NCERT SOLUTIONS
PHYSICS XI CLASS
CHAPTER - 5
LAWS OF MOTION

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,
(c) a kite skillfully held stationary in the sky,
(d) a car moving with a constant velocity of 30 km/h on a rough road,
(e) a high-speed electron in space far from all material objects, and free of electric and magnetic fields.

Sol. (a) Zero net force
The rain drop is falling with a constant speed. Hence, it acceleration is zero. As per Newton's second law of motion, the net force acting on the rain drop is zero.
(b) Zero net force
The weight of the cork is acting downward. It is balanced by the buoyant force exerted by the water in the upward direction. Hence, no net force is acting on the floating cork.
(c) Zero net force
The kite is stationary in the sky, i.e., it is not moving at all. Hence, as per Newton's first law of motion, no net force is acting on the kite.
(d) Zero net force
The car is moving on a rough road with a constant velocity. Hence, its acceleration is zero. As per Newton's second law of motion, no net force is acting on the car.
(e) Zero net force
The high speed electron is free from the influence of all fields. Hence, no net force is acting on the electron.

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,
(a) during its upward motion,
(b) during its downward motion,
(c) at the highest point where it is momentarily at rest. Do your answers change if the pebble was thrown at an angle of 45° with the horizontal direction? Ignore air resistance.

Sol. Here m = 0.05 kg, g = 10 m/s^2.
(i) During its upward motion, net force on pebble
F = mg = 0.05 × 10 = 0.5 N (vertically downwards)
(ii) During its downward motion, net force on the pebble
F = mg = 0.05 × 10 = 0.5 N (vertically downwards)
(iii) At the highest point also, net force on the pebble = 0.05 × 10 = 0.5 N (vertically downwards)
The answer 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 mass 0.1 kg,
(a) just after it is dropped from the window of a stationary train,
(b) just after it is dropped from the window of a train running at a constant velocity of 36 km/h,
(c) just after it is dropped from the window of a train accelerating with 1 ms^{-2},
(d) lying on the floor of a train which is accelerating with 1 ms^{-2}, the stone being at rest relative to the train.

Sol. (a) 1 N; vertically downward
Mass of the stone, m = 0.1 kg

Acceleration of the stone, $a = g = 10\ m/s^2$

As per Newton's second law of motion, the net force acting on the stone,

$$F = ma = mg = 0.1 \times 10 = 1\ N$$

Acceleration due to gravity always acts in the downward direction.

(b) 1 N; vertically downward

The train is moving with a constant velocity. Hence, its acceleration is zero in the direction of its motion, i.e., in the horizontal direction. Hence, no force is acting on the stone in the horizontal direction.

The net force acting on the stone is because of acceleration due to gravity and it always acts vertically downward. The magnitude of this force is 1 N.

(c) 1 N; vertically downward

It is given that the train is accelerating at the rate of $1\ m/s^2$.

Therefore, the net force acting on the stone, $F' = ma = 0.1 \times 1 = 0.1\ N$

This force is acting in the horizontal direction. Now, when the stone is dropped, the horizontal force F,' stops acting on the stone. This is because of the fact that the force acting on a body at an instant depends on the situation at that instant and not on earlier situations.

Therefore, the net force acting on the stone is given only by acceleration due to gravity.

$$F = mg = 1\ N$$

This force acts vertically downward.

(d) 0.1 N; in the direction of motion of the train

The weight of the stone is balanced by the normal reaction of the floor. The only acceleration is provided by the horizontal motion of the train.

Acceleration of the train, $a = 0.1\ m/s^2$

The net force acting on the stone will be in the direction of motion of the train. Its magnitude is given by: $F = ma = 0.1 \times 1 = 0.1\ N$

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) $T - m\frac{v^2}{\ell}$ (iii) $T + m\frac{v^2}{\ell}$ (iv) 0

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

Sol. **(i).** The net force on the particle directed towards the centre is T. This provides necessary centripetal force to the particle to move 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 $15\ m\ s^{-1}$. How long does the body take to stop?

Sol. Here $F = 50N$, $m = 20\ kg$, $u = 15\ m/s$

From formula, $F = ma$

$$a = \frac{F}{m} = \frac{50}{20} = 2.5\ ms^{-2} \text{ (It is retardation)}$$

$$v = u + at$$

$$0 = 15 - 2.5t \quad \text{or} \quad t = 6s$$

5.6 A constant force acting on a body of mass 3.0 kg changes its speed from $2.0\ m\ s^{-1}$ to $3.5\ m\ s^{-1}$ in 25 s. The direction of the motion of the body remains unchanged. What is the magnitude and direction of the force?

Sol. In the direction of motion of the body, Mass of the body, m = 3 kg

Initial speed of the body, u = 2 m/s, Final speed of the body, v = 3.5 m/s

Time, t = 25 s

Using the first equation of motion, the acceleration (a) produced in the body can be calculated as:

$$v = u + at$$

$$\therefore \quad a = \frac{v-u}{t} = \frac{3.5-2}{25} = \frac{1.5}{25} = 0.06\ m/s^2$$

As per Newton's second law of motion, force is given as:

$F = ma = 3 \times 0.06 = 0.18$ N

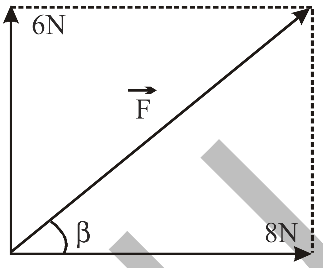
Since the application of force does not change the direction of the body, the net force acting on the body is in the direction of its motion.

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

Sol. In figure, net force, $F = \sqrt{8^2 + 6^2}$ N

or $F = \sqrt{100}$ N $= 10$N

Acceleration, $a = \frac{F}{m} = \frac{10N}{5kg} = 2\ ms^{-2}$



Acceleration is in the direction of the net force.
If the net force makes an angle β with the horizontal, then the acceleration will also make an angle β with the horizontal. This is because the acceleration is always in the direction of force.

Now, $\therefore$

5.8 The driver of a three-wheeler moving with a speed of 36 km/h sees a child standing in the middle of the road and brings his vehicle to rest in 4.0 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 65kg.

Sol. $u = 36$ km/h $= 36 \times \frac{5}{18} ms^{-1} = 10 ms^{-1}$, $v = 0$, $t = 4s$, $F = ?$

Total mass = 400 kg + 65 kg = 465 kg

$v = u + at$

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

Retarding force = 465 kg × 2.5 ms^{-2} = 1162.5 N ≈ 1.2×10^3 N

5.9 A rocket with a lift-off mass 20,000 kg is blasted upwards with an initial acceleration of $5.0 ms^{-2}$. Calculate the initial thrust (force) of the blast.

Sol. $m = 2 \times 10^4$ kg ; $\frac{\Delta v}{\Delta t} = 5ms^{-2}$; $v_r \frac{\Delta m}{\Delta t} = ?$

We know that, $\frac{\Delta v}{\Delta t} = \frac{v_r}{m}\frac{\Delta m}{\Delta t} - g$

$\therefore \quad v_r \frac{\Delta m}{\Delta t} = m\frac{\Delta v}{\Delta t} + mg = 2 \times 10^4 kg \times 5ms^{-2} + 2 \times 10^4 kg \times 9.8ms^{-2}$

$= 10^5$ N + 1.96×10^5 N = 2.96×10^5 N = 3.0×10^5 N

5.10 A body of mass 0.40 kg moving initially with a constant speed of 10 m s^{-1} to the north is subject to a constant force of 8.0 N directed towards the south for 30s. 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= –5s, 25s, 100s.

Sol. Here, u = 10 m/s, F = –8N (South to north is taken as +ve direction)

t = 30s m = 0.40 kg

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

(i) At t = – 5 sec.

$S = ut + \frac{1}{2}at^2 = 10\ (-5) = -50m$

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

$S = 10 \times 25 + \frac{1}{2}(-20)(25 \times 25) = 250 - 6250 = -6000\ m = -6$ km.

(iii) At t = 1000s, the force stops acting after t = 30s.

Distance covered during first 30s

$$S_1 = (10 \times 30) + \frac{1}{2}(-20)(30 \times 30) = 300 - 9000 = -8700 \text{ m}$$

Velocity at the end of 30s

$$v = u + at = 10 + (-20)(30) = -590 \text{ m/s}$$

∴ Distance covered in next 70s

$S_2 = (-590)(70) = -41300$ m

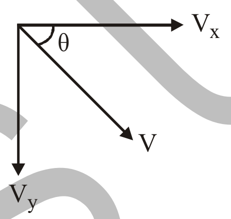
∴ $S = S_1 + S_2 = -8700 - 41300 = -50{,}000 \text{ m} = -50 \text{ km}$

5.11 A truck starts from rest and accelerates uniformly at 2.0ms^{-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 (a) velocity, and (b) acceleration of the stone at t = 11s? (Neglect air resistance.)

Sol. Here, u = 0, a = 2 m/s^2, t = 10s

Using first equation of motion

$v = u + at = 0 + 2 \times 10 = 20$ m/s



(a) When stone is dropped from the top of truck

$u_x = v = 20$ m/s

In vertical direction, u = 0, a = 9.8 m/s^2

t = 11 – 10 = 1 sec.

∴ v = u + at

$v_y = 0 + 9.1 \times 1 = 9.8$ m/s

Resultant velocity of stone $v = \sqrt{v_x^2 + v_y^2} = \sqrt{(20)^2 + (9.8)^2} = 22.3$ m/s

Let v makes angle θ with v_x

$$\therefore \tan\theta = \frac{v_x}{v_y} = \frac{9.8}{20} = 0.49 \qquad \therefore \theta = 29°$$

(b) The stone will be moving with constant acceleration of 9.8 ms^{-2} (vertically downward).

5.12 A bob of mass 0.1 kg hung from the ceiling of a room by a string 2m long is set into oscillation. The speed of the bob at its mean position is 1 m s^{-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.

Sol. (a) When the bob is at extreme position the velocity of the bob in zero. If the string is cut at extreme position, the bob will fall vertically downward.

(b) When the bob is at mean position, it has a velocity 1m/s along the tangent (in horizontal direction). If the string is cut at mean position, the bob will follow a parabolic path.

5.13 A man of mass 70 kg stands on a weighing scale in a lift which is moving

(a) upwards with a uniform speed of 10 m s^{-1},

(b) downwards with a uniform acceleration of 5 ms^{-2},

(c) upwards with a uniform acceleration of 5 m s^{-2}. What would be the readings on the scale in each case?

(d) What would be the reading if the lift mechanism failed and it hurtled down freely under gravity?

Sol. (a) When the lift moves upward with uniform speed, then acceleration is zero and reaction of the lift is equal to the weight of the mass.

Apparent weight = mg = 70 × 9.8 = 686 N

(b) When the lift moves downward with uniform acceleration a then

Apparent weight R = m (g – a) = 70 (9.8 – 5) = 70 × 4.8 N = 336 N

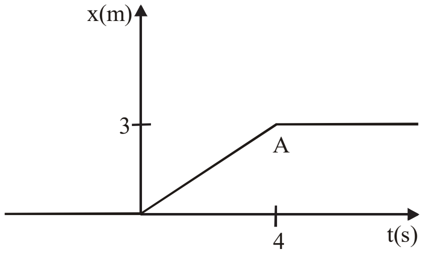
(c) When the lift moves upward with uniform acceleration a then

Apparent weight R = m (g + a) = 70 (9.8 + 5) = 70 × 14.8 N = 1036 N

(d) When the lift falls freely under gravity then a = g

Apparent weight R = m (g – a) = m (g – g) = 0

5.14 Figure shows the position-time graph of a particle of mass 4 kg. What is the (a) force on the particle for t < 0, t > 4 s, 0 < t < 4 s? (b) impulse at t = 0 and t = 4 s ? (Consider one-dimensional motion only).



Sol. (a) **For t < 0**

It can be observed from the given graph that the position of the particle is coincident with the time axis.

It indicates that the displacement of the particle in this time interval is zero. Hence, the force acting on the particle is zero.

For t > 4 s

It can be observed from the given graph that the position of the particle is parallel to the time axis. It indicates that the particle is at rest at a distance of 3 m from the origin. Hence, no force is acting on the particle.

For 0 < t < 4

It can be observed that the given position-time graph has a constant slope. Hence, the acceleration produced in the particle is zero. Therefore, the force acting on the particle is zero.

(b) **At t = 0**

Impulse = Change in momentum = mv – mu

Mass of the particle, m = 4 kg

Initial velocity of the particle, u = 0,

Final velocity of the particle, v = 3/4 m/s

$\therefore$ Impulse = $4\left(\frac{3}{4}-0\right)$ = 3 kg m/s

At t = 4 s

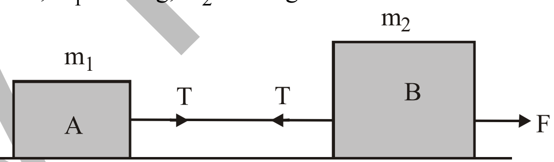
Initial velocity of the particle, u = 3/4 m/s

Final velocity of the particle, v = 0

$\therefore$ Impulse = $4\left(0-\frac{3}{4}\right)$ = – 3 kg m/s

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) A, (ii) B along the direction of string. What is the tension in the string in each case?

Sol. Here, F = 500N, m_1 = 10 kg, m_2 = 20 kg.



Let T be the tension in the string and acceleration in the system is a then

$$a = \frac{F}{m_1 + m_2} = \frac{500}{10+20} = \frac{50}{3} m/s^2$$

(a) When force is applied on body B, $T = m_1 a = 10 \times \frac{50}{3}$ = 166.67 N

(b) When force is applied on body A, $T = m_2 a = 20 \times \frac{50}{3}$ = 333.33 N

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.

Sol. Here m_1 = 12 kg, m_2 = 8 kg.

(a) Acceleration in the system = $\dfrac{m_1 - m_2}{m_1 + m_2} g = \left(\dfrac{12-8}{12+8}\right) 9.8$ = 1.96 m/s^2

Tension in the string, $T = \dfrac{2m_1m_2}{m_1 + m_2} g = \dfrac{2 \times 12 \times 8}{12+8} \times 9.8$ = 94.08 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.

Sol. Let the mass of two parts of nuclei be m and M. They move with velocities $\vec{v}$ and $\vec{V}$.

Applying law of conservation of momentum $m\vec{v} + M\vec{V} = 0$ or $\vec{V} = \dfrac{-m\vec{v}}{M}$

Negative sign shows that the two fragments must fly off in opposite directions.

5.18 Two billiard balls each of mass 0.05 kg moving in opposite directions with speed 6 m/s collide and rebound with the same speed. What is the impulse imparted to each ball due to the other ?

Sol. Initial momentum of 1st ball = mv = 0.05 × 6

P_i = 0.30 kg m/s

When the balls rebounds with the same speed the direction is reversed so final momentum of first ball = 0.05 × (–6)

P_f = – 0.30 kg m/s

Change in momentum = $P_f - P_i$ = (– 0.30) – (0.30) = – 0.60 kg m/s

5.19 A shell of mass 0.020 kg is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 m/s, what is the recoil speed of the gun?

Sol. m = 0.02 kg, M = 100 kg, v = 80 m s^{-1}, V =?

$$V = -\frac{mv}{M} = -\frac{0.20\text{kg} \times 80\text{ms}^{-1}}{100\text{kg}} = -0.016 \text{ ms}^{-1}$$

Negative sign indicates that the gun moves in a direction opposite to the direction of motion of the bullet.

5.20 A batsman deflects a ball by an angle of 45° without changing its initial speed which is equal to 54 km/h. What is the impulse imparted to the ball ? (Mass of the ball is 0.15 kg.

Sol. In figure ∠ AOB = 45°

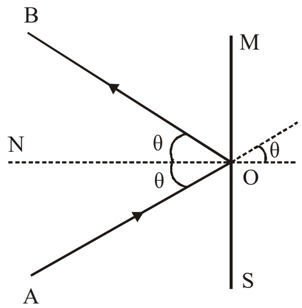
∴ ∠ AON = ∠ BON = 22.5°

Initial velocity along AO has two components

u cos θ along NO (produced) and u sin θ along OM.

Impulse imparted to the ball = change in linear momentum = mu cos θ – (–mu cos θ) = 2mu cos θ

= 2 × 0.15 × 15 cos 22.5° = 4.16 kg m/s



5.21 A stone of mass 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 with stand a maximum tension of 200 N?

Sol. Here m = 0.25 kg, r = 1.5m

$\nu = \dfrac{40}{60} = \dfrac{2}{3}$ rps

From formula, $T = \frac{mu^2}{r} = mr\omega^2 = 0.25 \times 1.5 \left(2\pi \times \frac{2}{3}\right)^2 = 6.6 \text{ N}$

$T_{max} = 200 \text{ N} \quad \therefore \; T_{max} = \frac{mV_{max}^2}{r}$

or $V_{max} = \sqrt{\frac{T_{max}.r}{m}} = \left[\frac{200 \times 1.5}{0.25}\right]^{1/2} = 34.6 \text{ m/s}$

5.22 If, in Q. 5.21, 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 moves 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 ?

Sol. **(b)** When the string breaks, the stone will move in the direction of the velocity at that instant. According to the first law of motion, the direction of velocity vector is tangential to the path of the stone at that instant. Hence, the stone will fly off tangentially from the instant the string breaks.

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,

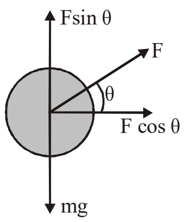
(c) It is easier to pull a lawn mower than to push it,

(d) A cricketer moves his hands backwards while holding a catch.

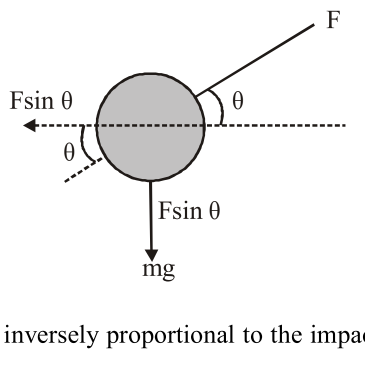
Sol. (a) In order to pull a cart, a horse pushes the ground backward with some force. The ground in turn exerts an equal and opposite reaction force upon the feet of the horse. This reaction force causes the horse to move forward. An empty space is devoid of any such reaction force. Therefore, a horse cannot pull a cart and run in empty space.

(b) When a speeding bus stops suddenly, the lower portion of a passenger's body, which is in contact with the seat, suddenly comes to rest. However, the upper portion tends to remain in motion (as per the first law of motion). As a result, the passenger's upper body is thrown forward in the direction in which the bus was moving.

(c) While pulling a lawn mower, a force at an angle θ is applied on it, as shown in the following figure. The vertical component of this applied force acts upward. This reduces the effective weight of the mower. On the other hand, while pushing a lawn mower, a force at an angle θ is applied on it, as shown in the following figure.



In this case, the vertical component of the applied force acts in the direction of the weight of the mower. This increases the effective weight of the mower.



(d) According to Newton's second law of motion, we have the equation of motion:

$$F = ma = m\frac{\Delta v}{\Delta t} \quad .... (1)$$

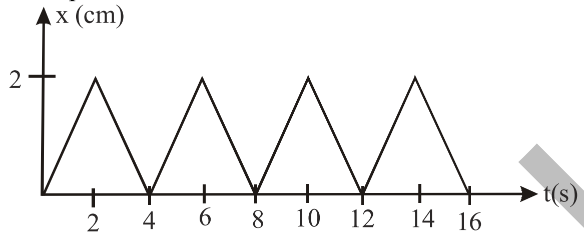
Where, F = Stopping force experienced by the cricketer as he catches the ball, m = Mass of the ball

Δt = Time of impact of the ball with the hand.

It can be inferred from equation (i) that the impact force is inversely proportional to the impact time, i.e., $F \propto 1/\Delta t$ .... (2)

Equation (2) shows that the force experienced by the cricketer decreases if the time of impact increases and vice versa.
While taking a catch, a cricketer moves his hand backward so as to increase the time of impact (Δt).
This is turn results in the decrease in the stopping force, thereby preventing the hands of the cricketer from getting hurt.

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

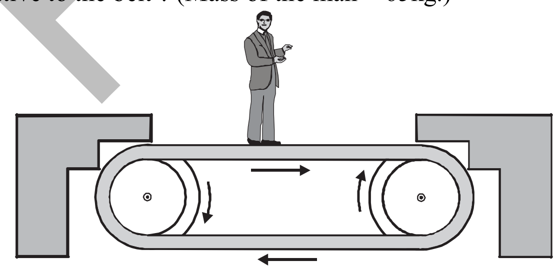


Sol. Following facts are clear from the figure:
(i) The velocity of the particle changes direction after every two second,
(ii) In both the directions, the magnitude of the velocity is same as is given by the slope of the lines OA and AB, and (iii).

The slope shows that the speed = $\frac{2}{2}$ cms^{-1} = 1 cm s^{-1}.

The impulse is change of momentum. At points Like O and A there is a change of momentum. The velocity of the particle changes from 1 cm s^{-1} to – 1cms^{-1}, i.e., by 2 cm s^{-1} or 0.02 m s^{-1}.
Now, impulse = change of momentum = m × change in velocity
= 0.04 kg × 0.02 m/s = 8×10^{-4} kg ms^{-1} (or Ns)
This graph may represent rebounding of a particle between two walls situated at x = 0 and x = 2 cm.
The impulse of magnitude 8×10^{-4} Ns is received by the particle after every two second.

5.25 Figure shows a man standing stationary with respect to a horizontal conveyor belt that is accelerating with 1 m/s^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, up to what acceleration of the belt can the man continue to be stationary relative to the belt ? (Mass of the man = 65kg.)



Sol. Acceleration of belt, a = 1 ms^{-2}.
Coefficient of static friction between man's shoes and belt, $\mu_s = 0.2$
Net force on the man = mass (m) of man × a = 65 kg × 1 ms^{-2}. = 65 N
The direction of this force is opposite to the direction of motion of the belt.
If a' is the acceleration of the belt up to which the man can continue to be stationary relative to the belt, then ma' = maximum value of static friction
or ma' = μ_sR or ma' = $\mu_s$mg or a' = μ_sg
∴ a' = 0.2 × 9.8 ms^{-2} = 1.96 ms^{-2}

5.26 A stone of mass m tied to the end of a string revolves in a vertical circle of radius R. The net forces at the lowest and highest points of the circle directed vertically downwards are :
[Choose the correct alternative]

Lowest Point	**Highest Point**
(a) $mg - T_1$	$mg + T_2$
(b) $mg + T_1$	$mg - T_2$
(c) $mg + T_1 - (mv_1^2)/R$	$mg - T_2 + (mv_1^2)/R$
(d) $mg - T_1 - (mv_1^2)/R$	$mg + T_2 + (mv_1^2)/R$

T_1 and v_1 denote the tension and speed at the lowest point. T_2 and v_2 denote corresponding values at the highest point.

Sol. **(a).** The net force at the lowest point, $F_L = mg - T_1$
and the net force at the highest point is $F_H = mg + T_2$

5.27 A helicopter of mass 1000 kg rises with a vertical acceleration of 15 m s^{-2}. The crew and the passengers weigh 300 kg. Give the magnitude and direction of the (a) force on the floor by the crew and passengers, (b) action of the rotor of the helicopter on the surrounding air, (c) force on the helicopter due to the surrounding air.

Sol. (a) Force on the floor by the crew and passengers = 300 kg (15 ms^{-2} + 10 ms^{-2}) = 7500 N
This force acts downwards.
(b) Action of the rotor of the helicopter on the surrounding air
= (1000 kg + 300 kg) (15ms^{-2}+10 ms^{-2}) =32500 N
It acts downward.
(c) Applying Newton's 3rd law of motion, we find that the force on the helicopter due to the surrounding air of 32500 N 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 a vertical wall nearby. What is the force exerted on the wall by the impact of water, assuming it does not rebound?

Sol. In one second, the distance travelled is equal to the velocity v.
$\therefore$ Volume of water hitting the wall per second, V = av
where a is the cross-sectional area of the tube and v is the speed of water coming out of the tube.
$V = 10^{-2}\ m^2 \times 15\ ms^{-1} = 15 \times 10^{-2}\ m^3\ s^{-1}$
Mass of water hitting the wall per second = $15 \times 10^{-2}\ m^3 \times 10^3\ kg\ s^{-1} = 150\ kg\ s^{-1}$
($\because$ density of water = 1000 kg m^{-3})
Initial momentum of water hitting the wall per second
$= 150\ kg\ s^{-1} \times 15\ ms^{-1} = 2250\ kg\ m\ s^{-2}$ or 2250 N
Final momentum per second = 0
Force exerted by the wall = 0 – 2250 N = – 2250 N
$\therefore$ Force exerted on the wall = – (–2250) N = 2250 N

5.29 Ten one-rupee coins are put on top of each other on a table. Each coin has a mass m. Give the magnitude and direction of
(a) the force on the 7^{th} coin (counted from the bottom) due to all the coins on its top,
(b) the force on the 7^{th} coin by the eighth coin,
(c) the reaction of the 6^{th} coin on the 7^{th} coin.

Sol. (a) The seventh coin shall experience a force equal to the weight of the three coins above the seventh coin. $\therefore$ Force on seventh coin = 3 mg
(b) The 8th coin has to support the weight of the two coins above it. So, the 8th coil shall exert a force F on the 7th coin such that F = weight of 8th coin + weight of two coins above the 8th coin. or F = mg + 2mg = 3 mg
(c) The 6^{th} coin shall experience a force equal to the weight of the 4 coins above the 6^{th} coin. This force is equal to 4 mg. So, the reaction of the 6th coin on the 7th coin is 4mg.

5.30 An aircraft executes a horizontal loop at a speed of 720km/h with its wings banked at 15°. What is the radius of the loop?

Sol. Speed, $v = 720 \text{ km h}^{-1} = \frac{720 \times 1000}{3600} \text{ms}^{-1} = 200 \text{ ms}^{-1}$

$$\tan\theta = \tan 15° = 0.2679$$

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

or $r = \frac{v^2}{g\tan\theta} = \frac{200 \times 200}{9.8 \times 0.2679} \text{m} = 15235.7\text{m} = 15.24 \text{ km}$

5.31 A train runs along an unbanked circular track of radius 30 m at a speed of 54 km/h. The mass of the train is 106 kg. What provides the centripetal force required for this purpose — The engine or the rails ? What is the angle of banking required to prevent wearing out of the rail ?

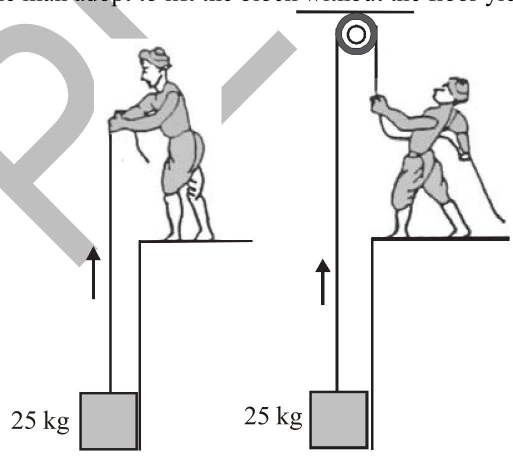
Sol. $r = 30\text{m}, \ m = 10^6 \text{ kg}, \ \theta = ?$

$$v = 54\text{kmh}^{-1} = \frac{54 \times 1000}{3600} = \text{ms}^{-1} = 15\text{ms}^{-1}$$

(i) The centripetal force is provided by the lateral thrust by the outer rail on the flanges of the wheel of the train. The train causes an equal and opposite thrust on the outer rail (Newton's third law of motion). Thus, the outer rail wears out faster.

(ii) $\tan\theta = \frac{v^2}{rg} = \frac{15 \times 15}{30 \times 9.8} = 0.7653 \quad \therefore \quad \theta = \tan^{-1}(0.7653) = 37.43°$

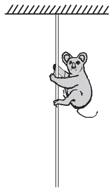
5.32 A block of mass 25 kg is raised by a 50 kg man in two different ways as shown in Figure. What is the action on the floor by the man in the two cases? If the floor yields to a normal force of 700 N, which mode should the man adopt to lift the block without the floor yielding?



(a) (b)

Sol. In mode (a), the man applies an upward force of 25 kg wt. (same as the weight of the block). According to Newton's third law of motion, there will be a downward reaction on the floor.
The action on the floor by the man = 50 kg wt + 25 kg wt = 75 kt wt = 75 × 9.8 N = 735 N
In mode (b), the man applies a downward force of 25 kg wt. According to Newton's third law, the reaction is in the upward direction.
In this case, action on the floor by the man = 50 kg wt – 25 kg wt = 25 kg wt = 25 × 9.8 N = 245 N
Since the floor yields to a downward force of 700 N therefore the man should adopt mode (b).

5.33 A monkey of mass 40 kg climbs on a rope (Fig.) which can stand a maximum tension of 600 N. In which of the following cases will the rope break: the monkey



(a) climbs up with an acceleration of 6 m s^{-2}
(b) climbs down with an acceleration of 4 m s^{-2}
(c) climbs up with a uniform speed of 5 m s^{-1}
(d) falls down the rope nearly freely under gravity? (Ignore the mass of the rope).

Sol. Here m = 40 kg
Maximum tension in the rope = 600 N

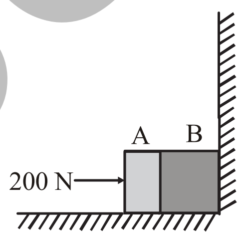
(a) When monkey climbs up with acceleration a = 6 m/s^2,
then R = m (g + a) = 40 (10 + 6) = 640 N
640 > 600 N so rope will break.

(b) When monkey climbs down with a = 4 m/s^2,
R = m (g – a) = 40 (10 – 4) = 240 N
240 < 600 N, the rope will not break.

(c) When monkey climbs up with a uniform speed
v = 5 m/s
a = 0
∴ R = mg = 40 × 10 = 400 N
400 N < 600 N, so rope will not break.

(d) When monkey falls down the rope, freely under gravity than a = g
∴ R = m (g – a) = 0 N
Hence, the rope will not break.

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 wall (Fig). The coefficient of friction between the bodies and the table is 0.15. A force of 200N is applied horizontally to A. What are (a) the reaction of the partition (b) the action-reaction forces between A and B ? What happens when the wall is removed? Does the answer to (b) change, when the bodies are in motion? Ignore the difference between μ_s and μ_k.



Sol. Here, mass of body m = 5 kg, Mass of body B = 10 kg, $\mu = 0.15$
Horizontal force = 200 N

(a) Force of limiting friction acting to he left
f = μ (m + M) g = 0.15 (5 + 10) × 9.8 = 22.05 N
∴ Net force towards right i.e., force exerted on the partition
= F – f = 200 – 22.05 = 177.95 N 178 N
Reaction of partition = 178 N

(b) Force of friction on block A = μ g
f_1 = 0.15 × 5 × 9.8 = 7.35 N
∴ Net force exerted by body A on B
F' = F – f_1 = 200 – 7.35 = 192.65 N (Towards right)
Reaction of body B on body A = 192.65 N (Towards left)
When the partition is removed the system of two bodies moves under the action of net force
F = 178 N

$$\text{Acceleration, } a = \frac{F}{m+M} = \frac{178}{5+10} = 11.87 \text{ ms}^{-2}$$

Force producing motion in body A, F_1 = ma = 5 × 11.87 = 59.3 N
Net force exerted by body A on body B.
When partition is removed = F' – F = 192.5 – 59.3 = 133.35 N
The same will be the reaction of body B on body A, i.e., of 133.5 N towards left.

5.35 A block of mass 15 kg is placed on a long trolley. The coefficient of static friction between the block and the trolley is 0.18. The trolley accelerates from rest with 0.5 m/s^2 for 20 s and then moves with uniform velocity. Discuss the motion of the block as viewed by (a) a stationary observer on the ground, (b) an observer moving with the trolley.

Sol. (a) Mass of the block, m = 15 kg

Coefficient of static friction, $\mu = 0.18$

Acceleration of the trolley, $a = 0.5\ m/s^2$

As per Newton's second law of motion, the force (F) on the block caused by the motion of the trolley is given by the relation: $F = ma = 15 \times 0.5 = 7.5$ N

This force is acted in the direction of motion of the trolley.

Force of static friction between the block and the trolley: $f = \mu\ mg = 0.18 \times 15 \times 10 = 27$ N

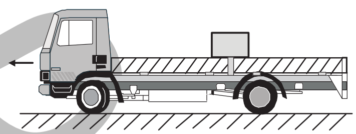
The force of static friction between the block and the trolley is greater than the applied external force. Hence, for an observer on the ground, the block will appear to be at rest.

When the trolley moves with uniform velocity there will be no applied external force.

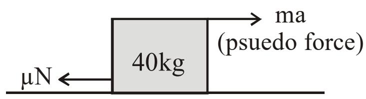
Only the force of friction will act on the block in this situation.

(b) An observer, moving with the trolley, has some acceleration. This is the case of non-inertial frame of reference. The frictional force, acting on the trolley backward, is opposed by a pseudo force of the same magnitude. However, this force acts in the opposite direction. Thus, the trolley will appear to be at rest for the observer moving with the trolley.

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. 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 (i.e. distance travelled by the truck)? [Ignore the size of the box]



Sol. In the reference frame of the truck FBD of 40 kg block



Net force $\Rightarrow$ $ma - \mu N \Rightarrow$ $40 \times 2 - \dfrac{15}{100} \times 40 \times 10$

$ma_{block} \Rightarrow 80 - 60 \Rightarrow a_{block} = \dfrac{20}{40} = \dfrac{1}{2}\ m/s^2$

This acceleration of the block in reference frame of truck so time taken by box to fall down from truck. $S_{rel} = u_{rel}t + \frac{1}{2}a_{rel}t^2 \Rightarrow 5 = 0 + \frac{1}{2} \times \frac{1}{2} \times t^2 \Rightarrow t^2 = 20$

So distance moved by the truck $\Rightarrow$ $\frac{1}{2} \times a_{truck} \times t^2 \Rightarrow \frac{1}{2} \times 2 \times (20) = 20$ meter

5.37 A disc revolves with a speed of $33\frac{1}{3}$ rev/min, and has a radius of 15 cm. Two coins are placed at 4 cm and 14 cm away from the centre of the record. If the co-efficient of friction between the coins and the record is 0.15, which of the coins will revolve with the record?

Sol. The coin will continue to move with the record if frictional force provides the required centripetal force.

Frictional force = μ R = μ mg

$\therefore\ \mu\ mg \geq \dfrac{mv^2}{r} \geq mr\omega^2$ or $\mu\ g \geq r\omega^2$

For first coin: $r = 4\ cm = 4 \times 10^{-2}$ m

$\nu = 33\frac{1}{3}\ rpm = \dfrac{100}{3 \times 60}\ rps$

$\therefore \quad r\omega^2 = r\,(2\pi\,\nu)^2 = 4 \times 10^{-2} \left[2 \times \frac{22}{7} \times \frac{100}{3 \times 60}\right]^2 = 0.49 ms^{-2}$

$\mu\, g = 0.15 \times 9.8 = 1.47\ ms^{-2}$ i.e., $\mu\, g > r\omega^2$

The coin will revolve with the record.

2nd coin : r = 14cm = 0.14m

$\therefore \quad r\omega^2 = 0.14 \left(2 \times \frac{22}{7} \times \frac{100}{3 \times 60}\right)^2 = 1.705\ ms^{-2}$

$\mu\, g = 0.15 \times 9.8 = 1.47\ ms^{-2}$

Since i.e., $\mu\, g < r\omega^2$

The coin will not revolve with the record.

5.38 You may have seen in a circus a motorcyclist driving in vertical loops inside a 'deathwell' (a hollow spherical chamber with holes, so 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 at the uppermost position to perform a vertical loop if the radius of the chamber is 25 m?

Sol. At the uppermost point of the death well, the motor cyclist does not fall because his weight is balanced by the centrifugal force.

At top most point $R + mg = \frac{mv^2}{r}$

For v to be minimum R = 0

$\therefore \quad mg = \frac{mv^2}{r}$ or $v = \sqrt{gr} = \sqrt{10 \times 25} = 15.8\ m/s$

5.39 A 70 kg man stands in contact against the inner wall of a hollow cylindrical drum of radius 3m 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?

Sol. Here, m = 70 kg, r = 3m

$\nu = \frac{200}{60} = \frac{10}{3}$ rps

$\mu = 0.15$

The horizontal force N by the wall on the man provides the necessary centripetal force. The frictional force is in upward direction which balances the weight of man.

The man remains stuck to the wall when

$mg \le f$ or $mg \le \mu N$ where $N = mr\omega^2$

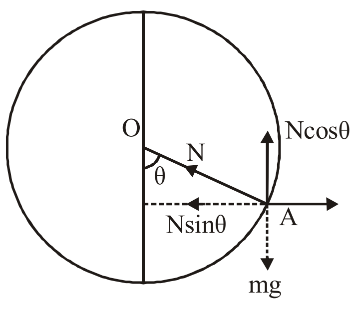
$mg \le \mu\, mr\omega^2$ or $g \le \mu\, r\omega^2$

Minimum angular speed of rotation of the cylinder

$\omega = \sqrt{\frac{g}{\mu r}} = \sqrt{\frac{10}{0.15 \times 3}} = 4.7\ rad/s$

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 loop remains at its lowermost point for $\omega \le \sqrt{g/R}$. What is the angle made by the radius vector joining the centre to the bead with the vertical downward direction for $\omega = \sqrt{2g/R}$? Neglect friction.

Sol. The radius vector joining the bead to the centre of the wire makes an angle θ with vertical as shown in figure.



Let N is normal reaction then

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

$mr\omega^2 = N \sin \theta$

or $m (R \sin \theta) \omega^2 = N \sin \theta$

or $mR\omega^2 = N$ .... (2)

Using eq. (1) and (2)

$mg = mR\omega^2 \cos \theta$

or $\cos \theta = g/R\omega^2$

As $| \cos \theta | \leq 1$ therefore the bead will remain stuck to its lowermost position, provided $\frac{g}{R}\omega^2 \leq 1$

or $\omega \leq \sqrt{\frac{g}{R}}$. If $\omega = \sqrt{\frac{2g}{R}}$; $\cos \theta = \frac{g}{R}\left[\frac{R}{2g}\right] = \frac{1}{2}$ or $\theta = 60°$