz is emitted by a source which moves away froman observer and moves towards a cliff at a speed of 6 ms^{-1}.

(a) Calculate the frequency of the sound which is coming directly from thesource.

(b) Compute the frequency of sound heard by the observer reflected off thecliff. Assume the speed of sound in air is 330 ms^{-1}.

Solution

(a) Source is moving away and observer is stationary, therefore, the frequency of sound heard directly from source is

$$f' = \left[\frac{v}{v+v_S}\right] f = \left[\frac{330}{330+6}\right] \times 1500 = 1473 \text{ Hz}$$

(b) Sound is reflected from the cliff and reaches observer, therefore,

$$f' = \left[\frac{v}{v-v_S}\right] f = \left[\frac{330}{330-6}\right] \times 1500 = 1528 \text{ Hz}$$

181. An observer observes two moving trains, one reaching the station and otherleaving the station with equal speeds of 8 m s−1. If each train sounds itswhistles with frequency 240 Hz, then calculate the number of beats heard bythe observer.

Solution

Observer is stationary

(i) Source (train) is moving towards an observer:
The observed frequency due to train arriving station is

$$f_{in} = \left[\frac{v}{v-v_S}\right] f = \left[\frac{330}{330-8}\right] \times 240 = 246 \text{ Hz}$$

(ii) Source (train) is moving away from an observer:
The observed frequency due to train leaving station is

$$f_{out} = \left[\frac{v}{v+v_S}\right] f = \left[\frac{330}{330+8}\right] \times 240 = 234 \text{ Hz}$$

So the number of beats = $|f_{in} - f_{out}|$ = (246 – 234) = 12

EXERCISE PROBLEM

182. The speed of a wave in a certain medium is 900 m/s. If 3000 waves passesover a certain point of the medium in 2 minutes, then compute its wavelength?

Solution

Since 3000 waves passes over in 2 minutes (120 s), the number of waves passes per second is, $f = \frac{3000}{120}$; = 25 per second.

The wavelength $\lambda = \frac{v}{f} = \frac{900}{25}$; λ =36m

183. A ship in a sea sends SONAR waves straight down into the seawater from thebottom of the ship. The signal reflects from the deep bottom bed rock andreturns to the ship after 3.5 s. After the ship moves to 100 km it sends anothersignal which returns back after 2s. Calculate the depth of the sea in each caseand also compute the difference in height between two cases.

Solution

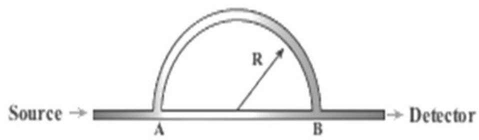
Depth at first place, $d_1 = \frac{v \times t_1}{2}$; $= \frac{1533 \times 3.5}{2}$; $= \frac{5365.5}{2}$; d_1 =2682.75m

Depth at second place, $d_2 = \frac{v \times t_2}{2}$; $= \frac{1533 \times 2}{2}$; $= \frac{5365.5}{2}$; d_2 =1533m

The difference in height between two cases $\Delta d = d_1 - d_2$

= 2682.75 – 1533 ;**Δd**= 1149.75m

184. A sound wave is transmitted into a tube asshown in figure. The sound waves splits intotwo waves at the point A which recombine atpoint B. Let R be the radius of the semi-circlewhich is varied until the first minimum. Calculate the radius of the semi-circle if the wavelength of the sound is 50.0m.



Solution

The length of semi-circle from A to B; $r_1 = \pi R$= 3.14R

The length of straight line from A to B; r_2 = 2R

Hence path difference, $\Delta r = r_1 - r_2$ = 3.14R– 2R

= R(3.14 − 2) = 1.14R

From the condition of minimum intensity,

$\Delta r = n\frac{\lambda}{2}$ (Here, n = 1, 3, 5,.......)

Hence condition for first minimum, $\Delta r = n\frac{\lambda}{2}$

(or) 1.14R = $\frac{\lambda}{2}$

$R = \frac{\lambda}{2 \times 1.14}$; $R = \frac{50}{2 \times 1.14}$; $= \frac{50}{2.28}$ R = 21.93m

No.	Log
50	1.6990
2.28	0.3579
(−)	1.3411
Antilog	2.193 x 10[1]

185. N tuning forks are arranged in order of increasing frequency and any two successive tuning forks give n beats per second when sounded together. If the last fork gives double the frequency of the first (called as octave), Show that the frequency of the first tuning fork is f = (N−1)n.

Solution

Number of tuning forks = N

Let f be the frequency of first tuning fork and 'n' be the number beats per second when two successive forks are sounding together, then the frequencies of N tuning forks in ascending order,

f, f$\pm$n, f$\pm$2n, f$\pm$3n, .. , 2 f

This is similar to the AP having 'n' number of terms

(i.e.) a, a+d, a+2d, a+3d,……

We know the nth term in AP is, $t_n = a + (n-1)d$

Here, the frequency of last tuning fork is 2f, *then*

2 f = f + $(\mathrm{N}-1)n$; 2 f − f = $(\mathrm{N}-1)\,n$; f = $(\mathrm{N} - \mathbf{1})\,\boldsymbol{n}$

186. Consider two organ pipes of same length in which one organ pipe is closed and another organ pipe is open. If the fundamental frequency of closed pipe is 250 Hz. Calculate the fundamental frequency of the open pipe.

Solution

The third harmonic of a closed organ pipe $f_c = \frac{v}{4L}$ ------------1

The fundamental frequency of open organ pipe is $f_0 = \frac{v}{2L}$ ----------2

Divide equation 2 by 1 $\frac{f_0}{f_c} = \frac{\left[\frac{v}{2L}\right]}{\left[\frac{v}{4L}\right]}$ = 2 $f_0 = 2f_c$ = 2 x 250 = 500Hz

187. A police in a siren car moving with a velocity 20 ms^{-1} chases a thief who is moving in a car with a velocity V_0 ms^{-1}. The police car sounds at frequency 300Hz, and both of them move towards a stationary siren of frequency 400Hz. Calculate the speed in which thief is moving. (Assume the thief does not observe any beat)

Solution

Velocity of sound v =330 m/s

Velocity of a police siren car v_s=20 m/s

Frequency of a police siren car f =300Hz

Frequency of police siren heard by thief is

$f_1 = \left[\frac{v - v_0}{v - v_s}\right] f; = \left[\frac{330 - v_0}{330 - 20}\right] \text{x } 300 \; ; = \left[\frac{330 - v_0}{310}\right] \text{x } 300$

Frequency of stationary siren f =400Hz

Frequency of stationary siren heard by thief

$$f_2 = \left[\frac{v + v_0}{v}\right] f; = \left[\frac{330 + v_0}{330}\right] x\, 400$$

It there are no beats then $f_1 = f_2$

$$\left[\frac{330 - v_0}{310}\right] x\, 300 = \left[\frac{330 + v_0}{330}\right] x\, 400$$

$$(330 - v_0)\, x\, 0.9677 = (330 + v_0)\, x\, 1.2121$$

$$319.341 - 0.9677v_0 = 399.993 + 1.2121v_0$$

$$1.2121v_0 + 0.9677v_0 = 319.341 - 399.993$$

$2.1798v_t = -80.652$; $v_0 = \frac{80.652}{2.1798}$; $= 36.99\boldsymbol{v_0} = 37 m/s$

PRACTICAL HAND BOOK

HIGHER SECONDARY
FIRST YEAR

இயற்பியல்
PHYSICS

PREPARED BY

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2024 - 2025

INSTRUCTIONS TO STUDENTS

01. Before coming to the laboratory, a student should plan the experiment in advance by consulting with his / her friends and reading this book.

02. As separate observation Note Book must be used and everything regarding the experiment **must be written before coming to the laboratory.**

03. Write the date, experiment number, aim, apparatus required, formula, procedure and result in the right-hand page and diagram (Ray diagrams, and Circuit diagrams), tabulations, observations and calculations, in the **left-hand page of the observation note book / record note book.**

04. After the completion of experiment with all observations in the laboratory, the **student should get the signature of the teacher. Within three days** of the experiment the **student should complete the calculations** and **get the signature of the teacher.**

05. Enter the observed reading with the relevant units (gram, cm, mm...) but the **final calculation must be done with SI units only**. The result must be given with proper SI Unit.

PHYSICS PRACTICAL – SCHEME OF EVALUATION

Internal Assessment	: 15 Marks
External Examination	: 15 Marks
Total Marks	:30 Marks

Internal Assessment (15)

(Teacher should maintain the Assessment Register and the Head of the Institution should monitor it)

Attendance (Above 80.01%)	:	02 Marks
Test	:	04 Marks
Assignment	:	02 Marks
Performance (while doing the experiment In the laboratory	:	02 Marks
Record Note Book	:	03 Marks
Co-curricular Activities	:	02 Marks

External Examination (15)

01. Formula (mere expression –1, explanation of notations –1)	:	02 Marks
02. Brief Procedure	:	03 Marks
03. Observations	:	05 Marks
04. Calculations (Including graphs)	:	04 Marks
05. Result (Correct Value –½ Mark, Mentioning SI Unit – ½ Mark)	:	01 Mark

LIST OF EXPERIMENTS

1. Moment of Inertia of solid sphere of known mass using Vernier Caliper.
2. Non-uniform bending – verification of relation between the load and the depression using pin and microscope.
3. Spring constant of a spring.
4. Acceleration due to gravity using Simple Pendulum.
5. Velocity of sound in air using resonance column.
6. Viscosity of a liquid by Stoke's method.
7. Surface tension by capillary rise method.
8. Verification of Newton's law of cooling using calorimeter.
9. Study of relation between the frequency and length of a given wire under constant tension using sonometer.
10. Study of relation between length of a given wire and tension for constant frequency using sonometer
11. Verification of parallelogram law of forces (Demonstration only. Not for examination)
12. Determination of density of a material of wire using screw gauge and physical balance (Demonstration only- Not for examination).

Expt. No. : 1 Date:

MOMENT OF INERTIA OF A SOLID SPHERE OF KNOWN MASS USING VERNIER CALIPER

Aim

To determine the moment of inertia of a solid sphere of known mass using Vernier caliper

Apparatus Required

Vernier caliper, Solid sphere

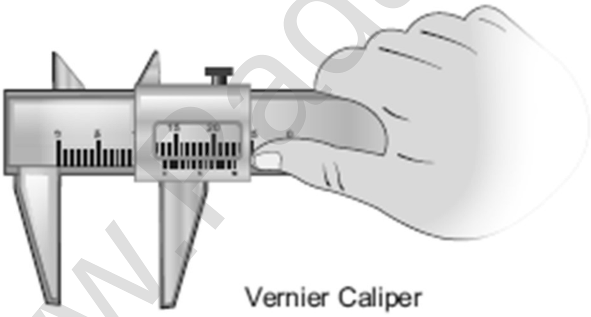
Formula

Moment of inertia of a solid sphere about its diameter $I_d = \frac{2}{5} MR^2$ (Kgm^2)

Where M → Mass of the sphere (known value to be given) in kg

R → Radius of the sphere in metre

Diagram



Vernier Caliper

(a) No error (b) +ve error of +0.03 cm (c) –ve error of -0.06 cm

(d) Vernier reading

A model reading
MSR = 2.2 cm ; VSC = 4 divisions;
Reading = [2.2 cm+(4x0.01cm)] = 2.24 cm

Procedure

1. The Vernier caliper is checked for zero errors and error if found is to be noted.
2. The sphere is kept in between the jaws of the Vernier caliper and the main scale reading (MSR) is noted.
3. Vernier scale division which coincides with some main scale division (VSC) is noted. Multiply this VSC by least count (LC) gives Vernier scale reading VSR).
4. Add MSR with VSR. This will be the diameter of the sphere.
5. Observations are to be recorded for different positions of the sphere and the average value of the diameter is found. From this value radius of the sphere R is calculated.
6. Using the known value of the mass of the sphere M and calculated radius of the sphere R the moment of inertia of the given sphere about its diameter can be calculated using the given formula.

Least Count (LC)

$$\text{Least Count (LC)} = \frac{\text{1 Main Scale Division (MSD)}}{\text{Total Vernier scale divisions}}$$

One main scale division (MSD) = 0.1cm
Number of Vernier scale division = 10
The length of the vernier scale = 0.9cm
L.C = 1 MSD – 1 VSD = 0.01cm

Observations

Zero Error: No Error

Zero Correction: No Correction

S. No.	MSR $\times 10^{-2}$m	Vernier coincidence VSC (div)	VSR = (VSC x LC) $\times 10^{-2}$m	TR = (MSR + VSR) $\times 10^{-2}$m	Diameter of the Sphere (2R) = (TR $\pm$ ZC) $\times 10^{-2}$m
01	1.9	10	0.10	2.0	2.0
02	1.9	10	0.10	2.0	2.0
03	1.9	10	0.10	2.0	2.0
04	1.9	10	0.10	2.0	2.0
05	1.9	10	0.10	2.0	2.0
06	1.9	10	0.10	2.0	2.0

Mean Diameter (2R) : 2.0 $\times 10^{-2}$m
Radius of the sphere (R) : 1.0$\times 10^{-2}$m

Calculation

Mass of the sphere M = 27.75×10^{-3} kg (Known value is given)

Radius of the sphere R =. 1.0×10^{-2}m

S. No. 1: Diameter of the Sphere (2R) = MSR + (VSR x LC) 10^{-2}m

= 1.9 + (0.10) ; 2R = 2.0×10^{-2}m

S. No. 2: Diameter of the Sphere (2R) = MSR + (VSR x LC) 10^{-2}m

= 1.9 + (0.10) ; 2R = 2.0×10^{-2}m

S. No. 3: Diameter of the Sphere (2R) = MSR + (VSR x LC) 10^{-2}m

= 1.9 + (0.10) ; 2R = 2.0×10^{-2}m

S. No. 4: Diameter of the Sphere (2R) = MSR + (VSR x LC) 10^{-2}m

= 1.9 + (0.10) ; 2R = 2.0×10^{-2}m

S. No. 5: Diameter of the Sphere (2R) = MSR + (VSR x LC) 10^{-2}m

= 1.9 + (0.10) ; 2R = 2.0×10^{-2}m

S. No. 6: Diameter of the Sphere (2R) = MSR + (VSR x LC) 10^{-2}m

= 1.9 + (0.10) ; 2R = 2.0×10^{-2}m

Moment of inertia of a solid sphere about its diameter $I_d = \frac{2}{5} MR^2$

$$I_d = \frac{2}{5} \times (27.75 \times 10^{-3} \times (1\times10^{-2})^2$$

$$= \frac{2}{5} \times 27.75 \times 10^{-3} \times 1\times10^{-4}$$

$$= 0.4 \times 27.75 \times 10^{-7}$$

$$I_d = 11.1 \times 10^{-7} kgm^2$$

Result

The moment of inertia of the given solid sphere about its diameter using Vernier caliper **$I_d = 11.1 \times 10^{-7} kgm^2$**

Expt. No. : 2 Date:

NON – UNIFORM BENDING – VERIFICATION OF RELATION BETWEEN LOAD AND DEPRESSION USING PIN AND MICROSCOPE

Aim

To verify the relation between the load and depression using non-uniform bending of a beam.

Apparatus Required

A long uniform beam (usually a metre scale), two knife – edge supports, mass hanger, slotted masses, pin, Vernier microscope

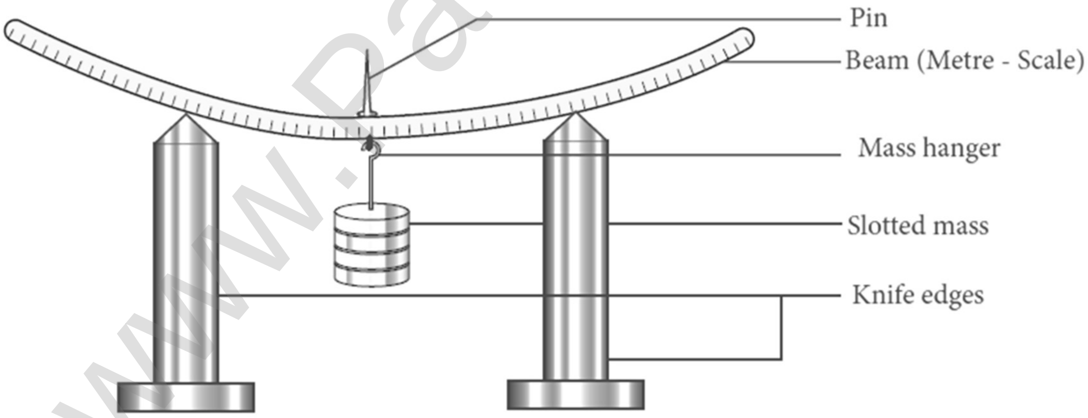
Formula

$\frac{M}{S}$ = a constant

where M ⟶ Load applied (mass) (kg)

s ⟶ depression for the applied load(metre)

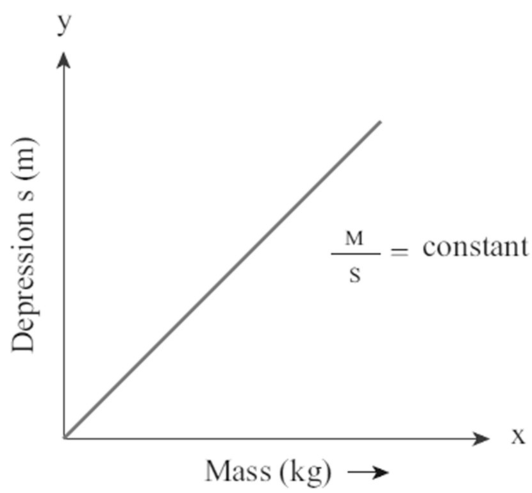
Diagram



Model Graph

Load (M) vs Depression (s)

A graph between M and s can be drawn by taking M along X- axis and s along Y – axis. This is a straight line.



Procedure

1. Place the two knife – edges on the table.
2. Place the uniform beam (metre scale) on top of the knife edges.
3. Suspend the mass hanger at the centre. A pin is attached at the centre of the scale where the hanger is hung.
4. Place a vernier microscope in front of this arrangement
5. Adjust the microscope to get a clear view of the pin
6. Make the horizontal cross-wire on the microscope to coincide with the tip of the pin. (Here mass hanger is the dead load M).
7. Note the vertical scale reading of the vernier microscope
8. Add the slotted masses to the mass hanger one by one in steps of 0.05 kg (50 g) and corresponding readings are noted down.
9. Repeat the experiment by removing masses one by one and note down the corresponding readings.
10. Subtract the mean reading of each load from dead load reading. This gives the depressions for the corresponding load M.

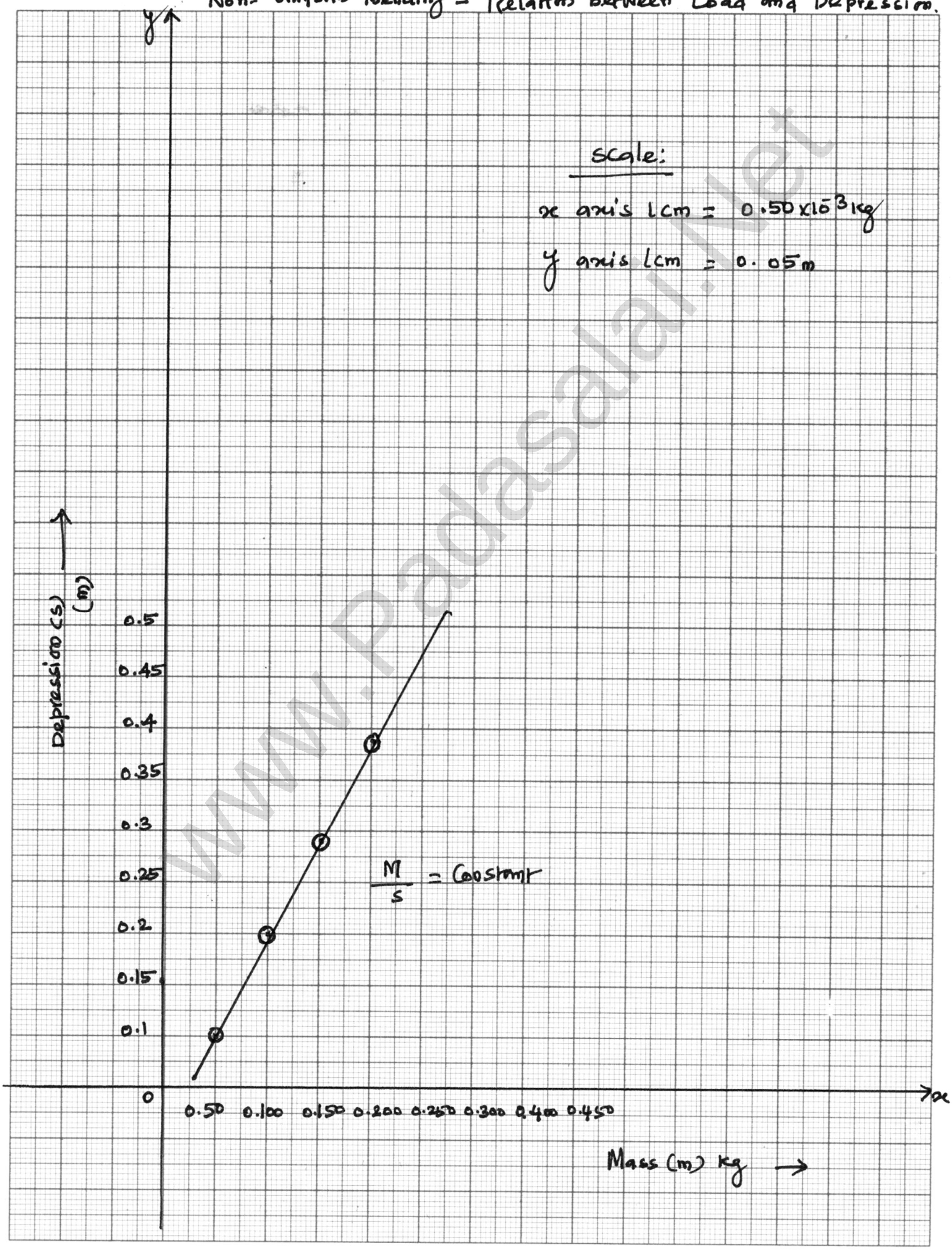
Observations

To find $\frac{M}{S}$

S. No.	Load (M) 10^{-3} (kg)	Microscope Reading (10^{-2}m)			Depression for M (kg)	$\frac{M}{S}$ (kgm^{-1})
		Increasing Load	Decreasing Load	Mean		
01	50	9.413	9.381	9.397	-	-
02	100	9.314	9.290	9.302	0.095	52.63
03	150	9.237	9.186	9.211	0.186	53.76
04	200	9.109	9.109	9.109	0.288	52.08
05	250	9.019	9.019	9.019	0.378	52.91

Mean $\frac{M}{S}$ = 52.85 kgm^{-1}

Non-uniform Bending - Relation between Load and Depression.



Calculation

(i) $\frac{M}{S} = \frac{0.05}{0.00095}$ = 52.63 kgm^{-1}

(ii) $\frac{M}{S} = \frac{0.100}{0.00186}$ = 53.76 kgm^{-1}

(iii) $\frac{M}{S} = \frac{0.150}{0.00288}$ = 52.08 kgm^{-1}

(iv) $\frac{M}{S} = \frac{0.200}{0.00378}$ = 52.91 kgm^{-1}

Result

The ratio between mass and depression for each load is calculated. This is found to be constant.

Thus the relation between load and depression is verified by the method of non-uniform bending of a beam.

Expt. No. : 3 Date:

SPRING CONSTANT OF A SPRING

Aim

To determine the spring constant of a spring by using the method of vertical oscillations

Apparatus Required

Spring, rigid support, hook, 50 g mass hanger, 50 g slotted masses, stop clock, metre scale, pointer

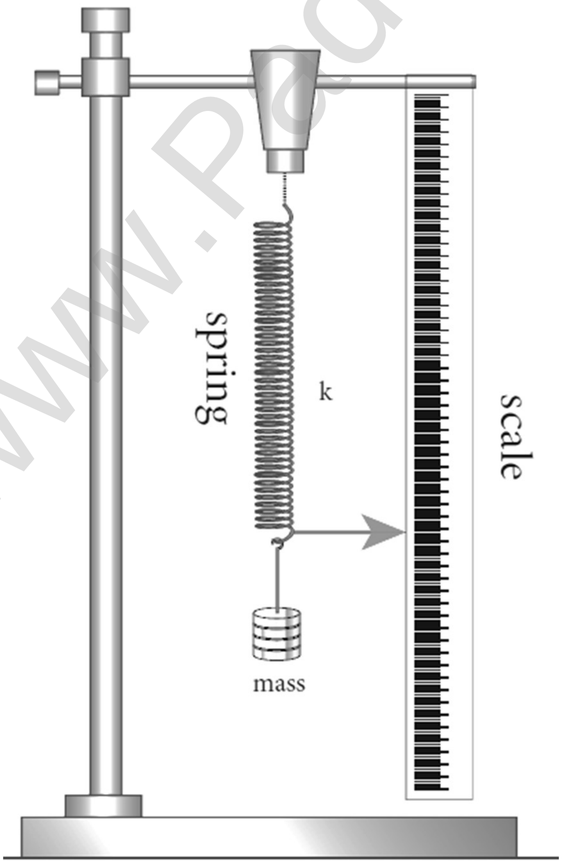
Formula

Spring constant of the spring $K = 4\pi^2 \left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right) kgs^{-2}$

where M_1, M_2 → selected loads in kg

T_1, T_2 → time period corresponding to masses M_1 and M_2 respectively in second

Diagram



Procedure:

1. A spring is firmly suspended vertically from a rigid clamp of a wooden stand at its upper end with a mass hanger attached to its lower end. A pointer fixed at the lower end of the spring moves over a vertical scale fixed.
2. A suitable load M (eg; 100 g) is added to the mass hanger and the reading on the scale at which the pointer comes to rest is noted. This is the equilibrium position.
3. The mass in the hanger is pulled downward and released so that the spring oscillates vertically on either side of the equilibrium position.
4. When the pointer crosses the equilibrium position a stop clock is started and the time taken for 20 vertical oscillations is noted. Then the period of oscillation T is calculated.
5. The experiment is repeated by adding masses in steps of 50 g to the mass hanger and period of oscillation at each time is calculated.
6. For the masses M_1 and M_2 (with a difference of 50 g), their corresponding time periods are T_1 and T_2. Then the value $\frac{M_2-M_1}{T_2^2-T_1^2}$ is calculated and its average is found.
7. Using the given formula the spring constant of the given spring is calculated

Observations

S. No.	Mass M x 10^{-3}kg	Time Taken for 20 Oscillations (t) (Sec)			Period of oscillation T $= \frac{t}{20}$ (s)	T^2 (s^2)	$\frac{M_2 - M_1}{T_2^2 - T_1^2}$ x 10^{-3} kgs^{-2}
		Trial 1 (s)	Trial 2 (s)	Mean (s)			
01	150	16.5	16.5	16.5	0.825	0.681	-----
02	200	18.5	18.5	18.5	0.925	0.856	0.286
03	250	20.5	20.5	20.5	1.025	1.05	0.258
04	300	22.5	22.5	22.5	1.125	1.26	0.238
05	350	24.0	24.0	24.0	1.200	1.44	0.278

Mean $\frac{M_2-M_1}{T_2^2-T_1^2}$ = 0.265 kgs^{-2}

Calculations

$\left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right) = \frac{(200-150)X10^{-3}}{0.856 - 0.681}$ $\frac{0.050}{0.175}$ = 0.286 kgs^{-2}	$\left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right) = \frac{(250-200)X10^{-3}}{1.05 - 0.856}$ $\frac{0.050}{0.194}$ = 0.258 kgs^{-2}
$\left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right) = \frac{(300-250)X10^{-3}}{1.26 - 1.05}$ $\frac{0.050}{0.210}$ = 0.238 kgs^{-2}	$\left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right) = \frac{(350-300)X10^{-3}}{1.44 - 1.26}$ $\frac{0.050}{0.18}$ = 0.278 kgs^{-2}
$\left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right) = \frac{0.286 + 0.258 + 0.238 + 0.278}{4}$ $\frac{1.060}{4}$ = 0.265 kgs^{-2}	Spring constant of a spring $K = 4\pi^2 \left(\frac{M_2 - M_1}{T_2^2 - T_1^2}\right)$ = 4 x 3.14 x 3.14 x 0.265x10^{-3} K = 10.45 kgs^{-2}

Result

The spring constant of the given spring K = 10.45 kgs^{-2}

Expt. No. : 4 Date:

ACCELERATION DUE TO GRAVITY USING SIMPLE PENDULUM

Aim

To measure the acceleration due to gravity using a simple pendulum.

Apparatus Required

Retort stand, pendulum bob, thread, meter scale, stop watch.

Formula

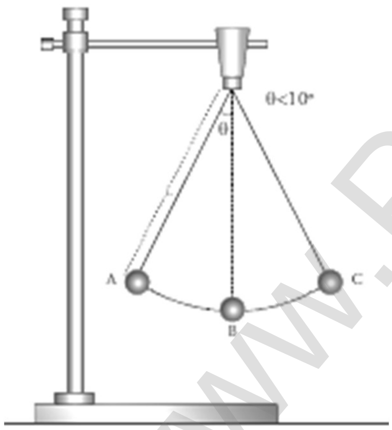
Acceleration due to gravity $g = 4\pi^2 \frac{L}{T^2}$ ms^{-2}

where T ⟶ Time period of simple pendulum (second)

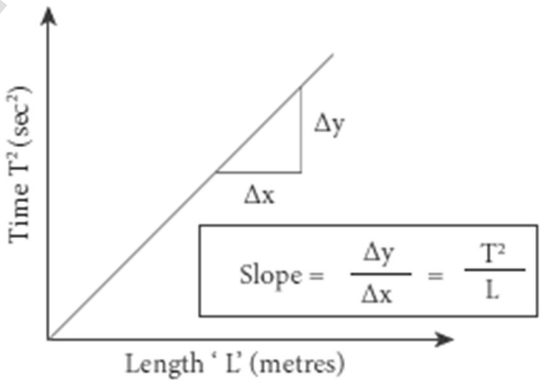
g ⟶ Acceleration due to gravity (metre sec^{-2})

L ⟶ Length of the pendulum (metre)

Diagram



Model Graph



Procedure

1. Attach a small brass bob to the thread.
2. Fix this thread on to the stand.
3. Measure the length of the pendulum from top of the suspension hook to the middle of the bob of the pendulum. Record the length of the pendulum in the table given below.
4. Note down the time (t) taken for 10 oscillations using stop watch.
5. The period of oscillation $T = \frac{t}{10}$ is calculated.
6. Repeat the experiment for different lengths of the pendulum 'L'.

Find acceleration due to gravity g using the given formula.

Observations

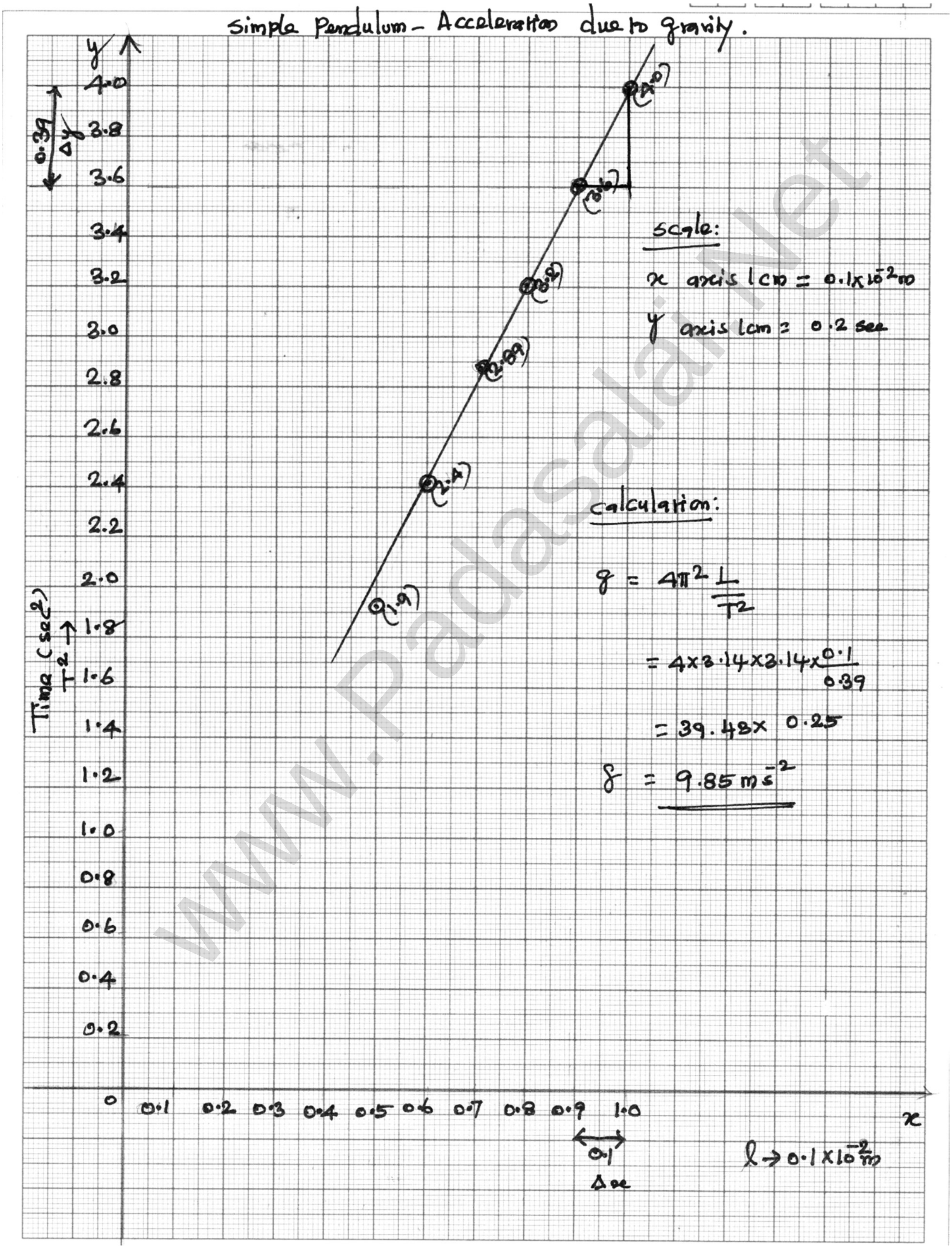
To find the acceleration due to gravity 'g'

S. No.	Length of Simple Pendulum L (metre)	Time Taken for 10 Oscillations t (s)			Period of oscillation $T = \frac{t}{10}$ (s)	T^2 (s^2)	$g = 4\pi^2 \frac{L}{T^2}$ ms^{-2}
		Trial 1 (s)	Trial 2 (s)	Mean (s)			
01	0.5	14	14	14	1.40	1.96	10.05
02	0.6	15	16	15.5	1.55	2.40	9.85
03	0.7	17	17	17	1.70	2.89	9.55
04	0.8	18	18	18	1.80	3.24	9.74
05	0.9	19	19	19	1.90	3.61	9.83
06	1.0	20	20	20	2.00	4.00	9.86

Mean: g= 9.81ms^{-2}

Calculation

$g = 4\pi^2 \frac{L}{T^2} = \frac{4 \times 3.14 \times 3.14 \times 0.50}{1.96}$ $g = \frac{19.71}{1.96}$; g = 10.05ms^{-2}	$g = 4\pi^2 \frac{L}{T^2} = \frac{4 \times 3.14 \times 3.14 \times 0.60}{2.40}$ $g = \frac{23.66}{2.40}$; g = 9.85ms^{-2}
$g = 4\pi^2 \frac{L}{T^2} = \frac{4 \times 3.14 \times 3.14 \times 0.70}{2.89}$ $g = \frac{27.61}{2.89}$; g= 9.55 ms^{-2}	$g = 4\pi^2 \frac{L}{T^2} = \frac{4 \times 3.14 \times 3.14 \times 0.80}{3.24}$ $g = \frac{31.55}{3.24}$; g= 9.74 ms^{-2}
$g = 4\pi^2 \frac{L}{T^2} = \frac{4 \times 3.14 \times 3.14 \times 0.90}{3.61}$ $g = \frac{35.50}{3.61}$; g= 9.83 ms^{-2}	$g = 4\pi^2 \frac{L}{T^2} = \frac{4 \times 3.14 \times 3.14 \times 1}{4.00}$ $g = \frac{39.44}{4.00}$; g= 9.86 ms^{-2}



Result

The acceleration due to gravity 'g' determined using simple pendulum is

i) By calculation g = 9.78ms^{-2} ii) By graph g = 9.85ms^{-2}

Expt. No. : 5 Date:

VELOCITY OF SOUND IN AIR USING RESONANCE COLUMN

Aim

To determine the velocity of sound in air at room temperature using the resonance column.

Apparatus Required

Resonance tube, three tuning forks of known frequencies, a rubber hammer, one thermometer, plumb line, set squares, water in a beaker.

Formula

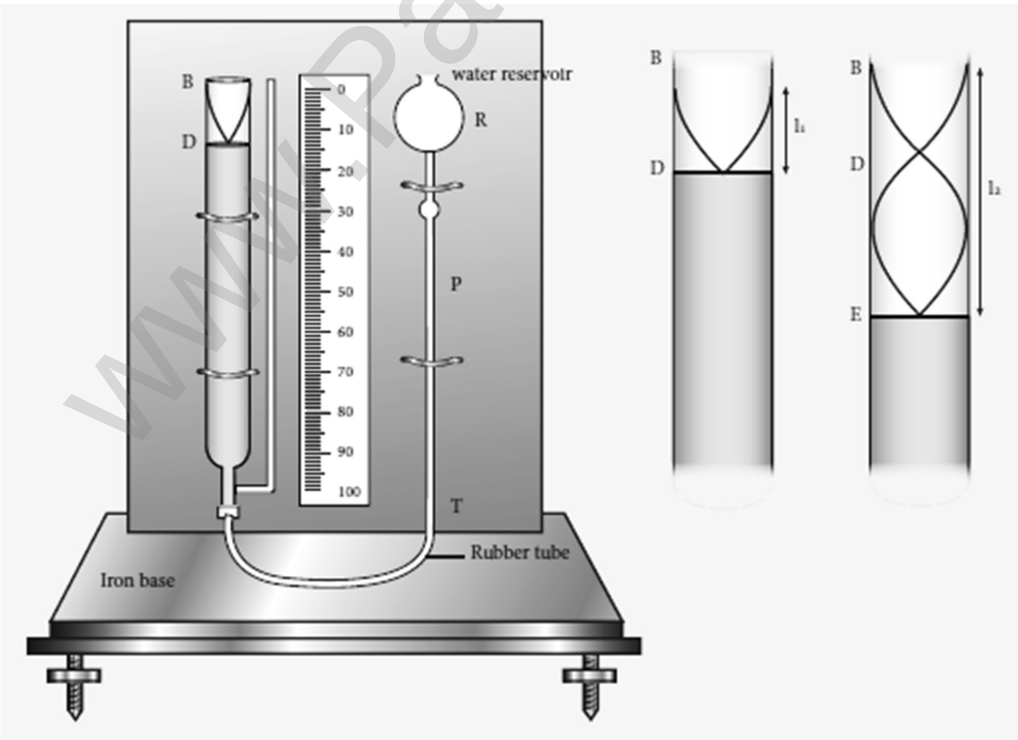
$V = 2\nu (l_2 - l_1)$ m s^{-1}

where V ⟶ Speed of sound in air (m s^{-1})

l_2, l_1⟶The length of the air column for the first and second resonance respectively (m)

ν ⟶ Frequency of the tuning fork (Hz)

Diagram



Procedure

1. Adjust the position of the resonance tube, so that the length of air column inside the tube is very small.
2. Take a tuning fork of known frequency and strike it with a rubber hammer. The tuning fork now produces longitudinal waves with a frequency equal to the natural frequency of the tuning fork.
3. Place the vibrating tuning fork horizontally at the open end of the resonance tube. Sound waves pass down the total tube and reflect back at the water surface.
4. Length of the water column in the tube is adjusted either by lowering or raising the reservoir or the tube, until a maximum sound(resonance) occurs.
5. Measure the length of air column at this position. This is taken as the first resonating length, l_1
6. Then raise the tube approximately about two times the first resonating length. Excite the tuning fork again and place it on the open end of the tube.
7. Adjust the height of the air column until the maximum sound is heard.
8. Measure the length of air column at this position. This is taken as the second resonating length l_2
9. We can now calculate the velocity of sound in air at room temperature by using the relation. V = $2v(l_2 - l_1)$
10. Repeat the experiment with tuning forks of different frequency and tabulate the corresponding values of $l_1$and l_2
11. The mean of the calculated values will give the velocity of sound in air at room temperature.

Observations

S. No	Frequency of tuning fork v (Hz)	First resonating length l_1 (x10^{-2}m)			Second resonating length l_2 (x10^{-2}m)			$l_2 - l_1$ (x10^{-2}m)	V = $2v\ (l_2 - l_1)$ms^{-1}
		Trial 1	Trail 2	Mean	Trial 1	Trail 2	Mean		
01	512	13.2	13.2	13.2	46.0	46.0	46.0	0.328	335.9
02	480	17.3	17.3	17.3	51.6	51.6	51.6	0.343	329.3
03	426	17.6	17.6	17.6	55.6	55.6	55.6	0.38	323.8

Mean V = 329.7 m s^{-1}

Calculation

1) V = $2v(l_2 - l_1)$ms^{-1}
= 2 x 512 x 0.328
V = 335.9 ms^{-1}

2) V = $2v(l_2 - l_1)$ms^{-1}
= 2 x 480 x 0.343
V = 329.3 ms^{-1}

3) V = $2v(l_2 - l_1)$ms^{-1}
= 2 x 426 x 0.380
V = 323.8 ms^{-1}

Mean (V) = $\frac{(335.9+329.3+323.8)}{3}$ = 329.7ms^{-1}

Result

Velocity of sound in air at room temperature, (V) = 329.7 m s^{-1}

Expt. No. : 6 Date:

VISCOSITY OF A LIQUID BY STOKE'S 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

$\eta = \frac{2r^2(\delta-\sigma)g}{9V}$ Nsm^{-2}

where η- Coefficient of viscosity of liquid (Nsm^{-2})

r ⟶ radius of spherical ball (m)

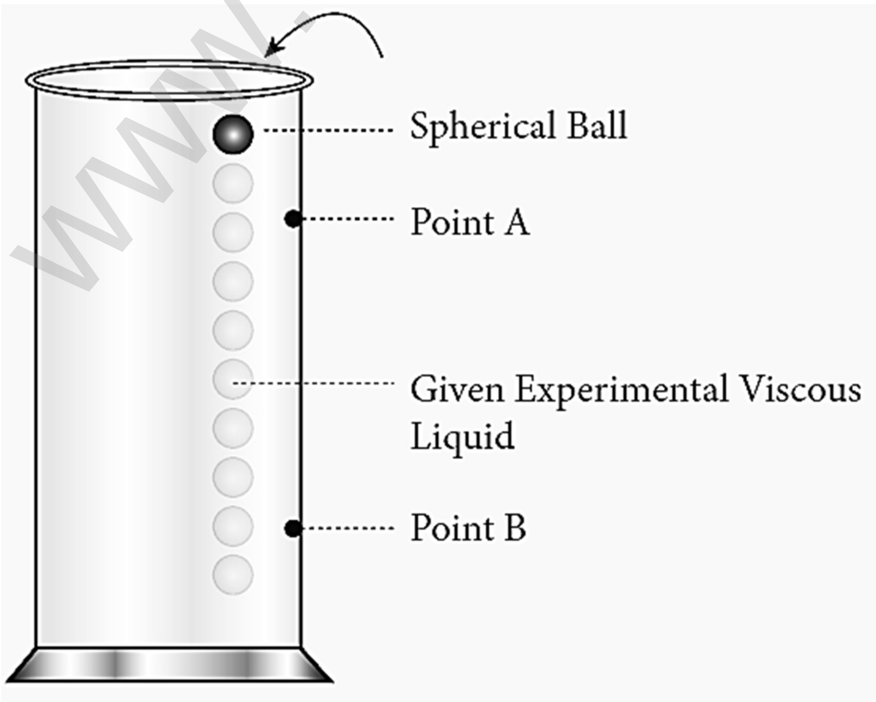
δ ⟶ density of the steel sphere (kgm^{-3})

σ ⟶ density of the liquid (kgm^{-3})

g ⟶ acceleration due to gravity (9.8 ms^{-2})

V ⟶ mean terminal velocity (ms^{-1})

Diagram



Procedure

1. A long cylindrical glass jar with markings is taken.
2. Fill the glass jar with the given experimental liquid.
3. 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.
4. The radius of the metal spherical ball is determined using screw gauge.
5. The spherical ball is dropped gently into the liquid.
6. Start the stop clock when the ball crosses the point A. Stop the clock when the ball reaches B and note down the time 't'.
7. Note the distance between A and B and use it to calculate terminal velocity.
8. Now repeat the experiment for different distances between A and B. Make sure that the point A is suitable for the ball to acquire terminal velocity.

Observations

Distance covered by the spherical ball (d) = 0.325(m)

Radius of spherical ball (r) = 5.5×10^{-3}m

To find the terminal velocity:

S. No.	**Distance covered by the spherical ball (d) (m)**	**Time taken t (s)**	**Terminal velocity (V) = $\frac{d}{t}$ ms^{-1}**
01	0.325	1.062	0.306
02	0.325	1.091	0.297
03	0.325	1.045	0.311
04	0.325	1.089	0.298
05	0.325	1.069	0.304
06	0.325	1.057	0.307

Average: V = 0.304 ms-1

Calculation

$$\eta = \frac{2r^2(\delta - \sigma)g}{9V} \text{Nsm}^{-2}$$

$$= \frac{2 \text{ x} (5.5 \text{ x } 10^{-3})^2 \text{ x } (7860 - 1260) \text{ x } 9.8}{9 \text{ x } 0.304}$$

$$= \frac{2 \text{ x } 30.25 \text{ x } 10^{-6} \text{ x } 6600 \text{ x } 9.8}{2.736}$$

$$= \frac{3913140 \text{ x } 10^{-6}}{2.736}$$

$$= \frac{3.913}{2.736}$$

η = 1.43Nsm^{-2}

Result

The coefficient of viscosity of the given liquid by stoke's method

η = 1.43 Nsm^{-2}

Expt. No. : 7 Date:

SURFACE TENSION BY CAPILLARY RISE METHOD

Aim

To determine surface tension of a liquid by capillary rise method.

Apparatus Required

A beaker of Water, capillary tube, vernier microscope, two holed rubber stopper, a knitting needle, a short rubber tubing and retort clamp.

Formula

The surface tension of the liquid $T = \frac{rh\rho g}{2} Nm^{-1}$

Where T ⟶ Surface tension of the liquid (Nm^{-1})

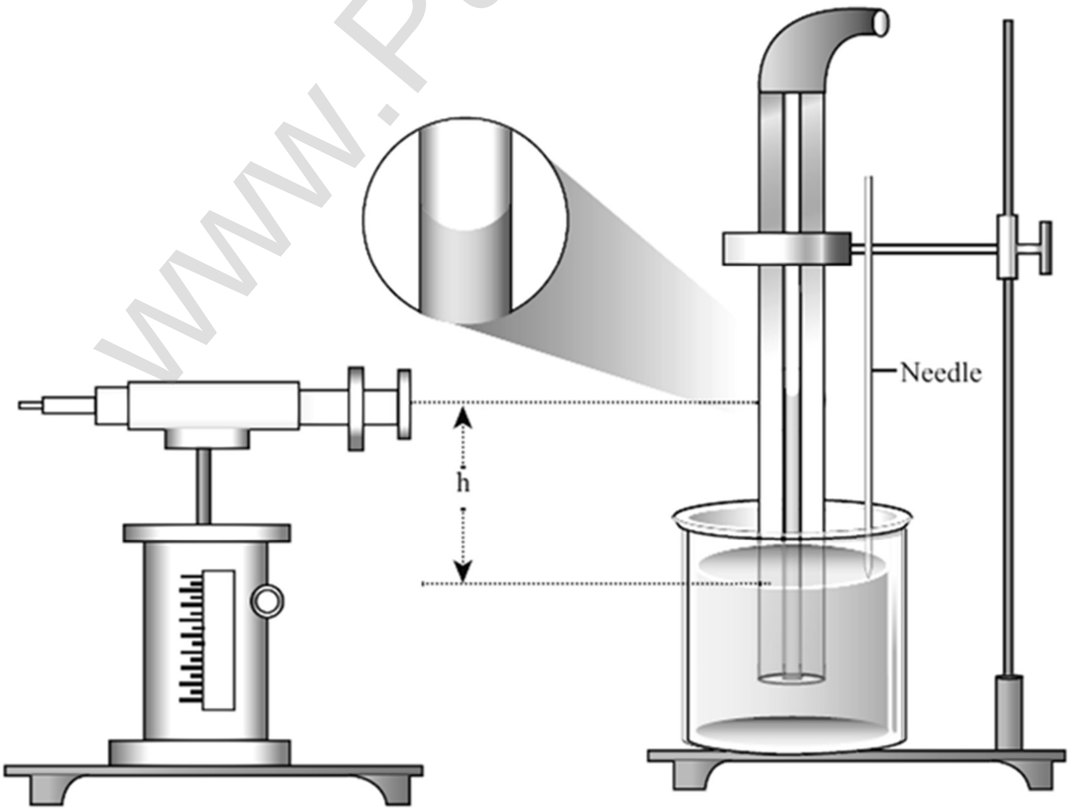
h ⟶ height of the liquid in the capillary tube (m)

r ⟶ radius of the capillary tube (m)

σ ⟶ Density of water ($kg\ m^{-3}$) (σ = 1000 kgm^{-3})

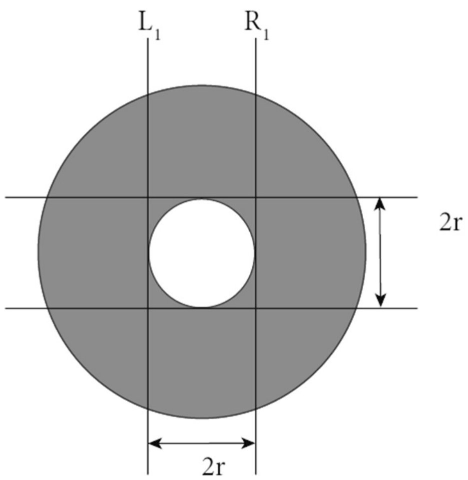
g ⟶ Acceleration due to gravity (g = 9.8 ms^{-2})

Diagram



Procedure

1. A clean and dry capillary tube is taken and fixed in a stand
2. A beaker containing water is placed on an adjustable platform and the capillary tube is dipped inside the beaker so that a little amount of water is raised inside.
3. Fix a needle near the capillary tube so that the needle touches the water surface
4. A Vernier microscope is focused at the lower meniscus of the water and the corresponding reading is taken after coinciding it with the horizontal line of the cross wire.
5. Tip of the needle is focused using vernier microscope after coinciding it with horizontal line of the cross wire
6. The difference between the two readings of the vertical scale gives the height (h) of the liquid raised in the capillary tube.
7. Now to find the radius of the tube, raise the capillary tube and remove the beaker. Carefully rotate the capillary tube so that the immersed lower end face towards you.
8. Focus the capillary tube using Vernier microscope to clearly see the inner walls of the tube.
9. Let the vertical cross wire coincide with the left side inner walls of the tube. Note down the reading (L_1)
10. Turn the microscope screws in horizontal direction to view the right side inner wall of the tube. Note the reading (R_1). Thus the radius of the tube can be calculated as $\frac{1}{2}(L_1 - R_1)$
11. Finally calculate the surface tension using the given formula.



Observations

To measure height of the liquid (h)

S. No.	Microscope Reading								Height of the liquid h $\times 10^{-2}$ m
	For the position of lower meniscus of liquid				For the position of lower tip of the needle				
	MSR $\times 10^{-2}$ m	VC (Div.)	VSR $\times 10^{-2}$ m	TR = MSR + VSR (a) $\times 10^{-2}$ m	MSR $\times 10^{-2}$ m	VC (Div.)	VSR $\times 10^{-2}$ m	TR = MSR + VSR (b) $\times 10^{-2}$ m	
01	5.15	39	0.039	5.189	4.05	16	0.016	4.066	1.123
02	5.30	26	0.26	5.326	4.15	5	0.005	4.155	1.171
03	5.65	4	0.004	5.654	4.50	49	0.049	4.549	1.105

Mean h = 1.133 $\times 10^{-2}$m

Radius of the capillary tube

S. No	Microscope Reading								Radius of the capillary tube. r = $\frac{1}{2}(l_1 - R_1)$
	For the position of inner left wall of the tube l_1				For the position of inner right wall of the tube R_1				
	MSR $\times 10^{-2}$ m	VC (Div.)	VSR $\times 10^{-2}$ m	TR = MSR + VSR (a) $\times 10^{-2}$ m	MSR $\times 10^{-2}$ m	VC (Div.)	VSR $\times 10^{-2}$ m	TR = MSR + VSR (b) $\times 10^{-2}$ m	
01	4.50	6	0.006	4.506	4.25	30	0.03	4.280	0.113
02	10.30	4	0.004	10.304	10.05	15	0.015	10.065	0.1195

Radius r = 0.116$\times 10^{-2}$m

Calculation

Radius of the capillary tube r = 0.116×10^{-2} m

Density of the liquid σ = 1000 kg m^{-3}

Acceleration due to gravity g = 9.8 m s^{-2}

The surface tension of the liquid T = $\frac{rh\rho g}{2}$ Nm^{-1}

Surface Tension T = $\frac{rh\rho g}{2}$

$= \frac{0.116 \text{ X } 10^{-2} \text{ X } 1.133 \text{ X } 10^{-2} \text{ X } 1000 \text{ X } 9.8}{2}$

$= \frac{128.79 \text{ X } 10^{-3}}{2}$

T = 64.39×10^{-3} Nm^{-1}

Result

Surface tension of the given liquid by capillary rise method

T = 64.39×10^{-3} Nm^{-1}

Expt. No. : 8 Date:

VERIFICATION OF NEWTON'S LAW OF COOLING USING CALORIMETER

Aim

To study the relationship between the temperature of a hot body and time by plotting a cooling curve.

Apparatus Required

Copper calorimeter with stirrer, one holed rubber cork, thermometer, stop clock, heater / burner, water, clamp and stand

Newton's Law of Cooling

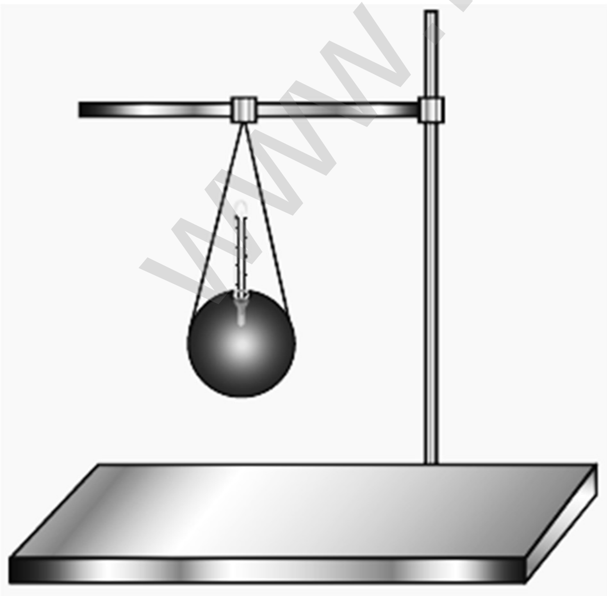
Newton's law of cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature. (i.e., the temperature of its surroundings)

$\frac{dT}{dt} \propto (T - T_0)$ where $\frac{dT}{dt} \longrightarrow$ Rate of change of temperature (°C)

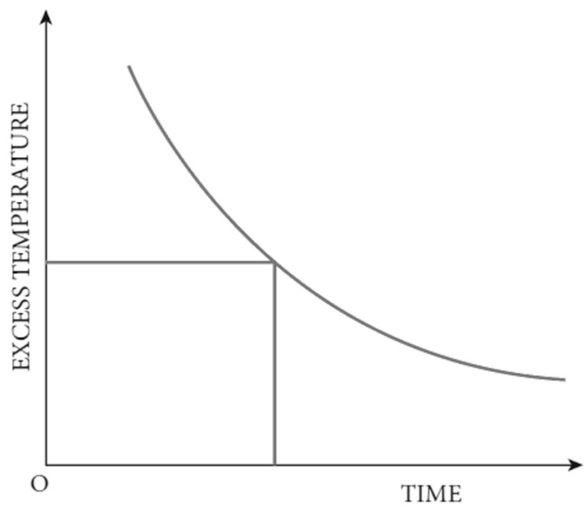
$T \longrightarrow$ Temperature of water (°C)

$T_0 \longrightarrow$ Room Temperature (°C)

Diagram



Model Graph



Procedure

1. Note the room temperature as (T_0) using the thermometer.
2. Hot water about 90°C is poured into the calorimeter.
3. Close the calorimeter with one holed rubber cork.
4. Insert the thermometer into calorimeter through the hole in rubber cork.
5. Start the stop clock and observe the time for every one degree fall of temperature from 80°C.
6. Take sufficient amount of reading, say closer to room temperature
7. The observations are tabulated
8. Draw a graph by taking time along the x axis and excess temperature along y axis.

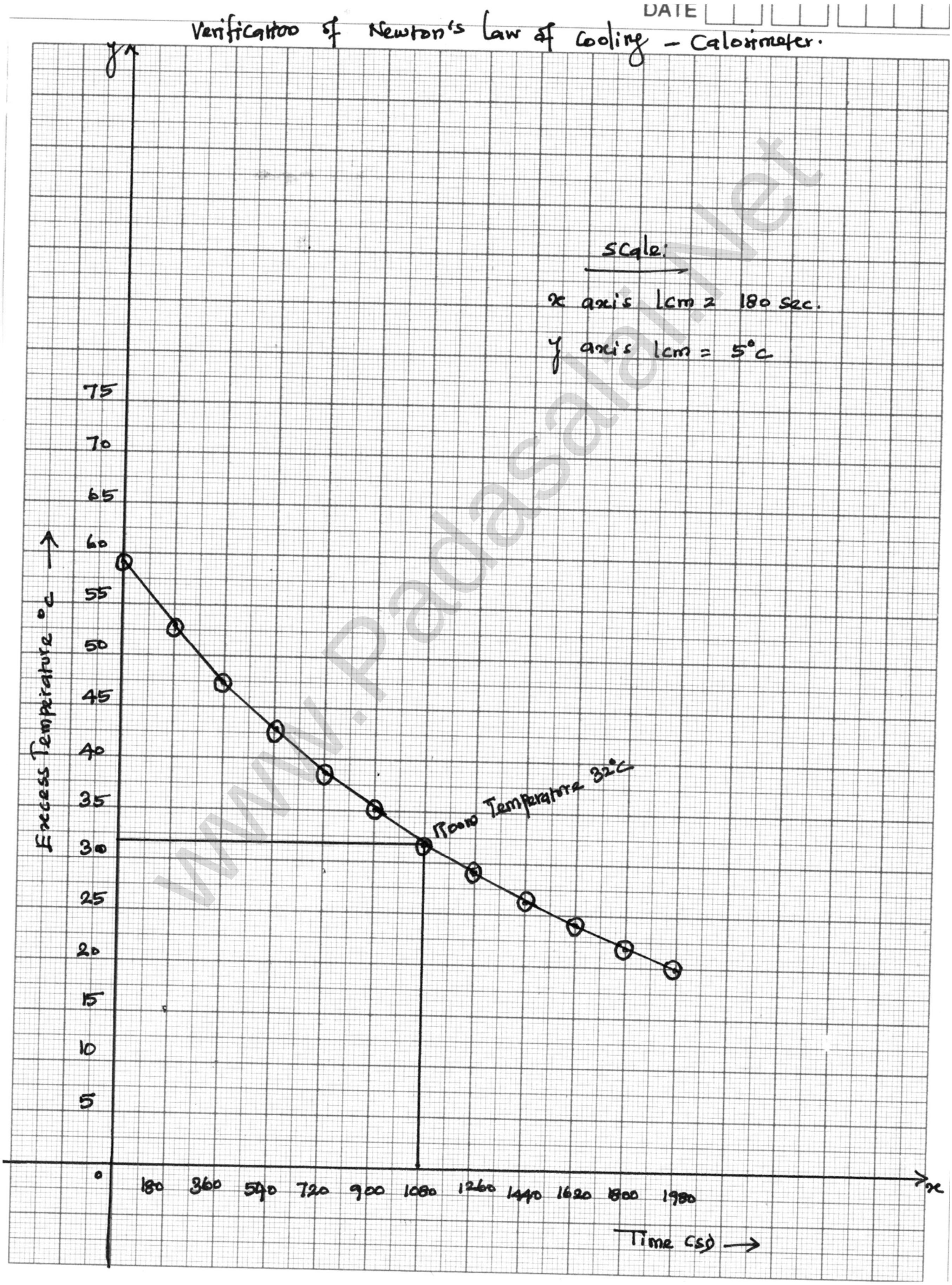
Observations

Measuring the change in temperature of water with time

Time (s)	Temperature of water (T) °C	Excess temperature ($T - T_0$) °C
0	89	59
180	83	53
360	77	47
540	72.5	42.5
720	68.5	38.5
900	65	35
1080	61.5	31.5
1260	59	29
1440	56.5	26.5
1620	54	24
1800	52.5	22.5
1980	50	20

Result

The cooling curve is plotted and thus Newton's law of cooling is verified.


DATE
Verification of Newton's law of cooling - Calorimeter.
Scale:
x axis 1cm = 180 sec.
y axis 1cm = 5°c
y
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Excess Temperature °c
Room Temperature 32°c
180
360
540
720
900
1080
1260
1440
1620
1800
1980
x
Time (s)

Expt. No. : 9 Date:

STUDY OF RELATION BETWEEN FREQUENCY AND LENGTH OF A GIVEN WIRE UNDER CONSTANT TENSION USING SONOMETER

Aim

To study the relation between frequency and length of a given wire under constant tension using a sonometer.

Apparatus Required

Sonometer, six tuning forks of known frequencies, Metre scale, rubber pad, paper rider, hanger with half – kilogram masses, wooden bridges

Formula

The frequency n of the fundamental mode of vibration of a string is given by $n = \frac{1}{2l}\sqrt{\frac{T}{m}}$ Hz

a) For a given m and fixed T. $n \propto \frac{1}{l}$ (or) nl = constant

where n⟶Frequency of the fundamental mode of vibration of the string (Hz)

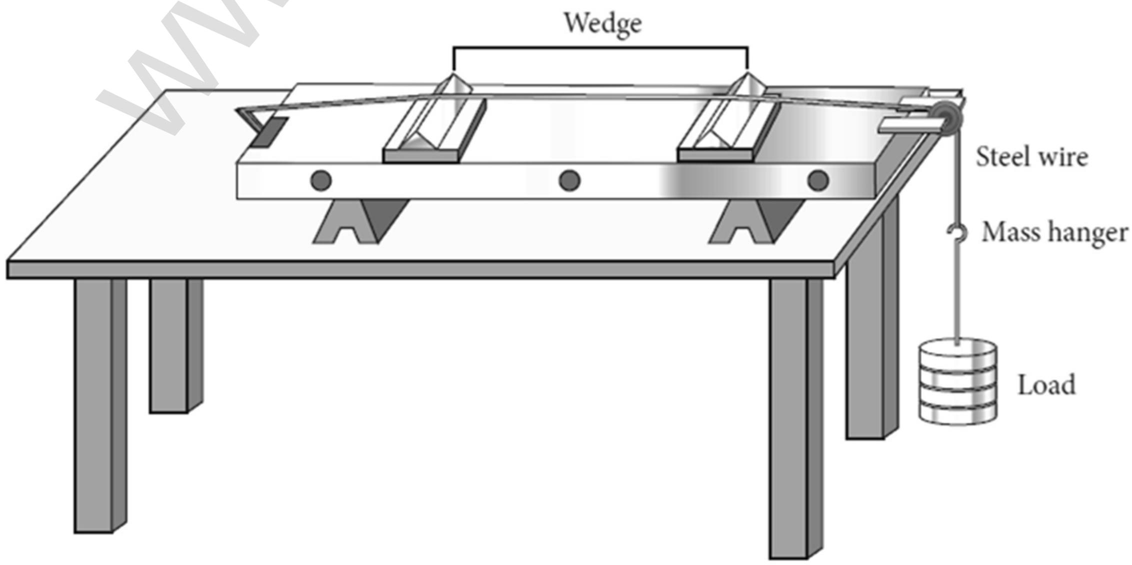
m ⟶ Mass per unit length of the string (kg m^{-1})

l ⟶ Length of the string between the wedges (m)

T ⟶ Tension in the string (including the mass of the hanger) = Mg (N)

M ⟶ Mass suspended, including the mass of the hanger (Kg)

Diagram

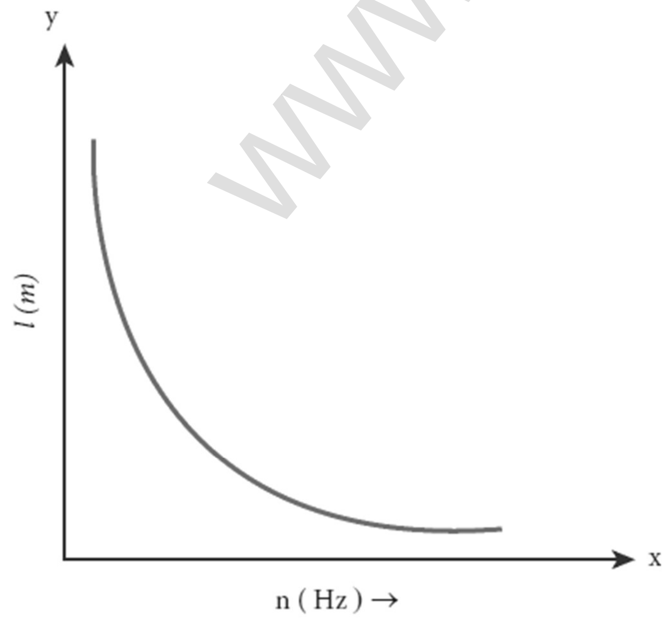


Procedure

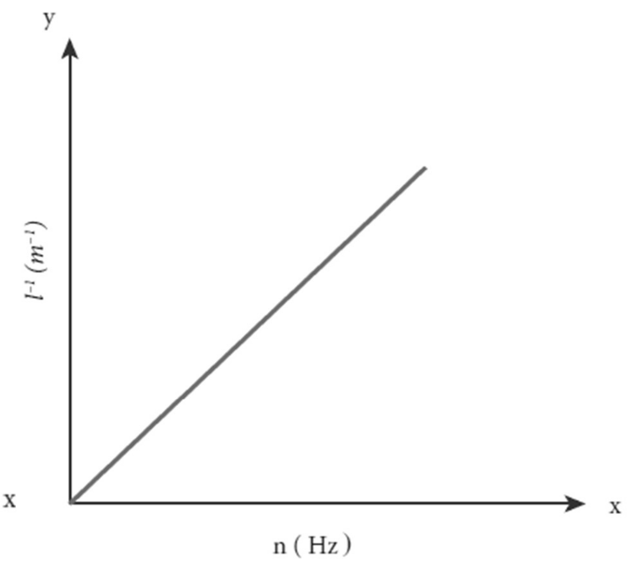
1. Set up the sonometer on the table and clean the groove on the pulley to ensure minimum friction
2. Stretch the wire by placing suitable mass in the hanger. Keep a small paper rider over the wire, between the two bridges.
3. Set the tuning fork into vibrations by striking it against the rubber pad and place it over the sonometer, by its stem.
4. Adjust the vibrating length of the wire by sliding the bridge B till the vibrating sound of the wire is maximum
5. when the frequency of vibration is in resonance with the frequency of the tuning fork, the paper rider falls down.
6. The length of the wire between the wedges A and B is measured using meter scale. It is called as resonant length.
7. Repeat the above procedure for tuning forks of different frequencies by keeping the same load in the hanger.

Observations

Tension (constant) on the wire (mass suspended from the hanger including its own mass) T = (mass suspended × 9.8) N



Graph 1: Relation between frequency and length



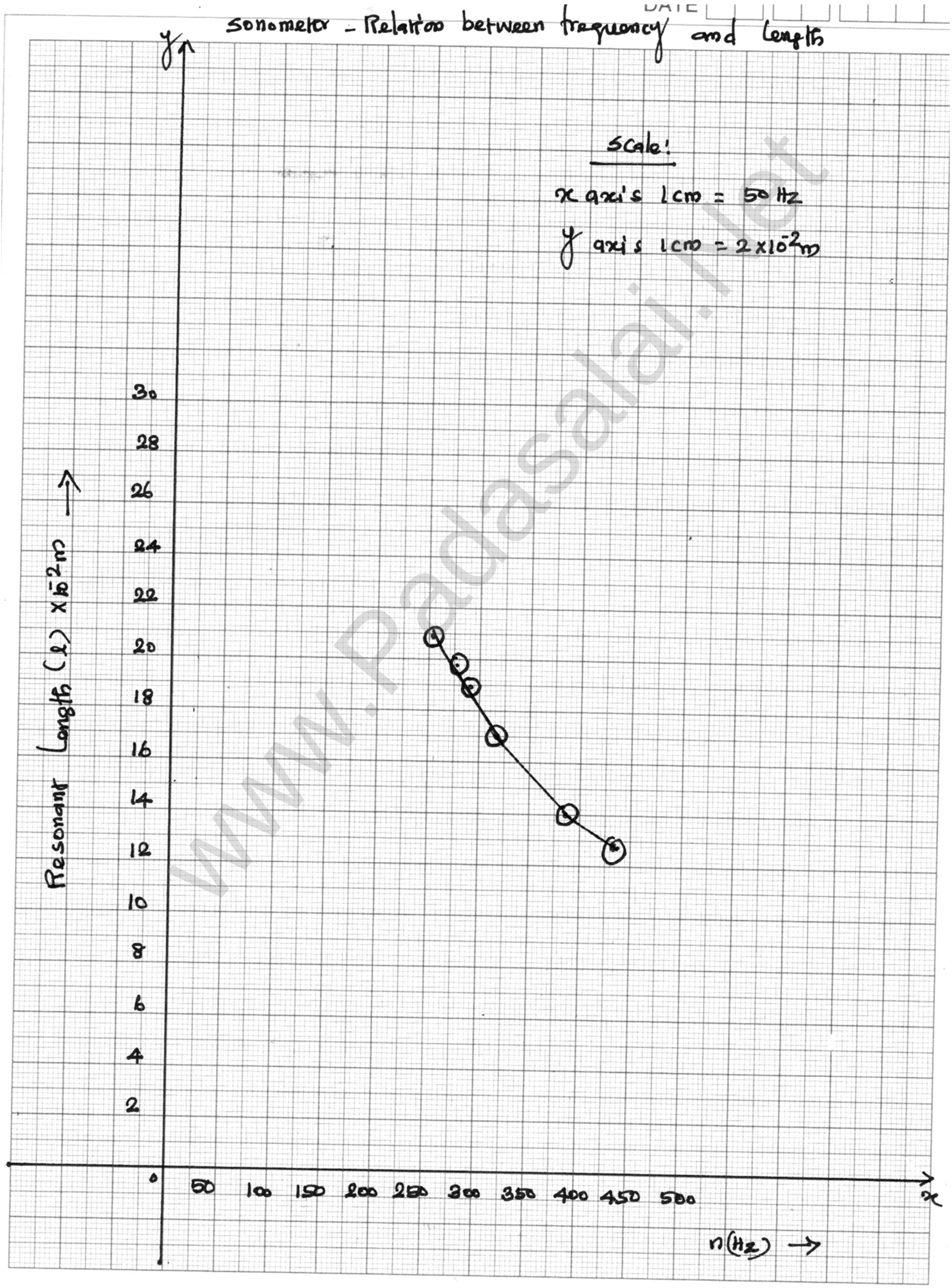
Graph 2: Relation between frequency and inverse of length

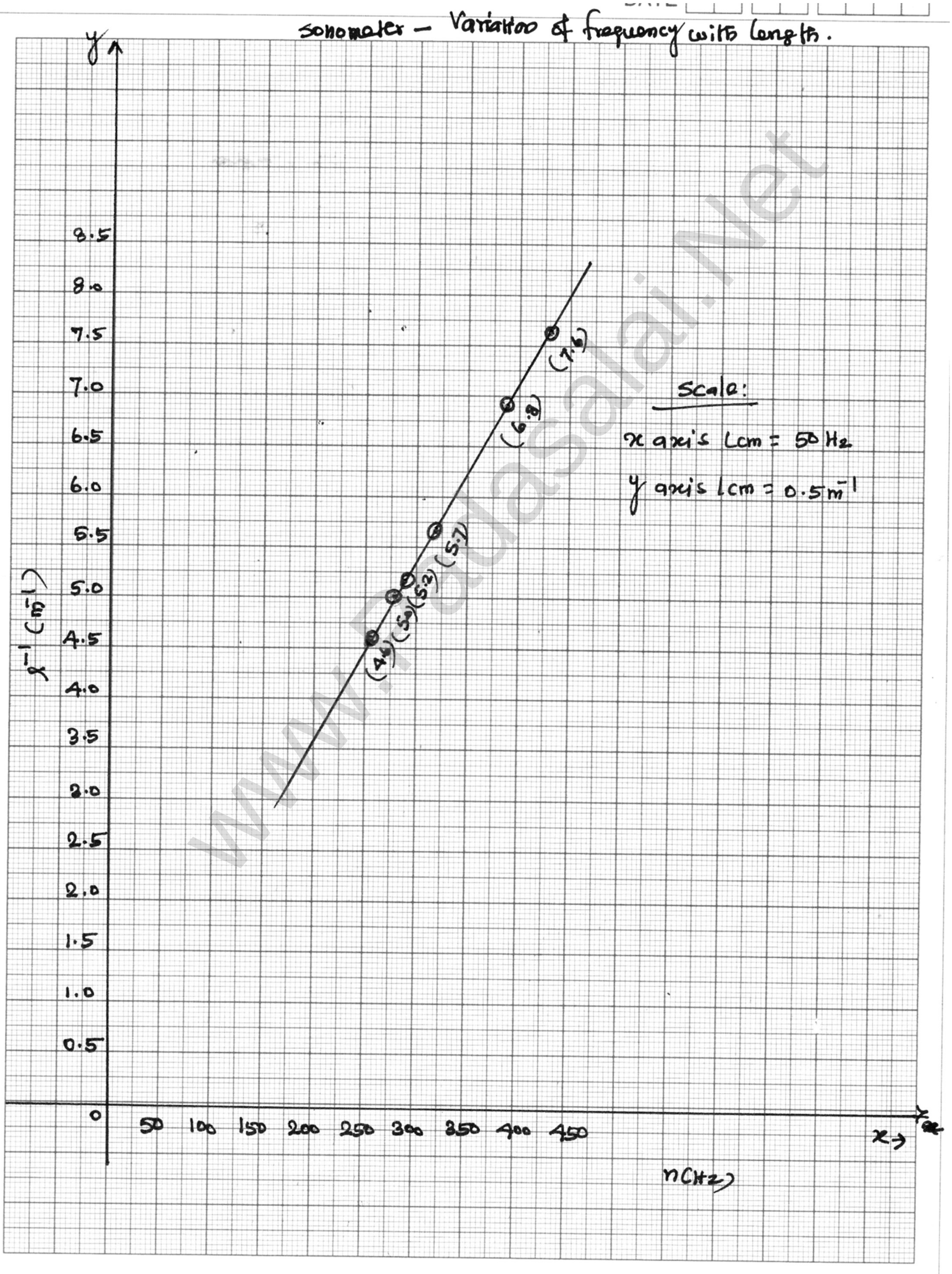
T = mg ; T= 3 x 9.8 ; T = 29.4 N : [Mass = 3kg; g = 9.8]

Variation of frequency with length			
Frequency of the tuning fork 'n' (Hz)	Resonant length 'l' $\times 10^{-2}$ m	$\frac{1}{l}$	nl
$n_1 = 256$	21.5	4.65	55.04
$n_2 = 280$	19.9	5.02	55.72
$n_3 = 288$	19.2	5.20	55.29
$n_4 = 320$	17.4	5.74	55.68
$n_5 = 384$	14.5	6.89	55.68
$n_6 = 426$	13.0	7.69	55.38

Mean = 332.79 / 6

55.46 Hzm


Sonometer - Relation between frequency and length
Scale!
x axis 1cm = 50 Hz
y axis 1cm = 2x10⁻²m
Resonant Length (l) x10⁻²m
n(Hz)
0
50 100 150 200 250 300 350 400 450 500
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
x
y


Sonometer – Variation of frequency with length.
y
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
l^{-1} (m^{-1})
50
100
150
200
250
300
350
400
450
x
n(Hz)
Scale:
x axis 1cm = 50 Hz
y axis 1cm = 0.5 m^{-1}

Calculation

The product nl for all the tuning forks remain constant (last column in the table)

1) n x l = 256 x 0.215 = 55.04 Hzm

2) n x l = 280 x 0.199 = 55.72 Hzm

3) n x l = 288 x 0.192 = 55.29 Hzm

4) n x l = 320 x 0.174 = 55.68 Hzm

5) n x l = 384 x 0.145 = 55.68Hzm

6) n x l = 426 x 0.130 = 55.38Hzm

$$n \text{ x } l = \frac{55.04+55.72+55.29+\quad .68+\quad .68+55.38}{6} = \frac{332.79}{6} = 55.46 \text{ Hz m}$$

Result

For a given tension, the resonant length of a given stretched string varies as reciprocal of the frequency (i.e., n $\propto \frac{1}{l}$)

The product nl is a constant and found to be 55.46 (Hz m)

Expt. No. : 10 Date:

STUDY OF RELATION BETWEEN LENGTH OF THE GIVEN WIRE AND TENSION FOR A CONSTANT FREQUENCY USING SONOMETER

Aim

To study the relationship between the length of a given wire and tension for constant frequency using a sonometer

Apparatus Required:

Sonometer, tuning fork of known frequency, meter scale, rubber pad, paper rider, hanger with half – kilogram masses, wooden bridges.

Formula

The frequency of the fundamental mode of vibration of a string is given by,

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} \text{ Hz}$$

If n is a constant, for a given wire (m is constant)

$$\frac{\sqrt{T}}{l} \text{ is constant}$$

where n ⟶ Frequency of the fundamental mode of vibration of a string (Hz)

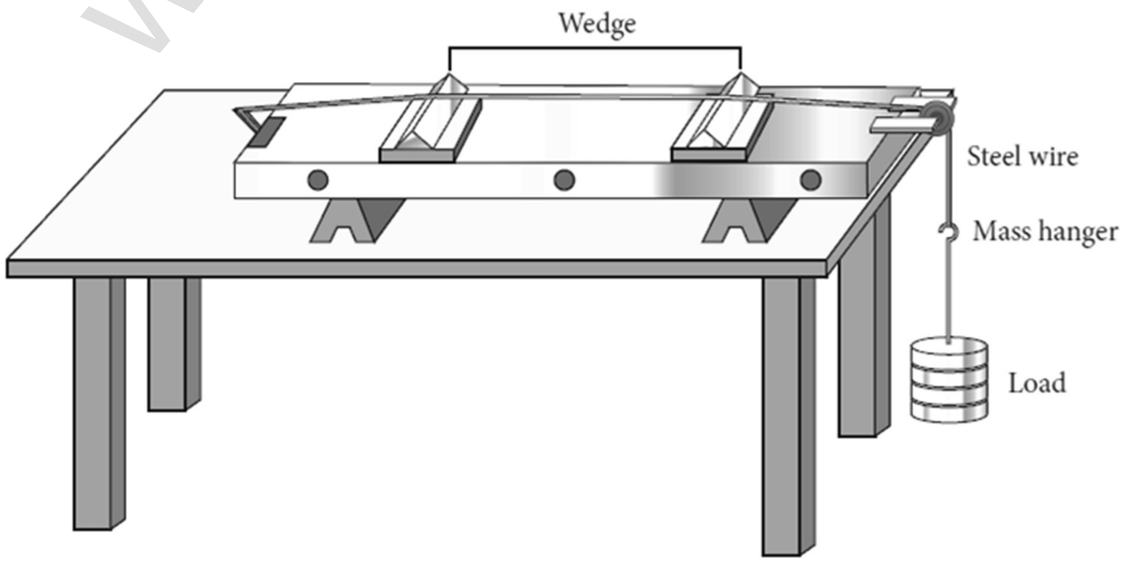
m ⟶ Mass per unit length of string (kg m^{-1})

T ⟶ Tension in the string (including the weight of the hanger) = Mg (N)

l ⟶ Length of the string between the wedges (metre)

M ⟶ Mass suspended, including the mass of the hanger (kg)

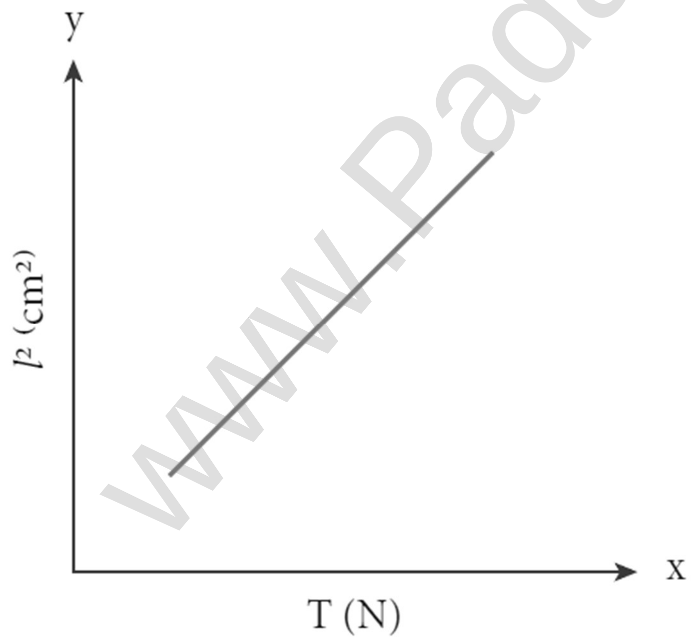
Diagram



Procedure

1. Set up the sonometer on the table and clean the groove on the pulley to ensure that it has minimum friction.
2. Keep a small paper rider on the wire, between the bridges.
3. Place a mass of 1 kg for initial reading in the mass hanger.
4. Now, strike the tuning fork and place its shank stem on the bridge A and then slowly adjust the position of the bridge B till the paper rider is agitated violently and might eventually fall due to resonance.
5. Measure the length of the wire between wedges at A and B which is the fundamental mode corresponding to the frequency of the tuning fork.
6. Increase the load on the hanger in steps of 0.5 kg and each time find the resonating length as done before with the same tuning fork.
7. Record the observations in the tabular column

Model Graph



Observations

Frequency of tuning fork = 320 Hz

Variation of resonant length with tension

S. No.	Mass M (kg)	Tension T = Mg (N)	$\sqrt{T}$	Vibrating length l(m) x 10^{-2} m	l^2	$\frac{\sqrt{T}}{l}$ x10^2 Nm^{-1}
1	2.0	19.6	4.43	27.5	756.25	16.11
2	2.5	24.5	4.95	30.1	906.01	16.44
3	3.0	29.4	5.42	32.6	1062.76	16.63
4	3.5	34.3	5.86	35.3	1246.09	16.60

$$\frac{\sqrt{T}}{l} = 16.42 Nm^{-1}$$

Calculation

Calculate the value $\frac{\sqrt{T}}{l}$ for the tension applied in each case.

$$\frac{\sqrt{T}}{l} = \frac{4.423}{0.275} = 16.11 Nm^{-1}$$

$$\frac{\sqrt{T}}{l} = \frac{4.95}{0.301} = 16.44 Nm^{-1}\backslash$$

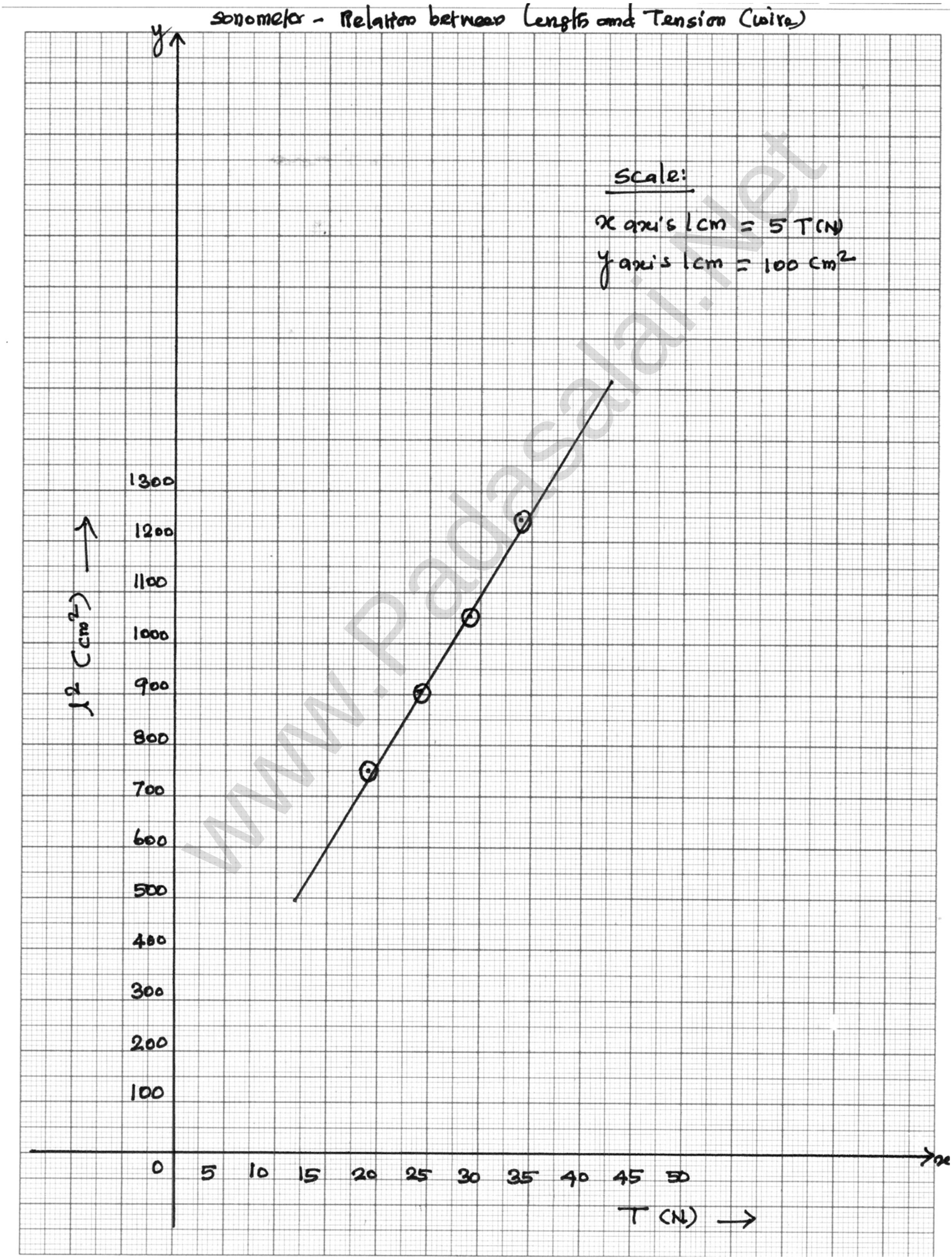
$$\frac{\sqrt{T}}{l} = \frac{5.42}{0.326} = 16.63 Nm^{-1}$$

$$\frac{\sqrt{T}}{l} = \frac{5.86}{0.353} = 16.60 Nm^{-1}$$

Mean: $\frac{\sqrt{T}}{l} = \frac{16.11+16.44+16.63+16.60}{4} = \frac{65.78}{4} = 16.45 Nm^{-1}$

Result

The resonating length varies as square root of tension for a given frequency of vibration of a stretched string $\frac{\sqrt{T}}{l}$ found to be a constant.


Sonometer - Relation between Length and Tension (wire)
Scale:
x axis 1cm = 5 T(N)
y axis 1cm = 100 cm²
y
x
l^2 (cm²)
T (N)
0
5
10
15
20
25
30
35
40
45
50
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300

SUGGESTED QUESTIONS FOR THE PRACTICAL EXAMINATION

1. Find the radius of the given solid sphere using Vernier Caliper. Hence determinethe moment of inertia of the solid sphere about its diameter (Mass of the solid sphere to be given) (Take at least 6 readings)

2. Verification of relation between the load and the depression using pin and microscope - Non-uniform bending (Take at least 4 readings)

3. By setting the given spring with various masses attached to vertical oscillations anddetermine the spring constant (Graphical Method is not necessary) (Take at least 6 readings)

4. Find the time period (T) of a simple pendulum for different lengths. Draw graph between L and T^2. Also calculate the acceleration due to gravity in the laboratory. L and T graph not necessary) (Take at least 6 readings)

5. Determine the velocity of sound in air at room temperature using resonance column apparatus (Take reading for 3 different frequencies)

6. Determine the terminal velocity of the given steel sphere in the given viscous liquid Hence, calculate the co-efficient of viscosity of the given liquid using Stoke's Method (Take at least 6 readings) (Radius of the steel ball to be given)

7. Determine the surface tension of water by the method of capillary use. (Radius of the capillary to be given) (Take at least 6 readings)

8. Verification of Newton's law of cooling using calorimeter (Take at least 6 readings)

9. Using Sonameter, Verify the first and second laws of vibrations of a stretched string nl = constant (Take at least 4 readings)

10. Using Sonameter, Verify the first and second laws of vibrations of a stretched string $\frac{\sqrt{T}}{l}$ = constant (Each 4 readings)

"நேர்மையான முயற்சியில் கிடைத்த
வெற்றியின் மூலமாகக் கிடைக்கும் மகிழ்ச்சியின்
சிகரத்தை யாரும் அளக்கவே முடியாது."

QR CODE & ICT CORNER

Unit	Topic	QR Code
1	Dimensional Analysis	
1	Propagation of Errors	
1	**ICT CORNER**	
2	Vector	
2	Projectile Motion	
2	**ICT CORNER**	

Unit	Topic	QR Code
1	Propagation of Errors	
1	Propagation of Errors	
2	Vector	
2	Vector	
2	Projectile Motion	
3	**ICT CORNER**	

Unit	Topic	QR Code
4	**ICT CORNER**	
5	Pure Rolling	
5	Torque	
6	Kepler's Law	
6	**ICT CORNER**	
7	Surface Tension	

Unit	Topic	QR Code
5	Moment of Inertia	
5	Conservation of Angular Momentum	
5	**ICT CORNER**	
6	Radius of Earth	
7	Moduli of Elasticity	
7	**ICT CORNER**	

Unit	Topic	QR Code
8	**ICT CORNER**	
9	Pressure & Kinetic Energy	
9	**ICT CORNER**	
11	Transverse Wave	

Unit	Topic	QR Code
9	Pressure exerts by gas	
9	Brownian Motion	
10	**ICT CORNER**	
11	**ICT CORNER**	

ONE MARK QUESTIONS (BOOK BACK)

UNIT 1 (NATURE OF PHYSICAL WORLD AND MEASUREMENT)

1. One of the combinations from the fundamental physical constants is $\frac{hc}{G}$. The unit of this expression is
(a) kg^2 (b) m^3 (c) s^{-1} (d) m

2. If the error in the measurement of radius is 2%, then the error in the determination of volume of the sphere will be
(a) 8% (b) 2% (c) 4% (d) 6%

3. If the length and time period of an oscillating pendulum have errors of 1% and 3% respectively then the error in measurement of acceleration due to gravity is
(a) 4% (b) 5% (c) 6% (d) 7%

4. The length of a body is measured as 3.51 m, if the accuracy is 0.01m, then the percentage error in the measurement is
(a) 351% (b) 1% (c) 0.28% (d) 0.035%

5. Which of the following has the highest number of significant figures?
(a) 0.007 m^2 (b) 2.64×10^{24}kg (c) 0.0006032 m^2 (d) 6.3200 J

6. If π = 3.14, then the value of π^2 is
(a) 9.8596 (b) 9.860 (c) 9.86 (d) 9.9

7. Round of the following number 19.95 into three significant figures.
(a) 19.9 (b) 20.0 (c) 20.1 (d) 19.5

8. Which of the following pairs of physical quantities have same dimension?
(a) force and power (b) torque and energy
(c) torque and power (d) force and torque

9. The dimensional formula of Planck's constant h is
(a) $[ML^2T^{-1}]$ (b) $[ML^2T^{-3}]$ (c) $[MLT^{-1}]$ (d) $[ML^3T^{-3}]$

10. The velocity of a particle v at an instant t is given by v = at +bt^2. The dimensions of bis
(a) [L] (b) $[LT^{-1}]$ (c) $[LT^{-2}]$ (d) $[LT^{-3}]$

11. The dimensional formula for gravitational constant G is
(a) $[ML^3T^{-2}]$ (b) $[M^{-1}L^3T^{-2}]$ (c) $[M^{-1}L^{-3}T^{-2}]$ (d) $[ML^{-3}T^2]$

12. The density of a material in CGS system of units is 4 g cm^{-3}. In a system of units in which unit of length is 10 cm and unit of mass is 100 g, then the value of density of material will be

(a) 0.04 (b) 0.4 **(c) 40** (d) 400

13. If the force is proportional to square of velocity, then the dimension of proportionality constant is

(a) $[MLT^0]$ (b) $[MLT^{-1}]$ (c) $[ML^{-2}T]$ **(d) $[ML^{-1}T^0]$**

14. The dimension of $(\mu_0 \varepsilon_0)^{\frac{1}{2}}$ is

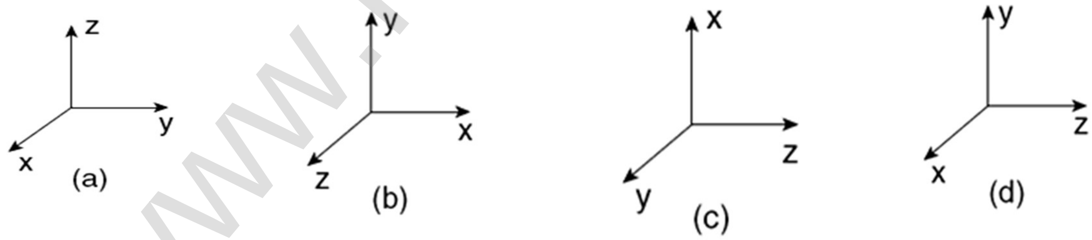
(a) length (b) time **(c) velocity** (d) force

15. Planck's constant (h), speed of light in vacuum (c) and Newton's gravitational constant (G) are taken as three fundamental constants. Which of the following combinations of these has the dimension of length?

(a) $\frac{\sqrt{hG}}{c^{\frac{3}{2}}}$ (b) $\frac{\sqrt{hG}}{c^{\frac{5}{2}}}$ (c) $\sqrt{\frac{hc}{G}}$ (d) $\sqrt{\frac{Gc}{h^{\frac{3}{2}}}}$

UNIT 2 (KINETICS)

1. Which one of the following Cartesian coordinate systems is not followed in physics?



2. Identify the unit vector in the following

(a) $\hat{\imath} + \hat{\jmath}$ (b) $\frac{\hat{\imath}}{\sqrt{2}}$ (c) $\hat{k} - \frac{\hat{\imath}}{\sqrt{2}}$ **(d) $\frac{\hat{\imath}+\hat{\jmath}}{\sqrt{2}}$**

3. Which one of the following physical quantities cannot be represented by a scalar?

(a) Mass (b) length
(c) momentum (d) magnitude of acceleration

4. Two objects of masses m_1 and m_2 fall from the heights h_1 and h_2 respectively. The ratio of the magnitude of their momenta when they hit the ground is

(a) $\sqrt{\frac{h_1}{h_2}}$ (b) $\sqrt{\frac{m_1 h_1}{m_2 h_2}}$ **(c) $\frac{m_1}{m_2}\sqrt{\frac{h_1}{h_2}}$** (d) $\frac{m_1}{m_2}$

5. If a particle has negative velocity and negative acceleration, its speed

(a) increases (b) decreases (c) remains same (d) zero

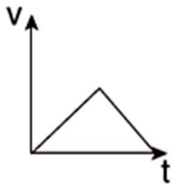
6. If the velocity is $\vec{v} = 2\hat{i} + t^2\hat{j} - 9\hat{k}$, then the magnitude of acceleration at t = 0.5 s is

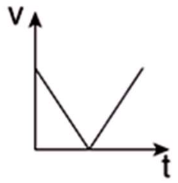
(a) 1m s^{-2} (b) 2 m s^{-2} (c) zero (d) -1 m s^{-2}

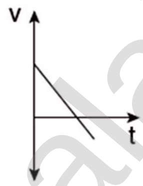
7. If an object is dropped from the top of a building and it reaches the ground at t = 4 s then the height of the building is (ignoring air resistance) (g = 9.8 ms^{-2})

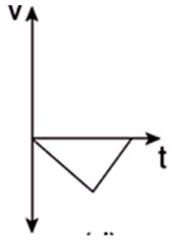
(a) 77.3 m **(b) 78.4 m** (c) 80.5 m (d) 79.2 m

8. A ball is projected vertically upwards with a velocity v. It comes back to ground in time t. Which v-t graph shows the motion correctly?

(a) 

(b) 

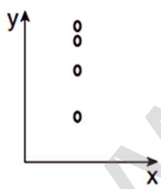
(c) 

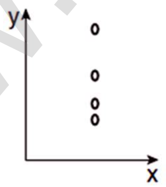
(d) 

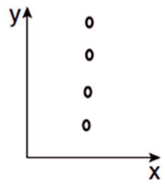
9. If one object is dropped vertically downward and another object is thrown horizontally from the same height, then the ratio of vertical distance covered by both objects at any instant t is

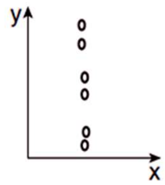
(a) 1 (b) 2 (c) 4 (d) 0.5

10. A ball is dropped from some height towards the ground. Which one of the following represents the correct motion of the ball?

(a) 

(b) 

(c) 

(d) 

11. If a particle executes uniform circular motion in the xy plane in clock wise direction, then the angular velocity is in

(a) +y direction (b) +z direction **(c) -z direction** (d) -x direction

12. If a particle executes uniform circular motion, choose the correct statement

(a) The velocity and speed are constant.

(b) The acceleration and speed are constant.

(c) The velocity and acceleration are constant.

(d) The speed and magnitude of acceleration are constant.

13. If an object is thrown vertically up with the initial speed u from the ground, then the time taken by the object to return back to ground is

(a) $\frac{u^2}{2g}$ (b) $\frac{u^2}{g}$ (c) $\frac{u}{2g}$ **(d) $\frac{2u}{g}$**

14. Two objects are projected at angles 30^0 and 60^0 respectively with respect to the horizontal direction. The ranges of two objects are denoted as R_{30^0} and R_{60^0}. Choose the correct relation from the following

(a) $R_{30^0} = R_{60^0}$ (b) $R_{30^0} = 4R_{60^0}$ (c) $R_{30^0} = \frac{R_{60^0}}{2}$ (d) $R_{30^0} = 2R_{60^0}$

15. An object is dropped in an unknown planet from height 50 m, it reaches the ground in 2 s . The acceleration due to gravity in this unknown planet is

(a) $g = 20\ m\ s^{-2}$ **(b)** $g = 25\ m\ s^{-2}$ (c) $g = 15\ m\ s^{-2}$ (d) $g = 30\ m\ s^{-2}$

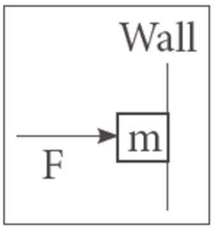
UNIT 3 (LAWS OF MOTION)

1. When a car takes a sudden left turn in the curved road, passengers are pushed towards the right due to

(a) inertia of direction (b) inertia of motion

(c) inertia of rest (d) absence of inertia

2. An object of mass m held against a vertical wall by applying horizontal force F as shown in the figure. The minimum value of the force F is



(a) Less than mg (b) Equal to mg

(c) Greater than mg (d) Cannot determine

3. A vehicle is moving along the positive x direction, if sudden brake is applied, then

(a) frictional force acting on the vehicle is along positive x direction

(b) no frictional force acts on the vehicle

(c) frictional force acts in downward direction

(d) frictional force acting on the vehicle is along negative x direction

4. A book is at rest on the table which exerts a normal force on the book. If this force is considered as reaction force, what is the action force according to Newton's third law?

(a) Gravitational force exerted by Earth on the book

(b) Gravitational force exerted by the book on Earth

(c) Normal force exerted by the book on the table

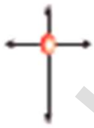
(d) None of the above

5. Two masses m_1 and m_2 are experiencing the same force where $m_1 < m_2$. The ratio of their acceleration $\frac{a_1}{a_2}$ is

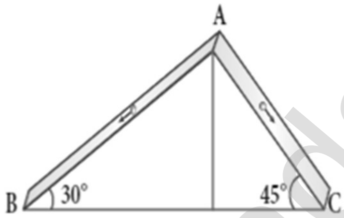
(a) 1 (b) less than 1

(c) greater than 1 (d) all the three cases

6. Choose appropriate free body diagram for the particle experiencing net acceleration along negative y direction. (Each arrow mark represents the force acting on the system).

(a)  (b)  (c)  (d) 

7. A particle of mass m sliding on the smooth double inclined plane (shown in figure) will experience



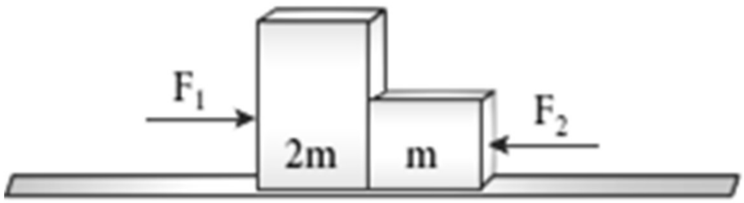
(a) greater acceleration along the path AB

(b) greater acceleration along the path AC

(c) same acceleration in both the paths

(d) no acceleration in both the paths

8. Two blocks of masses m and 2m are placed on a smooth horizontal surface as shown. In the first case only a force F_1 is applied from the left. Later only a force F_2 is applied from the right. If the force acting at the interface of the two blocks in the two cases is same, then $F_1 : F_2$ is



(a) 1:1 (b) 1:2 (c) 2:1 (d) 1:3

9. Force acting on the particle moving with constant speed is

(a) always zero (b) need not be zero

(c) always non zero (d) cannot be concluded

10. An object of mass m begins to move on the plane inclined at an angle θ. The coefficient of static friction of inclined surface is μ_s. The maximum static friction experienced by the mass is

(a) mg (b) $\mu_s$mg

(c) $\mu_s$mg sinθ **(d) $\mu_s$mg cos θ**

11. When the object is moving at constant velocity on the rough surface,

(a) no force acts on the object **(b) net force on the object is zero**

(c) only external force acts on the object

12. When an object is at rest on the inclined rough surface,

(a) static and kinetic frictions acting on the object is zero

(b) static friction is zero but kinetic friction is not zero

(c) static friction is not zero and kinetic friction is zero

(d) static and kinetic frictions are not zero

13. The centrifugal force appears to exist

(a) only in inertial frames **(b) only in rotating frames**

(c) in any accelerated frame

(d) both in inertial and non-inertial frames

14. Choose the correct statement from the following

(a) Centrifugal and centripetal forces are action reaction pairs

(b) Centripetal force acts towards the centre and centrifugal force appears to act away from the centre in a circular motion

(c) Centripetal forces is a natural force

(d) Centrifugal force arises from gravitational force

15. If a person moving from pole to equator, the centrifugal force acting on him

(a) increases (b) decreases

(c) remains the same (d) increases and then decreases

UNIT 4 (WORK, ENERGY AND POWER)

1. A uniform force of $(2\hat{\imath} + \hat{\jmath})$+ N acts on a particle of mass 1 kg. The particle displaces from position $(3\hat{\jmath} + \hat{k})$ m to $(5\hat{\imath} + 3\hat{\jmath})$.The work done by the force on the particle is

   (a) 9 J (b) 6 J **(c) 10 J** (d) 12 J

2. A ball of mass 1 kg and another of mass 2 kg are dropped from a tall building whose height is 80 m. After, a fall of 40 m each towards Earth, their respective kinetic energies will be in the ratio of

   (a) $\sqrt{2}:1$ (b) $1:\sqrt{2}$ (c) 2 : 1 **(d) 1 : 2**

3. A body of mass 1 kg is thrown upwards with a velocity 20 m s^{-1}. It momentarily comes to rest after attaining a height of 18 m. How much energy is lost due to air friction? (Take g = 10ms^{-2})

   (a) 20 J (b) 30 J (c) 40 J (d) 10 J

4. An engine pumps water continuously through a hose. Water leaves the hose with a velocity v and m is the mass per unit length of the water of the jet. What is the rate at which kinetic energy is imparted to water?

   (a) $\frac{1}{2}mv^3$ (b) mv^3 (c) $\frac{3}{2}mv^2$ (d) $\frac{5}{2}mv^2$

5. A body of mass 4 m is lying in xy-plane at rest. It suddenly explodes into three pieces. Two pieces each of mass m move perpendicular to each other with equal speed *v*. The total kinetic energy generated due to explosion is

   (a) mv^2 **(b) $\frac{3}{2}mv^2$** (c) $2mv^2$ (d) $4mv^2$

6. The potential energy of a system increases, if work is done

   (a) by the system against a conservative force

   (b) by the system against a non-conservative force

   (c) upon the system by a conservative force

   (d) upon the system by a non-conservative force

7. What is the minimum velocity with which a body of mass m must enter a vertical loop of radius R so that it can complete the loop?

   (a) $\sqrt{2gR}$ (b) $\sqrt{3gR}$ **(c) $\sqrt{5gR}$** (d) $\sqrt{gR}$

8. The work done by the conservative force for a closed path is

   (a) always negative **(b) zero**

   (c) always positive (d) not defined

9. If the linear momentum of the object is increased by 0.1%, then the kinetic energy is increased by

(a) 0.1 % (b) **0.2%** (c) 0.4% (d) 0.01%

10. If the potential energy of the particle is $\alpha - \frac{\beta}{2}x^2$, then force experienced by the particle is

(a) $F = \frac{\beta}{2}x^2$ (b) **$F = \beta x$** (c) $F = -\beta x$ (d) $F = -\frac{\beta}{2}x^2$

11. A wind-powered generator converts wind energy into electric energy. Assume that the generator converts a fixed fraction of the wind energy intercepted by its blades into electrical energy. For wind speed *v*, the electrical power output will be proportional to

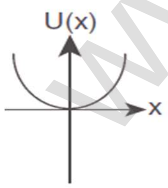
(a) v (b) v^2 **(c) v^3** (d) v^4

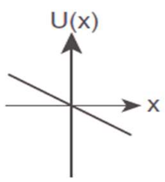
12. Two equal masses m_1 and m_2 are moving along the same straight line with velocities $5 ms^{-1}$ and $-9 ms^{-1}$ respectively. If the collision is elastic, then calculate the velocities after the collision of m_1 and m_2, respectively

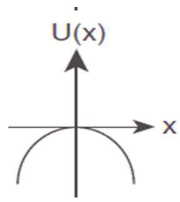
(a) $-4 ms^{-1}$ and $10 ms^{-1}$ (b) $10 ms^{-1}$ and $0 ms^{-1}$

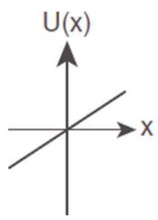
(c) $-9 ms^{-1}$ and $5 ms^{-1}$ (d) $5 ms^{-1}$ and $1 ms^{-1}$

13. A particle is placed at the origin and a force $F = kx$ is acting on it (where *k* is a positive constant). If U(0) =0 , the graph of U *(x)* versus x will be (where Uis the potential energy function)

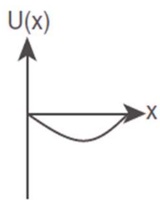
(a) 

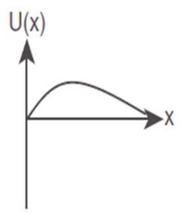
(b) 

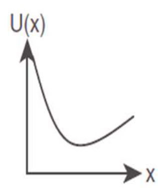
(c) 

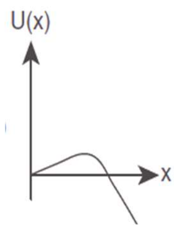
(d) 

14. A particle which is constrained to move along *x*-axis, is subjected to a force in the same direction which varies with the distance *x* of the particle from the origin as $F(x) = -kx + ax^3$. Here, *k* and a are positive constants. For x ≥ 0, the functional form of the potential energy *U(x)* of the particle is

(a) 

(b) 

(c) 

(d) 

15. A spring of force constant *k* is cut into two pieces such that one piece is double the length of the other. Then, the long piece will have a force constant of

(a) $\frac{2}{3}k$ (b) $\frac{3}{2}k$ (c) 3k (d) 6k

UNIT 5 (MOTION OF SYSTEM OF PARTICLES AND RIGID BODIES)

1. The centre of mass of a system of particles does not depend upon,
   (a) position of particles (b) relative distance between particles
   (c) masses of particles **(d) force acting on particle**
2. A couple produces,
   (a) pure rotation (b) pure translation
   (c) rotation and translation (d) no motion
3. A particle is moving with a constant velocity along a line parallel to positive X-axis. The magnitude of its angular momentum with respect to the origin is,
   (a) zero (b) increasing with x
   (c) decreasing with x **(d) remaining constant**
4. A rope is wound around a hollow cylinder of mass 3 kg and radius 40 cm. What is the angular acceleration of the cylinder if the rope is pulled with a force 30 N?
   (a) 0.25 rad s^{-2} **(b) 25 rad s^{-2}** (c) 5 m s s^{-2} (d) 25ms^{-2}
5. A closed cylindrical container is partially filled with water. As the container rotates in a horizontal planeabout a perpendicular bisector, its moment of inertia,
   (a) increases (b) decreases
   (c) remains constant (d) depends on direction of rotation
6. A rigid body rotates with an angular momentum L. If its kinetic energy is halved, the angular momentum becomes,
   (a) L (b) $\frac{L}{2}$ (c) 2L **(d) $\frac{L}{\sqrt{2}}$**
7. A particle undergoes uniform circular motion. The angular momentum of the particle remains conserved about,
   (a) the centre point of the circle.
   (b) the point on the circumference of the circle.
   (c) any point inside the circle.
   (d) any point outside the circle.

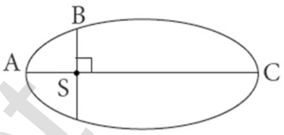
8. When a mass is rotating in a plane about a fixed point, its angular momentum is directed along,
   (a) a line perpendicular to the plane of rotation
   (b) the line making an angle of 45° to the plane of rotation
   (c) the radius
   (d) tangent to the path
9. Two discs of same moment of inertia rotating about their regular axis passing through centre and perpendicular to the plane of disc with angular velocities ω_1 and ω_2. They are brought in to contact face to face coinciding the axis of rotation. The expression for loss of energy during this process is,
   (a) $\frac{1}{4}I(\omega_1-\omega_2)^2$ (b $I(\omega_1-\omega_2)^2$
   (c) $\frac{1}{8}I(\omega_1-\omega_2)^2$ (d) $\frac{1}{2}I(\omega_1-\omega_2)^2$
10. The ratio of the acceleration for a solid sphere (mass m and radius R) rolling down an incline of angle θ without slipping and slipping down the incline without rolling is,
   (a) 5:7 (b) 2:3 (c) 2:5 (d) 7:5
11. A disc of moment of inertia I_a is rotating in a horizontal plane about its symmetry axis with a constant angular speed ω. Another disc initially at rest of moment of inertia$I_b$is dropped coaxially on to the rotating disc. Then, both the discs rotate with same constant angular speed. The loss of kinetic energy due to friction in this process is,
   (a) $\frac{1}{2}\frac{I_b^2}{(I_a+I_b)}\omega^2$ (b) $\frac{I_b^2}{(I_a+I_b)}\omega^2$ (c) $\frac{(I_b-I_a)^2}{(I_a+I_b)}\omega^2$ (d) $\frac{1}{2}\frac{I_bI_b}{(I_a+I_b)}\omega^2$
12. From a disc of radius R a mass M, a circular hole of diameter R, whose rim passes through the centre is cut. What is the moment of inertia of the remaining part of the disc about a perpendicular axis passing through it
   (a) $\frac{15\,MR^2}{32}$ (b) $\frac{13\,MR^2}{32}$ (c) $\frac{11\,MR^2}{32}$ (d) $\frac{9\,MR^2}{32}$
13. The speed of a solid sphere after rolling down from rest without sliding on an inclined plane of vertical height h is,
   (a) $\sqrt{\frac{4}{3}gh}$ (b) $\sqrt{\frac{10}{7}gh}$ (c) $\sqrt{2gh}$ (d) $\sqrt{\frac{1}{2}gh}$
14. The speed of the centre of a wheel rolling on a horizontal surface isv_0. A point on the rim in level with the centre will be moving at a speed of speed of,
   (a) zero (b) v_0 (c) $\sqrt{2}v_0$ (d) 2 v_0

15. A round object of mass M and radius R rolls down without slipping along an inclined plane. The frictional force,
    - (a) dissipates kinetic energy as heat.
    - (b) decreases the rotational motion.
    - (c) decreases the rotational and transnational motion
    - (d) converts transnational energy into rotational energy

UNIT – 6 (GRAVITATION)

1. The linear momentum and position vector of the planet is perpendicular to each other at
    - (a) perihelion and aphelion
    - (b) at all points
    - (c) only at perihelion
    - (d) no point
2. If the masses of the Earth and Sun suddenly double, the gravitational force between them will
    - (a) remain the same
    - (b) increase 2 times
    - (c) increase 4 times
    - (d) decrease 2 times
3. A planet moving along an elliptical orbit is closest to the Sun at distance $r_1$and farthest away at a distance of r_2. If v_1 and v_2 are linear speeds at these points respectively. Then the ratio $\frac{v_1}{v_2}$ is
    - (a) $\frac{r_2}{r_1}$
    - (b) $\left(\frac{r_2}{r_1}\right)^2$
    - (c) $\frac{r_1}{r_2}$
    - (d) $\left(\frac{r_1}{r_2}\right)^2$
4. The time period of a satellite orbiting Earth in a circular orbit is independent of .
    - (a) Radius of the orbit
    - (b) The mass of the satellite
    - (c) Both the mass and radius of the orbit
    - (d) Neither the mass nor the radius of its orbit
5. If the distance between the Earth and Sun were to be doubled from its present value, the number of days in a year would be
    - (a) 64.5
    - (b) 1032
    - (c) 182.5
    - (d) 730
6. According to Kepler's second law, the radial vector to a planet from the Sun sweeps out equal areas in equal intervals of time. This law is a consequence of
    - (a) conservation of linear momentum
    - (b) conservation of angular momentum
    - (c) conservation of energy
    - (d) conservation of kinetic energy
7. The gravitational potential energy of the Moon with respect to Earth is
    - (a) always positive
    - (b) always negative
    - (c) can be positive or negative
    - (d) always zero

8. The kinetic energies of a planet in an elliptical orbit about the Sun, at positions A, B and C are K_A, K_B and K_C respectively. AC is the major axis and SB is perpendicular to AC at the position of the Sun S as shown in the figure. Then



(a) $K_A > K_B > K_C$
(b) $K_B < K_A < K_C$
(c) $K_A < K_B < K_C$
(d) $K_B > K_A > K_C$

9. The work done by the Sun's gravitational force on the Earth is
(a) always zero
(b) always positive
(c) can be positive or negative
(d) always negative

10. If the mass and radius of the Earth are both doubled, then the acceleration due to gravity g′
(a) remain s same
(b) $\frac{g}{2}$
(c) 2 g
(d) 4 g

11. The magnitude of the Sun's gravitational field as experienced by Earth is
(a) same over the year
(b) decreases in the month of January and increases in the month of July
(c) decreases in the month of July and increases in the month of January
(d) increases during day time and decreases during night time

12. If a person moves from Chennai to Trichy, his weight
(a) increases
(b) decreases
(c) remains same
(d) increases and then decreases

13. An object of mass 10 kg is hanging on a spring scale which is attached to the roof of a lift. If the lift is in free fall, the reading in the spring scale is
(a) 98 N
(b) zero
(c) 49 N
(d) 9.8 N

14. If the acceleration due to gravity becomes 4 times its original value, then escape speed
(a) remains same
(b) 2 times of original value
(c) becomes halved
(d) 4 times of original value

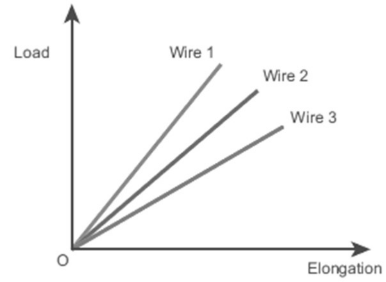
15. The kinetic energy of the satellite orbiting around the Earth is
(a) equal to potential energy
(b) less than potential energy
(c) greater than kinetic energy
(d) zero

UNIT – 7 (PROPERTIES OF MATTER)

1. Consider two wires X and Y. The radius of wire X is 3 times the radius of Y. If they are stretched by the same load, then the stress on Y is
(a) equal to that on X
(b) thrice that on X
(c) nine times that on X
(d) Half that on X

2. If a wire is stretched to double of its original length, then the strain in the wire is
(a) 1
(b) 2
(c) 3
(d) 4

3. The load – elongation graph of three wires of the same material are shown in figure. Which of the following wire is the thickest?



(a) wire 1 (b) wire 2
(c) wire 3 (d) all of them have same thickness

4. For a given material, the rigidity modulus is $\left(\frac{1}{3}\right)^{\text{rd}}$ of Young's modulus. Its Poisson's ratio is
(a) 0 (b) 0.25 (c) 0.3 **(d) 0.5**

5. A small sphere of radius 2cm falls from rest in a viscous liquid. Heat is produced due to viscous force. The rate of production of heat when the sphere attains its terminal velocity is proportional to
(a) 2^2 (b) 2^3 (c) 2^4 **(d) 2^5**

6. Two wires are made of the same material and have the same volume. The area of cross sections of the first and the second wires are A and 2A respectively. If the length of the first wire is increased by Δlon applying a force F, how much force is needed to stretch the second wire by the same amount?
(a) 2 F **(b) 4 F** (c) 8 F (d) 16 F

7. With an increase in temperature, the viscosity of liquid and gas, respectively will
(a) increase and increase (b) increase and decrease
(c) decrease and increase (d) decrease and decrease

8. The Young's modulus for a perfect rigid body is
(a) 0 (b) 1 (c) 0.5 **(d) infinity**

9. Which of the following is not a scalar?
(a) viscosity (b) surface tension
(c) pressure **(d) stress**

10. If the temperature of the wire is increased, then the Young's modulus will
(a) remain the same **(b) decrease**
(c) increase rapidly (d) increase by very a small amount

11. Copper of fixed volume V is drawn into a wire of length l. When this wire is subjected to a constant force F, the extension produced in the wire is Δl. If Y represents the Young's modulus, then which of the following graphs is a straight line?
(a) Δlversus V (b) Δlversus Y
(c) Δlversus F (d) Δlversus $\frac{1}{l}$

12. A certain number of spherical drops of a liquid of radius R coalesce to form a single drop of radius R and volume V. If T is the surface tension of the liquid, then
    (a) energy = 4 V T $\left(\frac{1}{r} - \frac{1}{R}\right)$ is released
    (b) energy = 3 V T $\left(\frac{1}{r} + \frac{1}{R}\right)$ is absorbed
    (c) energy =3 V T $\left(\frac{1}{r} - \frac{1}{R}\right)$ is released
    (d) energy is neither released nor absorbed
13. The following four wires are made of the same material. Which of these will have the largest extension when the same tension is applied?
    (a) length = 200 cm, diameter = 0.5 mm
    (b) length= 200 cm, diameter = 1 mm
    (c) length = 200 cm, diameter = 2 mm
    (d) length= 200 cm, diameter = 3 m
14. The wettability of a surface by a liquid depends primarily on
    (a) viscosity (b) surface tension
    (c) density
    (d) angle of contact between the surface and the liquid
15. In a horizontal pipe of non-uniform cross section, water flows with a velocity of $1 ms^{-1}$ at a point where the diameter of the pipe is 20 cm. The velocity of water ($1.5 ms^{-1}$) at a point where the diameter of the pipe is (in cm)
    (a) 8 **(b) 16** (c) 24 (d) 32

UNIT – 8 (HEAT AND THERMODYNAMICS)

1. In hot summer after a bath, the body's
    (a) internal energy decreases (b) internal energy increases
    (c) heat decreases
    (d) no change in internal energy and heat
2. The graph between volume and temperature in Charles' law is
    (a) an ellipse (b) a circle
    (c) a straight line (d) a parabola
3. When a cycle tyre suddenly bursts, the air inside the tyre expands. This process is
    (a) isothermal **(b) adiabatic**
    (c) isobaric (d) isochoric
4. An ideal gas passes from one equilibrium state (P_1, V_1, T_1, N) to another equilibrium state ($2P_1$, $3V_1$, T_2, N). Then
    (a) $T_1 = T_2$ **(b) $T_1 = \frac{T_2}{6}$** (c) $T_1 = 6T_2$ (d) $T_1 = 3T_2$

5. When a uniform rod is heated, which of the following quantity of the rod will increase

(a) mass (b) weight

(c) center of mass **(d) moment of inertia**

6. When food is cooked in a vessel by keeping the lid closed, after some time the steam pushes the lid outward. By considering the steam as a thermodynamic system, then in the cooking process

(a) $Q > 0$, $W > 0$ (b) $Q < 0$, $W > 0$

(c) $Q > 0$, $W < 0$ (d) $Q < 0$, $W < 0$

7. When you exercise in the morning, by considering your body as thermodynamic system, which of the following is true?

(a) $\Delta U > 0$, $W > 0$ **(b) $\Delta U < 0$, $W > 0$**

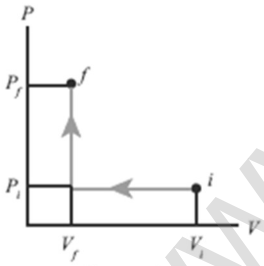
(c) $\Delta U < 0$, $W < 0$ (d) $\Delta U = 0$, $W > 0$

8. A hot cup of coffee is kept on the table. After some time, it attains a thermal equilibrium with the surroundings. By considering the air molecules in the room as a thermodynamic system, which of the following is true

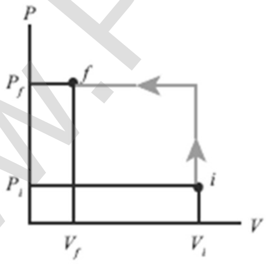
(a) $\Delta U > 0$, $Q = 0$ (b) $\Delta U > 0$, $W < 0$

(c) $\Delta U > 0$, $Q > 0$ (d) $\Delta U = 0$, $Q > 0$

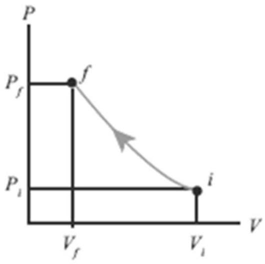
9. An ideal gas is taken from (P_i,V_i) to (P_f,V_f) in three different ways. Identify the process in which the work done on the gas the most.



Process A



Process B

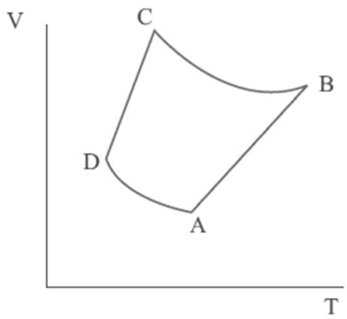


Process C

(a) Process A **(b) Process B**

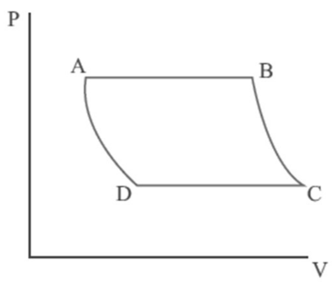
(c) Process C (d) Equal work is done in Process A,B&C

10. The V-T diagram of an ideal gas which goes through a reversible cycle A⟶B⟶C⟶D is shown below. (Processes D⟶A and B⟶C are adiabatic)

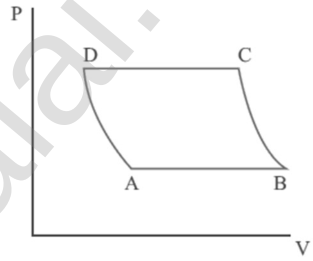


The corresponding PV diagram for the process is (all figures are schematic)

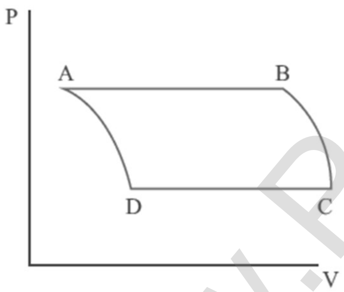
(a)



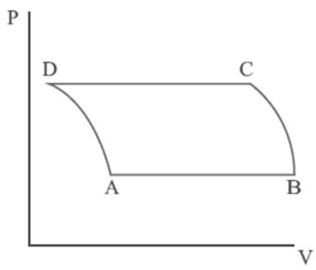
(b)



(c)



(d)



11. A distant star emits radiation with maximum intensity at 350 nm. The temperature of the star is

(a) 8280 K (b) 5000K (c) 7260 K (d) 9044 K

12. Identify the state variables given here?

(a) Q, T, W **(b) P, T, U** (c) Q, W (d) P, T, Q

13. In an isochoric process, we have

(a) W = 0 (b) Q = 0 (c) ΔU = 0 (d) ΔT = 0

14. The efficiency of a heat engine working between the freezing point and boiling point of water is

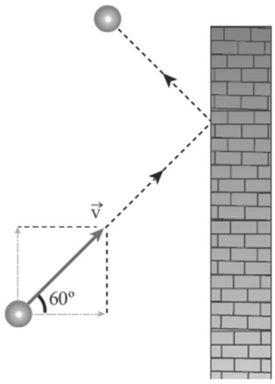
(a) 6.25% (b) 20% **(c) 26.8%** (d) 12.5%

15. An ideal refrigerator has a freezer at temperature −12°C. The coefficient of performance of the engine is 5. The temperature of the air (to which the heat ejected) is

(a) 50°C (b) 45.2°C **(c) 40.2°C** (d) 37.5°C

UNIT – 9 (KINETIC THEORY OF GASES)

1. A particle of mass m is moving with speed uin a direction which makes 60° with respect to x axis. It undergoes elastic collision with the wall. What is the change in momentum in x and y direction?



(a) $\boldsymbol{\Delta p_x = -mu, \Delta p_y = 0}$ (b) $\Delta p_x = -2mu, \Delta p_y = 0$
(c) $\Delta p_x = 0, \Delta p_y = mu$ (d) $\Delta p_x = mu, \Delta p_y = 0$

2. A sample of ideal gas is at equilibrium. Which of the following quantity is zero?
(a) rms speed (b) average speed
(c) average velocity (d) most probable speed

3. An ideal gas is maintained at constant pressure. If the temperature of an ideal gas increases from 100K to 10000K then the rms speed of the gas molecules
(a) increases by 5 times **(b) increases by 10 times**
(c) remains same (d) increases by 7 times

4. Two identically sized rooms A and B are connected by an open door. If the room A is air conditioned such that its temperature is 4°C lesser than room B, which room has more air in it?
(a) Room A (b) Room B
(c) Both room has same air (d) Cannot be determined

5. The average translational kinetic energy of gas molecules depends on
(a) number of moles and T (b) only on T
(c) P and T (d) P only

6. If the internal energy of an ideal gas U and volume V are doubled then the pressure
(a) doubles **(b) remains same**
(c) halves (d) quadruples

7. The ratio $\gamma = \frac{C_P}{C_V}$ for a gas mixture consisting of 8 g of helium and 16 g of oxygen is
(a) 23/15 (b) 15/23
(c) 27/17 (d) 17/2

8. A container has one mole of monoatomic ideal gas. Each molecule has f degrees of freedom. What is the ratio of $\gamma = \frac{C_P}{C_V}$
(a) f (b) $\frac{f}{2}$ (c) $\frac{f}{f+2}$ **(d)** $\boldsymbol{\frac{f+2}{f}}$

9. If the temperature and pressure of a gas is doubled the mean free path of the gas molecules

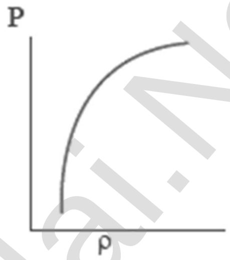
(a) remains same (b) doubled

(c) tripled (d) quadrapoled

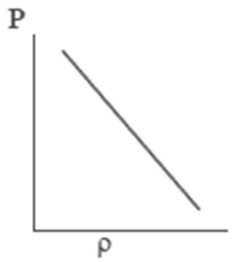
10. Which of the following shows the correct relationship between the pressure and density of an ideal gas at constant temperature?

(a)

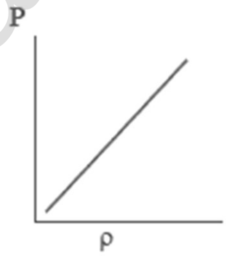
(b)



(c)



(d)



11. A sample of gas consists of μ_1 moles of monoatomic molecules, μ_2 moles of diatomic molecules and μ_3 moles of linear triatomic molecules. The gas is kept at high temperature. What is the total number of degrees of freedom?

(a) $[3\mu_1 + 7(\mu_2 + \mu_3)]\,N_A$ (b) $[3\mu_1 + 7\mu_2 + 6\mu_3]\,N_A$

(c) $[7\mu_1 + 3(\mu_2 + \mu_3)]\,N_A$ (d) $[3\mu_1 + 6(\mu_2 + \mu_3)]\,N_A$

12. If S_P and S_V denote the specific heats of nitrogen gas per unit mass at constant pressure and constant volume respectively, then

(a) $S_P - S_V = 28R$ **(b) $S_P - S_V = R/28$**

(c) $S_P - S_V = R/14$ (d) $S_P - S_V = R$

13. Which of the following gases will have least rms speed at a given temperature?

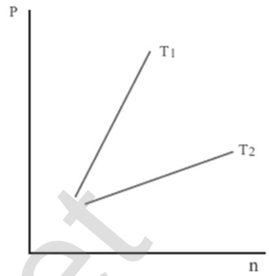
(a) Hydrogen (b) Nitrogen

(c) Oxygen **(d) Carbon dioxide**

14. For a given gas molecule at a fixed temperature, the area under the Maxwell-Boltzmann distribution curve is equal to

(a) $\frac{PV}{kT}$ (b) $\frac{kT}{PV}$ (c) $\frac{P}{NkT}$ (d) PV

15. The following graph represents the pressure versus number density for ideal gas at two different temperatures T_1 and T_2. The graph implies



(a) $T_1 = T_2$ (b) $T_1 > T_2$
(c) $T_1 < T_2$ (d) Cannot be determined

UNIT – 10 (KINETIC THEORY OF GASES)

1. In a simple harmonic oscillation, the acceleration against displacement for one complete oscillation will be
(a) an ellipse (b) a circle (c) a parabola **(d) a straight line**

2. A particle executing SHM crosses points A and B with the same velocity. Having taken 3 s in passing from A to B, it returns to B after another 3 s. The time period is
(a) 15 s (b) 6 s **(c) 12 s** (d) 9 s

3. The length of a second's pendulum on the surface of the Earth is 0.9 m. The length of the same pendulum on surface of planet X such that the acceleration of the planet X is n times greater than the Earth is
(a) 0.9n (b) $\frac{0.9}{n}m$ (c) $0.9n^2m$ (d) $\frac{0.9}{n^2}$

4. A simple pendulum is suspended from the roof of a school bus which moves in a horizontal direction with an acceleration a, then the time period is
(a) $T \propto \frac{1}{g^2+a^2}$ **(b) $T \propto \frac{1}{\sqrt{g^2+a^2}}$**
(c) $T \propto \sqrt{g^2 + a^2}$ (d) $T \propto (g^2 + a^2)$

5. Two bodies A and B whose masses are in the ratio 1:2 are suspended from two separate massless springs of force constants k_A and k_B respectively. If the two bodies oscillate vertically such that their maximum velocities are in the ratio 1:2, the ratio of the amplitude A to that of B is
(a) $\sqrt{\frac{k_B}{2k_A}}$ **(b) $\sqrt{\frac{k_B}{8k_A}}$** (c) $\sqrt{\frac{2k_B}{k_A}}$ (d) $\sqrt{\frac{8k_B}{k_A}}$

6. A spring is connected to a mass m suspended from it and its time period for vertical oscillation is T. The spring is now cut into two equal halves and the same mass is suspended from one of the halves. The period of vertical oscillation is
(a) $T' = \sqrt{2}\,T$ **(b) $T' = \frac{T}{\sqrt{2}}$** (c) $T' = \sqrt{2T}$ (d) $T' = \sqrt{\frac{T}{2}}$

7. The displacement of a simple harmonic motion is given by $y(t) = A \sin(\omega t + \phi)$ where Ais amplitude of the oscillation, ω is the angular frequency and ϕ is the phase. Let the amplitude of the oscillation be 8 cm and the time period of the oscillation is 24 s. If the displacement at initial time (t = 0 s) is 4 cm, then the displacement at t = 6 s is
(a) 8 cm (b) 4 cm (c) $4\sqrt{3}$ cm **(d) $8\sqrt{3}$ cm**

8. A simple pendulum has a time period T_1. When its point of suspension is moved vertically upwards according as $y = k\,t^2$, where y is vertical distance covered and k = 1 ms^{-2}, its time period becomes T_2. Then, $\frac{T_1^2}{T_2^2}$ is (g = 10 ms^{-2})

(a) $\frac{5}{6}$ (b) $\frac{11}{10}$ **(c) $\frac{6}{5}$** (d) $\frac{5}{4}$

9. An ideal spring of spring constant k, is suspended from the ceiling of a room and a block of mass M is fastened to its lower end. If the block is released when the spring is un-stretched, then the maximum extension in the spring is

(a) $4\frac{Mg}{k}$ (b) $\frac{Mg}{k}$ **(c) $2\frac{Mg}{k}$** (d) $\frac{Mg}{2k}$

10. A pendulum is hung in a very high building oscillates to and fro motion freely like a simple harmonic oscillator. If the acceleration of the bob is 16 ms^{-2} at a distance of 4 m from the mean position, then the time period is

(a) 2 s (b) 1 s (c) 2πs **(d) πs**

11. Ahollow sphere is filled with water. It is hung by a long thread. As the water flows out of a hole at the bottom, the period of oscillation will

(a) first increase and then decrease (b) first decrease and then increase
(c) increase continuously (d) decrease continuously

12. The damping force on an oscillator is directly proportional to the velocity. The units of the constant of proportionality are

(a) kg ms^{-1} (b) kg ms^{-2} **(c) kgs^{-1}** (d) kg s

13. Let the total energy of a particle executing simple harmonic motion with angular frequency is 1 rad s^{-1} is 0.256 J. If the displacement of the particle at time t=$\frac{\pi}{2}$s is $8\sqrt{3}$ cm then the amplitude of motion is

(a) 8 cm **(b) 16 cm** (c) 32 cm (d) 64 cm

14. A particle executes simple harmonic motion and displacement y at time t_0, $2t_0$ and $3t_0$ are A, B and C, respectively. Then the value of $\left(\frac{A+C}{2B}\right)$ is

(a) $\cos \omega t_0$ (b) $\cos 2\omega t_0$ (c) $\cos 3\omega t_0$ (d) 1

15. A mass of 3 kg is attached at the end of a spring moves with simple harmonic motion on a horizontal frictionless table with time period 2π and with amplitude of 2m, then the maximum fore exerted on the spring is

(a) 1.5 N (b) 3 N **(c) 6 N** (d) 12 N

UNIT – 11 (WAVES)

1. A student tunes his guitar by striking a 120 Hertz with a tuning fork, and simultaneously plays the 4th string on his guitar. By keen observation, he hears the amplitude of the combined sound oscillating thrice per second. Which of the following frequencies is the most likely the frequency of the 4th string on his guitar?
   (a) 130 **(b) 117** (c) 110 (d) 120
2. A transverse wave moves from a medium A to a medium B. In medium A, the velocity of the transverse wave is 500 ms^{-1} and the wavelength is 5 m. The frequency and the wavelength of the wave in medium B when its velocity is 600 ms^{-1}, respectively are
   (a) 120 Hz and 5 m (b) 100 Hz and 5 m
   (c) 120 Hz and 6 m **(d) 100 Hz and 6 m**
3. For a particular tube, among six harmonic frequencies below 1000 Hz, only four harmonic frequencies are given: 300 Hz, 600 Hz, 750 Hz and 900 Hz. What are the two other frequencies missing from this list?
   (a) 100 Hz, 150 Hz **(b) 150 Hz, 450 Hz**
   (c) 450 Hz, 700 Hz (d) 700 Hz, 800 Hz
4. Which of the following options is correct?

A	B
(1) Quality	(A) Intensity
(2) Pitch	(B) Waveform
(3) Loudness	(C) Frequency

   Options for (1), (2) and (3), respectively are
   (a) (B),(C) and (A) (b) (C), (A) and (B)
   (c) (A), (B) and (C) (d) (B), (A) and (C)
5. Equation of travelling wave on a stretched string of linear density 5 g/m is y = 0.03 sin(450t – 9x), where distance and time are measured in SI units. The tension in the string is
   (a) 5 N **(b) 12.5 N** (c) 7.5 N (d) 10 N
6. A sound wave whose frequency is 5000 Hz travels in air and then hits the water surface. The ratio of its wavelengths in water and air is
   (a) 4.30 (b) 0.23 (c) 5.30 (d) 1.23
7. A person standing between two parallel hills fi res a gun and hears the first echo after $t_1$sec and the second echo after $t_2$sec. The distance between the two hills is
   (a) $\frac{v(t_1-t_2)}{2}$ (b) $\frac{v(t_1 t_2)}{2(t_1+t_2)}$
   (c) $v(t_1+t_2)$ **(d) $\frac{v(t_1+t_2)}{2}$**
8. An air column in a pipe which is closed at one end, will be in resonance with the vibrating body of frequency 83Hz. Then the length of the air column is
   (a) 1.5 m (b) 0.5 m **(c) 1.0 m** (d) 2.0 m

9. The displacement *y* of a wave travelling in the *x* direction is given by $y = (2x10^{-3})\sin\left(300t - 2x + \frac{\pi}{4}\right)$, where x and y are measured in metres and tin second. The speed of the wave is

(a) 150 ms^{-1} (b) 300 ms^{-1} (c) 450 ms^{-1} (d) 600 ms^{-1}

10. Consider two uniform wires vibrating simultaneously in their fundamental notes. The tensions, densities, lengths and diameter of the two wires are in the ratio 8: 1, 1: 2, x : y and 4 : 1 respectively. If the note of the higher pitch has a frequency of 360 Hz and the number of beats produced per second is 10, then the value of x: y is

(a) 36: 35 (b) 35: 36 (c) 1: 1 (d) 1: 2

11. Which of the following represents a wave

(a) $(x - vt)^3$ (b) $x(x + vt)$ (c) $\frac{1}{(x + vt)}$ (d) $\sin(\boldsymbol{x} + \boldsymbol{vt})$

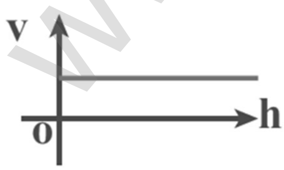
12. A man sitting on a swing which is moving to an angle of 60^0 from the vertical is blowing a whistle which has a frequency of 2.0 k Hz. The whistle is 2.0 m from the fixed support point of the swing. A sound detector which detects the whistle sound is kept in front of the swing. The maximum frequency the sound detector detected is

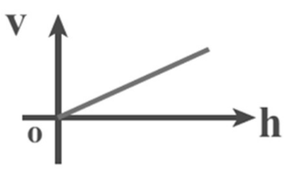
(a) 2.027 kHz (b) 1.974 kHz (c) 9.74 kHz (d) 1.011 kHz

13. Let $y = \frac{1}{1+x^2}$ at t = 0 s be the amplitude of the wave propagating in the positive x-direction. At t = 2 s, the amplitude of the wave propagating becomes $y = \frac{1}{1 + (x-2)^2}$. Assume that the shape of the wave does not change during propagation. The velocity of the wave is

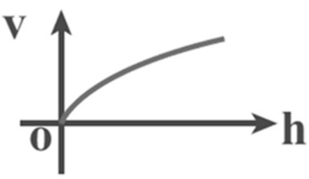
(a) 0.5m s^{-1} (b) 1.0m s^{-1} (c) 1.5m s^{-1} (d) 2.0m s^{-1}

14. A uniform rope having mass m hangs vertically from a rigid support. A transverse wave pulse is produced at the lower end. Which of the following plots shows the correct variation of speed *v* with height *h* from the lower end?

(a)


(b)


(c)


(d)


15. An organ pipe A closed at one end is allowed to vibrate in its first harmonic and another pipe B open at both ends is allowed to vibrate in its third harmonic. Both A and B are in resonance with a given tuning fork. The ratio of the length of A and B is

(a) $\frac{8}{3}$ (b) $\frac{3}{8}$ (c) $\frac{1}{6}$ (d) $\frac{1}{3}$

Do You Know?

The name Physics was introduced by Aristotle in the year 350 BC

The cgs, mks and SI are metric or decimal system of units. The fps system is not a metric system.

The supplementary quantities of plane and solid angle were converted into Derived quantities in 1995 (GCWM)

Why is the cylinder used in defining kilogram made up of platinum-iridium alloy? This is because the platinum-iridium alloy is least affected by environment and time.

In India, the National Physical Laboratory (New Delhi) has the responsibility of maintenance and improvement of physical standards of length, mass, time, etc.

In Tamil Nadu there is an interesting traditional game 'kitti pull'. When the 'pull' is hit by the kitti, the path followed by the pull is 'parabolic'.

Incandescent lamps glow for 1000 hours. CFL lamps glow for 6000 hours. But LED lamps glow for 50000 hrs (almost 25 years at 5.5 hour per day).

Tamil Nadu is known for creative and innovative traditional games played by children. One such very popular game is "silli" (சில்லி) or "sillukodu" (சில்லுக்கோடு). There is a rectangular area which is further partitioned as seen in the Figure. One has to hop through the rectangles. While doing so, children lean on one side, because of the reason that naturally the body takes this position to balance the gravitational force (mg) and normal force (N) acting on the body and to nullify the torque. Failing which, both these forces act along different lines leading to a net torque which makes one to fall.

Obesity and associated ailments like back pain, joint pain etc. are due to the shift in centre of mass of the body. Due to this shift in centre of mass, unbalanced torque acting on the body leads to ailments. As the mass is spread away from centre of the body the moment of inertia is more and turning will also be difficult.

In the year 1798, Henry Cavendish experimentally determined the value of gravitational constant 'G' by using a torsion balance. He calculated the value of 'G' to be equal to 6.75×10^{-11} Nm^2kg^{-2}. Using modern techniques, a more accurate value of G could be measured. The currently accepted value of G is 6.75×10^{-11} Nm^2kg^{-2}

In addition to the three physical states of matter (solid, liquid, and gas), in extreme environments, matter can exist in other states such as plasma, Bose-Einstein condensates. Additional states, such as quark-gluon plasmas are also believed to be possible. A major part of the atomic matter of the universe is hot plasma in the form of rarefied interstellar medium and dense stars.

After pumping the air in the cycle tyre, usually we press the cycle tyre to check whether it hasenough air. What is checked here is essentially the compressibility of air. The tyre should be less compressible for its easy rolling. In fact, the rear tyre is less compressible than front tyre for a smooth ride.

Which one is more elastic? Rubber or steel? Steel is more elastic than rubber. If an equal stress is applied to both steel and rubber, the steel produces less strain. So the Young's modulus is higher for steel than rubber. The object which has higher Young's modulus is more elastic.

The atmospheric pressure at a place is the gravitational force exerted by air above that place per unit surface area. It changes with height and weather conditions (i.e. density of air). In fact, the atmospheric pressure decreases with increasing elevation.

The decrease of atmospheric pressure with altitude has an unwelcome consequence in daily life. For example, it takes longer time to cook at higher altitudes. Nose bleeding is another common experience at higher altitude because of larger difference in atmospheric pressure and blood pressure. Its value on the surface of the Earth at sea level is 1atm.

1 atm pressure = 1.013×10^5pa

Submarines can sink or rise in the depth of water by controlling its buoyancy. To achieve this, the submarines have ballast tanks that can be filled with water or air alternatively. When the ballast tanks are filled with air, the overall density of the submarine becomes lesser than the surrounding water and it surfaces (positive buoyancy). If the tanks are flooded with water replacing air, the overall density becomes greater than the surrounding water and submarine begins to sink (negative buoyancy). To keep the submarine at any depth, tanks are filled with air and water (neutral buoyancy).

The smaller the radius of a liquid drop, the greater is the excess of pressure inside the drop. It is due to this excess of pressure inside; the tiny fog droplets are rigid enough to behave like solids.

When an ice-skater skate over the surface of the ice, some ice melts due to the pressure exerted by the sharp metal edges of the skates, the tiny droplets of water act as rigid ball- bearings and help the skaters to run along smoot

A spider web is much stronger than what we think. A single strand of spider silk can stop flying insects which are tens and thousands times its mass. **The young's modulus of the spider web is approximately 4.5×10^9N m^{-2}**. Compare this value with Young's modulus of wood.

When two objects ofsame mass are heated atequal rates, the objectwith smaller specific heatcapacity will have a faster temperatureincrease.
When two objects of same massare left to cool down, the temperatureof the object with smaller specific heatcapacity will drop faster.

When the lid of aglass bottle is tight, keepthe lid near the hot waterwhich makes it easier toopen. It is because the lid has higherthermal expansion than glass.

When the hot boiled egg is droppedin cold water, the egg shell can beremoved easily. It is because of thedifferent thermal expansions of theshell and egg.

During the day, sun rays warm up the land more quickly than sea water. It is because land has less specific heat capacity than water. As a result, the air above the land becomes less dense and rises. At the same time the cooler air above the sea flows to land and it is called 'sea breeze'. During the night time the land gets cooled faster than sea due to the same reason (specific heat). The air molecules above sea are warmer than air molecules above the land. So air molecules above the sea are replaced by cooler air molecules from the land. It is called 'land breeze'.

When the piston is compressed so quickly that there is no time to exchange heat to the surrounding, the temperature of the gas increases rapidly. This is shown in the figure. This principle is used in the diesel engine. The air-gasoline mixer is compressed so quickly (adiabatic compression) that the temperature increases enormously, which is enough to produce a spark.

Diesel engines used in cars and petrol engines used in our motor bikes are all real heat engines. The efficiency of diesel engines has maximum up to 44% and the efficiency of petrol engines are maximum up to 30%. Since these engines are not ideal heat engines (Carnot engine), their efficiency is limited by the second law of thermodynamics. Now a day's typical bikes give a mileage of 50 km per Liter of petrol. This implies only 30% of 1 Liter of petrol is converted into mechanical work and the remaining 70% goes out as wasted heat and ejected into the surrounding atmosphere!

In hot summer, we use earthern pots to drink cold water. The pot reduces the temperature of water inside it. Does the earthern pot act as a refrigerator? No. cyclic process is the basic necessity for heat engine or refrigerator. In earthern pot, the cooling process is not due to any cyclic process. The cooling occurs due to evaporation of water molecules which oozes out through pores of the pot. Once the water molecules evaporate, they never come back to the pot. Even though the heat flows from cold water to open atmosphere, it is not a violation of second law of thermodynamics. The water inside the pot is an open thermodynamic system, so the entropy of water + surrounding always increases.

Soldiers are not allowed to march on a bridge. This is to avoid resonant vibration of the bridge. While crossing a bridge, if the period of stepping on the ground by marching soldiers equals the natural frequency of the bridge, it may result in resonance vibrations. This may be so large that the bridge may collapse.

Supersonic speed:

An object moving with a speed greater than the speed of sound is said to move with a supersonic speed.

Mach number:

It is the ratio of the velocity of source to the velocity of sound.

NOTES:

In uniform circular motion, the centripetal force is perpendicular to the displacement. Hence, work done by this force is zero

Kinematic equations for linear motion are applicable for only constant acceleration. Similarly, kinematic equations for angular motion are applicable to only constant angular acceleration.

It is dangerous to stand near the open door (or) steps while travelling in the bus. When the bus takes a sudden turn in a curved road, due to centrifugal force the person is pushed away from the bus. Even though centrifugal force is a pseudo force, its effects are real.

The terminal speed of a sphere is directly proportional to the square of the radius of the sphere. Hence, larger raindrops fall with greater speed as compared to the smaller raindrops.

If the density of the material of the sphere is less than the density of the medium, then the sphere shall attain terminal velocity in the upward direction. That is why gas bubbles rise up in soda water.

There is a misconception that heat is a quantity of energy. People often talk 'this water has more heat or less heat'. These words are meaningless. Heat is not a quantity. Heat is an energy in transit which flows from higher temperature object to lower temperature object. Once the heating process is stopped we cannot use the word heat. When we use the word 'heat', it is the energy in transit but not energy stored in the body.

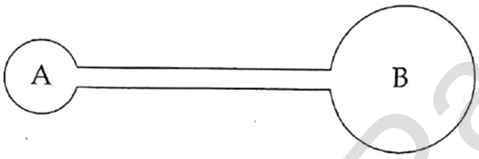
The term heat capacity or specific heat capacity does not mean that object contains a certain amount of heat. Heat is energy transfer from the object at higher temperature to the object at lower temperature. The correct usage is 'internal energy capacity'. But for historical reason the term 'heat capacity' or 'specific heat capacity' are retained.

All reversible processes are quasi-static but all quasi-static processes need not be reversible. For example, when we push the piston very slowly, if there is friction between cylinder wall and piston some amount of energy is lost to surroundings, which cannot be retrieved back.

PUBLIC EXAM – ONE MARK QUESTION

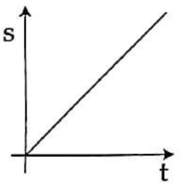
MARCH 2019

1. What is the angular displacement made by a particle after 5s, when it starts from rest with an angular acceleration 0.2 rad s^{-2}?
   (a) 4 rad (b) 1 rad **(c) 2.5 rad** (d) 5 rad
2. The process in which heat transfer is by actual movement of molecules in fluids such as liquids and gases is called:
   (a) thermal conductivity **(b) Convection**
   (c) Conduction (d) Radiation
3. Which of the following pairs of physical quantities have the same dimensions?
   (a) Torque and Power (b) Force and torque
   (c) Force and Power **(d) Torque and Energy**
4. For a satellite moving in an orbit around the earth, the ratio of kinetic energy to potential energy is :
   (a) 2 (b) $\sqrt{2}$ **(c)** $\mathbf{\frac{1}{2}}$ (d) $\frac{1}{\sqrt{2}}$
5. There is a small bubble at one end and bigger bubble at other end of a pipe. Which among the following will happen?



   (a) remains in equilibrium
   (b) smaller will grow until they collapse
   (c) bigger will grow until they collapse (d) none of the above
6. A refrigerator has COP of 3. How much work must be supplied to a refrigerator in order to remove 200 J of heat from its interior?
   (a) 33.33 J (b) 44.44 J **(c) 66.67 J** (d) 50 J
7. If the temperature of the wire is increased, then the Young's Modulus will:
   (a) increase rapidly (b) increase by very small amount
   (c) remain the same **(d) decrease**
8. If the internal energy of an ideal gas U and volume V are doubled, then the pressure of the gas:
   (a) halves (b) quadruples (c) doubles **(d) remains same**
9. A body of mass 5 kg is thrown up vertically with a kinetic energy of 1000 J. If acceleration due to gravity is 10 ms^{-2}, find the height at which the kinetic energy becomes half of the original value.
   (a) 10 m (b) 20 m (c) 50 m (d) 100 m

10. Which graph represents uniform acceleration?

(a)


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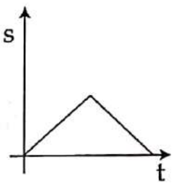

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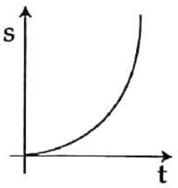
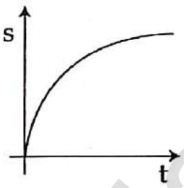


(d)


(c)

11. In an isochoric process, find which is relevant among the following:
(a) $\Delta U = 0$ (b) $\Delta T = 0$ **(c) W = 0** (d) Q = 0

12. The amplitude and time period of a simple pendulum bob are 0.05 m and 2 s respectively. Then the maximum velocity of the bob is :
(a) 0.157 ms^{-1} (b) 0.257 ms^{-1} (c) 0.10 ms^{-1} (d) 0.025 ms^{-1}

13. A closed cylindrical container is partially filled with water. As the container rotates in a horizontal plane about a perpendicular bisector, its moment of inertia:
(a) remains constant (b) depends on the direction of rotation
(c) increase (d) decrease

14. Which of the following represents a wave?
(a) $\frac{1}{x+vt}$ **(b) sin $(x+vt)$** (c) $(x-vt)^3$ (d) $x(x+vt)$

15. If the linear momentum of the object is increased by 0.1 %, then the kinetic energy is increased by:
(a) 0.4 % (b) 0.01 % (c) 0.1 % **(d) 0.2 %**

MARCH 2020

1. Identify the unit vector in the following
(a) $\frac{\hat{\imath}+\hat{\jmath}}{\sqrt{2}}$ (b) $\hat{\imath}+\hat{\jmath}$ (c) $\frac{\hat{\imath}}{\sqrt{2}}$ (d) $\hat{k}-\frac{\hat{\jmath}}{\sqrt{2}}$

2. Human audible wavelength range (velocity of sound in air = 340 ms^{-1}) is :
(a) 17 m to 170 m (b) 0.17 m to 17 m
(c) 0.017 m to 17 m (d) 1.7 m to 17 m

3. An air column in a pipe which is closed at one end, is in resonance with the vibrating body of frequency 83 Hz. Then the length of the air column is :
(velocity of sound in air = 332 ms^{-1})
(a) 1.5 m (b) 0.5 m (c) 2.0 m **(d) 1.0 m**

4. rms speed of hydrogen molecule at 27^0 C:
(a) 193 kms^{-1} **(b) 1.93 kms^{-1}** (c) 19.3 kms^{-1} (d)0.193kms^{-1}

5. Which one of the following is a scalar quantity?
(a) Speed (b) Velocity
(c) Displacement (d) Linear momentum

6. The length of a body is measured as 3.51 m. If the accuracy is 0.01m, then the percentage error in the measurement is :
(a) 0.035 % (b) 351 % (c) 1 % **(d) 0.28 %**

7. A body of mass 20 kg moving with a speed of 10 ms^{-1} on a horizontal smooth surface collides with a massless spring of spring constant 5 N/m. If the mass stops after collision, distance of compression of the spring will be :
(a) 10 m (b) 50 m (c) 5 m **(d) 20 m**

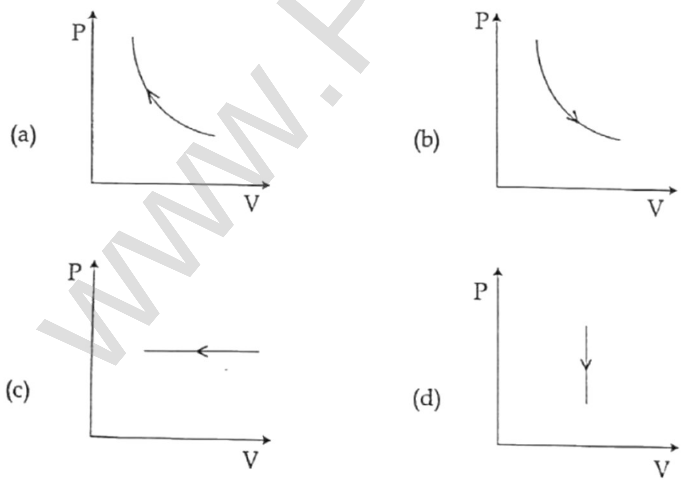
8. When a car takes a sudden left turn on a curved road, passengers are pushed towards the right due to :
(a) absence of inertia **(b) inertia of direction**
(c) inertia of motion (d) inertia of rest

9. The efficiency of a heat engine working between the freezing point and boiling point of water is :
(a) 12.5 % (b) 6.25 % (c) 20 % **(d) 26.8 %**

10. A spring of force constant k is cut into two pieces such that the length of one piece is double the length of the other. Then the longer piece will have a force constant of :
(a) 6 k (b) $\frac{2}{3}$ k **(c) $\frac{3}{2}$ k** (d) 3k

11. The dimensional formula for Moment of Inertia:
(a) $ML^{-1}T^{-1}$ (b) ML^2T^{-2} (c) MLT^2 **(d) ML^2**

12. Which one of the following P-V diagrams correspondents to isobaric compression?



(c)

13. The ratio between the rms speed and most probable speed of gas molecules at a given temperature is :
(a) $2\sqrt{2} : \sqrt{1}$ **(b) $\sqrt{3} : \sqrt{2}$** (c) $\sqrt{2} : \sqrt{3}$ (d) $\sqrt{1} : 2\sqrt{2}$

14. If the distance between the Earth and Sun is twice its present value, the number of days in a year will be :
(a) 730 **(b) 1032** (c) 64.5 (d) 182.5

15. Moment of inertia of a solid of Mass M, length l and radius r about its own axis is :
(a) $M\left(\frac{r^2}{2} + \frac{l^2}{12}\right)$ (b) Mr^2
(c) $\frac{1}{4}Mr^2$ **(d) $\frac{1}{2}Mr^2$**

SEPTEMBER 2020

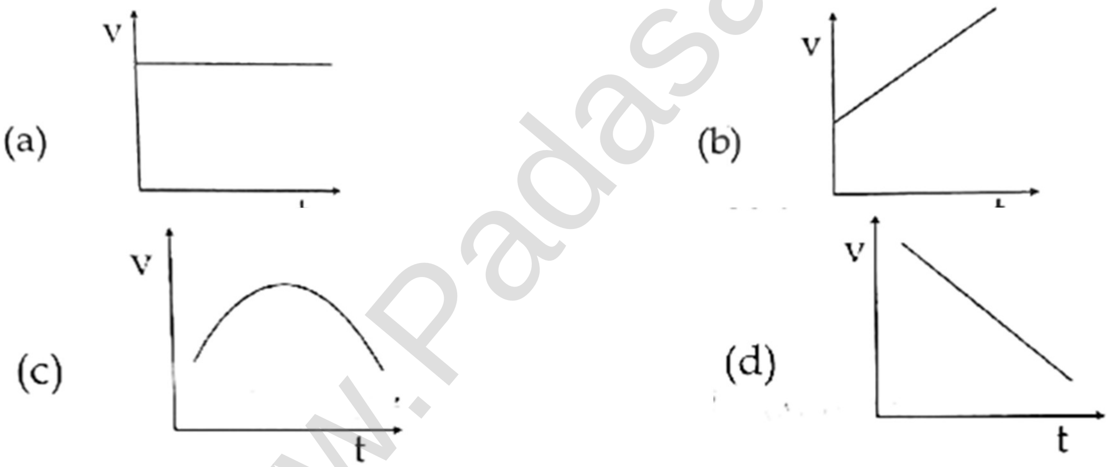
1. If the error in the measurement of radius of a sphere is 2%, then the error in the determination of its volume will be :
(a) 8 % (b) 2 % (c) 4 % **(d) 6 %**

2. A stone of mass 0.5 kg tied to a string executes uniform circular motion in a circle of radius 2 m with a speed of 4 ms^{-1}. The magnitude of tension acting on the stone will be :
(a) 3 N (b) 10 N (c) 0.5 N **(d) 4 N**

3. If a particle executes uniform circular motion in the xy plane in clockwise direction, then the angular velocity is in:
(a) + y direction (b) + z direction
(c) – z direction (d) – x direction

4. The velocity – time (v-t) graph representing motion of particle moving with uniform velocity is :

(a)



5. A rigid body rotates with an angular momentum L. If its kinetic energy is halved, then angular momentum becomes:
(a) L (b) $\frac{L}{2}$ (c) 2L **(d)** $\frac{L}{\sqrt{2}}$

6. The energy consumed in electrical units when a 60 W fan is used for 8 hours daily one month (30 days) is nearly:
(a) 14 units (b) 18 units (c) 16 units (d) 20 units

7. In a vertical circular motion, the minimum speed at the lowest point required by the mass to complete circular motion is (Radius of the circular path is r) :
(a) $\sqrt{2gr}$ (b) 2gr **(c)** $\sqrt{5gr}$ (d) 5gr

8. The wettability of a surface by a liquid depends primary on :
(a) viscosity (b) surface tension
(c) density
(d) angle of contact between surface and the liquid

9. An object of mass 10 kg is hanging from a spring scale which is attached to the roof of a lift. If the lift is in free fall, the reading in the spring scale is :
(a) 98 N **(b) zero** (c) 49 N (d) 9.8 N

10. All natural processes occur such that entropy should:
    (a) always increase (b) always decrease
    (c) first increase and then decrease (d) does not change
11. The graph between volume of a given mass of gas and temperature when its pressure remains constant is :
    (a) an ellipse (b) a circle
    (c) a straight line (d) a parabola
12. When a damped harmonic oscillator completes 100 oscillations, its amplitude is reduced to $\frac{1}{3}$ of its initial value. What will be its amplitude when it completes 200 oscillations?
    (a) $\frac{1}{5}$ (b) $\frac{2}{3}$ (c) $\frac{1}{6}$ (d) $\frac{1}{9}$
13. Which of the following is an example of non-linear triatomic molecule?
    (a) Water (b) Hydrogen (c) Helium (d) Nitrogen
14. If S_P and S_V denote the specific heats of nitrogen gas per unit mass at constant pressure and constant volume respectively, then :
    (a) $S_P - S_V = 28\,R$ **(b) $S_P - S_V = R/28$**
    (c) $S_P - S_V = R/14$ (d) $S_P - S_V = R$
15. The first three frequencies of harmonics of a closed organ pipe will be in the ratio :
    (a) 1 : 2 : 3 **(b) 1 : 3 : 5** (c) 1 : 4 : 9 (d) 2 : 4 : 6

AUGUST 2021

1. Two equal masses m_1 and m_2 are moving along the same straight line with velocities 5 ms^{-1} and −9 ms^{-1} respectively. If the collision is elastic, then calculate the velocities after the collision of m_1 and m_2, respectively.
    (a) −9 ms^{-1} and 5 ms^{-1} (b) −4 ms^{-1} and 10 ms^{-1}
    (c) 5 ms^{-1} and 1 ms^{-1} (d) 10 ms^{-1} and 0 ms^{-1}
2. If a particle executes uniform circular motion in the xy plane in clockwise direction, then the angular velocity is in:
    (a) −z direction (b) +y direction
    (c) −x direction (d) +z direction
3. A hollow sphere is filled with water. It is hung by a long thread. As the water flows out of a hole at the bottom, the period of oscillation will:
    (a) increase continuously
    (b) first increase and then decrease
    (c) decrease continuously (d) first decrease and then increase
4. Which of the following is not a Scalar?
    (a) Pressure (b) Viscosity
    (c) Stress (d) Surface tension
5. If an object is thrown vertically up with the initial speed u from the ground, then the time taken by the object to return back to ground is:
    (a) $\frac{u}{2g}$ (b) $\frac{u^2}{2g}$ **(c) $\frac{2u}{g}$** (d) $\frac{u^2}{g}$

6. The efficiency of a heat engine working between the freezing point and boiling point of water is:
   (a) 26.8% (b) 6.25% (c) 12.5% (d) 20%
7. When an object is at rest on the inclined rough surface:
   (a) Static friction is not zero and kinetic friction is zero
   (b) Static and kinetic frictions acting on the object is zero
   (c) Static and kinetic frictions are not zero
   (d) Static friction is zero but kinetic friction is not zero
8. A couple produces:
   (a) rotation and translation **(b) pure rotation**
   (c) no motion (d) pure translation
9. A transverse wave moves from a medium A to a medium B. In medium A, the velocity of the transverse wave is 500 ms^{-1} and the wavelength is 5 m. The frequency and the wavelength of the wave in medium B when its velocity is 600 ms^{-1}, respectively are:
   (a) 120 Hz and 6 m (b) 120 Hz and 5 m
   (c) 100 Hz and 6 m (d) 100 Hz and 5 m
10. The dimensional formula of Planck's constant h is:
   (a) $[MLT^{-1}]$ **(b) $[ML^2T^{-1}]$** (c) $[ML^3T^{-3}]$ (d) $[ML^2T^{-3}]$
11. The unit of surface energy is:
   (a) Nm^3 (b) Nm^{-2} (c) Nm **(d) Nm^{-1}**
12. The gravitational potential energy of the Moon with respect to Earth is:
   (a) can be positive or negative (b) always positive
   (c) always zero **(d) always negative**
13. A spring is connected to a mass 'm' suspended from it and its time period for vertical oscillation is 'T'. The spring is now cut into two equal halves and the same mass is suspended from one of the halves. The period of vertical oscillation is:
   (a) $T' = \sqrt{2T}$ (b) $T' = \sqrt{2}\,T$ (c) $T' = \sqrt{\frac{T}{2}}$ **(d) $T' = \frac{T}{\sqrt{2}}$**
14. If the internal energy of an ideal gas U and Volume V are doubled then, the Pressure:
   (a) halves (b) doubles
   (c) quadruples **(d) remains same**
15. Consider a circular levelled road of radius 10 m having coefficient of static friction 0.81. With what speed a car has to move on the turn so that it will have safe turn? ($g=10\ ms^{-2}$)
   (a) 12 ms^{-1} **(b) 8 ms^{-1}** (c) 14 ms^{-1} (d) 10 ms^{-1}

MAY 2022

1. A transverse wave moves from a medium A to a medium B. In medium A, the velocity of the transverse wave is 500 ms^{-1} and the wavelength is 5 m. The frequency and the wavelength of the wave in medium B when its velocity is 600 ms^{-1}, respectively are
   (a) 120 Hz and 6 m (b) 120 Hz and 5 m
   (c) 100 Hz and 6 m (d) 100 Hz and 5 m
2. When a car takes a sudden left turn in the curved road, passengers are pushed towards the right due to
   (a) inertia of rest **(b) inertia of direction**
   (c) absence of inertia (d) inertia of motion
3. Two equal masses m_1 and m_2 are moving along the same straight line with velocities 5 ms^{-1} and -9ms^{-1} respectively. If the collision is elastic, then calculate the velocities after the collision of m_1 and m_2, respectively
   (a) -9ms^{-1} and 5 ms^{-1} (b) -4ms^{-1} and 10 ms^{-1}
   (c) 5 ms^{-1} and 1 ms^{-1} (d) 10ms^{-1} and 0 ms^{-1}
4. Two objects are projected at angles 30^0 and 60^0 respectively with respect to the horizontal direction. The ranges of two objects are denoted as R_{30^0} and R_{60^0}. Choose the correct relation from the following
   (a) $R_{30^0} = \frac{R_{60^0}}{2}$ **(b) $R_{30^0} = R_{60^0}$** (c) $R_{30^0} = 2R_{60^0}$ (d) $R_{30^0} = 4R_{60^0}$
5. The dimensional formula strain:
   (a) $ML^{-2}T^{-1}$ **(b) $M^0L^0T^0$** (c) $ML^{-1}T^{-2}$ (d) M^0LT^0
6. The efficiency of a heat engine working between the freezing point and boiling point of water is
   (a) 26.8% (b) 6.25% (c) 12.5% (d) 20%
7. Which of the following is not a scalar?
   (a) pressure (b) viscosity
   (c) stress (d) surface tension
8. If a particle executes uniform circular motion in the xy plane in clock wise direction, then the angular velocity is in
   (a) -z direction (b) +y direction (c) -x direction (d)+z direction
9. The ratio $\gamma = \frac{C_p}{C_v}$ for a gas mixture consisting of 8 g of helium and 16 g of oxygen is
   (a) 27/17 (b) 23/15 (c) 17/27 (d) 15/23
10. 1 kilowatt hour (1 kWh) is:
    (a) 36 x 10^5 J (b) 36 x 10^5 WS
    (c) 3.6 x 10^6 J **(d) All the above (mere attempt)**
11. A simple pendulum is suspended from the roof of a school bus which moves in a horizontal direction with an acceleration a, then the time period is
    (a) $T \propto \sqrt{g^2 + a^2}$ (b) $T \propto \frac{1}{g^2+a^2}$
    (c) $T \propto (g^2 + a^2)$ **(d) $T \propto \frac{1}{\sqrt{g^2+a^2}}$**

12. A couple produces,
(a) rotation and translation (b) pure rotation
(c) no motion (d) pure translation

13. If the mass and radius of the Earth are both doubled, then the acceleration due to gravity g′
(a) 2 g (b) remain s same
(c) 4 g **(d) $\frac{g}{2}$**

14. If π = 3.14, then the value of π^2 is
(a) 9.86 (b) 9.8596 (c) 9.9 (d) 9.860

15. If the acceleration due to gravity becomes 4 times its original value, then escape speed
(a) becomes halved (b) remains same
(c) 4 times of original value **(d) 2 times of original value**

AUGUST 2022

1. A ball of mass 1 kg and another of mass 2 kg are dropped from a tall building whose height is 80 m. After, a fall of 40 m each towards Earth, their respective kinetic energies will be in the ratio of
(a) $\sqrt{2}:1$ (b) $1:\sqrt{2}$ (c) 2 : 1 **(d) 1 : 2**

2. If an object is dropped from the top of a building and it reaches the ground at t = 4 s then the height of the building is (ignoring air resistance) (g = 9.8 ms^{-2})
(a) 77.3 m **(b) 78.4 m** (c) 80.5 m (d) 79.2 m

3. A pendulum is hung in a very high building oscillates to and fro motion freely like a simple harmonic oscillator. If the acceleration of the bob is 16 ms^{-2} at a distance of 4 m from the mean position, then the time period is
(a) 2 s (b) 1 s (c) 2πs **(d) πs**

4. g_e and g_p denote the acceleration due to gravity in the Earth and a planet. The mass and radius of the planet are twice that of the Earth. Then ___________
(a) $g_p = \frac{g_e}{2}$ (b) $g_p = 2g_e$ (c) $g_p = g_e$ (d) $g_p = \frac{g_e}{\sqrt{2}}$

5. A rope is wound around a hollow cylinder of mass 3 kg and radius 40 cm. What is the angular acceleration of the cylinder if the rope is pulled with a force 30 N?
(a) 0.25 rad s^{-2} **(b) 25 rad s^{-2}** (c) 5 m s s^{-2} (d) 25ms^{-2}

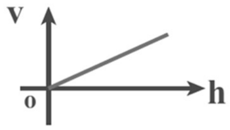
6. When a cycle tyre suddenly bursts, the air inside the tyre expands. This process is
(a) isothermal **(b) adiabatic** (c) isobaric (d) isochoric

7. If a particle executes uniform circular motion, choose the correct statement
(a) The velocity and speed are constant.
(b) The acceleration and speed are constant.
(c) The velocity and acceleration are constant.
(d) The speed and magnitude of acceleration are constant.

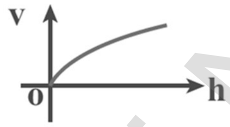
8. An object of mass 10 kg is hanging on a spring scale which is attached to the roof of a lift. If the lift is in free fall, the reading in the spring scale is
(a) 98 N **(b) zero** (c) 49 N (d) 9.8 N

9. A uniform rope having mass m hangs vertically from a rigid support. A transverse wave pulse is produced at the lower end. Which of the following plots shows the correct variation of speed *v* with height *h* from the lower end?

(a) 

(b) 

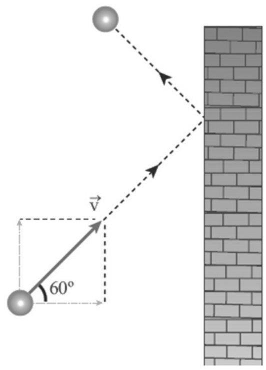
(c) 

(d) 

10. If an object is at rest and no external force is applied on the object, the static friction acting on the object is:
(a) zero (b) $\mu_s mg$ (c) $\mu_s mg \sin\theta$ (d) $\mu_s mg \cos\theta$

11. In a horizontal pipe of non-uniform cross section, water flows with a velocity of 1 ms^{-1} at a point where the diameter of the pipe is 20 cm. The velocity of water (1.5m s^{-1}) at a point where the diameter of the pipe is (in cm)
(a) 8 **(b) 16** (c) 24 (d) 32

12. A particle of mass m is moving with speed uin a direction which makes 60° with respect to x axis. It undergoes elastic collision with the wall. What is the change in momentum in x and y direction?



(a) $\boldsymbol{\Delta p_x = -mu, \Delta p_y = 0}$ (b) $\Delta p_x = -2mu, \Delta p_y = 0$
(c) $\Delta p_x = 0, \Delta p_y = mu$ (d) $\Delta p_x = mu, \Delta p_y = 0$

13. Which of the following pairs of physical quantities have same dimension?
(a) force and power **(b) torque and energy**
(c) torque and power (d) force and torque

14. A book is at rest on the table which exerts a normal force on the book. If this force is considered as reaction force, what is the action force according to Newton's third law?
(a) Gravitational force exerted by Earth on the book.
(b) Gravitational force exerted by the book on Earth
(c) Normal force exerted by the book on the table.
(d) Normal force exerted by the table on the book.

15. In stationary waves, the distance between a node and its neighbouring anti-node is:
(a) $\frac{\lambda}{4}$ (b) $\frac{\lambda}{2}$ (c) $\frac{3\lambda}{4}$ (d) λ

MARCH 2023

1. If a wire is stretched to double of its original length, then the strain in the wire is
   (a) 3 **(b) 1** (c) 4 (d) 2
2. Round of the following number 19.95 into three significant figures.
   (a) 20.1 (b) 19.9 (c) 19.5 **(d) 20.0**
3. The graph between volume and temperature in Charles' law is
   (a) a straight line (b) an ellipse
   (c) a parabola (d) a circle
4. In the given SHM y = 2 sin (20πt+1.5) the frequency of oscillation is:
   (a) 10 Hz (b) 20 Hz (c) 15 Hz (d) π Hz
5. The kinetic energy of the satellite orbiting around the Earth is
   (a) greater than kinetic energy (b) equal to potential energy
   (c) zero **(d) less than potential energy**
6. The centrifugal force appears to exist
   (a) in any accelerated frame
   (b) only in inertial frames
   (c) both in inertial and non-inertial frames
   (d) only in rotating frames
7. If an object is falling from a height of 20 m, then the time taken by the object to reach the ground: (ignore air resistance and take g = 10 ms^{-2})
   (a) 2 s (b) 1.732 s (c) 1.532 s (d) 1.414 s
8. The fundamental frequency of closed organ pipe whose length is 10 cm is:
   (a) 4.5 vHz **(b) 2.5 vHz** (c) 10 vHz(d) 2 vHz
9. A particle executing SHM crosses points A and B with the same velocity. Having taken 3 s in passing from A to B, it returns to B after another 3 s. The time period is
   (a) 12 s (b) 15 s (c) 9 s (d) 6 s
10. If the temperature and pressure of a gas is doubled the mean free path of the gas molecules
    (a) tripled **(b) remains same**
    (c) quadrupled (d) doubled
11. A uniform force of $(2\hat{\imath} + \hat{\jmath})$+ N acts on a particle of mass 1 kg. The particle displaces from position $(3\hat{\jmath} + \hat{k})$ m to $(5\hat{\imath} + 3\hat{\jmath})$.The work done by the force on the particle is :
    (a) 10 J (b) 9 J (c) 12 J (d) 6 J
12. A rigid body rotates with an angular momentum L. If its kinetic energy is halved, the angular momentum becomes,
    (a) 2L (b) L **(c) $\frac{L}{\sqrt{2}}$** (d) $\frac{L}{2}$
13. Which one of the following physical quantities cannot be represented by a scalar?
    (a) momentum (b) Mass
    (c) magnitude of acceleration (d) length
14. The dimensional formula for coefficient of viscosity is :
    (a) $ML^{-2}T^{-2}$ (b) MLT^{-2} (c) $ML^{-1}T^{-2}$ **(d) $ML^{-1}T^{-1}$**

15. A sound wave whose frequency is 5000 Hz travels in air and then hits the water surface. The ratio of its wavelengths in water and air is
    (a) 5.30 **(b) 4.30** (c) 1.23 (d) 0.23

JUNE 2023

1. Which of the following pairs of physical quantities have same dimension?
   (a) force and power **(b) torque and energy**
   (c) torque and power (d) force and torque
2. If the velocity of the particle is $\vec{v} = 2\hat{\imath} + t^2\hat{\jmath} - 9\hat{k}$, then the magnitude of acceleration of the particle at t=0.5 s is :
   (a) 1 ms^{-2} (b) 2 ms^{-2} (c) Zero (d) –1 ms^{-2}
3. An object of mass m begins to move on the plane inclined at an angle θ . The coefficient of static friction of inclined surface is μ_s. The maximum static friction experienced by the mass is :
   (a) mg (b) $\mu_s$mg
   (c) $\mu_s$mg sinθ **(d) $\mu_s$mg cos θ**
4. The work done by the conservative force for a closed path is :
   (a) always negative **(b) zero**
   (c) always positive (d) not defined
5. The centre of mass of a system of particles does not depend upon:
   (a) position of particles
   (b) relative distance between particles
   (c) masses of particles **(d) force acting on particle**
6. If the masses of the Earth and Sun suddenly double, the gravitational force between them will :
   (a) remain the same (b) increase 2 times
   (c) increase 4 times (d) decrease 2 times
7. With an increase in temperature, the viscosity of liquid and gas, respectively will
   (a) increase and increase (b) increase and decrease
   (c) decrease and increase (d) decrease and decrease
8. When a cycle tyre suddenly bursts, the air inside the tyre expands. This process is:
   (a) isothermal **(b) adiabatic** (c) isobaric (d) isochoric
9. The average translational kinetic energy of gas molecules depends on :
   (a) number of moles and T (b) only on T
   (c) P and T (d) P only
10. The damping force on an oscillator is directly proportional to the velocity. The units of the constant of proportionality is :
    (a) kg m s^{-1} (b) kg m s^{-2} **(c) kg s^{-1}** (d) kg s

11. An organ pipe A closed at one end is allowed to vibrate in its first harmonic and another pipe B open at both ends is allowed to vibrate in its third harmonic. Both A and B are in resonance with a given tuning fork. The
ratio of the length of A and B is :
(a) $\frac{8}{3}$ (b) $\frac{3}{8}$ **(c)** $\frac{1}{6}$ (d) $\frac{1}{3}$

12. If the linear momentum of the object is increased by 0.1%, then the kinetic energy is increased by :
(a) 0.1 % **(b) 0.2%** (c) 0.4% (d) 0.01%

13. If an object is thrown vertically up with the initial speed 'u'from the ground, then the time taken by the object to return back to ground is :
(a) $\frac{u^2}{2g}$ (b) $\frac{u^2}{g}$ (c) $\frac{u}{2g}$ **(d)** $\frac{2u}{g}$

14. Which of the following represents a wave?
(a) $(x - vt)^3$ (b) $x(x + vt)$
(c) $\frac{1}{(x+vt)}$ **(d)** $\sin(x + vt)$

15. The graph between volume and temperature in Charles' law is
(a) an ellipse (b) a circle
(c) a straight line (d) a parabola

MARCH 2024

1. Two resistances $R_1 = (100 \pm 3)\Omega$, $R_2 = (150 \pm 2)\Omega$ are connected in series. What is their equivalent resistance?
(a) $(250 \pm 1)\Omega$ **(b) $(250 \pm 5)\Omega$** c) $(250 \pm 3)\Omega$ (d) $(205 \pm 5)\Omega$

2. If a person moving from pole to equator, the centrifugal force acting on him :
(a) remains the same **(b) increases**
(c) increases and then decreases (d) decreases

3. The work done by the conservative force for a closed path is :
(a) always positive (b) always positive
(c) not defined **(d) zero**

4. An air column in a pipe which is closed at one end, will be in resonance with the vibrating body of frequency 83Hz. Then the length of the air column is :
(a) 1.0 m (b) 1.5 m (c) 2.0 m (d) 0.5 m

5. A transverse wave moves from a medium A to a medium B. In medium A, the velocity of the transverse wave is 500 ms^{-1} and the wavelength is 5 m. The frequency and the wavelength of the wave in medium B when its velocity is 600 ms^{-1}, respectively are
(a) 120 Hz and 6 m (b) 120 Hz and 5 m **(c) 100 Hz and 6 m** (d) 100 Hz and 5 m

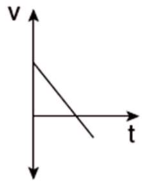
6. If the velocity of the particle is $\vec{v} = 2\hat{i} + t^2\hat{j} - 9\hat{k}$, then the magnitude of accelerationat t=1 s is :
(a) Zero (b) 1 ms^{-2} (c) -1 ms^{-2} **(d) 2 ms^{-2}**

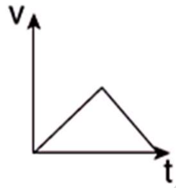
7. A couple produces,
(a) rotation and translation **(b) pure rotation**
(c) no motion (d) pure translation

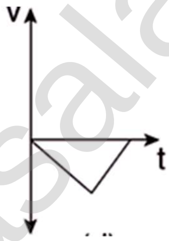
8. Which of the following gases will have least rms speed at a given temperature?
(a) Oxygen (b) Hydrogen (c) **Carbon-di-oxide** (d) Nitrogen

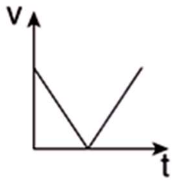
9. With an increase in temperature, the viscosity of liquid and gas, respectively will:
(a) decrease and increase (b) increase and increase
(c) decrease and decrease (d) increase and decrease

10. A ball is projected vertically upwards with a velocity v. It comes back to ground in time t. Which v-t graph shows the motion correctly?

(a)


(b)


(c)


(d)


11. If the error in the measurement of radius of a sphere is 2%, then the error in the determination of its volume will be :
(a) 4 % (b) 8 % **(c) 6 %** (d) 6 %

12. The SI unit for specific heat capacity is :
(a) $Jkg^{-1}K^{-1}$ (b) Jkg^{-1} (c) $K\,Kg^{-1}\,J^{-1}$ (d) $J\,Kg\,K^{-1}$

13. Two bodies A and B whose masses are in the ratio 1:2 are suspended from two separate massless springs of force constants k_A and k_B respectively. If the two bodies oscillate vertically such that their maximum velocities are in the ratio 1:2, the ratio of the amplitude A to that of B is
(a) $\sqrt{\frac{2k_B}{k_A}}$ (b) $\sqrt{\frac{k_B}{2k_A}}$ (c) $\sqrt{\frac{8k_B}{k_A}}$ **(d)** $\sqrt{\frac{k_B}{8k_A}}$

14. When a cycle tyre suddenly bursts, the air inside the tyre expands. This process is
(a) isobaric (b) isothermal (c) isochoric **(d) adiabatic**

15. If the masses of the Earth and Sun suddenly double, the gravitational force between them will
(a) increase 4 times (b) remain the same
(c) decrease 2 times (d) increase 2 times

JUNE 2024

1. A couple produces :
   (a) pure rotation (b) pure translation
   (c) rotation and translation (d) no motion
2. If the internal energy of an ideal gas U and volume V are doubled then the pressure
   (a) doubles **(b) remains same**
   (c) halves (d) quadruples
3. If the length and time period of an oscillating pendulum have errors of 1% and 3% respectively then the error in measurement of acceleration due to gravity is :
   (a) 4% (b) 5% (c) 6% **(d) 7%**
4. If the potential energy of the particle is $\alpha - \frac{\beta}{2}x^2$, then force experienced by the particle is:
   (a) $F = \frac{\beta}{2}x^2$ **(b) $F = \beta x$** (c) $F = -\beta x$ (d) $F = -\frac{\beta}{2}x^2$
5. A transverse wave moves from a medium A to a medium B. In medium A, the velocity of the transverse wave is 500 ms^{-1} and the wavelength is 5 m. The frequency and the wavelength of the wave in medium B when its velocity is 600 ms^{-1}, respectively are
   (a) 120 Hz and 5 m (b) 100 Hz and 5 m
   (c) 120 Hz and 6 m **(d) 100 Hz and 6 m**
6. A sound wave whose frequency is 500 Hz travels in air and then hits the water surface. The ratio of its wavelength in water and air is:
   (a) 4.30 (b) 0.23 (c) 5.30 (d) 1.23
7. The wettability of a surface by a liquid depends primary on :
   (a) viscosity (b) surface tension
   (c) density
   (d) angle of contact between surface and the liquid
8. If a particle executes uniform circular motion, choose the correct statement
   (a) The velocity and speed are constant.
   (b) The acceleration and speed are constant.
   (c) The velocity and acceleration are constant.
   (d) The speed and magnitude of acceleration are constant.
9. The gravitational potential energy of the Moon with respect to Earth is:
   (a) always positive **(b) always negative**
   (c) can be positive or negative (d) always zero
10. In hot summer after a bath, the body's
    (a) internal energy decreases (b) internal energy increases
    (c) heat decreases
    (d) no change in internal energy and heat
11. The centrifugal force appears to exist
    (a) only in inertial frames
    (b) only in rotating frames
    (c) in any accelerated frame
    (d) both in inertial and non-inertial frames

12. In a simple harmonic oscillation, the acceleration against displacement for one complete oscillation will be
    (a) an ellipse (b) a circle (c) a parabola **(d) a straight line**
13. If a particle has negative velocity and negative acceleration, its speed:
    (a) increases (b) decreases (c) remains same (d) zero
14. Which of the following gases will have rms speed at a given temperature?
    (a) Hydrogen (b) Nitrogen (c) Oxygen (d) Carbon dioxide
15. Two objects of masses m_1 and m_2 fall from the heights h_1 and h_2 respectively. The ratio of the magnitude of their momenta when they hit the ground is
    (a) $\sqrt{\frac{h_1}{h_2}}$ (b) $\sqrt{\frac{m_1 h_1}{m_{2} h_2}}$ **(c)** $\boldsymbol{\frac{m_1}{m_2}\sqrt{\frac{h_1}{h_2}}}$ (d) $\frac{m_1}{m_2}$

PUBLIC EXAM – TWO MARKS QUESTIONS

MARCH 2019

1. Write any two errors of systematic errors. Explain them.
2. What is projectile? Give two examples.
3. State Newton's Second Law of Motion.
4. A car takes a turn with the velocity 50 ms^{-1} on a circular road of radius of curvature 10 m. Calculate the centrifugal force experienced by a person of mass 60 kg inside the car.
5. Why is it more difficult to revolve a stone tied to a longer string than a stone tied to a shorter string?
6. State Stefan – Boltzmann Law and write its expression.
7. List the factors affecting Brownian motion.
8. "Soldiers are not allowed to march on a bridge." Give reason.
9. The surface tension of a soap solution is 0.03 Nm^{-1}. How much work is done in producing soap bubble of radius 0.05 m

MARCH 2020

1. Check the correctness of the equation $\frac{1}{2} mv^2 = mgh$ using dimensional analysis.
2. Define distance and displacement.
3. Why there is no lunar eclipse and solar eclipse every month?
4. State the law of conservation of angular momentum.
5. What is coefficient of restitution?
6. During a cyclic process, a heat engine absorbs 500 J of heat from a hot reservoir, does work and ejects an amount of heat 300 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine.
7. Why there is no hydrogen in the earth's atmosphere?
8. Write down the factors affecting velocity of sound in gases.
9. If the length of the simple pendulum is increased by 44% from its original length, calculate the percentage increase in time period of the pendulum.

SEPTEMBER 2020

1. What are fundamental quantities? Give an example.
2. The position vector and angular velocity vector of a particle executing uniform circular motion at an instant are $2\hat{\imath}$ and $4\hat{k}$ respectively. Find its linear velocity at that instant.
3. When walking on ice one should take short steps. Why?
4. What is radius of gyration?
5. State Newton's Universal Law of Gravitation.
6. Explain red shirt and blue shift in Doppler effect.
7. What is P-V diagram?
8. List the factors affecting the mean free path.
9. A metal cube of side 0.20 m is subjected to a shearing force of 4000 N. The top surface is displaced through 0.50 cm with respect to the bottom. Calculate the shear modulus of elasticity of the metal.

AUGUST 2021

1. Define angular velocity.
2. State Wien's law.
3. Check the correctness of the equation v=u+at using dimensional analysis method.
4. Give any two examples of torque in day-to-day life.
5. Define frequency of simple harmonic motion.
6. A book of mass m is at rest on the table. Draw the free body diagram for the book.
7. Compute the distance between anti-node and neighbouring node.
8. Why the energy of a satellite or any other planet is negative?
9. Calculate the energy consumed in electrical units when a 75 W fan is used for 8 hours daily for one month (30 days).

MAY 2022

1. What is Reynold's number?
2. Define the term 'degrees of freedom'.
3. In a submarine equipped with sonar, the time delay between the generation of a pulse and its echo after reflection from an enemy submarine is observed to be 80 s. If the speed of sound in water is 1460 ms^{-1}, what is the distance of enemy submarine?
4. State Wien's Displacement Law.
5. Define - gravitational potential.
6. What is simple harmonic motion?
7. State Newton's second law.
8. State conservation of angular momentum.
9. A particle moves along the x-axis in such a way that its coordinates x varies with time 't' according to equation x=2--5t+6t?. What is the initial velocity of the particle?

AUGUST 2022

1. Write any two limitations of dimensional analysis?
2. What is meant by Escape speed in the case of the Earth?
3. A mobile phone tower transmits a wave signal of frequency 900 MHz. Calculate the length of the waves transmitted from the mobile phone tower.
4. State Stefan – Boltzmann Law.
5. Define Centre of mass.
6. What is meant by periotic and non-periodic motion?
7. State Hooke's Law of Elasticity.
8. Define Inertia.
9. Consider two trains A and B moving along parallel tracks with same velocity in the same direction. Let the velocity of each train be 50 km / hr due east. Calculate the relative velocities of the trains.

MARCH 2023

1. Write the rules for determining significant figures.
2. Define scalar. Give examples.
3. Under what condition will a car skid on a levelled circular road?
4. Write any two differences between conservative and non-conservative Force.
5. What are the conditions in which Force cannot produce Torque?
6. State Newton's Universal Law of Gravitation.
7. Define Poisson's ratio.
8. State Zeroth Law of Thermodynamics.
9. Two objects of masses 3 kg and 6 kg are moving with the same momentum of 30kgms^{-1}. Will they have same kinetic energy?

JUNE 2023

1. What is the principle of homogeneity of dimensions?
2. A metal cube of side 0.20 m is subjected to a shearing force of 4000 N. The top surface is displaced through 0.50 cm with respect to the bottom. Calculate the shear modulus of elasticity of the metal.
3. What is the meaning of 'pseudo force'?
4. During a cyclic process, a heat engine absorbs 500 J of heat from a hot reservoir, does work and ejects an amount of heat 300 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine.
5. What is the difference between velocity and average velocity?
6. Why there is no lunar eclipse and solar eclipse every month?
7. Mention the four different types of oscillations.
8. State the law of equipartition of energy.
9. A fly wheel rotates with a uniform angular acceleration. If its angular velocity increases from 20πrad/s to 40 πrad/sin 10 seconds. Find the number of rotations in that period.

MARCH 2024

1. Which one of these is more elastic, steel or rubber? Why?
2. Define – Vector. Give examples.
3. A car takes a turn with the velocity 50ms^{-1} on a circular road of radius of curvature 10m.Calculate the centrifugal force experienced by a person of mass 60 kg inside the car.
4. Write the factors affecting Brownian Motion.
5. A rolling wheel has velocity of its centre of mass as 5 ms^{-1}. If its radius is 1.5 m and angular velocity is 3 rads^{-1}, then check whether it is in pure rolling or not.
6. What is meant by free oscillation?
7. Define – Coefficient of Restitution.
8. What are the limitations of dimensional analysis?
9. A person does 30 kJ work on 2 kg of water by stirring using a paddle wheel. While stirring, around 5 kcal of heat is released from water through its container to the surface and surroundings by thermal conduction and radiation. What is the change in internal energy of the system?

JUNE 2024

1. Define: Power
2. Why Moon has no atmosphere?
3. State the principle of homogeneity of dimensions.
4. A wire 10 m long has a cross-sectional area 1.25×10^{-4} m^2. It is subjected to a load of 5 kg. If Young's modulus of the material is 4×10^{10} Nm^{-2}, calculate the elongation produced in the wire. Take g = 10 ms^{-2}.
5. Define the gravitational field. Give its unit.
6. A force of $(4\hat{\imath} - 3\hat{\jmath} + 5\hat{k})$N is applied at a point whose position vector is $(7\hat{\imath} + 4\hat{\jmath} - 2\hat{k})$ m. find the torque of force about the origin.
7. Define one Newton.
8. What is a epoch?
9. A particle is in circular motion with an acceleration α = 0.2 rads^{-2}.
   (a) What is the angular displacement made by the particle after 5 s?
   (b) What is the angular velocity at t = 5 s?. Assume the initial angular velocity is zero.

PUBLIC EXAM – THREE MARKS QUESTIONS

MARCH 2019

1. What is the torque of the force $\vec{F} = 3\hat{\imath} - 2\hat{\jmath} + 4\hat{k}$ acting at a point $\vec{r} = 2\hat{\imath} + 3\hat{\jmath} + 5\hat{k}$ about the origin?
2. What are the various of friction? Suggest few methods to reduce friction.
3. A heavy body and a light body have same momentum. Which one of them has more kinetic energy and why?
4. Find the rotational kinetic energy of a ring of mass 9 kg and radius 3m rotating with 240 rpm about an axis passing through its centre and perpendicular to its plane.
5. What do you mean by the term weightlessness? Explain the state of weightlessness of a freely falling body.
6. Derive an expression for the terminal velocity of a sphere falling through a viscous liquid.
7. Explain linear expansion of solid.
8. Write down any six postulates of kinetic theory of gases.
9. Two waves of wavelength 99 cm and 100 cm both travelling with the velocity of 396 ms^{-1} are made to interfere. Calculate the number of beats produced by them per sec.

MARCH 2020

1. Explain RADAR pulse method for determining large distances.
2. An object is thrown with initial speed $5ms^{-1}$ with an angle of projection 30^0. Calculate the maximum height reached and the horizontal range.
3. When a cricket player catches the ball, he pulls his hands in the direction of the ball's motion. Why?
4. State Kepler's three laws.
5. Write the differences between transverse and longitudinal waves.
6. We use straw to suck soft drinks. Why?
7. Explain Resonance. Give an example.
8. What are the conditions for reversible process?
9. A force of $(4\hat{\imath} - 3\hat{\jmath} + 5\hat{k})$ N is applied at a point whose position vector is $(7\hat{\imath} + 4\hat{\jmath} - 2\hat{k})$m. Find the torque of force about the origin.

SEPTEMBER 2020

1. Write about dimensional variables and dimensionless variables with an example.
2. A train was moving at the rate of 54 kmh^{-1} when brakes were applied. It came to rest within a distance of 225 m. Calculate the retardation produced in the train.
3. Compare elastic and inelastic collisions.
4. Derive an expression for kinetic energy of a rigid body in rotational motion.
5. Suppose we go 200 km above and below the surface of the Earth, what are the g values at these two points? In which case, is the value of g small?
6. Write any three applications of Surface Tension.
7. Why does heat flow from a hot object to cold object?
8. Write any six postulates of kinetic theory of gases.

9. Calculate the amplitude, angular frequency, frequency, time period and initial phase of the simple harmonic oscillation for the given equation
   $y = 0.3 \sin (40\pi t + 1.1)$.

AUGUST 2021

1. Derive the relation between Momentum and Kinetic energy.
2. State the law of transverse vibrations in stretched strings.
3. Show that in horizontal projection, the path of a projectile is a Parabola.
4.. Define centre of gravity.
5. State Stefan-Boltzmann Law.
6. What are the salient features of Static and Kinetic friction?
7. What are the applications of Dimensional Analysis?
8. Define the degrees of freedom. Give an example.
9. If excess pressure is balanced by a column of oil with specific gravity 0.8, 4 mm high, where R=2.0 cm, find the surface tension of the soap bubble.

MAY 2022

1. Compare Elastic and Inelastic collision.
2. Discuss the Law of Transverse Vibrations in stretched strings.
3. Using free body diagram, show that whether it is easy to pull an object than to' push it.
4. What are the resultants of the vector product of two vectors given by
   $\vec{A} = 4\hat{\imath} - 2\hat{\jmath} + \hat{k}$ and $\vec{B} = 5\hat{\imath} + 3\hat{\jmath} - 4\hat{k}$?
5. Write a short note on polar satellites.
6. Give any three applications of viscosity.
7. Define torque. Give any two examples of torque in day-to-day life.
8. What is meant by periodic and non-periodic motion? Give any two examples, for each motion.
9. A person docs 30 kJ work on 2 kg of water by stirring using a paddle wheel. While stirring, around 5 kcal of heat is released from water through its container to the surface and surroundings by thermal conduction and radiation. What is the change in internal energy of the system?

AUGUST 2022

1. State Newton's three laws of motion.
2. An electron of mass 9.1×10^{-31} kg revolves around a nucleus in a circular orbit of radius 0.53Å. What is the angular momentum of the electron?
   (Velocity of electron $v=2.2 \times 10^{6}\ ms^{-1}$)
3. Distinguish between streamlined flow and turbulent flow.
4. What is meant by Gross Error? How shall we minimize it?
5. Derive an expression for Energy of Satellite.
6. Show that path of a projectile is a parabola in horizontal projection.
7. Derive the relation between momentum and kinetic energy.
8. State the laws of Simple Pendulum.

9. During a cyclic process, a heat engine absorbs 500 J of heat from a hot reservoir, Doeswork and ejects an amount of heat 300 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine.

MARCH 2023

1. What is Gross Error? State the reasons for it and how to minimize the errors.
2. Write the properties of scalar product of two vectors.
3. State the differences between centripetal force and centrifugal force.
4. State the various types of potential energy. Explain its formulae.
5. Explain geostationary satellites.
6. Write the practical applications of capillarity.
7. State the Laws of Simple Pendulum.
8. Write down the postulates of kinetic theory of gases.
9. During a cyclic process, a heat engine absorbs 600 J of heat from a hot reservoir, does work and ejects an amount of heat 200 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine.

JUNE 2023

1. Write a note on triangulation method to measure larger distances.
2. Define "molar specific heat capacity". Give its unit.
3. Write the various types of potential energy.
4. State the laws of transverse vibrations in stretched strings.
5. A car takes a turn with velocity 50 ms^{-1} on the circular road of radius of curvature 10 m. calculate the centrifugal force experienced by a person of mass 60 kg inside the car?
6. What are the differences between sliding and slipping?
7. A train was moving at the rate of 54 km h^{-1} when brakes were applied. It came to rest within a distance of 225 m. Calculate the retardation produced in the train.
8. What are the factors affecting the surface tension of a liquid?
9. Ten particles are moving at the speed of 2, 3, 4, 5, 5, 5, 6, 6, 7 and 9 m s^{-1}. Calculate root mean square speed (V_{rms}) and most probable speed (V_{mp}).

MARCH 2024

1. Derive an expression for the work done by torque.
2. Explain the variation of g with altitude.
3. What are the factors affecting the surface tension of a liquid?
4. What is the relation between the average kinetic energy and pressure?
5. What is forced oscillation?
6. Two vibrating tuning forks produce waves whose equation is given by $y_1 = 5 \sin(240\pi t)$ and $y_2 = 4 \sin(244\pi t)$. Compute the number of beats per second.
7. What are the fundamental and derived quantities? Give examples.
8. State the law of Conservation of energy.
9. A object is thrown with initial speed 5 ms^{-1} with an angle of projection 30^0. What is the height and range reached by the particle?

JUNE 2024

1. Write the differences between conservative and non-conservative forces.
2. Derive the expression for gravitational potential energy.
3. What are the factors affecting the mean free path?
4. A cyclist while negotiating a circular path with speed 20 m s^{-1} is found to bend an angle by 30^{o} with vertical. What is the radius of the circular path? (given, g= 10 ms^{-2})
5. How is surface tension related to surface energy?
6. An ideal refrigerator keeps its content at 0 °C while the room temperature is 27 °C. Calculate its coefficient of performance.
7. Explain the properties of scalar products.
8. Using free body diagram, show whether it is easy to pull an object than to push it.
9. Consider two sound waves with wavelength 5 m and 6 m. If these two waves propagate in a gas with velocity 330 ms^{-1}. Calculate the number of beats per sound.

PUBLIC EXAM – FIVE MARKS QUESTIONS

MARCH 2019

1. (a) Explain the principle of homogeneity of dimensions and derive an expression for the force F acting on a body moving in a circular path depending on the mass of the body (m), velocity (v) and radius (r) of the circular path. Obtain the expression for the force by the dimensional analysis method (take the value k = 1).

(OR)

(b) State and prove Bernoulli's Theorem for a flow of incompressible, non-viscous and streamlined flow of liquid.

2. (a) Prove the law of conservation of momentum. Use it to find the recoil velocity of a gun when a bullet is fired from it.

(OR)

(b) State and prove parallel axes theorem.

3. (a) What is elastic collision? Derive an expression for final velocities of two bodies which undergo elastic collision in one dimension.

(OR)

(b) How will you determine the velocity of sound using resonance air column apparatus?

4. (a) Derive the Mayer's relation for an ideal gas.

(OR)

(b) Explain the horizontal oscillations of a spring.

5. (a) (i) Write down the equation of a freely falling body under gravity.
(ii) A ball is thrown vertically upwards with the speed of 19.6 ms^{-1} from the top of a building and reaches the earth in 6 s. Find the height of the building.

(OR)

(b) (i) Define orbital velocity and establish an expression for it.
(ii) Calculate the value of orbital velocity for an artificial satellite of earth orbiting at a height of 1000 km (Mass of the earth = $6x10^{24}$ kg, radius of the earth = 6400 km).

MARCH 2020

1. (a) Derive the expression for centripetal acceleration.

(OR)

(b) State and explain work energy theorem. Mention any three examples for it.

2. (a) What do you mean by propagation of errors? Explain propagation of errors in division of two quantities.

(OR)

(b) Derive the work done in an adiabatic process.

3. (a) (i) Derive the expression for the variation of acceleration due to gravity (g) with depth from the surface of the earth (d).

(ii) Find the ratio of the acceleration due to gravity at a height R/2 from the surface of the earth to the value at a depth R/2 from the surface of the earth (R – radius of the earth).

(OR)

(b Explain bending of cyclist in curves and arrive at an expression for angle of bending.

4. (a) Derive the expression for moment of inertia of a thin uniform rod about an axis passing through the centre and perpendicular to its length.

(OR)

(b) Explain in detail the four different types of oscillations.

5. (a) (i) Determine the height of an accessible object using Triangulation method.

(ii) From a point on the ground, the top of a tree is seen to have an angle of elevation 60^0. The distance between the tree and a point is 50 m. Calculate the height of the tree.

(OR)

(b) Derive the expression for the terminal velocity of a sphere moving in a high viscous fluid, using Stoke's formula.

SEPTEMBER 2020

1. (a) Prove the law of conservation of linear momentum. Use it to find the recoil velocity of a gun when a bullet is fired from it.

(OR)

(b) What is meant by angular harmonic oscillation? Derive an expression for the time period of angular harmonic oscillation.

2. (a) (i) What are the applications of dimensional analysis?
(ii) Express 76 cm of mercury pressure in terms of Nm^{-2} using the method of dimensions.

(OR)

(b) (i) Obtain a relation between momentum and kinetic energy.
(ii) Two objects of masses 2 kg and 4 kg are moving with same momentum of 20 $kgms^{-1}$.
(A) Will they have same kinetic energy?
(B) Will they have same speed?

3. (a) Derive the linear kinematic equations of motion for constant accelerated motion.

(OR)

(b) Explain the types of equilibrium with suitable examples.

4. (a) What is thermal expansion? Explain the three types of thermal expansion and obtain the relation between them.

(OR)

(b) What are stationary waves? Explain the formation of stationary waves.

5. (a) Derive an expression for Orbital Velocity and Time Period of the satellite.

(OR)

(b) Derive Poiseuille's formula for the volume of a liquid flowing per second through a pipe under stream lined flow.

AUGUST 2021

1. (a) Explain the oscillations of liquid column in U-tube.

(OR)

(b) Derive the kinematics equations of motion for constant acceleration.

2. (a) State and explain work energy principle.

(OR)

(b) Explain how overtones are produced in a closed organ pipe.

3. (a) Convert 76 cm of mercury pressure into Nm^{-2} using the method of dimensions.

(OR)

(b) Explain in detail Newton's law of cooling.

4. (a) State and Prove Bernoulli's theorem.

(OR)

(b) Derive an expression for Kinetic Energy in Rotation.

5. (a) Explain the need for banking of tracks.

(OR)

(b) Explain the variation of g with depth from the Earth's surface.

MAY 2022

1. (a) (i) Write the applications of the Dimensional Analysis.

(ii) Check the correctness of the equation $\frac{1}{2}mv^2 = mgh$ using Dimensionalanalysis method.

(OR)

(b) Obtain an expression for the surface tension of a liquid by capillary rise method.

2. (a) State and explain equipartition of energy.

(OR)

(b) Derive the kinematic equations of motion for constant acceleration.

3. (a) Explain the motion of blocks connected by a string in vertical motion.

(OR)

(b) Explain the variation of acceleration due to gravity (g) with altitude.

4. (a) Explain the horizontal oscillations of a spring.

(OR)

(b) State and explain work-kinetic energy theorem. Discuss the inferences of work-kinetic energy theorem.

5. (a) Discuss rolling on inclined plane and arrive at the expression for the acceleration.

(OR)

(b) Explain how overtones are produced in a closed organ pipe.

<u>AUGUST 2022</u>

1. (a) Derive an expression for moment of Inertia of a rod about its centre and perpendicular to the axis of the rod.

(OR)

(b) What is a Sonometer? Give its construction and working. Explain how to determine the frequency of tuning fork using Sonometer.

2. (a) What is Inelastic collision? Derive an expression for loss of kinetic energy in perfect inelastic collision.

(OR)

(b) Explain in detail the kinetic interpretation of temperature.

3. (a) Explain in detail about the Newton's Law of cooling.

(OR)

(b) Describe the method of measuring angle of repose.

4. (a) Explain in detail the Triangle Law of Vector Addition.

(OR)

(b) Derive Poiseuille's formula for the volume of a liquid flowing per second through a pipe under streamlined flow.

5. (a) Write a note on Triangulation method and radar method to measure larger distances.

(OR)

(b) Explain the variation of 'g' with depth from the Earth's surface.

<u>MARCH 2023</u>

1. (a) Obtain an expression for the time period T of a simple pendulum. The time period depends on :
   (i) mass 'm' of the bob
   (ii) length 'l' of the pendulum and
   (iii) acceleration due to gravity 'g' at the place where the pendulum is suspended. (Constant $k = 2\pi$)

(OR)

(b) Explain in detail the Triangle Law of Vector Addition.

2. (a) Show that in an inclined plane, angle of friction is equal to angle of repose.

(OR)

(b) Derive an expression for power and velocity.

3. (a) Derive the expression for moment of inertia of a rod about its centre and perpendicular to the rod.

(OR)

(b) Explain the variation of Acceleration due to gravity (g) with depth from the earth's surface.

4. (a) Derive the expression for the terminal velocity of a sphere moving in a high viscous fluid using Stoke's law.

(OR)

(b) Derive Meyer's relation for an ideal gas.

5. (a) Derive the expression of pressure exerted by the gas molecules on the walls of the container.

(OR)

(b) Derive Newton's formula for velocity of sound waves in air. Explain the Laplace's correction in it.

JUNE 2023

1. (a) What is an error? Explain the systematic errors.

(OR)

(b) State and prove Bernoulli's theorem for a flow of incompressible, non-viscous and streamlined flow of liquid.

2. (a) Discuss in detail the energy in simple harmonic motion

(OR)

(b) State Newton's three laws and discuss their significance.

3. (a) State and explain work – energy principle.

(OR)

(b) Derive an expression for escape speed.

4. (a) Explain in detail the working of a refrigerator.

(OR)

(b) Derive the kinematic equations of motion for constant acceleration.

5. (a) How will you determine the velocity of sound using resonance air column apparatus?

(OR)

(b) State and prove parallel axis theorem.

MARCH 2024

34. (a) Assuming that the frequency γ of a vibrating string may depend upon.

(i) applied force (F)

(ii) length (l)

(iii) mass per unit length (m), prove that $\gamma \propto \frac{1}{l}\sqrt{\frac{F}{m}}$ using dimensional analysis.

(OR)

(b) State and prove Bernoulli's theorem for a flow of incompressible, non-viscous, and streamlined flow of fluid.

35. (a) State and explain work energy principle. Mention any three examples for it.

(OR)

(b) Define coefficient of Performance. Explain in detail the working of a refrigerator.

36. (a) Explain the motion of blocks connected by a string in vertical motion.

(OR)

(b) State and explain Kepler's three Laws of Planetary Motion.

37. (a) Derive the kinematic equations of motion for constant acceleration.

(OR)

(b) Derive the expression for mean free path of the gas.

38. (a) Derived the expression for moment of inertia of a uniform ring about an axis passing through the centre and perpendicular to the plane.

(OR)

(b) Explain how overtones are produced in a closed organ pipe.

JULY 2024

1. (a) (i) Explain RADAR pulse method for measuring larger distances.

   (ii) A RADAR signal is beamed towards a planet and its echo is received 7minutes later. If the distance between the planet and the Earth is 6.3×10^{10} m. Calculate the speed of the signal?

OR

   (b) (i) What is meant by DOPPLER effect?

   Explain the observed and source frequency in the following cases.

   (ii) Source in motion and observer at rest

   (A) Source moves towards observer.

   (B) Source moves away from the observer

2. (a) Derive the expression for centripetal acceleration.

OR

   (b) Derive Poiseuille's formula for the volume of a liquid flowing per second through a pipe under streamlined flow.

3. (a) Explain the motion of blocks connected by a string in vertical motion.

OR

   (b) Derive an expression for escape speed.

4. (a) What is an elastic collision? Derive an expression for final velocities of two bodies which undergo elastic collision in one dimension.

OR

   (b) Derive the equation for the work done in an isothermal process.

5. (a) State and prove parallel axis theorem.

OR

   (b) Explain the simple pendulum in detail.

PUBLIC EXAMINATION – TWO MARKS NUMERICAL PROBLEM QUESTION WITH SOLUTION (MARCH 2019 – JULY 2024)

1. **A car takes a turn with the velocity 50 ms^{-1} on a circular road of radius of curvature 10 m. Calculate the centrifugal force experienced by a person of mass 60 kg inside the car. (MARCH – 2019, MARCH – 2024)**

   Centrifugal force is given by, $F_{cf} = \frac{mv^2}{r}$;

   $= \frac{60 \text{ x } 50 \text{ x } 50}{10}$; = 6 x 2500

   F_{cf} =15000 N

2. **The surface tension of a soap solution is 0.03 Nm^{-1}. How much work is done in producing soap bubble of radius 0.05 m (MARCH – 2019)**

   W = 2T x A (or) W = 2T x $4\pi r^2$

   W = 2 x 4 x 3.14 x $(0.05)^2$ x 0.03

   W = 1.884 x 10^{-3} J

3. **During a cyclic process, a heat engine absorbs 500 J of heat from a hot reservoir, does work and ejects an amount of heat 300 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine. (MARCH – 2020, JUNE – 2023)**

   The efficiency of heat engine is given by $\eta = 1 - \frac{Q_L}{Q_H}$; $\eta = 1 - \frac{300}{500}$;

   $= 1 - \frac{3}{5}$; $\eta = 1 - 0.6$; 0.4

   The **heat engine has 40% efficiency**, implying that this heat engine converts only 40% of the input heat into work.

4. **If the length of the simple pendulum is increased by 44% from its original length, calculate the percentage increase in time period of the pendulum. (MARCH – 2020)**

   T ∝ $\sqrt{l}$; T = constant $\sqrt{l}$

   $\frac{T_f}{T_i} = \sqrt{\frac{1+\frac{44}{100}l}{l}}$; $\sqrt{1.44}$ = 1.2 ;

   Therefore, T_f = 1.2 T_i = T_i + 20% T_i

5. **From a point on the ground, the top of a tree is seen to have an angle of elevation 60^0. The distance between the tree and a point is 50 m. Calculate the height of the tree. (MARCH – 2020)**

   For triangulation method tan θ = $\frac{h}{x}$

   h = x tan θ ; = 50 × tan 60^0 ; = 50 × 1.732

   h= 86.6 m; The height of the tree is 86.6 m

6. **The position vector and angular velocity vector of a particle executing uniform circular motion at an instant are $2\hat{\imath}$ and $4\hat{k}$ respectively. Find its linear velocity at that instant. (SEPTEMBER – 2020)**

v = rw ;
$= 2\hat{\imath} \times 4\hat{k}$ **v = 8**$\hat{\jmath}$

7. **A metal cube of side 0.20 m is subjected to a shearing force of 4000 N. The top surface is displaced through 0.50 cm with respect to the bottom. Calculate the shear modulus of elasticity of the metal. (SEPTEMBER – 2020, JUNE - 2023)**

L = 0.20m, F=4000N, x=0.50cm ; =0.005m and
Area A = L^2 = 0.04 m^2
Therefore, $\eta_R = \left(\frac{F}{A}\right) \times \left(\frac{L}{x}\right)$; $= \left(\frac{4000}{0.04}\right) \times \left(\frac{0.20}{0.005}\right)$; $\eta_R = 4 \times 10^6$ Nm^{-2}

8. **Two objects of masses 2 kg and 4 kg are moving with same momentum of 20 kgms^{-1}. (A) Will they have same kinetic energy?**
(B) Will they have same speed? (SEPTEMBER – 2020)

(a) The kinetic energy of the mass is given by KE $=\frac{P^2}{2m}$
For the object of mass 2kg, kinetic energy is KE$_1$ $= \frac{(20)^2}{2x2} = \frac{400}{4}$ = 100J
For the object of mass 4kg, kinetic energy is KE$_2$ $= \frac{(20)^2}{2x4} = \frac{400}{8}$ = 50J
the kinetic energy of **both masses is not the same.** The kinetic energy of the **heavier object has lesser kinetic energy than smaller mass.**
(b) As the momentum, p = mv, the two objects **will not have same speed.**

9. **Calculate the energy consumed in electrical units when a 75 W fan is used for 8 hours daily for one month (30 days). (AUGUST – 2021)**

Power, P = 75 W
Time of usage, t = 8 hour × 30 days = 240 hours
Electrical energy consumed is the product of power and time of usage.
Electrical energy = power × time of usage = P × t
=75 watt x 240 hour
=18000 watt hour
=18 kilowatt hour = 18kWh
1 electrical unit = 1kWh ; **Electrical energy =18 unit**

10. **In a submarine equipped with sonar, the time delay between the generation of a pulse and its echo after reflection from an enemy submarine is observed to be 80 s. If the speed of sound in water is 1460 ms^{-1}, what is the distance of enemy submarine? (MAY – 2022)**

$D = \frac{v\,t}{2} = \frac{1460 \times 80}{2}$; = 1460 x 40 ; 58400m
D = 58.4km

11. **A particle moves along the x-axis in such a way that its coordinates x varies with time 't' according to equation x=2--5t+6t?. What is the initial velocity of the particle? (MAY – 2022)**

Velocity , $v = \frac{dx}{dt}$; $\frac{d}{dt}$(2 – 5t + 6t^2) (or) v = –5 + 12t
For initial velocity, t =0; Initial velocity = –5ms^{-1}

The negative sign implies that at t = 0 the velocity of the particle is along negative x direction.

Average speed = total path length / total time period

12. **A mobile phone tower transmits a wave signal of frequency 900 MHz. Calculate the length of the waves transmitted from the mobile phone tower. (AUGUST – 2022)**

Frequency, f = 900 MHz; = 900 x 10^6 Hz
The speed of wave is c = 3 × 10^8ms^{-1}
$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{900 \times 10^6}$; = 0.33m

13. **Consider two trains A and B moving along parallel tracks with same velocity in the same direction. Let the velocity of each train be 50 km / hr due east. Calculate the relative velocities of the trains. (AUGUST – 2022)**

Relative velocity of B with respect to A, $v_{BA} = v_B - v_A$
= 50 km h^{-1} + (—50) km h^{-1} ; = 0 km h^{-1}
Similarly, relative velocity of A withrespect to B i.e., v_{AB} is also zero.
Thus each train will appear to be at restwith respect to the other.

14. **Two objects of masses 3 kg and 6 kg are moving with the same momentum of 30kgms^{-1}. Will they have same kinetic energy? (MARCH – 2023)**

a) The kinetic energy of the mass is given by KE $= \frac{P^2}{2m}$
For the object of mass 2kg, kinetic energy is $KE_1 = \frac{(30)^2}{2x3} = \frac{900}{6}$ = 150J
For the object of mass 4kg, kinetic energy is $KE_2 = \frac{(30)^2}{2x6} = \frac{900}{12}$ = 75J
the kinetic energy of **both masses is not the same.** The kinetic energy of the **heavier object has lesser kinetic energy than smaller mass.**
(b) As the momentum, p = mv, the two objects **will not have same speed.**

15. **A fly wheel rotates with a uniform angular acceleration. If its angular velocity increases from 20π rad/s to 40 π rad/s in 10 seconds. Find the number of rotations in that period. (JUNE – 2023)**

Kinematic equations for circular motion,

$\omega = \omega_0 + \alpha t$ or $\alpha = \frac{\omega - \omega_0}{t}$ ------------------1

$\omega^2 = \omega_0^2 + 2\alpha\theta$ or $\theta = \frac{\omega^2 - \omega_0^2}{2\alpha}$ ------------------2

Put equation 2 in 1, $\theta = \frac{\omega^2 - \omega_0^2}{2\left[\frac{\omega - \omega_0}{t}\right]}$; $= \frac{(\omega+\omega_0)\,(\omega-\omega_0)t}{2\,(\omega-\omega_0)}$

$= \frac{(\omega+\omega_0)\,t}{2}$; $\theta = \frac{(40\pi+2\quad)\text{x } 10}{2}$; $\theta = 300\,\pi$

The number of rotations in that period, n = $\frac{\theta}{2\pi}$ **; n = 150 rotations**

16. **A rolling wheel has velocity of its centre of mass as 5 ms^{-1}. If its radius is 1.5 m and angular velocity is 3 rads^{-1}, then check whether it is in pure rolling or not. (MARCH – 2024)**

Translational velocity (v_{TRANS}) or velocity of centre of mass,

v_{CM} = 5 m s^{-1}

The radius is, R = 1.5 m and the angular velocity is, ω = 3 rads^{-1}

Rotational velocity, v_{ROT} = Rω

v_{ROT} = 1.5×3; v_{ROT} = 4.5 ms^{-1}

As v_{CM} > Rω (or) v_{TRANS}> Rω, It is not in pure rolling, but sliding

17. **A person does 30 kJ work on 2 kg of water by stirring using a paddle wheel. While stirring, around 5 kcal of heat is released from water through its container to the surface and surroundings by thermal conduction and radiation. What is the change in internal energy of the system? (MARCH – 2024)**

Work done on the system (by the person while stirring),

W = −30 kJ = −30,000J

Heat flowing out of the system, Q = −5 kcal = −5×4184 J =−20920 J

Using First law of thermodynamics, ΔU = Q−W

ΔU = −20,920 J− (−30,000) J

ΔU = −20,920 J+30,000 **J = 9080 J**

Here, the heat lost is less than the work done on the system, so the change in internal energy is positive.

18. **A force of $(4\vec{i} - 3\vec{j} + 5\vec{k})$N is applied at a point whose position vector is $(7\vec{i} + 4\vec{j} - 2\vec{k})$m. find the torque of force about the origin. (JULY – 2024)**

$$\begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 7 & 4 & -2 \\ 4 & -3 & 5 \end{vmatrix}$$

$= (20 - 6)\hat{\imath} - (35 + 8)\hat{\jmath} + (-21 - 16)\hat{k}$;

$= (14\hat{\imath} - 43\hat{\jmath} - 37\hat{k})$ Nm

19. **A wire 10 m long has a cross-sectional area 1.25×10^{-4} m². It is subjected to a load of 5 kg. If Young's modulus of the material is 4×10^{10} Nm^{-2}, calculate the elongation produced in the wire. Take g = 10 ms^{-2}. (JULY – 2024)**

$\frac{F}{A} = Y \times \frac{\Delta L}{L}$; $\Delta L = \left(\frac{F}{A}\right)\left(\frac{L}{Y}\right)$; $\left(\frac{50}{1.25 \times 10^{-4}}\right)\left(\frac{10}{4 \times 10^{10}}\right)$; $= 10^{-4}$ m

20. **A particle is in circular motion with an acceleration α = 0.2 rads^{-2}. What is the angular displacement made by the particle after 5 s? (JULY – 2024)**

Since the initial angular velocity is zero$(\omega_0 = 0)$

The angular displacement made by the particle is given by

$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$; $= \frac{1}{2} \times 2 \times 10^{-1} \times 25$; $\theta = 2.5$ rad

21. **A RADAR signal is beamed towards a planet and its echo is received 7minutes later. If the distance between the planet and the Earth is 6.3×10^{10} m. Calculate the speed of the signal? (JULY – 2024)**

The distance of the planet from the Earth

d = 6.3×10^{10} m

Time t = 7 minutes = 7 × 60 s.

the speed of signal V=?

The speed of signal V = $\frac{2d}{t} = \frac{2 \times 6.3 \times 10^{10}}{7 \times 60}$;

V=3×10^8 ms^{-1}

No.	Log
12.6	1.1004
420	2.6232
(−)	$\bar{2}$.4772
Antilog	3.000×10^8

PUBLIC EXAMINATION – THREE MARKS NUMERICAL PROBLEM QUESTION WITH SOLUTION
(MARCH 2019 – JULY 2024)

1. **What is the torque of the force $\vec{F} = 3\hat{\imath} - 2\hat{\jmath} + 4\hat{k}$ acting at a point $\vec{r} = 2\hat{\imath} + 3\hat{\jmath} + 5\hat{k}$ about the origin? (MARCH – 2019)**

$$\vec{\tau} = \vec{r} \text{ x } \vec{F} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 2 & 3 & 5 \\ 3 & -2 & 4 \end{vmatrix}$$

$= (12-(-10)\hat{\imath} + (15-8)\hat{\jmath} + (-4-9)\hat{k}$; $\boldsymbol{\vec{\tau} = 22\hat{\imath} + 7\hat{\jmath} - 13\hat{k}}$

2. **Find the rotational kinetic energy of a ring of mass 9 kg and radius 3m rotating with 240 rpm about an axis passing through its centre and perpendicular to its plane. (MARCH – 2019)**

The rotational kinetic energy is , KE = $\frac{1}{2}I\omega^2$.

The moment of Inertia of the ring is, I = MR^2

I = 9 x 3^2 ; = 9 x 9; = 81 kgm^2

The angular speed of the ring is, ω = 240 rpm ; = $\frac{240 \text{ x } 2\pi}{60} rads^{-1}$

KE = $\frac{1}{2}$ x 81 x $\left(\frac{240 \text{ x } 2\pi}{60}\right)^2$. ; = $\frac{1}{2}$ x 81 x$(8\pi)^2$; KE = $\frac{1}{2}$ x 81 x 64$(\pi)^2$;

= 2592 x $(\pi)^2$; KE ≈ 25920J KE = 25.920 kJ $[(\boldsymbol{\pi})^2 \approx 10]$

3. **Two waves of wavelength 99 cm and 100 cm both travelling with the velocity of 396 ms^{-1} are made to interfere. Calculate the number of beats produced by them per sec. (MARCH – 2019)**

$f_1 = \frac{v}{\lambda_1}$; $\frac{396}{0.99}$; f_1 = 400 Hz

$f_2 = \frac{v}{\lambda_2}$; $\frac{396}{1}$; f_2 = 396 Hz

n = | $f_1 - f_2$| = 400 – 396; **n = 4 Beats per second**

4. **A ball is thrown vertically upwards with the speed of 19.6 ms^{-1} from the top of a building and reaches the earth in 6 s. Find the height of the building. (MARCH – 2019)**

h = ut – ½ gt^2

= 19.6 x 6 x ½ x 9.8 x 6^2

h = –58.8 m or h = 58.8 m

(As the top of a building is the origin, the download displacement becomes negative)

5. **Calculate the value of orbital velocity for an artificial satellite of earth orbiting at a height of 1000 km (Mass of the earth = 6x10²⁴ kg, radius of the earth = 6400 km). (MARCH – 2019)**

$v = \sqrt{\frac{GM_E}{(R_E+h)}}$;

$= \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6400+1000) \times 10^3}}$; **$v = 7.35 \times 10^3\ ms^{-1}$**

6. **An object is thrown with initial speed $5ms^{-1}$ with an angle of projection 30^0. Calculate the maximum height reached and the horizontal range. (MARCH – 2020, MARCH – 2024)**

i) maximum height of the projectile, $h_{max} = \frac{u^2\sin^2\theta}{2g}$

$h_{max} = \frac{5^2 \sin 30^0 \sin 30^0}{2 \times 9.8}$; $= \frac{25 \times \left[\frac{1}{2}\right] \times \left[\frac{1}{2}\right]}{2 \times 9.8}$; $= \frac{25}{8 \times 9.8}$; $= \frac{25}{78.4}$; $h_{max} = 0.3188m$

ii) Horizontal Range $R = \frac{u^2\sin 2\theta}{g}$; $= \frac{u^2 2 \sin\theta \cos\theta}{g}$; $= \frac{5^2 \times 2 \sin 30^0 \cos 30^0}{9.8}$

$= \frac{25 \times 2 \left[\frac{1}{2}\right] \times \left[\frac{\sqrt{3}}{2}\right]}{9.8}$; $= \frac{25 \times 1.732}{2 \times 9.8} = \frac{43.300}{19.6}$; $R = 2.21m$

7. **A force of $(4\hat{\imath} - 3\hat{\jmath} + 5\hat{k})$ N is applied at a point whose position vector is $(7\hat{\imath} + 4\hat{\jmath} - 2\hat{k})$m. Find the torque of force about the origin. (MARCH – 2020)**

$$\vec{\tau} = \vec{r} \times \vec{F} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 7 & 4 & -2 \\ 4 & -3 & 5 \end{vmatrix}$$

$= (20 - 6)\hat{\imath} - (35 + 8)\hat{\jmath} + (-21 - 16)\hat{k}$;
$= (14\hat{\imath} - 43\hat{\jmath} - 37\hat{k})$ Nm

8. **Find the ratio of the acceleration due to gravity at a height R/2 from the surface of the earth to the value at a depth R/2 from the surface of the earth (R – radius of the earth). (MARCH – 2020)**

At height 'h'

$g_h = \frac{g}{\left(1+\frac{h}{R}\right)^2}$; $g_h = \frac{GM}{(R+h)^2}$

At depth 'd'

$g_d = g\left(1 - \frac{d}{R}\right)$ or $g_d = \frac{GM}{(R-d)^2}$

$h = d = \frac{R}{2}$; $\frac{g_h}{g_d} = \frac{8}{9}$

9. **A train was moving at the rate of 54 km h^{-1} when brakes were applied. It came to rest within a distance of 225 m. Calculate the retardation produced in the train. (SEPTEMBER – 2020), JUNE – 2023)**

The final velocity of the particle v = 0

The initial velocity of the particle u = 54 x $\frac{5}{18}$ ms^{-1} = 15 ms^{-1} ; s = 225 m

Retardation is always against the velocity of the particle.

$v^2 = u^2 - 2aS$; $0 = (15)^2 - 2a(225)$; 450 a = 225

$a = \frac{225}{450}\ ms^{-2}$; =0.5 ms^{-2} ; Retardation = =0.5 ms^{-2}

10. **Suppose we go 200 km above and below the surface of the Earth, what are the g values at these two points? In which case, is the value of g small? (SEPTEMBER – 2020)**

$g_{height} = g\left[1 - \frac{2h}{R}\right]$; $g_{depth} = g\left[1 - \frac{d}{R}\right]$

$g_{height} = g\left[1 - \frac{2 \times 200}{6400}\right]$; $= g\left[\frac{64-4}{64}\right]$;

$= g\left[\frac{60}{64}\right]$; $\mathbf{g_{height} = 0.94g}$

$g_{depth} = g\left[1 - \frac{200}{6400}\right]$; $= g\left[\frac{64-2}{64}\right]$;

$= g\left[\frac{62}{64}\right]$; $\mathbf{g_{height} = 0.968g}$

11. **Calculate the amplitude, angular frequency, frequency, time period and initial phase of the simple harmonic oscillation for the given equation y = 0.3 sin (40πt + 1.1). (SEPTEMBER – 2020)**

$y = A \sin(\omega t + \varphi_0)$ (or) $y = A \cos(\omega t + \varphi_0)$

a. For the wave, **y = 0.3 sin (40πt + 1.1)**

Amplitude is A = 0.3 unit

Angular frequency ω =40π rad s^{-1}

Frequency $f = \frac{\omega}{2\pi}$; $= \frac{40\pi}{2\pi}$; f = 20 Hz

Time period $T = \frac{1}{f}$; $= \frac{1}{20}$; T = 0.05 s

Initial phase φ_0 = 1.1 rad

12. **Express 76 cm of mercury pressure in terms of Nm^{-2} using the method of dimensions. (SEPTEMBER – 2020, AUGUST – 2021)**

In cgs system 76 cm of mercury pressure = 76 × 13.6 × 980 dyne cm^{-2}

The dimensional formula of pressure P is $[ML^{-1}T^{-2}]$

$$P_1[M_1^aL_1^bT_1^c] = P_2[M_2^aL_2^bT_2^c]\ ;\ P_2 = P_1\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$$

M_1 = 1g, M_2 = 1kg; L_1 = 1 cm, L_2 = 1m; T_1 = 1 s, T_2 = 1s

As a =1, b= -1, and c = -2

Then $P_2 = 76 \times 13.6 \times 980 \left[\frac{1g}{1kg}\right]^1\left[\frac{1cm}{1m}\right]^{-1}\left[\frac{1s}{1s}\right]^{-2}$

$= 76 \times 13.6 \times 980 \left[\frac{10^{-3}kg}{1kg}\right]^1\left[\frac{10^{-2}m}{1m}\right]^{-1}\left[\frac{1s}{1s}\right]^{-2}$

$= 76 \times 13.6 \times 980 \times [10^{-3}] \times 10^2$;$P_2 = 1.01 \times 10^5\ Nm^{-2}$

13. **If excess pressure is balanced by a column of oil with specific gravity 0.8, 4 mm high, where R=2.0 cm, find the surface tension of the soap bubble. (AUGUST – 2021)**

The excess of pressure inside the soap bubble is $\Delta p = P_2 - P_1 = \frac{4T}{R}$

$\Delta p = P_2 - P_1 = \rho gh\ \ [\rho gh = \frac{4T}{R}]$

Surface tension, $T = \frac{\rho ghR}{4}$; = $\frac{(800)(9.8)(4 \times 10^{-3})(2 \times 10^{-2})}{4}$;**$T=15.68\times10^{-2}\ Nm^{-1}$**

14. **What are the resultants of the vector product of two vectors given by $\vec{A} = 4\hat{\imath} - 2\hat{\jmath} + \hat{k}$ and $\vec{B} = 5\hat{\imath} + 3\hat{\jmath} - 4\hat{k}$? (MAY – 2022)**

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 4 & -2 & 1 \\ 5 & 3 & -4 \end{vmatrix}$$

$= (8 - 3)\hat{\imath} + (5+16)\hat{\jmath} + (12 + 10)\hat{k}$;

$\vec{A} \times \vec{B} = 5\hat{\imath} + 21\hat{\jmath} + 22\hat{k}$

15. **A person does 30 kJ work on 2 kg of water by stirring using a paddle wheel. While stirring, around 5 kcal of heat is released from water through its container to the surface and surroundings by thermal conduction and radiation. What is the change in internal energy of the system? (MAY – 2022)**

Work done on the system (by the person while stirring),
W = −30 kJ = −30,000J
Heat flowing out of the system, Q = −5 kcal = −5×4184 J =−20920 J
Using First law of thermodynamics, ΔU = Q−W
ΔU = −20,920 J− (−30,000) J

$\Delta U = -20{,}920$ J+30,000 **J = 9080 J**

Here, the heat lost is less than the work done on the system, so the change in internal energy is positive.

16. **An electron of mass 9.1 x 10^{-31} kg revolves around a nucleus in a circular orbit of radius 0.53Å. What is the angular momentum of the electron? (Velocity of electron v=2.2 x 10^{6} ms^{-1}) (AUGUST – 2022)**

Angular momentum = $I \times \omega$ **;** $= \frac{I \times \omega}{R}$ **;**

= mR x v

= 9 x 10^{-31} x 0.53 x 10^{-10} x 2.2 x 10^{6}

Angular momentum = 10.4 x 10^{-35} kgm^2s^{-1}

17. **During a cyclic process, a heat engine absorbs 500 J of heat from a hot reservoir, does work and ejects an amount of heat 300 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine. (AUGUST – 2022)**

The efficiency of heat engine is given by $\eta = 1 - \frac{Q_L}{Q_H}$; $\eta = 1 - \frac{300}{500}$;

$= 1 - \frac{3}{5}$; $\eta = 1 - 0.6$; 0.4

The **heat engine has 40% efficiency**, implying that this heat engine converts only 40% of the input heat into work.

18. **During a cyclic process, a heat engine absorbs 600 J of heat from a hot reservoir, does work and ejects an amount of heat 200 J into the surroundings (cold reservoir). Calculate the efficiency of the heat engine. (MARCH – 2023)**

The efficiency of heat engine is given by $\eta = 1 - \frac{Q_L}{Q_H}$; $\eta = 1 - \frac{200}{600}$;

$= 1 - \frac{2}{6}$; $\eta = 1 - 0.33$; 0.67

The **heat engine has 67% efficiency**, implying that this heat engine converts only 67% of the input heat into work.

19. **A car takes a turn with velocity 50 ms^{-1} on the circular road of radius of curvature 10 m. calculate the centrifugal force experienced by a person of mass 60 kg inside the car? (JUNE – 2023)**

Centrifugal force is given by, $F_{cf} = \frac{mv^2}{r}$;

$= \frac{60 \times 50 \times 50}{10}$; = 6 x 2500

F_{cf} =15000 N

21. **Ten particles are moving at the speed of 2, 3, 4, 5, 5, 5, 6, 6, 7 and 9 m s⁻¹. Calculate root mean square speed (V_{rms}) and most probable speed (V_{mp}). (JUNE – 2023)**

The average speed $\bar{v} = \frac{2+3+4+5+5+5+6+6+7+9}{10}$; = 5.2 ms⁻¹

To find the rms speed, first calculate the mean square speed

$\overline{v^2} = \frac{2^2+3^2+4^2+5^2+5^2+5^2+6^2+6^2+7^2+9^2}{10}$; = 30.6 m^2s^{-2}

$V_{max}=\sqrt{\overline{v^2}} = \sqrt{30.6}$; = 5.53 ms^{-1}

The most probable speed is 5 ms^{-1} because three of the particles have that speed.

22. **Two vibrating tuning forks produce waves whose equation is given by $y_1 = 5 \sin(240\pi t)$ and $y_2 = 4 \sin(244\pi t)$. Compute the number of beats per second. (MARCH – 2024)**

Given $y_1 = 5 \sin(240\pi t)$ and $y_2 = 4 \sin(244\pi t)$

Comparing with $y = A \sin(2\pi f_1 t)$, we get

$2\pi f_1 = 240\pi \Rightarrow f_1 = 120Hz$; $2\pi f_2 = 244\pi \Rightarrow f_2 = 122Hz$

The number of beats produced is $| f_1 - f_2| = |120 - 122| = |-2|$

=2 beats per sec

23. **A cyclist while negotiating a circular path with speed 20 m s⁻¹ is found to bendan angle by 30o with vertical. What is the radius of the circular path? (given, g= 10 ms⁻²) (JULY– 2024)**

Speed of the cyclist, v = 20 ms^{-1} ;

Angle of bending with vertical, $\theta = 30^0$

Equation for angle of bending, $\tan\theta = \frac{v^2}{rg}$

Rewriting the above equation for radius $r = \frac{v^2}{\tan\theta g}$

$r = \frac{(20)^2}{\tan 30^0 \times 10}$; $= \frac{20 \times 20}{(\tan 30^0) \times 10}$; $= \frac{400}{\left(\frac{1}{\sqrt{3}}\right) \times 10}$; $= (\sqrt{3}) \times 40$;

= 1.732 x 40 ;r = 69.28m

24. **An ideal refrigerator keeps its content at 0°C while the room temperature is27°C. Calculate its coefficient of performance. (JULY – 2024)**

Coefficient of performance (COP) of refrigerator, when

$T_H = (27 + 273) = 300$ K & $T_L = (0 + 273) = 273$ K

$COP = \beta = \frac{T_L}{T_H - T_L}$; $\beta = \frac{273}{300-273}$; $= \frac{273}{27}$;

β =10.11

No.	Log
273	2.4362
27	1.4314
(–)	1.0048
Antilog	1.011 x 10¹

25. **Consider Two waves of wavelength 5 m and 6 m. If these two waves propagate in a gas with velocity of 330 ms^{-1}, calculate the number of beats per second.**

(JULY – 2024)

$f_1 = \frac{v}{\lambda_1}$; $\frac{330}{5}$; $f_1 = 66$ Hz

$f_2 = \frac{v}{\lambda_2}$; $\frac{330}{6}$; $f_2 = 55$ Hz

$n = |f_1 - f_2| = 66 - 55$; **n = 11 Beats per second**

Notes:

UNIT – VIII (HEAT AND THERMODYNAMICS)

80. Define Coefficient of performance (COP) (β).

COP is a measure of the efficiency of a refrigerator. It is defined as the ratio of heat extracted from the cold body (sink) to the external work done by the compressor W. COP = $\beta = \frac{Q_L}{W}$ -------------- 1

From the equation (1) $\beta = \frac{Q_L}{Q_H - Q_L}$; $\beta = \frac{1}{\frac{Q_H}{Q_L} - 1}$ ------------ 2

But we know that $\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$

Substituting this equation into equation (2) we get $\beta = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{T_L}{T_H - T_L}$

Inferences:

1. The greater the COP, the better is the condition of the refrigerator. A typical refrigerator has COP around 5 to 6.
2. Lesser the difference in the temperatures of the cooling chamber and the atmosphere, higher is the COP of a refrigerator.
3. In the refrigerator the heat is taken from cold object to hot object by doing external work. Without external work heat cannot flow from cold object to hot object. It is not a violation of second law of thermodynamics, because the heat is ejected to surrounding air and total entropy of (refrigerator + surrounding) is always increased.

Notes:

Notes: