HIGHER SECONDARY FIRST YEAR

PHYSICS

DO YOU KNOW? The name Physics was introduced by Aristotle in the year 350 BC

"When you can measure what you are speaking about and can express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind" - Lord Kelvin

DO YOU KNOW? The cgs, mks and SI are metric or decimal system of units. The fps system is not a metric system.

Relations between radian, degree and minutes:

$$1° = \frac{\pi}{180} \text{ rad} = 1.744 \times 10^{-2} \text{ rad}$$

$$\therefore 1' = \frac{1°}{60} = \frac{1.744 \times 10^{-2}}{60} = 2.906 \times 10^{-4} rad$$

$$\approx 2.91 \times 10^{-4} rad$$

$$\therefore 1'' = \frac{1°}{3600} = \frac{1.744 \times 10^{-2}}{3600} = 4.844 \times 10^{-6} rad$$

$$\approx 4.84 \times 10^{-6} rad$$

The Radian (rad): *One radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.*

The Steradian (sr): *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*

DO YOU KNOW? The supplementary quantities of plane and solid angle were converted into Derived quantities in 1995 (GCWM)

Table 1.4 Prefixes for Powers of Ten

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

RADAR method

The word RADAR stands for radio detection and ranging. A 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. 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

Speed = distance travelled / time taken
(Speed is explained in unit 2)
Distance(d) = Speed of radio waves × time taken

$$d = \frac{v \times t}{2}$$

Table 1.5 Range and Order of Lengths

Size of objects and distances	Length (m)
Distance to the boundary of observable universe	10^{26}
Distance to the Andromeda galaxy	10^{22}
Size of our galaxy	10^{21}
Distance from Earth to the nearest star (other than the Sun)	10^{16}
Average radius of Pluto's orbit	10^{12}
Distance of the Sun from the Earth	10^{11}
Distance of Moon from the Earth	10^{8}
Radius of the Earth	10^{7}
Height of the Mount Everest above sea level	10^{4}
Length of a football field	10^{2}
Thickness of a paper	10^{-4}
Diameter of a red blood cell	10^{-5}
Wavelength of light	10^{-7}
Length of typical virus	10^{-8}
Diameter of the hydrogen atom	10^{-10}
Size of atomic nucleus	10^{-14}
Diameter of a proton	10^{-15}

Table 1.6 Range of masses

Object	Order of mass (kg)
Electron	10^{-30}
Proton or Neutron	10^{-27}
Uranium atom	10^{-25}
Red blood corpuscle	10^{-14}
A cell	10^{-10}
Dust particle	10^{-9}
Raindrop	10^{-6}
Mosquito	10^{-5}
Grape	10^{-3}
Frog	10^{-1}
Human	10^{2}
Car	10^{3}
Ship	10^{5}
Moon	10^{23}
Earth	10^{25}
Sun	10^{30}
Milky way	10^{41}
Observable Universe	10^{55}

5. The measurement value of length of a simple pendulum is 20 cm known with 2 mm accuracy. The time for 50 oscillations was measured to be 40 s within 1 s resolution. Calculate the percentage accuracy in the determination of acceleration due to gravity 'g' from the above measurement.
Ans: (6%)

Types of motion

In our day-to-day life the following kinds of motion are observed:

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

Examples

- An athlete running on a straight track
- A particle 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

- The whirling motion of a stone attached to a string

2. **Unit vector:** A vector divided by its magnitude is a unit vector. The unit vector for $\vec{A}$ is denoted by $\hat{A}$ (read as A cap or A hat). It has a magnitude equal to unity or one.

Since, $\hat{A} = \frac{\vec{A}}{A}$ we can write $\vec{A} = A\hat{A}$

Thus, we can say that the unit vector specifies only the direction of the vector quantity.

EXAMPLE 2.4

Two vectors $\vec{A}$ and $\vec{B}$ are given in the component form as $\vec{A} = 5\hat{i} + 7\hat{j} - 4\hat{k}$ and $\vec{B} = 6\hat{i} + 3\hat{j} + 2\hat{k}$. Find $\vec{A} + \vec{B}$, $\vec{B} + \vec{A}$, $\vec{A} - \vec{B}$, $\vec{B} - \vec{A}$

Solution

$$\vec{A} + \vec{B} = (5\hat{i} + 7\hat{j} - 4\hat{k}) + (6\hat{i} + 3\hat{j} + 2\hat{k})$$
$$= 11\hat{i} + 10\hat{j} - 2\hat{k}$$
$$\vec{B} + \vec{A} = (6\hat{i} + 3\hat{j} + 2\hat{k}) + (5\hat{i} + 7\hat{j} - 4\hat{k})$$
$$= (6+5)\hat{i} + (3+7)\hat{j} + (2-4)\hat{k}$$
$$= 11\hat{i} + 10\hat{j} - 2\hat{k}$$
$$\vec{A} - \vec{B} = (5\hat{i} + 7\hat{j} - 4\hat{k}) - (6\hat{i} + 3\hat{j} + 2\hat{k})$$
$$= -\hat{i} + 4\hat{j} - 6\hat{k}$$
$$\vec{B} - \vec{A} = \hat{i} - 4\hat{j} + 6\hat{k}$$

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.

EXAMPLE 2.7

Given two vectors $\vec{A} = 2\hat{i} + 4\hat{j} + 5\hat{k}$ and $\vec{B} = \hat{i} + 3\hat{j} + 6\hat{k}$, Find the product $\vec{A}.\vec{B}$, and the magnitudes of $\vec{A}$ and $\vec{B}$. What is the angle between them?

Solution

$$\vec{A}.\vec{B} = 2 + 12 + 30 = 44$$

$$\text{Magnitude A} = \sqrt{4+16+25} = \sqrt{45} \text{ units}$$

$$\text{Magnitude B} = \sqrt{1+9+36} = \sqrt{46} \text{ units}$$

The angle between the two vectors is given by

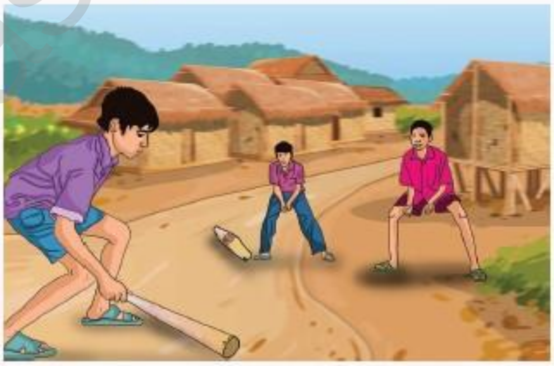
$$\theta = \cos^{-1}\left(\frac{\vec{A}.\vec{B}}{AB}\right)$$

$$= \cos^{-1}\left(\frac{44}{\sqrt{45 \times 46}}\right) = \cos^{-1}\left(\frac{44}{45.49}\right)$$
$$= \cos^{-1}(0.967)$$

$$\therefore \theta \cong 15^\circ$$

Function	Derivative
$y = x$	$dy/dx = 1$
$y = x^2$	$dy/dx = 2x$
$y = x^3$	$dy/dx = 3x^2$
$y = x^n$	$dy/dx = nx^{n-1}$
$y = \sin x$	$dy/dx = \cos x$
$y = \cos x$	$dy/dx = -\sin x$
$y = \text{constant}$	$dy/dx = 0$
$y = AB$	$\frac{dy}{dx} = A\left(\frac{dB}{dx}\right) + \left(\frac{dA}{dx}\right)B$

Projectile motion !



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'.

EXAMPLE 2.40

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

$$v = 3t = 6 m s^{-1}$$

The centripetal acceleration at t = 2 s is

$$a_c = \frac{v^2}{r} = \frac{(6)^2}{10} = 3.6 m s^{-2}$$

The tangential acceleration is $a_t = \frac{dv}{dt} = 3 m s^{-2}$

The angle between the radius vector with resultant acceleration is given by

$$\tan\theta = \frac{a_t}{a_c} = \frac{3}{3.6} = 0.833$$

$$\theta = \tan^{-1}(0.833) = 0.69 \text{ radian}$$

$$\text{In terms of degree } \theta = 0.69 \times 57.27° \approx 40°$$

21. The Moon is orbiting the Earth approximately once in 27 days, what is the angle transversed by the Moon per day?

[Ans: 13°3']

22. An object of mass m has angular acceleration $\alpha = 0.2 rad s^{-2}$. What is the angular displacement covered by the object after 3 second? (Assume that the object started with angle zero with zero angular velocity).

[Ans: 0.9 rad or 51°]

EXAMPLE 3.10

A particle of mass 2 kg experiences two forces, $\vec{F}_1 = 5\hat{i} + 8\hat{j} + 7\hat{k}$ and $\vec{F}_2 = 3\hat{i} - 4\hat{j} + 3\hat{k}$. What is the acceleration of the particle?

Solution

We use Newton's second law, $\vec{F}_{net} = m\vec{a}$ where $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2$. From the above equations the acceleration is $\vec{a} = \frac{\vec{F}_{net}}{m}$, where

$$\vec{F}_{net} = (5+3)\hat{i} + (8-4)\hat{j} + (7+3)\hat{k}$$

$$\vec{F}_{net} = 8\hat{i} + 4\hat{j} + 10\hat{k}$$

$$\vec{a} = \left(\frac{8}{2}\right)\hat{i} + \left(\frac{4}{2}\right)\hat{j} + \left(\frac{10}{2}\right)\hat{k}$$

$$\vec{a} = 4\hat{i} + 2\hat{j} + 5\hat{k}$$

3.4 LAMI'S THEOREM

If a system of three concurrent and coplanar forces is in equilibrium, then Lami's theorem states 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.

Note When $\theta = 0°$, the strings are vertical and the tension on each string is $T = \frac{mg}{2}$

Table 3.2 Salient Features of Static and Kinetic Friction

Static friction	Kinetic friction
It opposes the starting of motion	It opposes the relative motion of the object with respect to the surface
Independent of surface area of contact	Independent of surface area of contact
μ_s depends on the nature of materials in mutual contact	μ_k depends on nature of materials and temperature 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 $v < 10\ ms^{-1}$)
$f_s^{max} > f_k$	It is less than maximum value of static friction
$\mu_s > \mu_k$	Coefficient of kinetic friction is less than coefficient of static friction

3.7.1 Centripetal force

If a particle is in uniform circular motion, there must be centripetal acceleration towards the centre 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.

As we have seen in chapter 2, the centripetal acceleration of a particle in the circular motion is given by $a = \frac{v^2}{r}$ and it acts towards centre of the circle. According to Newton's second law, the centripetal force is given by

$$F_{cp} = ma_{cp} = \frac{mv^2}{r}$$

EXAMPLE 3.25

Consider a circular road of radius 20 meter banked at an angle of 15 degree. With what speed a car has to move on the turn so that it will have safe turn?

Solution

$$v = \sqrt{(rg\tan\theta)} = \sqrt{20 \times 9.8 \times \tan 15^\circ}$$

$$= \sqrt{20 \times 9.8 \times 0.26} = 7.1\ m\,s^{-1}$$

The safe speed for the car on this road is $7.1\ m\,s^{-1}$

EXAMPLE 3.26

Calculate the centrifugal force experienced by a man of 60 kg standing at Chennai? (Given: Latitude of Chennai is 13°)

Solution

The centrifugal force is given by $F_c = m\omega^2 R\cos\theta$

The angular velocity (ω) of Earth $= \frac{2\pi}{T}$, where T is time period of the Earth (24 hours)

$$\omega = \frac{2\pi}{24 \times 60 \times 60} = \frac{2\pi}{86400} = 7.268 \times 10^{-5}\ rad\,sec^{-1}$$

The radius of the Earth R = 6400 Km = 6400×10^3 m

Latitude of Chennai = 13°

$$F_{cf} = 60 \times (7.268 \times 10^{-5})^2 \times 6400 \times 10^3 \times \cos(13^\circ) = 1.9678\,N$$

A 60 kg man experiences centrifugal force of approximately 2 Newton. But due to Earth's gravity a man of 60 kg experiences a force = mg = 60 × 9.8 = 588N. This force is very much larger than the centrifugal force.

3.7.7 Centripetal Force Versus Centrifugal Force

Salient features of centripetal and centrifugal forces are compared in Table 3.4.

14. 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 60kg inside the car?

 Ans: 15,000 N

15. 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 that it hits the stick. (Assume the coefficient of kinetic friction is 0.7).

 Ans: 11.71 ms^{-1}

Table 4.2 SI equivalent of other units of energy

Unit	Equivalent in joule
1 erg (CGS unit)	10^{-7} J
1 electron volt (eV)	1.6×10^{-19} J
1 calorie (cal)	4.186 J
1 kilowatt hour (kWh)	3.6×10^{6} J

Table 4.3 Comparison of conservative and non-conservative forces

S.No	Conservative forces	Non-conservative forces
1.	Work done is independent of the path	Work done depends upon the path
2.	Work done in a round trip is zero	Work done in a round trip is not zero
3	Total energy remains constant	Energy is dissipated as heat energy
4	Work done is completely recoverable	Work done is not completely recoverable.
5	Force is the negative gradient of potential energy	No such relation exists.

DO YOU KNOW?

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).

2. A ball with a velocity of 5 ms^{-1} impinges at angle of 60° with the vertical on a smooth horizontal plane. If the coefficient of restitution is 0.5, find the velocity and direction after the impact.

Ans: $v = 4.51\ m\ s^{-1}$

EXAMPLE 5.3

The position vectors of two point masses 10 kg and 5 kg are $(-3\hat{i}+2\hat{j}+4\hat{k})$ m and $(3\hat{i}+6\hat{j}+5\hat{k})$ m respectively. Locate the position of centre of mass.

Solution

$$m_1 = 10\,kg$$
$$m_2 = 5\,kg$$
$$\vec{r}_1 = (-3\hat{i}+2\hat{j}+4\hat{k})m$$
$$\vec{r}_2 = (3\hat{i}+6\hat{j}+5\hat{k})m$$
$$\vec{r} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2}{m_1+m_2}$$
$$\therefore \vec{r} = \frac{10(-3\hat{i}+2\hat{j}+4\hat{k})+5(3\hat{i}+6\hat{j}+5\hat{k})}{10+5}$$
$$= \frac{-30\hat{i}+20\hat{j}+40\hat{k}+15\hat{i}+30\hat{j}+25\hat{k}}{15}$$
$$= \frac{-15\hat{i}+50\hat{j}+65\hat{k}}{15}$$
$$\vec{r} = \left(-\hat{i}+\frac{10}{3}\hat{j}+\frac{13}{3}\hat{k}\right) m$$

The centre of mass is located at position $\vec{r}$.

Table 5.4 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, $\omega = \frac{d\theta}{dt}$
4	Acceleration, $a = \frac{dv}{dt}$	Angular acceleration, $\alpha = \frac{d\omega}{dt}$
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	Angular impulse, τΔt = ΔL
9	Work done, w = F s	Work done, w = τ θ
10	Kinetic energy, $KE = \frac{1}{2}mv^2$	Kinetic energy, $KE = \frac{1}{2}I\omega^2$
11	Power, P = F v	Power, P = τω

6. Find the moment of inertia of a hydrogen molecule about an axis passing through 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.

Ans: 1.36×10^{-46} kg m^2

DO YOU KNOW? 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} N m^{2}kg^{-2}. Using modern techniques a more accurate value of G could be measured. The currently accepted value of G is 6.67259×10^{-11} N m^{2}kg^{-2}.

14. 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?

Ans: $g_{down} = 0.96$ g

$g_{up} = 0.94$ g

15. Calculate the change in g value in your district of Tamil nadu. (Hint: Get the latitude of your district of Tamil nadu from the Google). What is the difference in g values at Chennai and Kanyakumari?

Ans: $g_{chennai} = 9.7677$ m s^{-2}

$g_{Kanyakumari} = 9.7667$ m s^{-2}

$\Delta g = 0.001$ m s^{-2}

DO YOU KNOW? 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.

Table 7.2 Poisson's ratio of some of the materials

Material	Poisson's ratio
Rubber	0.4999
Gold	0.42 -0.44
Copper	0.33
Stainless steel	0.30-0.31
Steel	0.27-0.30
Cast iron	0.21-0.26
Concrete	0.1-0.2
Glass	0.18-0.3
Foam	0.10-0.50
Cork	0.0

EXAMPLE 7.5

A wire of length 2 m with the area of cross-section 10^{-6} m^2 is used to suspend a load of 980 N. Calculate i) the stress developed in the wire ii) the strain and iii) the energy stored. Given: Y=12 × 10^{10}N m^{-2}.

Solution

(i) $\text{stress} = \frac{F}{A} = \frac{980}{10^{-6}} = 98\times10^7\, N m^{-2}$

(ii) $\text{strain} = \frac{\text{stress}}{Y} = \frac{98\times10^7}{12\times10^{10}} = 8.17\times10^{-3}$ (no unit)

(iii) Since volume = 2 × $10^{-6} m^3$,

$$\text{Energy} = \frac{1}{2}(\text{stress}\times\text{strain})\times\text{volume}$$

$$= \frac{1}{2}(98\times10^7)\times(8.17\times10^{-3})\times2\times10^{-6} = 8\text{ J}$$

EXAMPLE 7.7

Two pistons of a hydraulic lift have diameters of 60 cm and 5 cm. What is the force 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, $A_2 = \pi\left(\frac{60}{2}\right)^2 = \pi(30)^2$

$$F_2 = \frac{A_2}{A_1}\times F_1 = (50N)\times\left(\frac{30}{2.5}\right)^2 = 7200\,N$$

This means that with the force of 50 N, the force of 7200 N can be lifted.

EXAMPLE 7.9

A metal plate of area 2.5×10^{-4} m^2 is placed on a 0.25×10^{-3}m thick layer of castor 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} m^2, dx = 0.25×10^{-3}m, F=2.5 N and dv = 3×10^{-2} m s^{-1}

Solution

$$F = -\eta A\frac{dv}{dx}$$

In magnitude, $\eta = \frac{F}{A}\frac{dx}{dv}$

$$= \frac{(2.5N)}{(2.5\times10^{-4}\text{m}^2)}\frac{(0.25\times10^{-3}\text{m})}{(3\times10^{-2}\text{m s}^{-1})}$$

= 0.083×10^3 N m^{-2}s

7.4.7 Poiseuille's equation

Poiseuille analyzed the steady flow of liquid through a capillary tube. He derived an expression for the volume of the liquid flowing per second through the capillary tube.

As per the theory, the following conditions must be retained while deriving the equation.

- The flow of liquid through the tube is streamlined.
- The tube is horizontal so that gravity does not influence the flow
- The layer in contact with the wall of the tube is at rest
- The pressure is uniform over any cross section of the tube

EXAMPLE 7.10

Let $2.4\times10^{-4}J$ of work is done to increase the area of a film of soap bubble from 50 cm^2 to 100 cm^2. Calculate the value of surface tension of soap solution.

Solution:

A soap bubble has two free surfaces, therefore increase in surface area ΔA = A_2-A_1 = 2(100–50) × $10^{-4}m^2$ = 100 × $10^{-4}m^2$.

Since, work done $W=T\times\Delta A \Rightarrow T=\frac{W}{\Delta A}$

$$=\frac{2.4\times10^{-4}\,\text{J}}{100\times10^{-4}\,\text{m}^2}=2.4\times10^{-2}\,\text{N}\,\text{m}^{-1}$$

EXAMPLE 7.11

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.

Solution

The excess of pressure inside the soap bubble is $\Delta P=P_2-P_1=\frac{4T}{R}$

But $\Delta P=P_2-P_1=\rho gh \Rightarrow \rho gh=\frac{4T}{R}$

$\Rightarrow$ Surface tension,

$$T=\frac{\rho ghR}{4}=\frac{(800)(9.8)(4\times10^{-3})(2\times10^{-2})}{4}=$$

$$T=15.68\times10^{-2}Nm^{-1}$$

EXAMPLE 7.13

Mercury has an angle of contact equal to 140° with soda lime glass. A narrow tube of radius 2 mm, made of this glass is dipped in a trough containing mercury. By what amount does the mercury dip down in the tube relative to the liquid surface outside? Surface tension of mercury T=0.456 N m^{-1}; Density of mercury ρ = 13.6 × 10^3 kg m^{-3}

Solution

Capillary descent, cos140 = cos(90+50)
–sin50 = –0.7660

$$h=\frac{2T\cos\theta}{r\rho g}=\frac{2\times(0.456\,N\,m^{-1})(\cos140^0)}{(2\times10^{-3}m)(13.6\times10^3)(9.8\,ms^{-2})}$$

$$=\frac{2\times0.456\times(-0.7660)}{2\times13.6\times9.8}$$

$$=\frac{-0.6986}{266.56}=-2.62\times10^{-3}m$$

where, negative sign indicates that there is fall of mercury (mercury is depressed) in glass tube.

DO YOU KNOW? 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 $4.5\times10^9 N\,m^{-2}$. Compare this value with Young's modulus of wood.

4. A block of Ag of mass x kg hanging from a string is immersed in a liquid of relative density 0.72. If the relative density of Ag is 10 and tension in the string is 37.12 N then compute the mass of Ag block. (Answer: x = 4 kg)

5. The reading of pressure meter attached with a closed pipe is 5 × 10^5 N m^{-2}. On opening the valve of the pipe, the reading of the pressure meter is 4.5 × 10^5 Nm^{-2}. Calculate the speed of the water flowing in the pipe.

(Answer: 10 ms^{-1})

Table 8.2 Specific heat capacity of some common substances at 1 atm (20°C)

Material	Specific heat capacity ($Jkg^{-1}K^{-1}$)
Air	1005
Lead	130
Copper	390
Iron (steel)	450
Glass	840
Aluminium	900
Human body	3470
Water	4186

Note

Steady state: The state at which temperature attains constant value everywhere and there is no further transfer of heat anywhere is called steady state.

DO YOU KNOW?

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'.

DO YOU KNOW?

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 days 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!

15. An ideal refrigerator keeps its content at 0°C while the room temperature is 27°C. Calculate its coefficient of performance.

Answer: β=10.11

EXAMPLE 9.3

Ten particles are moving at the speed of 2, 3, 4, 5, 5, 5, 6, 6, 7 and 9 m s^{-1}. Calculate rms speed, average speed and most probable speed.

Solution

The average speed

$$\bar{v} = \frac{2+3+4+5+5+5+6+6+7+9}{10} = 5.2\, m\, s^{-1}$$

To find the rms speed, first calculate the mean square speed $\overline{v^2}$

$$\overline{v^2} = \frac{2^2+3^2+4^2+5^2+5^2+5^2+6^2+6^2+7^2+9^2}{10}$$

$$= 30.6\, m^2 s^{-2}$$

The rms speed

$$v_{rms} = \sqrt{\overline{v^2}} = \sqrt{30.6} = 5.53\, m\, s^{-1}$$

The most probable speed is 5 m s^{-1} because three of the particles have that speed.

EXAMPLE 9.6

An oxygen molecule is travelling in air at 300 K and 1 atm, and the diameter of oxygen molecule is $1.2 \times 10^{-10} m$. Calculate the mean free path of oxygen molecule.

Solution

From (9.26) $\lambda = \frac{1}{\sqrt{2}\pi n d^2}$

We have to find the number density n

By using ideal gas law

$$n = \frac{N}{V} = \frac{P}{kT} = \frac{101.3 \times 10^3}{1.381 \times 10^{-23} \times 300}$$

$= 2.449 \times 10^{25}$ *molecues*/m^3

$$\lambda = \frac{1}{\sqrt{2} \times \pi \times 2.449 \times 10^{25} \times (1.2 \times 10^{-10})^2}$$

$$= \frac{1}{15.65 \times 10^5}$$

$\lambda = 0.63 \times 10^{-6} m$

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.

9. Estimate the total number of air molecules in a room of capacity of 25 m^3 at a temperature of 27°C with 1atm pressure.

Ans: 6.1×10^{26} molecules

Note A simple harmonic motion is a special type of oscillatory motion. But all oscillatory motions need not be simple harmonic .

Note The time period obtained for horizontal oscillations of spring and for vertical oscillations of spring are found to be equal.

Note The reciprocal of stiffness constant is called flexibility constant or compliance, denoted by C. It is measured in m N^{-1}

If n springs are connected in series :

net compliance $C_s = \sum_{i=1}^{n} C_i$

If n springs are connected in parallel :

$$\frac{1}{C_p} = \sum_{i=1}^{n} \frac{1}{C_i}$$

EXAMPLE 10.9

Consider two springs whose force constants are 1 N m^{-1} and 2 N m^{-1} which are connected in series. Calculate the effective spring constant (k_s) and comment on k_s.

Solution

$$k_1 = 1\ \text{N m}^{-1}, k_2 = 2\ \text{N m}^{-1}$$

$$k_s = \frac{k_1 k_2}{k_1 + k_2}\ \text{N m}^{-1}$$

$$k_s = \frac{1 \times 2}{1+2} = \frac{2}{3}\ \text{N m}^{-1}$$

$$k_s < k_1 \text{ and } k_s < k_2$$

Therefore, the effective spring constant is lesser than both k_1 and k_2.

Note

From Newton's 2nd law, $\vec{F} = m\vec{a}$ Here, the net force on the L.H.S is $T\text{-}F_{as}$
In R.H.S, $m\vec{a}$ is equivalent to the centripetal force $= \frac{mv^2}{l}$ which makes the bob oscillate.

DO YOU KNOW?

Dummy variable

The integrating variable x' (read x' as "x prime") is a dummy variable

$$\int_0^y t\,dt = \int_0^y x\,dx = \int_0^y p\,dp = \frac{y^2}{2}$$

Notice that the integrating variables like t, x and p are dummy variables because, in this integration, whether we put t or x or p as variable for integration, we get the same answer.

2. Consider a simple pendulum of length $l = 0.9\ m$ which is properly placed on a trolley rolling down on a inclined plane which is at $\theta = 45°$ with the horizontal. Assuming that the inclined plane is frictionless, calculate the time period of oscillation of the simple pendulum.

Answer: 0.86 s

11.1.4 Characteristics of wave motion

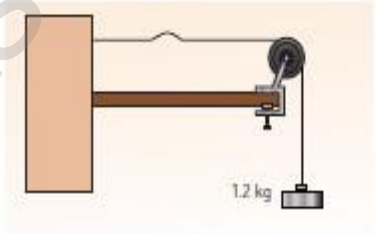
- For the propagation of the waves, the medium must possess both inertia and elasticity, which decide the velocity of the wave in that medium.
- In a given medium, the velocity of a wave is a constant whereas the constituent particles in that medium move with different velocities at different positions. Velocity is maximum at their mean position and zero at extreme positions.
- Waves undergo reflections, refraction, interference, diffraction and polarization.

Table 11.1: Comparison of transverse and longitudinal waves

S.No.	Transverse waves	Longitudinal waves
1.	The direction of vibration of particles of the medium is perpendicular to the direction of propagation of waves.	The direction of vibration of particles of the medium is parallel to the direction of propagation of waves.
2.	The disturbances are in the form of crests and troughs.	The disturbances are in the form of compressions and rarefactions.
3.	Transverse waves are possible in elastic medium.	Longitudinal waves are possible in all types of media (solid, liquid and gas).

EXAMPLE 11.6

Calculate the velocity of the travelling pulse as shown in the figure below. The linear mass density of pulse is 0.25 kg m^{-1}. Further, compute the time taken by the travelling pulse to cover a distance of 30 cm on the string.



Solution

The tension in the string is $T = mg = 1.2 \times 9.8 = 11.76$ N

The mass per unit length is $\mu = 0.25$ kg m^{-1}

Therefore, velocity of the wave pulse is

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{11.76}{0.25}} = 6.858\ m\,s^{-1} = 6.8\ m\,s^{-1}$$

The time taken by the pulse to cover the distance of 30 cm is

$$t = \frac{d}{v} = \frac{30 \times 10^{-2}}{6.8} = 0.044\,s = 44\,ms$$ where,

ms = milli second.

Table 11.3: Comparison between progressive and stationary 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.

11.11 DOPPLER EFFECT

Imagine that you are standing on a railway platform and listening to the blowing whistle of a train moving past you, the pitch (or frequency) of the sound you listen as the train approaches you is higher than the pitch you listen as it moves away from you. This is an example of Doppler effect.

3. A ship in a sea sends SONAR waves straight down into the seawater from the bottom of the ship. The signal reflects from the deep bottom bed rock and returns to the ship after 3.5 s. After the ship moves to 100 km it sends another signal which returns back after 2s. Calculate the depth of the sea in each case and also compute the difference in height between two cases.

Answer : $\Delta d = 1149.75$ m

8. 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)

Answer: $v_{thief} = 10$ m s^{-1}