Guidelines to NCERT Exercises

5.1. *Give the magnitude and direction of the net force acting on*

(*a*) *a drop of rain falling down with a constant speed,*

(*b*) *a cork of mass 10 g floating on water,* **[Delhi 13]**

(*c*) *a kite skilfully held stationary in the sky,*

(*d*) *a car moving with a constant velocity of 30 km/h on a rough road,* **[Delhi 12]**

(*e*) *a high-speed electron in space far from all gravitating objects, and free of electric and magnetic fields.*

Ans.

(*a*) As the rain drop is falling down with a constant speed, no net force is acting on it. The weight of the drop is balanced by the upthrust and viscosity of air.

(*b*) Zero, because the weight of the cork is balanced by the upthrust exerted by water.

(*c*) As the kite is held stationary, no net force acts on it. The force exerted by air on the kite is balanced by the tension produced in the string.

(*d*) As the car is moving with a constant velocity, no net force acts it. The force exerted by the engine is balanced by the friction due to rough road.

(*e*) As no field (gravitational/electric/magnetic) is acting on the electron, the net force on it is zero.

5.2. *A pebble of mass 0.05 kg is thrown vertically upwards. Give the direction and magnitude of the net force on the pebble*

(*i*) *during its upward motion.*

(*ii*) *during its downward motion.*

(*iii*) *at the highest point where it is momentarily at rest.*

Do your answers alter if the pebble were thrown at an angle of say 45° with the horizontal direction ? Take $g = 10\ ms^{-2}$

Ans. Here $m = 0.05$ kg, $g = 10$ ms^{-2}

(i) Net force on the pebble = mg

$= 0.05 \times 10 = \mathbf{0.5\ N}$, vertically downwards

(ii) Net force on the pebble = mg

$= 0.05 \times 10 = \mathbf{0.5\ N}$, vertically downwards

(iii) Net force on the pebble

$= mg = 0.05 \times 10 = \mathbf{0.5\ N}$, vertically downwards

The answers will not alter if the pebble were thrown at an angle of 45° with the horizontal because the horizontal component of velocity remains constant.

5.3. *Give the magnitude and direction of the net force acting on a stone of 0.1 kg,*

(i) *just after it is dropped from the window of a stationary train.*

(ii) *just after it is dropped from the window of a train running at a constant velocity of 36 kmh^{-1}.*

(iii) *just after it is dropped from the window of a train accelerating with 1 ms^{-2}.*

(iv) *lying on the floor of a train which is accelerating with 1 ms^{-2}, the stone being at rest relative to the train. Neglect air resistance throughout, and take $g = 10$ ms^{-2}.*

Ans. Here $m = 0.1$ kg, $g = 10$ ms^{-2}

(i) When the stone is just dropped from the window of a stationary train,

$F = mg = 0.1 \times 10 = \mathbf{1\ N}$, vertically downwards

(ii) When the stone is dropped from the window of a train running at a constant velocity, no force acts on the stone due to the motion of the train.

$\therefore$ $F = mg = \mathbf{1\ N}$, vertically downwards.

(iii) In the train accelerating with 1 ms^{-2}, the stone experiences an additional force,

$F' = ma = 0.1 \times 1 = 0.1$ N, along horizontal.

As the stone is dropped, the force F' no longer acts on the stone and so net force on the stone is

$F = mg = \mathbf{1\ N}$, vertically downwards

(iv) Here weight of the stone is balanced by the normal reaction of the floor.

Acceleration of the stone

= Acceleration of the train = 1 ms^{-2}

$\therefore$ $F = ma = 0.1 \times 1 = \mathbf{0.1\ N}$, along horizontal.

5.4. *One end of a string of length l is connected to a particle of mass m and the other to a small peg on a smooth horizontal table. If the particle moves in a circle with speed v the net force on the particle (directed towards the centre) is :*

(i) T, (ii) $T - \frac{mv^2}{l}$, (iii) $T + \frac{mv^2}{l}$, (iv) 0.

T is the tension in the string. Choose the correct alternative.

Ans. Alternative (i) is correct. The net force on the particle directed towards the centre is T. This provides the necessary centripetal force to the particle moving in the circle.

5.5. *A constant retarding force of 50 N is applied to a body of mass 20 kg moving initially with a speed of 15 ms^{-1}. How long does the body take to stop ?*

Ans. Here $F = -50$ N, $m = 20$ kg, $u = 15$ ms^{-1}, $v = 0$

As $F = ma$

$\therefore$ $a = \frac{F}{m} = \frac{-50}{20} = -2.5$ ms^{-2}

Also, $v = u + at$ $\therefore$ $0 = 15 - 2.5 \times t$

or $t = \mathbf{6\ s.}$

5.6. *A constant force acting on a body of mass 3 kg changes its speed from 2 ms^{-1} to 3.5 ms^{-1} in 25 s. The direction of motion of the force remains unchanged. What is the magnitude and the direction of the force ?* **[Delhi 06]**

Ans. Here $m = 3$ kg, $u = 2$ ms^{-1}, $v = 3.5$ ms^{-1}, $t = 25$ s

As $v = u + at$

$\therefore$ $3.5 = 2 + a \times 25$

or $a = \frac{3.5 - 2}{25} = 0.06$ ms^{-2}

Force, $F = ma = 3 \times 0.06 = \mathbf{0.18\ N}$

As the applied force increases the speed of the body, it acts in the direction of motion of the body.

5.7. *A body of mass 5 kg is acted upon by two perpendicular forces of 8 N and 6 N. Give the magnitude and direction of the acceleration of the body.*

Ans. As shown in Fig. 5.125,

$F_1 = 8$ N, $F_2 = 6$ N, $m = 5$ kg

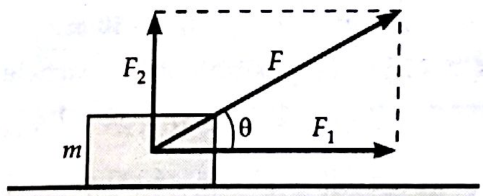

Fig. 5.125

The magnitude of the resultant force,

$$F = \sqrt{F_1^2 + F_2^2} = \sqrt{8^2 + 6^2} = 10\ \text{N}$$

The magnitude of the acceleration produced,

$$a = \frac{F}{m} = \frac{10}{5} = \mathbf{2\ ms^{-2}}.$$

If the force F makes angle θ with F_1, then

$$\cos\theta = \frac{F_1}{F} = \frac{8}{10} = 0.8$$

$\therefore$ $\theta = \cos^{-1}(0.8) = \mathbf{36.87°}$,

with the 8 N force.

5.8. *The driver of a three wheeler moving with a speed of 36 kmh^{-1} sees a child standing in the middle of the road and brings his vehicle to rest in 4 s just in time to save the child.*

What is the average retarding force on the vehicle ? The mass of the three-wheeler is 400 kg and the mass of the driver is 65 kg.

Ans. Here $u = 36\ kmh^{-1} = 10\ ms^{-1},\ v = 0,$

$$t = 4\,s,\ m = 400 + 65 = 465\ kg$$

As $\qquad v = u + at$

$\therefore \qquad 0 = 10 + a \times 4 \quad$ or $\quad a = -2.5\ ms^{-2}$

Magnitude of the retarding force on the vehicle is

$$F = ma = 465 \times 2.5 = \mathbf{1162.5\ N.}$$

5.9. *A rocket with a lift off mass 20,000 kg is blasted upwards with an initial acceleration of 5 ms^{-2}. Calculate the initial thrust of the blast.*

Ans. Initial thrust = upthrust required to impart acceleration a + upthrust required to overcome gravitational pull

$$= ma + mg = m(a + g)$$
$$= 20,000\,(5 + 9.8) = 20,000 \times 14.8\ N$$
$$= \mathbf{2.96 \times 10^5\ N.}$$

5.10. *A body of mass 0.4 kg moving with a constant speed of 10 ms^{-1} to the north is subjected to a constant force of 8 N directed towards the south for 30 s. Take the instant the force is applied to be $t = 0$, the position of the body at that time to be $x = 0$ and predict its position at $t = -5$ s, 25 s and 100 s.*

Ans. We take south to north as the positive direction. Then $u = +10\ ms^{-1}$ (due north), $F = -8$ N (due south), $t = 30$ s, $m = 0.4$ kg

$$a = \frac{F}{m} = \frac{-8}{0.4} = -20\ ms^{-2}$$

(*i*) At $t = -5$s, no force acts on the particle.

$\therefore \qquad x = ut = 10 \times (-5) = \mathbf{-50\ m.}$

(*ii*) At $t = 25$ s, the position of the particle will be

$$x = ut + \frac{1}{2}at^2 = 10 \times 25 - \frac{1}{2} \times 20 \times (25)^2$$
$$= 250 - 6250 = -6000\ m = \mathbf{-6\ km.}$$

(*iii*) At $t = 100$ s, there is no force because force stops acting after $t = 30$ s.

$\therefore$ Distance covered during first 30 s is

$$x_1 = ut + \frac{1}{2}at^2 = 10 \times 30 - \frac{1}{2} \times 20 \times (30)^2$$
$$= -8700\ m$$

Velocity acquired at $t = 30$ s will be

$$v = u + at = 10 - 20 \times 30 = -590\ ms^{-1}$$

Distance covered in next 70 s with constant velocity of $-590\ ms^{-1}$ is

$$x_2 = vt = -590 \times 70 = -41300\ m$$

$\therefore$ Position of the particle at $t = 100$ s is

$$x_1 + x_2 = -8700 - 41300$$
$$= -50,000\ m = \mathbf{-50\ km.}$$

5.11. *A truck starts from rest and accelerates uniformly with 2.0 ms^{-2}. At $t = 10$ s, a stone is dropped by a person standing on the top of the truck (6 m high from the ground). What are the (i) velocity, and (ii) acceleration of the stone at $t = 11$ s ? Neglect air resistance. Take $g = 10\ ms^{-2}$*

Ans. Here $u = 0,\ a = 2\ ms^{-2},\ g = 10\ ms^{-2},\ t = 10$ s.

(*i*) During first 10 s, the horizontal component of the velocity is

$$v_x = u + at = 0 + 2 \times 10 = 20\ ms^{-1}$$

From 10 s to 11 s (*i.e.*, for 1 s), the vertical component of the velocity is

$$v_y = u + gt = 0 + 10 \times 1 = 10\ ms^{-1}$$

$\therefore$ Resultant velocity,

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(20)^2 + (10)^2} = 10\sqrt{5} = \mathbf{22.4\ ms^{-1}}$$

The direction of resultant velocity with the horizontal is given by

$$\tan\theta = \frac{v_y}{v_x} = \frac{10}{20} = \frac{1}{2} \quad \text{or} \quad \theta = \tan^{-1}(1/2) = \mathbf{26.7°.}$$

(*ii*) As there is no horizontal acceleration, the only acceleration is vertical.

$\therefore$ Vertically downward acceleration = g = **10 ms^{-2}.**

5.12 *A bob of mass 0.1 kg hung from the ceiling of a room by a string 2 m long is set into oscillation. The speed of the bob at its mean position is 1 ms^{-1}. What is the trajectory of the bob if the string is cut when the bob is (a) at one of its extreme positions, (b) at its mean position ?*

Ans.

(*a*) At the extreme position the speed of bob is zero. The bob is momentarily at rest. If the string is cut, the bob will fall vertically downwards.

(*b*) At the mean position, the bob has a horizontal velocity. If the string is cut, it will fall along a parabolic path under the effect of gravity.

5.13. *A man weighs 70 kg. He stands on a weighing machine in a lift, which is moving*

(*i*) *upwards with a uniform speed of 10 ms^{-1}.*

(*ii*) *downwards with a uniform acceleration of 5 ms^{-2}.*

(*iii*) *upwards with a uniform acceleration of 5 ms^{-2}.*

What would be the readings on the scale in each case ? What would be the reading, if the lift mechanism failed and it came down freely under gravity ? **[Delhi 05C ; Central Schools 08]**

Ans. The apparent weight measured by the weighing machine is the measure of the reaction R exerted on the man due to the lift.

(*i*) When the lift moves upward with uniform velocity, reaction of the lift is equal to the weight of the man.

$\therefore$ Apparent weight,

$$R = mg = 70 \times 9.8 = \mathbf{686\ N = 70\ kg\ wt}$$

(*ii*) When the lift moves downwards with uniform acceleration,

$$a = 5\ ms^{-2}$$

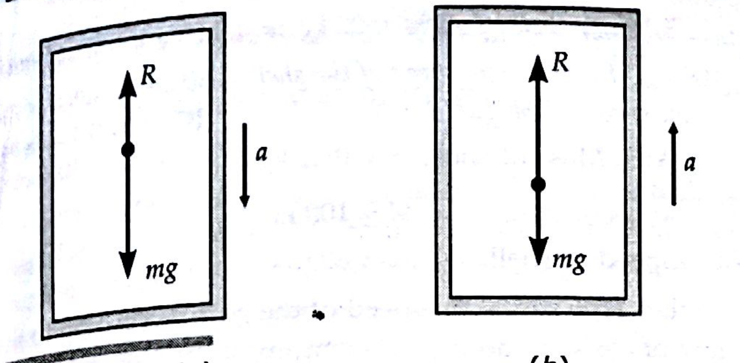

Fig. 5.126 (a) (b)

Resultant downward force,

$$F = mg - R \quad \text{or} \quad ma = mg - R$$

$\therefore$ Apparent weight,

$$R = m(g - a) = 70\,(9.8 - 5)$$

$$= 70 \times 4.8 = \mathbf{336\ N} = \mathbf{34.29\ kg\ wt.}$$

(*iii*) When the lift moves upwards with uniform acceleration, $a = 5\ \text{ms}^{-2}$

Resultant upward force,

$$F = R - mg \quad \text{or} \quad ma = R - mg$$

$\therefore$ Apparent weight,

$$R = m(g + a) = 70\,(9.8 + 5)$$

$$= 70 \times 14.8 = 1036\ \text{N} = \mathbf{105.7\ kg\ wt.}$$

When the lift falls freely under gravity, $a = g$

$\therefore$ Apparent weight, $R = m(g - a) = m(g - g) = 0$

This is the condition of weightlessness.

5.14. *Fig. 5.127 shows the position-time graph of a particle of mass 4 kg. What is the (i) force acting on the particle for $t < 0, t >> 4$ s, $0 < t < 4$ s ? (ii) impulse at $t = 0$ and $t = 4$ s ? Assume that the motion is one dimensional.* **[Delhi 09]**

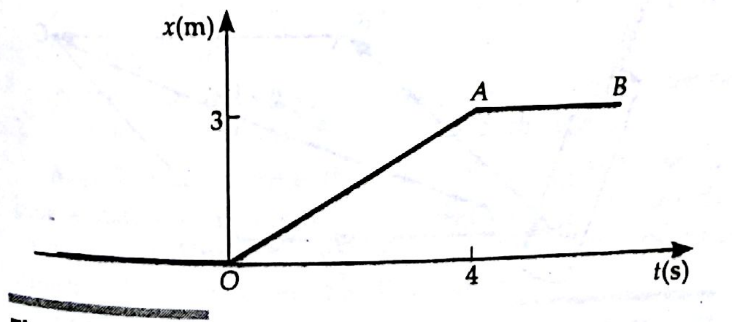

Fig. 5.127

Ans. (*i*) For $t < 0$ and $t > 4$ s, the position of the particle is not changing *i.e.* the particle is at rest. So no force is acting on the particle during these intervals.

For $0 < t < 4$ s, the position of the particle is continuously changing. As the position-time graph is a straight line, the motion of the particle is uniform, so acceleration, $a = 0$. Hence no force acts on the particle during this interval also.

(*ii*) Before $t = 0$, the particle is at rest, so $u = 0$

After $t = 0$, the particle has a constant velocity,

$$v = \text{Slope of } OA = \frac{3}{4}\ \text{ms}^{-1}$$

$\therefore$ At $t = 0$,

Impulse = Change in momentum

$$= m(v - u) = 4\left(\frac{3}{4} - 0\right) = \mathbf{3\ kg\ ms^{-1}}.$$

Before $t = 4$ s, the particle has a constant velocity,

$$u = \text{Slope of } OA = \frac{3}{4}\ \text{ms}^{-1}$$

After $t = 4$ s, the particle is at rest, so $v = 0$

At $t = 4$ s,

$$\text{Impulse} = m(v - u) = 4\left(0 - \frac{3}{4}\right) = \mathbf{-3\ kg\ ms^{-1}}.$$

5.15. *Two bodies of masses 10 kg and 20 kg respectively kept on a smooth, horizontal surface are tied to the ends of a light string. A horizontal force F = 600 N is applied to (i) B (ii) A along the direction of string. What is the tension in the string in each case ?* **[Central Schools 04, 09]**

Ans. Here $F = 600$ N, $m_1 = 10$ kg, $m_2 = 20$ kg

Let T be the tension in the string and a be the acceleration produced in the system, in the direction of applied force F. Then

$$a = \frac{F}{m_1 + m_2} = \frac{600}{10 + 20} = 20\ \text{ms}^{-2}.$$

(*i*) Suppose the pull F is applied on the body B of mass 20 kg, as shown in Fig. 5.128(*a*).

Let T_1 be the tension in the string. As T_1 is the only force acting on mass 10 kg, so

$$T_1 = m_1 a = 10 \times 20 = \mathbf{200\ N.}$$

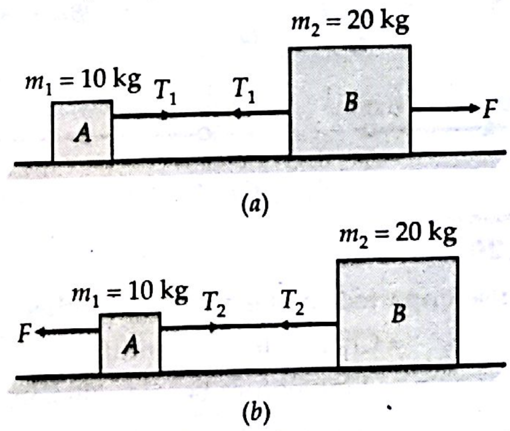

Fig. 5.128

(*ii*) When the pull F is applied on body A of mass 10 kg [Fig. 5.128(*b*)], tension in the string will be

$$T_2 = m_2 a = 20 \times 20 = \mathbf{400\ N.}$$

Clearly, the tension depends on which mass end the pull is applied.

5.16. *Two masses 8 kg and 12 kg are connected at the two ends of a light inextensible string that goes over a frictionless pulley. Find the acceleration of the masses and the tension in the string when the masses are released.* **[Delhi 10]**

Ans. Here $m = 8$ kg, $M = 12$ kg, $g = 10\ \text{ms}^{-2}$

From the derivation of connected motion in Q.45 on page 5.31, we have

$$a = \frac{M-m}{M+m}\cdot g = \frac{12-8}{12+8} \times 10 = \mathbf{2\ ms^{-2}}$$

$$T = \frac{2\,Mm}{M+m}\cdot g = \frac{2\times 12\times 8}{12+8} \times 10 = \mathbf{96\ N.}$$

5.17. *A nucleus is at rest in the laboratory frame of reference. Show that if it disintegrates into two smaller nuclei, the products must move in opposite directions.*

Ans. Let M be the mass of the nucleus at rest. Suppose it disintegrates into two smaller nuclei of masses m_1 and m_2 which move with velocities v_1 and v_2 respectively.

$\therefore$ Momentum before disintegration $= M \times 0 = 0$

Momentum after disintegration $= m_1 v_1 + m_2 v_2$

According to the law of conservation of momentum,

$$m_1 v_1 + m_2 v_2 = 0 \quad \text{or} \quad v_2 = -\frac{m_1}{m_2}\cdot v_1$$

As masses m_1 and m_2 cannot be negative, the above equation shows that v_1 and v_2 must have opposite signs *i.e.* the two products must move in opposite directions.

5.18. *Two billiard balls each of mass 0.05 kg moving in opposite directions with speed of 6 ms^{-1} collide and rebound with the same speed. What is the impulse imparted to each ball by the other ?*

Ans. Fig. 5.129(*a*) and 5.129(*b*) show the situations of the two balls before and after the collision.

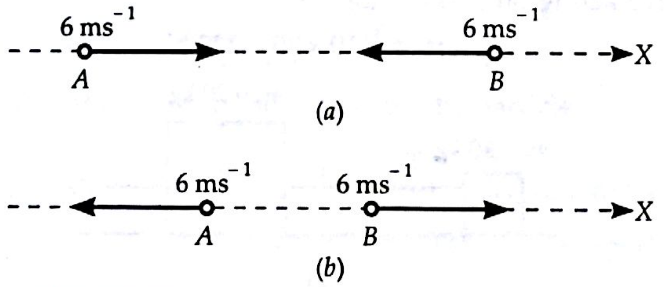

Fig. 5.129

Impulse imparted to one ball by the other

= Change in momentum.

For ball A : p_i = Momentum before collision

$= 0.05 \times 6 = 0.3$ kg ms^{-1}

p_f = Momentum after collision

$= 0.05 \times (-6) = -0.3$ kg ms^{-1}.

$\therefore$ Impulse imparted to ball A due to ball B

$= p_f - p_i = -0.3 - 0.3 = \mathbf{-0.6\ kg\ ms^{-1}}$.

For ball B : p_i = Momentum before collision

$= 0.05 \times (-6) = -0.3$ kg ms^{-1}

p_f = Momentum after collision

$= 0.05 \times (6) = 0.3$ kg ms^{-1}

$\therefore$ Impulse imparted to ball B due to ball A

$= p_f - p_i = 0.3 - (-0.3) = \mathbf{0.6\ kg\ ms^{-1}}$.

5.19. *A shell of mass 0.02 kg is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 ms^{-1}, what is the recoil speed of the gun ?* **[Central Schools 14]**

Ans. Mass of shell, $m = 0.02$ kg

Mass of gun, $M = 100$ kg

Speed of shell, $v = 80$ ms^{-1}

Let V be the recoil speed of the gun. According to the law of conservation of momentum,

Initial momentum = Final momentum

or $0 = mv + MV$

$$\therefore \quad V = -\frac{mv}{M} = -\frac{0.02 \times 80}{100} = \mathbf{-0.016\ ms^{-1}}.$$

Negative sign indicates that the gun moves backward as the bullet moves forward.

5.20. *A batsman deflects a ball by an angle of 45° without changing its initial speed which is equal to 54 kmh^{-1}. What is the impulse imparted to the ball ? Mass of the ball is 0.15 kg.*

Ans. Speed of the ball $= 54$ kmh^{-1} $= 15$ ms^{-1}

Let $\vec{v}_1$ and $\vec{v}_2$ be the velocities of the ball before and after deflection.

As the speed of the ball remains unchanged even after deflection, so

$$|\vec{v}_1| = |\vec{v}_2| = 15\ \text{ms}^{-1}$$

In Fig. 5.130, $\vec{AO} = \vec{v}_1$ and $\vec{OB} = \vec{v}_2$. Clearly, the change in velocity of the ball is

$$\vec{v}_2 - \vec{v}_1 = \vec{v}_2 + (-\vec{v}_1) = \vec{OB} + \vec{BC} = \vec{OC} = \vec{v}\ \text{(say)}$$

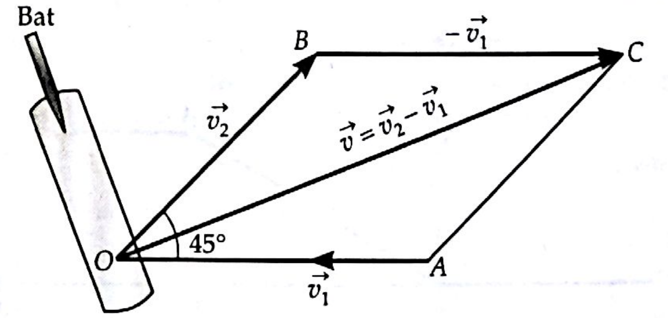

Fig. 5.130

Then $v = \sqrt{v_1^2 + v_2^2 + 2v_1 v_2 \cos 45°}$

$= \sqrt{(15)^2 + (15)^2 + 2 \times 15 \times 15 \times (1/\sqrt{2})}$

$= \sqrt{225 + 225 + 225\sqrt{2}} = 27.72$ ms^{-1}

Impulse imparted to the ball

= Mass × Change in velocity of the ball

$= 0.15 \times 27.72 = 4.16$ kg ms^{-1}

Impulse is imparted along $\vec{v}$. As the velocity $\vec{v}$ is the resultant of two velocities $-\vec{v}_1$, and $\vec{v}_2$, which have equal magnitude, so $\vec{v}$ equally divides the angle between $\vec{v}_1$ and $\vec{v}_2$ *i.e.* impulse is directed along the bisector of initial and final directions.

5.21. *A stone of 0.25 kg tied to the end of a string is whirled round in a circle of radius 1.5 m with a speed of 40 rev./min in a horizontal plane. What is the tension in the string ? What is the maximum speed with which the stone can be whirled around if the string can withstand a maximum tension of 200 N ?* **[Chandigarh 04 ; Central Schools 14]**

Ans. (*i*) Here $m = 0.25$ kg, $r = 1.5$ m

$$\nu = 40 \text{ rev min}^{-1} = 40 \text{ rev } (60\text{ s})^{-1} = \frac{2}{3} \text{ rps}$$

$$\omega = 2\pi\nu = 2\pi \times \frac{2}{3} = \frac{4\pi}{3} \text{ rad s}^{-1}$$

Tension in the string = Centripetal force

or $$T = mr\,\omega^2 = 0.25 \times 1.5 \times \left(\frac{4\pi}{3}\right)^2 = \mathbf{6.6\ N.}$$

(*i*) Given $T_{max} = 200$ N

As $$\frac{mv_{max}^2}{r} = T_{max}$$

$$\therefore \quad v_{max} = \sqrt{\frac{T_{max} \times r}{m}} = \sqrt{\frac{200 \times 1.5}{0.25}} = \mathbf{34.6\ ms^{-1}}.$$

5.22. *A stone tied to the end of string is whirled round in a circle in a horizontal plane. If the speed of the stone is increased beyond the maximum permissible value, and the string breaks suddenly, which of the following correctly describes the trajectory of the stone after the string breaks :*

(*a*) *the stone jerks radially outwards,*

(*b*) *the stone flies off tangentially from the instant the string breaks,*

(*c*) *the stone flies off at an angle with the tangent whose magnitude depends on the speed of the particle ?*

Ans. The alternative (*b*) is correct. When the string breaks, the stone flies off tangentially from the instant, the string breaks. This is because the velocity at any point is directed along the tangent at that point.

5.23. *Explain why*

(*a*) *a horse cannot pull a cart and run in empty space,*

(*b*) *passengers are thrown forward from their seats when a speeding bus stops suddenly,*

(*c*) *it is easier to pull a lawn mower than to push it,*

(*d*) *a cricketer moves his hands backwards while holding a catch.* **[Chandigarh 09; Central Schools 13, 14]**

Ans. (*a*) For pulling a cart or for running, the horse pushes the earth with its feet and reaction of the earth makes it move in the forward direction. Since in empty space there is no reaction force, therefore the horse cannot run in empty space.

(*b*) Refer to solution of Problem 7 on page 5.62.

(*c*) Refer to Figs. 5.96 and 5.97. A lawn mower is pulled or pushed by applying force at an angle. The vertical component of the applied force reduces the effective weight of the mower in case of pull and increases the effective weight in case of push. Consequently, the normal reaction and hence the force of friction is less in case of pull than that in push. Hence it is easier to pull a lawn mower than to push it.

(*d*) When the ball is caught, the impulse received by the hands is equal to the product of the force exerted by the ball and the time taken to complete the catch. By moving the hands backwards, the cricketer increases the time of catch. The force exerted on his hands becomes much smaller and it does not hurt him.

5.24. *Fig. 5.131 below shows the position-time graph of a particle of mass 0.04 kg. Suggest a suitable physical context for this motion. What is the time between two consecutive impulses received by the particle ? What is the magnitude of each impulse ?*

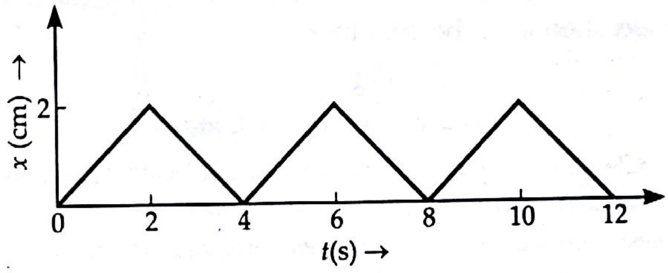

Fig. 5.131

Ans. Fig. 5.131 shows that (*i*) the direction of motion of the particle changes after every 2 s and (*ii*) in both directions, the particle moves with a uniform speed.

Before $t = 2$ s, velocity of the particle,

$$u = \text{Slope of } x\text{-}t \text{ graph}$$
$$= \frac{(2-0)\text{ cm}}{(2-0)\text{ s}} = 1\text{ cms}^{-1} = 0.01\text{ ms}^{-1}$$

After $t = 2$ s, velocity of the particle,

$$v = \frac{(0-2)\text{ cm}}{(4-2)\text{ s}} = -1\text{ cms}^{-1} = -0.01\text{ ms}^{-1}$$

Mass of particle, $m = 0.04$ kg.

At $t = 2$ s, magnitude of impulse

$$= \text{Change in momentum} = m(u - v)$$
$$= 0.04\,[0.01 - (-0.01)]\text{ kg ms}^{-1}$$
$$= \mathbf{8 \times 10^{-4}\ kg\ ms^{-1}}.$$

The given x-t graph may represent the repeated rebounding of a particle between two walls situated at $x = 0$ and $x = 2$ cm. The particle receives an impulse of 8×10^{-4} kg ms^{-1} after every 2 s.

5.25. *Fig. 5.132 shows a man standing stationary with respect to a horizontal conveyor belt that is accelerating with 1 ms^{-2}. What is the net force on the man ? If the coefficient of static friction between the man's shoes and the belt is 0.2, upto what acceleration of the belt can the man continue to be stationary relative to the belt ? Mass of the man = 65 kg.*

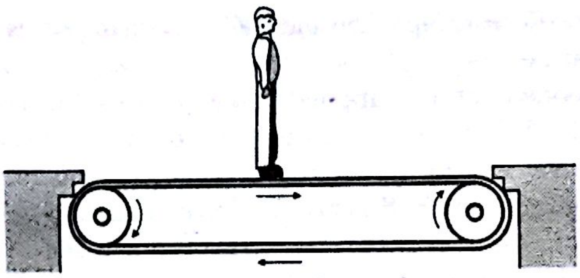

Fig. 5.132

Ans. As the man is standing stationary w.r.t. the belt,

$\therefore$ Acceleration of the man

$= $ Acceleration of the belt $= a = 1\ ms^{-2}$

Mass of the man, $m = 65$ kg

Net force on the man $= ma = 65 \times 1 = $ **65 N.**

Given coefficient of friction, $\mu = 0.2$

$\therefore$ Limiting friction, $f = \mu R = \mu\ mg$

If the man remains stationary w.r.t. the maximum acceleration a' of the belt, then

$$ma' = f = \mu mg$$

$$\therefore \quad a' = \mu\ g = 0.2 \times 9.8 = \mathbf{1.96\ ms^{-2}}.$$

5.26. *A stone of mass m tied to the end of a string is revolved in a vertical circle of radius R. The net forces at the lowest and highest points of the circle directed vertically downwards are :*

Lowest Point	Highest Point
(*i*) $mg - T_1$	$mg + T_2$
(*ii*) $mg + T_1$	$mg - T_2$
(*iii*) $mg + T_1 - (mv_1^2)/R$	$mg - T_2 + (mv_2^2)/R$
(*iv*) $mg - T_1 - (mv_1^2)/R$	$mg + T_2 + (mv_2^2)/R$

Here T_1, T_2 (and v_1, v_2) denote the tension in the string (and the speed of the stone) at the lowest and the highest point respectively. Choose the correct alternative.

Ans. The alternative (*i*) is correct because the net force at the lowest point L is $F_L = mg - T_1$, and the net force at highest point H is $F_H = mg + T_2$.

5.27. *A helicopter of mass 1000 kg rises with a vertical acceleration of 15 ms^{-2}. The crew and the passengers weigh 300 kg. Give the magnitude and direction of*

(*i*) *force on the floor by the crew and passengers.*

(*ii*) *action of the rotor of the helicopter on the surrounding air.*

(*iii*) *force on the helicopter due to the surrounding air.*

Take $g = 10\ ms^{-2}$. **[Delhi 03]**

Ans. Mass of helicopter, $M = 1000$ kg

Mass of the crew and passengers, $m = 300$ kg

Vertically upward acceleration, $a = 15\ ms^{-2}$

(*i*) Force on the floor by the crew and passengers,

$F = $ Apparent weight $= m(g + a)$

$= 300(10 + 15) = $ **7500 N,** vertically downwards.

(*ii*) Action of the rotor of the helicopter on the surrounding air

$= $ Apparent weight of the helicopter, crew and passengers

$= (M + m)(g + a) = (1000 + 300)(10 + 15)$

$= $ **32500 N,** vertically downwards.

(*iii*) Force on the helicopter due to the surrounding air is equal and opposite to the action of the rotor of the helicopter on the surrounding air.

$\therefore$ Force on surrounding air

$= $ **32500 N,** vertically upwards.

5.28. *A stream of water flowing horizontally with a speed of 15 ms^{-1} gushes out of a tube of cross-sectional area 10^{-2} m^2, and hits at a vertical wall nearby. What is the force exerted on the wall by the impact of water, assuming it does not rebound ?*

Ans. Here $u = 15\ ms^{-1}$, $v = 0$, $t = 1$s, $A = 10^{-2}\ m^2$

Density of water $= 1000\ kgm^{-3}$

$m = $ Mass of water gushed out per second

$$= \frac{\text{Volume} \times \text{density}}{\text{Time}} = \frac{\text{Area} \times \text{distance} \times \text{density}}{\text{Time}}$$

$= $ Area $\times$ velocity $\times$ density

$= Au\rho = 10^{-2} \times 15 \times 1000 = 150$ kg

Force exerted by the wall on water,

$$F = ma = m\left(\frac{v-u}{t}\right) = 150 \times \frac{0-15}{1} = -2250 \text{ N}$$

Force exerted on the wall by the impact of water,

$$F' = -F = \mathbf{2250\ N}.$$

5.29. *Ten one-rupee coins are put on top of each other on a table. Each coin has a mass m kg. Give the magnitude and direction of*

(*i*) *the force on the 7th coin (counted from the bottom) due to all the coins on its top.*

(*ii*) *the force on the 7th coin by the eighth coin.*

(*iii*) *the reaction of the 6th coin on the 7th coin.*

[Central Schools 09]

Ans. (*i*) Force on the 7th coin

$= $ Force due to 3 coins on its top $= \mathbf{3}\boldsymbol{mg}$.

(*ii*) Force on the 7th coin by the 8th coin

$= $ Masses of 8th, 9th and 10th coins $\times g = \mathbf{3}\boldsymbol{mg}$

(*iii*) Reaction of the 6th coin on the 7th coin

$= $ Force on the 6th coin due to 7th coin $= \mathbf{4}\boldsymbol{mg}$.

5.30. *An aircraft executes a horizontal loop at a speed of 720 kmh^{-1} with its wings banked at 15°. What is the radius of the loop ?* **[Central Schools 07]**

Ans. Here $\theta = 15°$, $g = 9.8\ ms^{-2}$

$$v = 720\ kmh^{-1} = \frac{720 \times 5}{18} = 200\ ms^{-1}$$

As $\quad \tan\theta = \dfrac{v^2}{rg}$

$$\therefore \quad r = \frac{v^2}{g \tan \theta} = \frac{200 \times 200}{9.8 \times \tan 15°}$$

$$= \frac{200 \times 200}{9.8 \times 0.2679} = 15.24 \times 10^3 \text{ m} = \mathbf{15.24\ km.}$$

5.31. *A train runs along an unbanked circular track of radius 30 m at a speed of 54 kmh^{-1}. The mass of the train is 10^6 kg. What provides the centripetal force required for this purpose ? The engine or the rails ? The outer or the inner rail ? Which rail will wear out faster, the outer or the inner rail ? What is the angle of banking required to prevent wearing out of the rails ?*

Ans. Here

$$r = 30 \text{ m}, \ v = 54 \text{ kmh}^{-1} = 15 \text{ ms}^{-1}, \ m = 10^6 \text{ kg}$$

The centripetal force required for the purpose is provided by the lateral thrust *by the outer rail* on the flanges of the wheels. By Newton's third law of motion, the train exerts an equal and opposite thrust on the outer rail, causing its wear and tear.

$$\tan \theta = \frac{v^2}{rg} = \frac{(15)^2}{30 \times 9.8} = 0.7653$$

$\therefore$ Angle of banking, $\theta = \mathbf{37.4°}$.

5.32. *A block of mass 25 kg is raised by a 50 kg man in two different ways as shown in Fig. 5.133. What is the action on the floor by the man in the two cases ? If the floor yields to a normal force of 700 N, which mode should the man adopt to lift the block without the floor yielding ?*

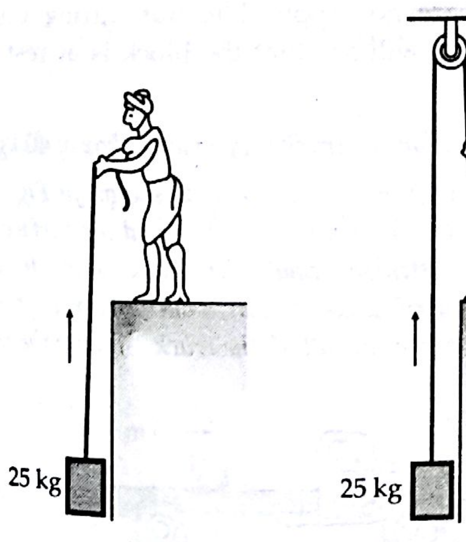

Fig. 5.133

Ans. In mode (*a*), the man applies force equal to 25 kg wt in the upward direction. According to Newton's third law of motion, there will be a downward force of reaction on the floor.

$\therefore$ Total action on the floor by the man

$$= 50 \text{ kg wt} + 25 \text{ kg wt} = 75 \text{ kg wt}$$

$$= 75 \times 9.8 \text{ N} = \mathbf{735\ N.}$$

In mode (*b*), the man applies a downward force equal to 25 kg wt. According to Newton's third law, the reaction will be in the upward direction.

$\therefore$ Total action on the floor by the man

$$= 50 \text{ kg wt} - 25 \text{ kg wt} = 25 \text{ kg wt} = 25 \times 9.8 \text{ N} = \mathbf{245\ N.}$$

As the floor yields to a downward force of 700 N, so the man should adopt mode (*b*).

5.33. *A monkey of mass 40 kg climbes on a rope which can stand a maximum tension of 600 N [Fig. 5.134]. In which of the following cases will the rope break : the monkey*

(*i*) *climbs up with an acceleration of 6 ms^{-2}*

(*ii*) *climbs down with an acceleration of 4 ms^{-2}*

(*iii*) *climbs up with a uniform speed of 5 ms^{-1}*

(*iv*) *falls down the rope nearly freely under gravity ?*

Take $g = 10$ ms^{-2}. Ignore the mass of the rope.

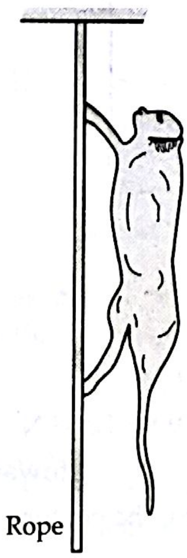

Fig. 5.134

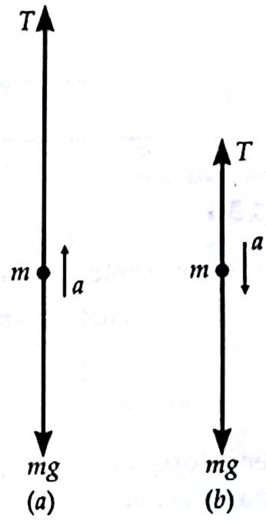

Fig. 5.135

Ans. (*i*) When the monkey climbs up with an acceleration $a = 6$ ms^{-2}, the tension T in the string must be greater than the weight of the monkey [Fig. 5.135(*a*)],

$$T - mg = ma$$

or $$T = m(g + a) = 40\,(10 + 6) = \mathbf{640\ N.}$$

(*ii*) When the monkey climbs down with an acce- leration,

$$a = 4 \text{ ms}^{-2} \text{ [Fig. 5.135(}b\text{)]},$$

$$mg - T = ma$$

or $$T = m(g - a) = 40\,(10 - 4) = \mathbf{240\ N.}$$

(*iii*) When the monkey climbs up with uniform speed,

$$T = mg = 40 \times 10 = \mathbf{400\ N.}$$

(*iv*) When the monkey falls down the rope nearly freely, $a = g$

$$\therefore \quad T = m(g - a) = m(g - g) = \mathbf{0.}$$

As the tension in the rope in case (*i*) is greater than the maximum permissible tension (600 N), so the rope will break in case (*i*) only.

5.34. *Two bodies A and B of masses 5 kg and 10 kg in contact with each other rest on a table against a rigid partition. The coefficient of friction between the bodies and the table is 0.15. A force of 200 N is applied horizontally at A. What are (i) the reaction of the partition (ii) the action-reaction forces between A and B ? What happens when the partition is removed ? Does answers to (ii) change, when the bodies are in motion ? Ignore difference between μ_s and μ_k.*

Ans. Mass of body A,

$$m_A = 5 \text{ kg}$$

Mass of body B,

$$m_B = 10 \text{ kg}$$

Coefficient of friction,

$$\mu = 0.15$$

Applied force, $P = 200$ N

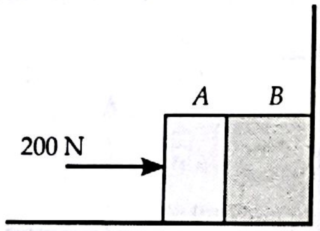

Fig. 5.136

(*i*) Force of limiting friction is

$$f = \mu R = \mu\,(m_1 + \mu_2)\,g$$

$$= 0.15 \times (5 + 10) \times 9.8 = 22.05 \text{ N}$$

(towards left)

When a force of 200 N is applied, the net force exerted on the partition is

$$P' = P - f = 200 - 22.05 = 177.95 \text{ N}$$

(towards right)

Reaction of the partition = **177.95 N** (towards left)

(*ii*) Force of limiting friction on body A is

$$f_1 = \mu m_1 g = 0.15 \times 5 \times 9.8 = 7.35 \text{ N}$$

Net force exerted by body A on body B is

$$P_1 = P - f_1 = 200 - 7.35 = \mathbf{192.65\ N}$$

(towards right)

Reaction of body B on A = **192.65 N** (towards left)

When the partition is removed. The system of the two bodies moves under the action of the net force,

$$P' = 177.95 \text{ N}$$

Acceleration produced in the system,

$$a = \frac{P'}{m_1 + m_2} = \frac{177.95}{5 + 10} = \mathbf{11.86\ ms^{-2}}$$

Force producing motion in the body A

$$= m_1\, a = 5 \times 11.86 = 59.3 \text{ N}$$

Net force exerted by A on B after the removal of partition

$$= P_1 - 59.3 = 192.65 - 59.3 = \mathbf{133.35\ N}$$

(towards right)

Reaction of the body B on A = 133.5 N.

(towards left)

5.35. *A block of mass 15 kg is placed on a long trolley. The coefficient of friction between the block and the trolley is 0.18. The trolley accelerates from rest with 0.5 ms^{-2} for 20 s and then moves with uniform velocity. Discuss the motion of the block as viewed by (i) a stationary observer on the ground (ii) an observer moving with the trolley.*

Ans. Mass of block, $m = 15$ kg

$$\mu_s = 0.18,\ a = 0.5 \text{ ms}^{-2},\ t = 20 \text{ s}$$

Maximum value of static friction,

$$f_{ms} = \mu_s R = \mu_s\, mg = 0.18 \times 15 \times 9.8 = 26.46 \text{ N}$$

Force acting on the block during the accelerated motion,

$$F = ma = 15 \times 0.5 = 7.5 \text{ N}$$

As $f_{ms} > F$, so the block does not move. It remains at rest w.r.t. the trolley, even when it is accelerated. When the trolley moves with uniform velocity, acceleration is zero and hence no force is acting on the trolley.

(*i*) The stationary observer will see the accelerated and the uniform motions.

(*ii*) When the observer is in the trolley, he is in an accelerated or non-inertial frame. The laws of motion are not applicable. But during uniform motion he will see that the block is at rest w.r.t. him.

5.36. *The rear side of a truck is open and a box of 40 kg mass is placed 5 m away from the open end as shown in Fig. 5.137. The coefficient of friction between the box and the surface below it is 0.15. On a straight road, the truck starts from rest and accelerates with 2 ms^{-2}. At what distance from the starting point does the box fall off the truck ? Ignore the mass of the box.*

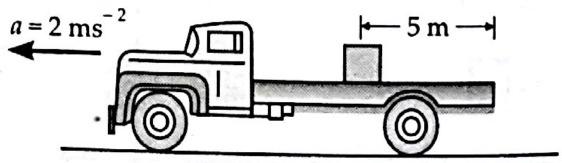

Fig. 5.137

Ans. Mass of box, $m = 40$ kg

Acceleration of truck,

$$a = 2 \text{ ms}^{-2}$$

Distance of the box from the rear end,

$$s = 5 \text{ m}$$

Coefficient of friction,

$$\mu = 0.15$$

As the box is in an accelerated frame, it experiences a backward force,

$$F = ma$$

Motion of the box is opposed by the frictional force,

$$f = \mu R = \mu\ mg$$

$\therefore$ Net force on the box in the backward direction is

$$F' = F - f = ma - \mu\ mg = m(a - \mu\ g)$$

$$= 40(2 - 0.15 \times 9.8) = \mathbf{21.2\ N.}$$

Acceleration produced in the box in the backward direction,

$$a' = \frac{F'}{m} = \frac{21.2}{40} = 0.53\ \text{ms}^{-2}$$

If the box takes time t to fall off the truck, then

$$s = ut + \frac{1}{2}a't^2 \text{ or } 5 = 0 \times t + \frac{1}{2} \times 0.53 \times t^2$$

or $$t^2 = \frac{5 \times 2}{0.53} = \frac{10}{0.53}$$

The distance covered by the truck accelerating at $2\ \text{ms}^{-2}$ during this time is

$$s' = \frac{1}{2}at^2 = \frac{1}{2} \times 2 \times \frac{10}{0.53} = \mathbf{18.57\ m.}$$

5.37. *A disc revolves with a speed of $33\frac{1}{3}$ rev min^{-1}, and has a radius of 15 cm. Two coins are placed at 4 cm and 14 cm away from the centre of the disc. If the coefficient of friction between the coins and the disc is 0.15, which of the two coins will revolve with the disc ? Take $g = 9.8\ ms^{-2}$.*

Ans. Here $\nu = 33\frac{1}{3}\ \text{rpm} = \frac{100}{3}\ \text{rpm} = \frac{100}{3 \times 60}\ \text{rps}$

$$\omega = 2\pi\nu = 2 \times \frac{22}{7} \times \frac{100}{3} \times \frac{1}{60} = \frac{220}{63}\ \text{rad s}^{-1}$$

$$r = 15\ \text{cm},\ \mu = 0.15$$

The coin will revolve with the disc if the force of friction is enough to provide the necessary centripetal force,

i.e. $$mr\omega^2 \leq \mu\ mg \quad \text{or} \quad r \leq \frac{\mu\ g}{\omega^2}$$

Now $$\frac{\mu g}{\omega^2} = \frac{0.5 \times 9.8}{\left(\frac{220}{63}\right)^2} = 0.12\ \text{m} = 12\ \text{cm}$$

Thus the coin placed at a distance of 4 cm from the centre of the disc will revolve with the disc.

5.38. *You may have seen in a circus a motorcyclist driving in vertical loops inside a 'death-well' (a hollow spherical chamber with holes, so that the spectators can watch from outside). Explain clearly why the motorcyclist does not drop down when he is at the uppermost point, with no support from below. What is the minimum speed required to perform a vertical loop if the radius of the chamber is 25 m ?*

Ans. At the highest point of the death-well, the normal reaction R of the walls of the chamber acts downwards. The centripetal force is provided by his weight mg and the normal reaction R.

$$\therefore \quad \frac{mv^2}{r} = R + mg$$

The motorcyclist does not fall down due to the balancing of these forces. For minimum speed, at the highest point, $R = 0$, so that

$$\frac{mv_{min}^2}{r} = mg$$

or $$v_{min} = \sqrt{rg} = \sqrt{25 \times 9.8} = \mathbf{15.65\ ms^{-1}}.$$

5.39. *A 70 kg man stands in contact against the wall of a cylindrical drum of radius 3 m rotating about its vertical axis with 200 rev/min. The coefficient of friction between the wall and his clothing is 0.15. What is the minimum rotational speed of the cylinder to enable the man to remain stuck to the wall (without falling) when the floor is suddenly removed ?*

[Central Schools 14]

Ans. Here $r = 3\ \text{m}, \mu = 0.15$,

$$\nu = 200\ \text{rpm} = \frac{200}{60}\ \text{rps}$$

$$\omega = 2\pi\nu = 2 \times \frac{22}{7} \times \frac{200}{60} = \frac{400}{7}\ \text{rad s}^{-1}$$

The horizontal reaction R of the wall on the man provides the necessary centripetal force.

$$R = \frac{mv^2}{r} = mr\omega^2 \qquad [\because v = r\omega]$$

The frictional force f acting vertically upwards balances the weight of the man. The man will remain struck to the wall after the floor is removed, if

$$f \leq \mu R$$

or $$mg \leq \mu mr\omega^2 \qquad [\because f = mg]$$

or $$g \leq \mu r\omega^2 \text{ or } \omega^2 \geq \frac{g}{\mu r}$$

The minimum rotational speed of the cylinder is

$$\omega_{min} = \sqrt{\frac{g}{\mu r}} = \sqrt{\frac{9.8}{0.15 \times 3}} = \sqrt{21.78} = \mathbf{4.7\ rad\ s^{-1}}.$$

5.40. *A thin circular loop of radius R rotates about its vertical diameter with an angular frequency ω. Show that a small bead on the wire remains at its lowermost point for $\omega \leq \sqrt{\frac{g}{R}}$. What is the angle made by the radius vector joining the centre to the bead with the vertical downward direction for $\omega = \sqrt{\frac{2g}{R}}$? Neglect friction.*

Ans. Fig. 5.138 shows the free-body diagram of the bead when the radius vector joining the centre to the bead makes an angle θ with the vertical downward direction. The normal reaction here is equal to the centrifugal force,

i.e., $$N = \frac{mv^2}{R} = m\omega^2 R$$

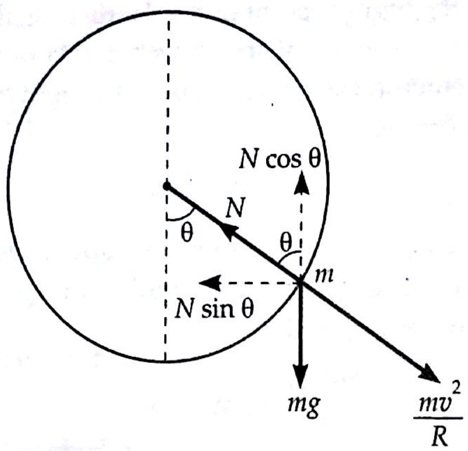

Fig. 5.138

Also $\quad mg = N\cos\theta = m\omega^2 R\cos\theta$

$$\therefore \quad \omega^2 = \frac{g}{R\cos\theta} \quad \text{or} \quad \omega = \sqrt{\frac{g}{R\cos\theta}}$$

For the bead to remain in the lowermost position, $\theta = 0°$ and $\cos\theta = 1$. Hence

$$\omega = \sqrt{\frac{g}{R}}$$

Thus the bead will remain in the lower-most position, if

$$\omega \le \sqrt{\frac{g}{R}}.$$

For $\omega = \sqrt{\frac{2g}{R}}$, we have

$$\cos\theta = \frac{g}{\omega^2 R} = \frac{g}{\frac{2g}{R}\cdot R} = \frac{1}{2}$$

$\therefore \quad \theta = 60°$.