CHAPTER 4 LAWS OF MOTION

EXERCISES PAGE:68

Question 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 skilfully 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.

Answer: (a) As the drop of rain is falling with constant speed, in accordance with first law of motion, the net force on the drop of rain is zero.
(b) As the cork is floating on water, its weight is being balanced by the upthrust (equal to.weight of water displaced). Hence net force on the cork is zero.
(c) Net force on a kite skilfully held stationary in sky is zero because it is at rest.
(d) Since car is moving with a constant velocity, the net force on the car is zero.
(e) Since electron is far away from all material agencies producing electromagnetic and gravitational forces, the net force on electron is zero.

Question 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 1 Ignore air resistance.

Answer: (a) When the pebble is moving upward, the acceleration g is acting downward, so the force is acting downward is equal to F = mg = 0.05 kg x 10 ms^{-2} = 0.5 N.
(b) In this case also F = mg = 0.05 x 10 = 0.5 N. (downwards).
(c) The pebble is not at rest at highest point but has horizontal component of velocity. The direction and magnitude of the net force on the pebble will not alter even if it is thrown at 45° because no other acceleration except ‘g’ is acting on pebble.

Question 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 m s~2, the stone being at rest relative to the train. Neglect air resistance throughout.
Answer: (a) Mass of stone = 0.1 kg
Net force, F = mg = 0.1 x 10 = 1.0 N. (vertically downwards).
(b) When the train is running at a constant velocity, its acceleration is zero. No force acts on the stone due to this motion. Therefore, the force on the stone is the same (1.0 N.).
(c) The stone will experience an additional force F' (along horizontal) i.e.,F = ma = 0.1 x l = 0.1 N
As the stone is dropped, the force F' no longer acts and the net force acting on the stone F = mg = 0.1 x 10 = 1.0 N. (vertically downwards).
(d) As the stone is lying on the floor of the train, its acceleration is same as that of the train.
.•. force acting on the stone, F = ma = 0.1 x 1 = 0.1 N.
It acts along the direction of motion of the train.

Question 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 – mv^2/l, (iii) T +mv^2/l, (iv) 0
T is the tension in the string. [Choose the correct alternative].
Answer: (i) T
The net force T on the particle is directed towards the centre. It provides the centripetal force required by the particle to move along a circle.

Question 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^{-3}. How long does the body take to stop?
Answer: Here m = 20 kg, F = – 50 N (retardation force)
As F = ma

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

Using equation, $v = u + at$
Given, $u = 15 \text{ ms}^{-1}, \quad v = 0$
Now, $0 = 15 + (-25)\, t$
or, $t = 6$ s.

Question 6. A constant force acting on a body of mass 3.0 kg changes its speed from 2.0 ms^{-1} to 3.5 ms^{-1} in 25 s. The direction of the motion of the body remains

unchanged. What is the magnitude and direction of the force?
Answer:

Here, $m = 3.0$ kg, $u = 2.0$ ms^{-1}

$v = 3.5$ ms^{-1}, $t = 25$ s

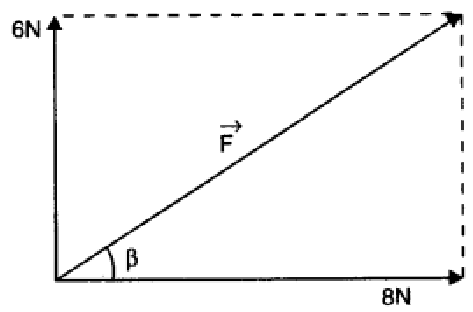
As $F = ma$

or $F = m\left(\frac{v-u}{t}\right)$ $\left[\because a = \frac{v-u}{t}\right]$

$\Rightarrow$ $F = \frac{3.0\,(3.5-2.0)}{25} = 0.18$ N.

The force is along the direction of motion.

Question 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.
Answer:



Here $m = 5$ kg

$F_1 = 8$ N and $F_2 = 6$ N

The resultant force on the body

$F =$

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

$\Rightarrow$ $F = \sqrt{64 + 36}$ N $= 10$ N.

The acceleration, $a = \frac{F}{m}$

$\Rightarrow$ $a = \frac{10}{5} = 2$ ms^{-2} in the same direction as the resultant force.

The direction of acceleration,

$\tan\beta = \frac{6}{8} = \frac{3}{4} = 0.75$

or $\beta = \tan^{-1}(0.75)$

$= 37°$ with 8 N force.

Question 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 65 kg.

Answer: Here mass of three-wheeler mi = 400 kg, mass of driver = m_2 = 65 kg, initial speed of auto, u = 36 km/h = 36 x — m/s 10 ms^{-1}, final speed, v – 0 and t = 4s.

As acceleration, $a = \frac{v-u}{t} = \frac{0-10}{4} = -2.5\ ms^{-2}$

Now $F = (m_1 + m_2)\ a = (400 + 65) \times (-2.5)$

$= -1162.5\ N = -1.2 \times 10^3\ N.$

The $-ve$ sign shows that the force is retarding force.

Question 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.

Answer: Here, m = 20000 kg = 2 x 10^4 kg

Initial acceleration = 5 ms^{-2}

Clearly, the thrust should be such that it overcomes the force of gravity besides giving it an upward acceleration of 5 ms^{-2}.

Thus the force should produce a net acceleration of 9.8 + 5.0 = 14.8 ms^{-2}.

Since, thrust = force = mass x acceleration

F = 2 x 10^4 x 14.8 = 2.96 x 10^5 N.

Question 10. A body of mass 0.40 kg moving initially with a constant speed of 10 ms^{-1} to the north is subject to a constant force of 8.0 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, 100 s.

Answer:

Here $m = 0.40$ kg, $u = 10$ ms^{-1}, $F = -8$ N (retarding force)

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

Also $S = ut + \frac{1}{2}at^2$

(*i*) Position at $t = -5$s

$$S = 10(-5) + \frac{1}{2} \times 0 \times (-5)^2 = -50 \text{ m}$$

(*ii*) Position at $t = 25$ s

$$S_1 = 10 \times 25 + \frac{1}{2} \times (-20) \times (25)^2 = -6000 \text{ m} = -6 \text{ km}$$

(*iii*) Position at $t = 100$ s

$$S_2 = 10 \times 30 + \frac{1}{2} \times (-20) \times (30)^2 = -8700 \text{ m}$$

At $t = 30$ s, $v = u + at$

$$v = 10 - 20 \times 30 = -590 \text{ ms}^{-1}$$

Now, for motion from 30 s to 100 s

$$S_3 = -590 \times 70 + \frac{1}{2}(0) \times (70)^2 = -41300 \text{ m}$$

Total distance $= S_2 + S_3 = -8700 - 41300 = -50000$ m $= -50$ km.

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

Answer: u = 0, a = 2 ms^{-2}, t 10 s

Using equation, v = u + at, we get

v = 0 + 2 x 10 = 20 ms^{-1}

(a) Let us first consider horizontal motion. The only force acting on the stone is force of gravity which acts vertically downwards.

Its horizontal component is zero. Moreover, air resistance is to be neglected. So, horizontal motion is uniform motion.

.-. vx = v = 20 ms^{-1}

Let us now consider vertical motion which is controlled by force of gravity.

u=0, a = g = 10 ms^{-2}, t = (11 — 10) s = 1 s

Using $v = u + at$, $v_y = 0 + 10 \times 1 = 10\ ms^{-1}$

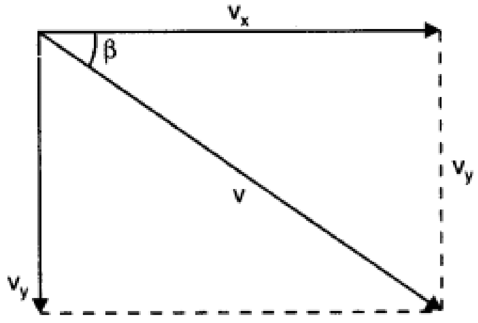
Resultant velocity,

$$v = \sqrt{v_x^2 + v_y^2}$$

$$\Rightarrow v = \sqrt{20^2 + 10^2}\ ms^{-1}$$

$$= \sqrt{500}\ ms^{-1}$$

$$= 22.36\ ms^{-1}.$$



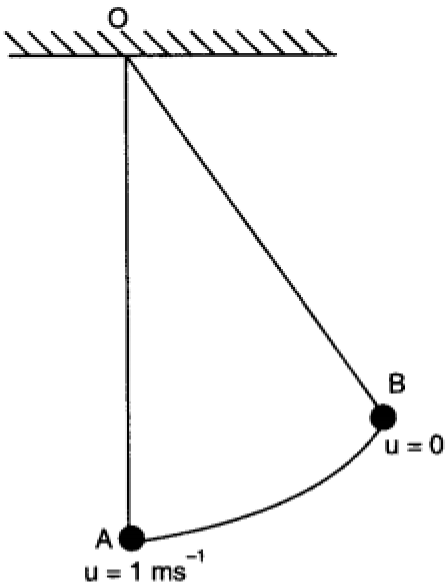
$$\tan\beta = \frac{v_y}{v_x} = \frac{10}{20} = \frac{1}{2} = 0.5$$

or $\beta = \tan^{-1}(0.5) = 26.56°$

or $\beta = 26° 34'$. This angle is with the horizontal.

(b) The moment the stone is dropped from the car, horizontal force on the stone is zero. The only acceleration of the stone is that due to gravity. This gives a vertically downward acceleration of 10 ms-2. This is also the net acceleration of the stone.

Question 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 o its mean position ?



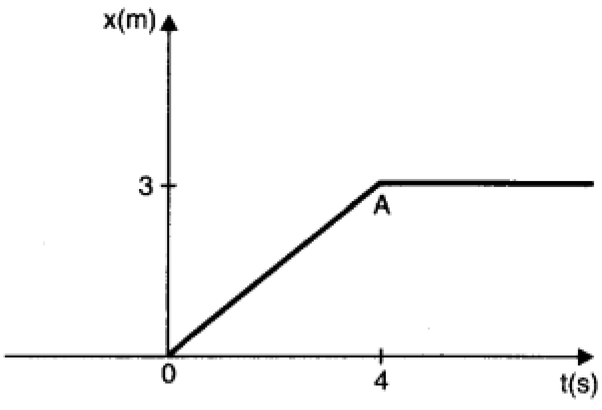
Answer: Let the bob be oscillating as shown in the figure.

(a) When the bob is at its extreme position (say B), then its velocity is zero. Hence on cutting the string the bob will fall vertically downward under the force of its weight F = mg.

(b) When the bob is at its mean position (say A), it has a horizontal velocity of v = 1 ms^{-1} and on cutting the string it will experience an acceleration a = g = 10 ms^{-2} in vertical downward direction. Consequently, the bob will behave like a projectile and will fall on ground after describing a parabolic path.

Question 13. A man of mass 70 kg, stands on a weighing machine in a lift, which is moving
(a) upwards with a uniform speed of 10 ms^{-1}.
(b) downwards with a uniform acceleration of 5 ms^{-2}.
(c) upwards with a uniform acceleration of 5 ms^{-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?
Answer: Here, m = 70 kg, g = 10 m/s^2
The weighing machine in each case measures the reaction R i.e., the apparent weight.
(a) When the lift moves upwards with a uniform speed, its acceleration is zero.
R = mg = 70 x 10 = 700 N
(b) When the lift moves downwards with a = 5 ms^{-2}
R = m (g – a) = 70 (10 – 5) = 350 N
(c) When the lift moves upwards with a = 5 ms^{-2}
R = m (g + a) = 70 (10 + 5) = 1050 N
(d) If the lift were to come down freely under gravity, downward acc. a = g
:. R = m(g -a) = m(g-g) = Zero.

Question 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).



Answer:

(*a*) When $t < 0$. As this part is horizontal, thus it can be concluded that distance covered by the particle is zero and hence force on the particle is zero.

When $0 < t < 4$s. As OA has a constant slope, hence in this interval, particle moves with constant velocity $\left(\frac{3}{4} = 0.75 \text{ ms}^{-1}\right)$. Hence force on the particle is zero.

When $t > 4$s. As this portion shows that particle always remains at a distance of 3 m from the origin *i.e.*, the particle is at rest. Hence force on the particle is zero.

(*b*) Impulse at $t = 0$. Here $u = 0$, $v = 0.75 \text{ ms}^{-1}$, $M = 4$ kg

$$\therefore \quad \text{Impulse} = \text{total change in momentum} = Mv - Mu$$
$$= M(v - u) = 4(0.75 - 0) = 3 \text{ kg ms}^{-1}$$

Impulse at $t = 4$s. Here $u = 0.75 \text{ ms}^{-1}$, $v = 0$

$$\therefore \quad \text{Impulse} = M(v - u) = 4(0 - 0.75) = -3 \text{ kg ms}^{-1}.$$

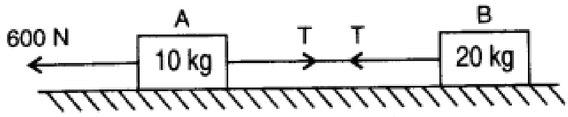
Question 15. Two bodies of masses 10 kg and 20 kg respectively kept on a smooth, horizontal surface are tied to the ends of a tight string. A horizontal force F = 600 N is applied to (i) A, (ii) B along the direction of string. What is the tension in the string in each case?

Answer:

$$\text{Acceleration} = \frac{600 \text{ N}}{10 \text{ kg} + 20 \text{ kg}} = 20 \text{ ms}^{-2}$$

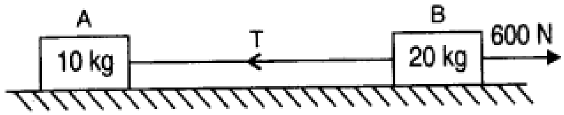
(*i*) When force is applied on 10 kg mass

$$600 - T = 10 \times 20 \quad \text{or}$$
$$T = 400 \text{ N}$$



(*ii*) When force is applied on 20 kg mass,

$$600 - T = 20 \times 20 \quad \text{or}$$
$$T = 200 \text{ N}$$



Question 16. Two masses 8 kg and 12 kg are connected at the two ends of a light in extensible string that goes over a friction less pulley. Find the acceleration of the masses, and the tension in the string when the masses are released.

Answer:

For block $m_2 \rightarrow m_2 g - T = m_2 a$ ...(*i*)
and for block $m_1 \rightarrow T - m_1 g = m_1 a$ ...(*ii*)
Adding (*i*) and (*ii*), we obtain

$$(m_2 - m_1) g = (m_2 + m_1) a$$

or

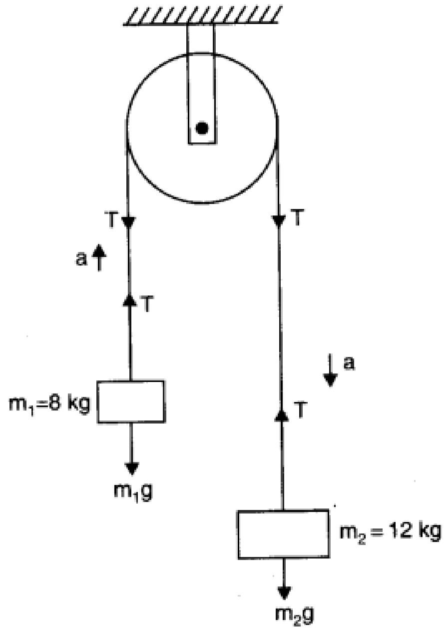
$$a = \left(\frac{m_2 - m_1}{m_2 + m_1}\right) g$$

$$= \frac{12-8}{12+8} \times 10$$

$$= \frac{4 \times 10}{20} = 2\ ms^{-2}$$

Substituting value of *a* in equation (*ii*), we obtain

$$T = m_1 (g + a)$$
$$= 8 \times (10 + 2)$$
$$= 8 \times 12 = 96\ N.$$



Question 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.
Answer: Let m1, m2 be the masses of products and v_1,v_2 be their respective velocities. Therefore, total linear momentum after disintegration = $m_1 v_1 + m_2 v_2$.
Before disintegration, the nucleus is at rest.
Therefore, its linear momentum before disintegration is zero.
According to the principle of conservation of linear momentum,

$$m_1 \vec{v}_1 + m_2 \vec{v}_2 = 0 \quad \text{or} \quad \vec{v}_2 = -\frac{m_1 \vec{v}_1}{m_2}$$

Negative sign shows that v_1 and v_2 are in opposite directions.

Question 18. Two billiard balls, each of mass 0.05 kg, moving in opposite directions with speed 6 ms^{-1} collide and rebound with the same speed. What is the impulse imparted to each ball due to the other?
Answer: Initial momentum of each ball before collision
= 0.05 x 6 kg ms^{-1} = 0.3 kg ms^{-1}
Final momentum of each ball after collision
= – 0.05 x 6 kg ms^{-1} = – 0.3 kg ms^{-1} Impulse imparted to each ball due to the other
= final momentum – initial momentum = 0.3 kg m s-1 – 0.3 kg ms^{-1}
= – 0.6 kg ms^{-1} = 0.6 kg ms^{-1} (in magnitude)
The two impulses are opposite in direction.

Question 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 ms^{-1} what is the recoil speed of the gun?

Answer: m = 0.02 kg, M = 100 kg, v = 80 ms^{-1}, V = ?

$$V = -\frac{mv}{M} = -\frac{0.020 \text{ kg} \times 80 \text{ m s}^{-1}}{100 \text{ kg}}$$

$$= -0.016 \text{ m s}^{-1} = \mathbf{-1.6 \text{ cm s}^{-1}}$$

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

Question 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.)

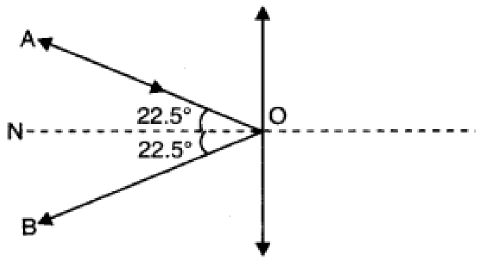
Answer:

Suppose the point O as the position of bat. AO line shows the path along which the ball strikes the bat with velocity u and OB is the path showing deflection such that $\angle AOB$ = 45°. Now initial momentum of ball

$$= mu \cos\theta$$

$$= \frac{0.15 \times 54 \times 1000 \times \cos 22.5}{3600}$$

$$= 0.15 \times 15 \times 0.9239 \text{ along } NO$$



Final momentum of ball = $mu \cos\theta$ along ON

$$\text{Impulse} = \text{change in momentum} = mu\cos\theta - (-mu\cos\theta)$$

$$= 2\,mu\cos\theta = 2 \times 0.15 \times 15 \times 0.9239 = 4.16 \text{ kg m}^{-1}.$$

Question 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 withstand a maximum tension of 200 N?

Answer:

Here, $m = 0.25 \text{ kg}, \quad r = 1.5 \text{ m}$

$$n = 40 \text{ rpm} = \frac{40}{60}\text{ rps} = \frac{2}{3}\text{ rps}$$

Now $T = mr\omega^2 = mr(2\pi n)^2 = 4\pi^2 mrn^2$

$$T = 4 \times \frac{22}{7} \times \frac{22}{7} \times 0.25 \times 1.5 \times \left(\frac{2}{3}\right)^2 = 6.6 \text{ N}$$

If $T_{max} = 200$ N, then from ,

$$T_{max} = \frac{mv_{max}^2}{r} \Rightarrow v_{max}^2 = \frac{T_{max} \times r}{m}$$

or $$v_{max}^2 = \frac{200 \times 1.5}{0.25} = 1200 \Rightarrow v_{max} = \sqrt{1200} = 34.6 \text{ ms}^{-1}.$$

Question 22. If, in Exercise 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 stoneflies off at an angle with the tangent whose magnitude depends on the speed of the particle?
Answer: (b) The velocity is tangential at each point of circular motion. At the time the string breaks, the particle continues to move in the tangential direction according to Newton's first law of motion.

Question 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.
Answer: (a) A horse by itself cannot move in space due to law of inertia and so cannot pull a cart in space.
(b) The passengers in a speeding bus have inertia of motion. When the bus is suddenly stopped the passengers are thrown forward due to this inertia of motion.
(c) In the case of pull, the effective weight is reduced due to the vertical component of the pull. In the case of push, the vertical component increases the effective weight.
(d) The ball comes with large momentum after being hit by the batsman. When the player takes catch it causes large impulse on his palms which may hurt the cricketer. When he moves his hands backward the time of contact of ball and hand is increased so the force is reduced.