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.

Solution:

(a)The raindrop is falling at a constant speed. Therefore, acceleration will become zero. When acceleration is zero, the force acting on the drop will become zero since F = ma.

(b) The cork is floating on water, which means the weight of the cork is balanced by the upthrust. Therefore, the net force on the cork will be zero

(c) Since the car moves with a constant velocity, the acceleration becomes zero. Therefore, the force will be zero.

(d) The net force acting on the high-speed electron will be zero since the electron is far from the material objects and free of electric and magnetic fields.

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 solutions change if the pebble was thrown at an angle of 45° with the horizontal direction? Ignore air resistance

Solution:

(a) During the upward motion of the pebble, the acceleration due to gravity acts downwards, so the magnitude of the force on the pebble is

$F = mg = 0.05 \text{ kg} \times 10 \text{ ms}^{-2} = 0.5 \text{ N}$

The direction of the force is downwards

(b) During the downward motion also the magnitude of the force will be equal to 0.5 N and the force acts downwards

(c) If the pebble is thrown at an angle of 45° with the horizontal direction, it will have both horizontal and vertical components of the velocity. At the highest point, the vertical component of velocity will be zero but the horizontal component of velocity will remain throughout the motion of the pebble. This component will not have any effect on the force acting on the pebble. The direction of the force acting on the pebble will be downwards and the magnitude will be 0.5 N because no other force other than acceleration acts on the pebble.

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 with1 m s^{-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.

Solution:

(a) Mass of stone = 0.1 kg

Acceleration = 10 ms^{-2}

Net force, F = mg = 0.1 x 10 = 1.0 N

The force acts vertically downwards

(b) The train moves at a constant velocity. Therefore the acceleration will be equal to zero. So there is no force acting on the stone due to the motion of the train. Therefore, the force acting on the stone will remain the same (1.0 N)

(c) When the train accelerates at 1m/s^2, the stone experiences an additional force of F' = ma

= 0.1 x 1 = 0.1 N. The force acts in the horizontal direction.

But 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 train floor, its acceleration will be the same as that of the train.

Therefore, the magnitude of the force acting on the stone, F = ma

= 0.1 x 1 = 0.1 N.

It acts along the direction of motion of the train.

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].

Solution:

(i) T

The net force acting on the particle is T, and it is directed towards the centre. It provides the centripetal force required by the particle to move along a circle.

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?

Solution:

Here,

Force = – 50 N (since it is a retarding force)

Mass m = 20 kg

v = 0

u = 15 m s^{-1}

Force F = ma

a = F/m = -50/20 = – 2.5 ms^{-2}

Using the equation, v = u + at

0 = 15 + (- 2.5) t

t = 6 s

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?

Solution:

Given,

Mass, m = 3.0 Kg

u = 2.0 m/s

v = 3.5 m/s

t = 25 s

F = ma

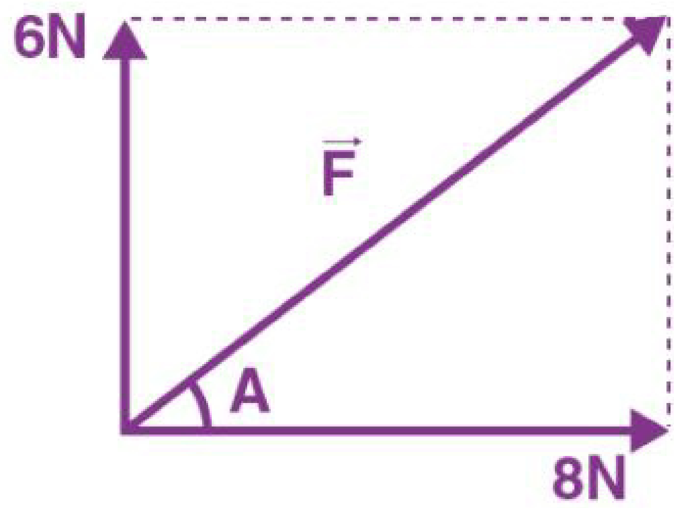
F = m [(v-u)/t] (since a = (v -u)/t)

F = 3 [(3.5 – 2)/25] = 0.18 N

The force acts in the direction of motion of the body

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.

Solution:



Given,

Mass, m = 5 kg

Force, F_1 = 8N and F_2 = 6N

The resultant force of the body

$$F = \sqrt{F_1^2 + F_2^2} = \sqrt{8^2 + 6^2} = \sqrt{64 + 36} = 10N$$

Acceleration, a = F/m

a = 10/ 5 = 2m/s in the direction of the resultant force

The direction of the acceleration,

tan β = 6/8 = 0.75

β = $\tan^{-1}$ (0.75)

β = 37^0 with 8N

8. The driver of a three-wheeler moving at 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.

Solution:

Given,

Initial velocity, u= 36 km/h

Final velocity, v = 0

Mass of the three-wheeler, m_1= 400 Kg

Mass of the driver, m_2 = 65 Kg

Time taken to bring the vehicle to rest = 4.0 s

Acceleration, a = v- u/t = (0 – 10)/ 4 = – 2.5 m/s

Now, F = (m_1 + m_2)/ a = (400 + 65) x (-2.5)

= – 1162.5 N = – 1.16 x 10^3 N

The negative sign shows that the force is retarding

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

Solution:

Given,

Mass of the rocket, m = 20000 kg = 2 x 10^4 kg

Initial acceleration = 5 ms^{-2}

g = 9.8 m/s^2

The initial thrust (force) should give an upward acceleration of 5 ms^{-2} and should overcome the force of gravity.

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

Using Newton's second law of motion, the initial thrust acting on the rocket

Thrust = force = mass x acceleration

F = 20000 x 14.8 = 2.96 x 10^5 N

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.

Solution:

Given,

Mass of the body = 0.40 kg

Initial velocity, u = 10 m/s

Force, f = -8 N (retarding force)

Using the equation $S = ut + (½) at^2$

(a) Position at the time t = – 5 s

The force starts acting on the body from t = 0 s

So the acceleration of the body when the time is – 5 s is 0

$S_1 = (10)(-5) + (½) (0) (-5)^2 = – 50$ m

(b) Position at the time t = 25 s

The acceleration of the body due to the force acting in the opposite direction

Acceleration, a = F/a = -8 /0.4 = -20 ms^{-2}

$S_2 = (10)(25) + (½) (-20) (25)^2 = – 6000$ m

(c) Position at the time t = 100 s

For the first 30 sec, the body will move under the retardation of the force and after that, the speed will remain constant.

Therefore, distance covered in 30 sec

$S_3 = (10)(30) + (½)(-20)(30^2)$

= 300 – 9000 = – 8700m

The speed after 30 sec is

v = u + at

v = 10 – (20 x 30) = 590 m/s

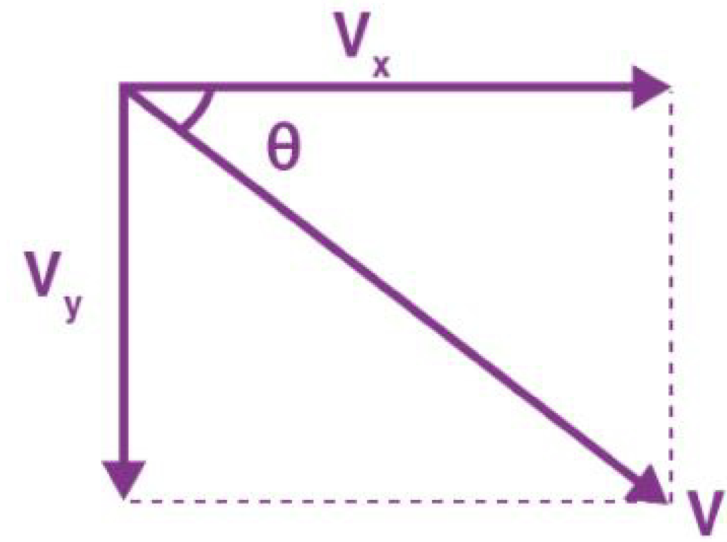
The distance covered in the next 70 sec is

$S_4 = – 590 \times 70 + (½) (0) (70)^2 = – 41300$ m

Therefore the position after 100 sec = $S_3 + S_4$ = – 8700 – 41300 = – 50000m

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.)

Solution:



Initial velocity, u = 0

Acceleration, a = 2 ms^{-2},

t=10 s

Using equation, v = u + at, we get

v = 0 + 2 x 10 = 20 m/s

The final velocity, v = 20 m/s

At time, t = 11 sec, the horizontal component of the velocity in the absence of the air resistance remains unchanged

V_x =20 m/s

The vertical component of the velocity is given by the equation

$V_y = u + a_y t$

Here t = 11 – 10 = 1s and a_y= a = 10 m/s

Therefore, the resultant velocity v of the stone is

$v = (v_x^2 + v_y^2)^{½}$

$v = (20^2 + 10^2)^{1/2}$

v = 22.36 m/s

tan θ = v_y/v_x = 10/20 = ½ = 0.5

θ = tan -1 (0.5) = 26. 56^0 from the horizontal

(b) When the stone is dropped from the truck, the horizontal force on the stone is zero. The only acceleration of the stone is that due to gravity which is equal to 10 m/s^2 and it acts vertically downwards.

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?

Solution:

(a) When the bob is at one of its extreme positions, the velocity is zero. So, if the string is cut the bob will fall vertically downward under the force of its weight F = mg.

(b) At its mean position the bob has a horizontal velocity. If the string is cut, the bob will behave like a projectile and will fall on the ground after taking a parabolic path.

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?

Solution:

Mass of the man, 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 of 10 m/s, it’s acceleration= 0.

R = mg = 70 x 10 = 700 N

(b) Lift moving downwards with a = 5 ms^{-2}

Using Newton’s second law of motion, the equation of motion can be written as

R+mg = ma

R = m (g – a) = 70 (10 – 5) = 350 N

(c) Lift moving upwards with a = 5 ms^{-2}

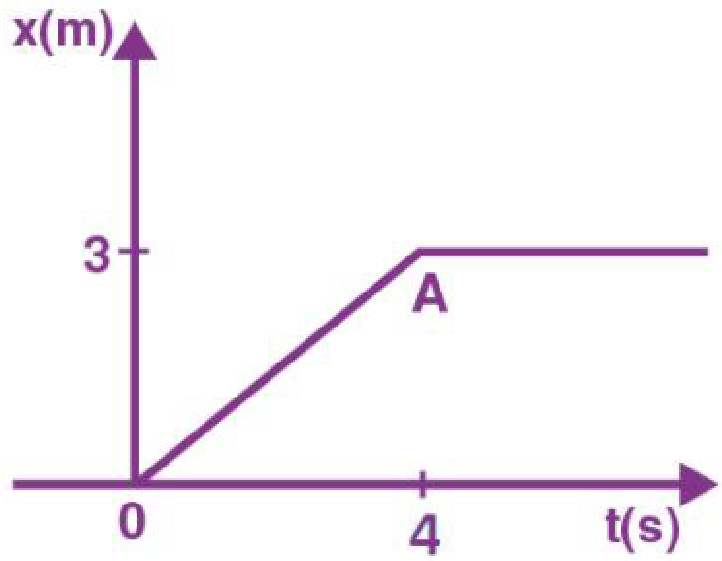
R = m (g + a) = 70 (10 + 5) = 1050 N

(d) If the lift were to come down freely under gravity, downward a = g

:. R = m(g -a) = m(g – g) = 0

The man will be in a state of weightlessness

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).



Solution:

When $t < 0$, the distance covered by the particle is zero. Therefore, the force on the particle is zero.

When $0 < t < 4s$, the particle is moving with a constant velocity. Therefore, the force will be zero.

When $t > 4s$, the particle remains at a constant distance. Therefore, the force of the particle will be zero.

Impulse at t = 0.

Here, u = 0

v = ¾ = 0.75 m/s

M = 4 kg

Impulse= total change in momentum = mv – mu = m (v – u)

= 4 (0 – 0.75) = -3 kg m/s

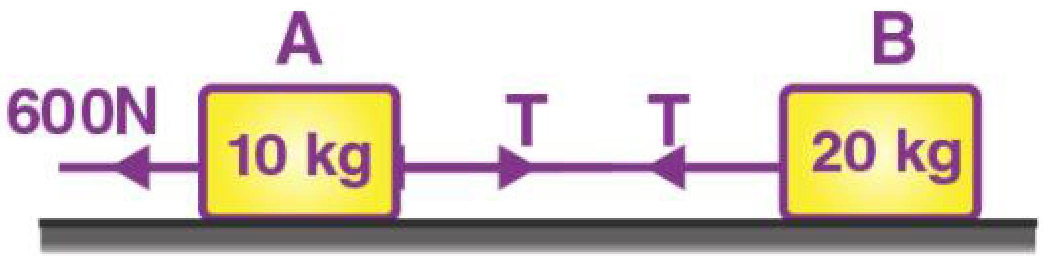
Impulse at t= 4s

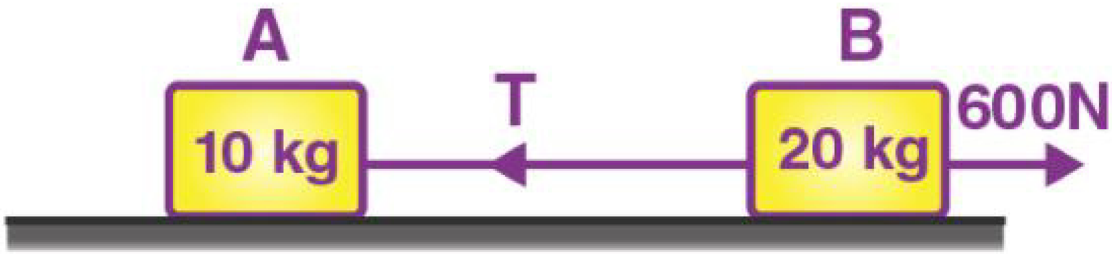
u = 0.75 m/s, v = 0

Impulse = m (v – u) = 4 (0 – 0.75) = -3 kg m/s

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?

Solution:





Given,

Mass of the body A, $m_1 = 10$ kg

Mass of the body B, $m_2 = 20$ kg

Horizontal force = 600 N

Total mass of the system, $m = m_1 + m_2 = 30$ kg

Applying Newton's second law of motion, we have

F = ma

a = F/m = 600/30 = 20 m/s^2

(i) When the force is applied on A (10 kg)

$F – T = m_1a$

$T = F – m_1a$

T = 600 – (10 x 20)

= 600 – 200 = 400 N

(ii) When the force is applied on B (20 kg)

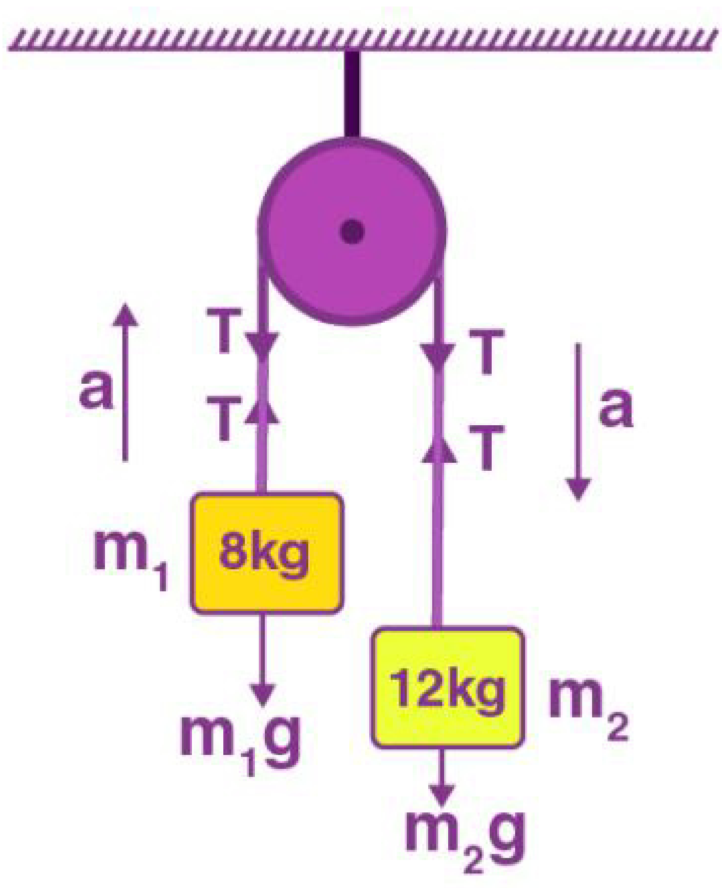
$F - T = m_2a$

$T = F - m_2a$

$= 600 - (20 \times 20) = 200$ N

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.

Solution:



Given,

Smaller mass, $m_1 = 8$ kg

Larger mass, $m_2 = 12$ kg

Tension in the string = T

The heavier mass m_2 will move downwards and the smaller mass m_1 will move upwards.

Applying Newton's second law,

For mass m_1:

$T – m_1g = m_1a$ —– (1)

For mass m_2:

$m_2g – T = m_2a$ ——(2)

Add (1) and (2)

$(m_2 – m_1) g = (m_1 + m_2) a$

$a = (m_2 – m_1) g/ (m_1 + m_2)$

$=[(12 – 8)/(12 + 8)] x 10 = (4 /20) x 10= 2m/s$

Therefore, acceleration of the mass is 2 m/s^2

Substituting this value of acceleration in equation (ii) we get

$m_2g – T = m_2a$

$m_2g – T = m_2 [(m_2 – m_1) g/ (m_1 + m_2)]$

$= 2m_1m_2g/(m_1 + m_2)$

T = 2 x 12 x 8 x 10/ (12 + 8)

T = 96 N

Therefore, the tension on the string is 96 N

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.

Solution:

Let m_1, m_2 be the masses of the two daughter nuclei and v_1,v_2 be their respective velocities of the daughter nuclei. Let m be the mass of the parent nucleus.

Total linear momentum after disintegration = $m_1v_1 +m_2 v_2$.

Before disintegration, the nucleus is at rest. Therefore, its linear momentum before disintegration is zero.

Applying the law of conservation of momentum,

Total linear momentum before disintegration = Total linear momentum after disintegration

$0 = m_1v_1 + m_2v_2$

$v_1=-m_2v_2/m_1$

The negative sign indicates v_1 and v_2 are in opposite directions.

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?

Solution:

Mass of each ball = 0.05 kg

Initial velocity of each ball = 6 m/s

The initial momentum of each ball before the collision

= 0.05 x 6 = 0.3 kg m/s

After the collision, the balls change in the direction of motion without a change in the magnitude of the velocity

Final momentum after collision of the first ball = – 0.05 x 6 = – 0.3 kg m/s

Final momentum after collision of the second ball = 0.3 kg m/s

Impulse imparted to the first ball = (-0.3) – (0.3) = – 0.6 kg m/s

Impulse imparted to the second ball = (0.3) – (-0.3) = 0.6 kg m/s

The two impulses are opposite in direction.

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?

Solution:

Mass of the shell, m = 0.020 kg

Mass of the gun, M = 100 Kg

Speed of the shell = 80 m/s

The initial velocity of the shell and the gun is zero. So, the initial momentum of the system is zero.

Applying the law of conservation of momentum, the initial momentum is equal to the final momentum.

So,

0 = mv – MV

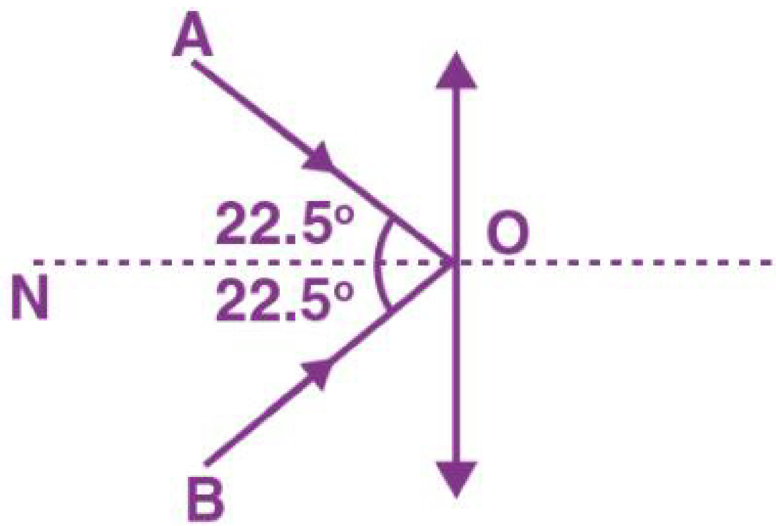
Recoil speed of the gun, v = mv/M

v = (0.020 x 80)/100

v = 0.016 m/s

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.)

Solution:



Velocity of the ball = 54 km/h

The ball is deflected back such that the total angle = 45^0

The initial momentum of the ball is mucosϴ = (0.15 x 54 x 1000 x cos 22. 5)/3600

= 0.15 x 15 x 0.9239 along NO

Final momentum of the ball = mucosϴ along ON

Impulse = change in the momentum = mucosϴ – (-mucosϴ) = 2mucosϴ = 2 x 0.15 x 15 x 0.9239

= 4.16 kg m/s

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?

Solution:

Mass of the stone = 0.25 kg

Radius, r = 1.5 m

Number of revolution in a second, n= 40/60 = (⅔) rev/sec

The angular velocity, ω = 2πn = 2 x 3.14 x (⅔)

The tension on the string provides the necessary centripetal force

$T = m\omega^2 r$

$T = 0.25 \times 1.5 \times [2 \times 3.14 \times (⅔)]^2$

= 6.57 N

Maximum tension on the string, T_{max}= 200 N

T_{max}= mv^2_{max}/r

v^2_{max} = (T_{max} x r)/m

= (200 x 1.5)/0.25 = 1200

v_{max} = 34. 6 m/s

Therefore, the maximum speed of the stone is 34.64 m/s

22. If in problem 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?

Solution:

(b)

At each point of the circular motion, the velocity will be tangential. If the string breaks suddenly the stone moves in the tangential direction according to Newton's first law of motion.

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 lawnmower than to push it,

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

Solution:

1. The horse pushes the ground with a certain force when it pulls the cart. By applying the third law of motion, the ground will exert an equal and opposite reaction force upon the feet of the horse. This causes the horse to move forward. In empty space, the horse will not experience a reaction force. Therefore, the horse cannot pull the cart in empty space.

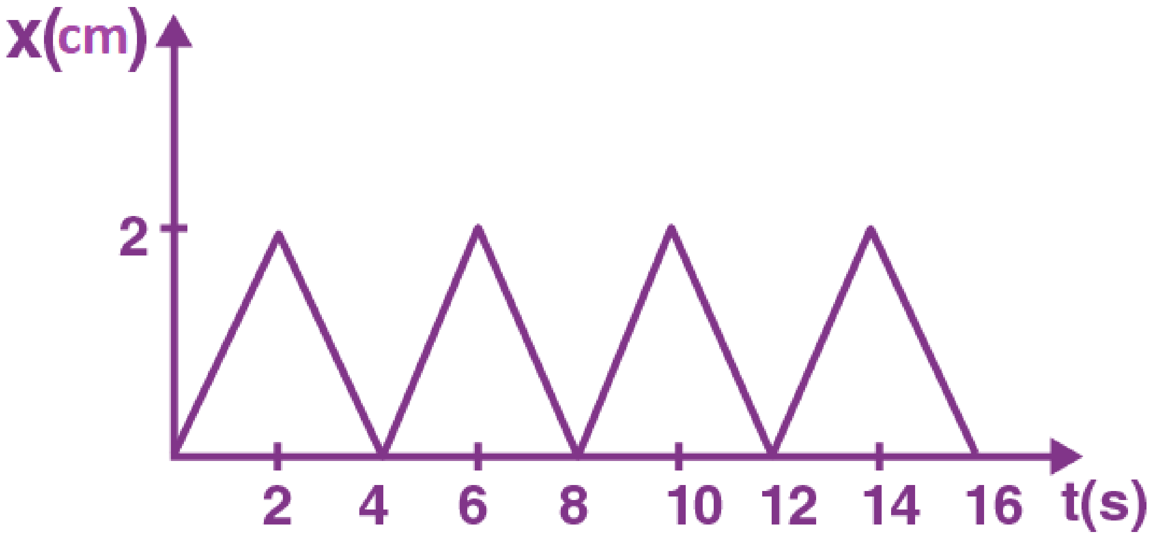
2. Due to inertia of motion. When a bus stops all of a sudden, the lower part of a person's body that is in contact with the seat comes to rest suddenly but the upper part will continue to be in motion. As a result, the person's upper half of the body is thrown forward in the direction of the motion of the bus.

3. When the lawnmower is pulled, the vertical component of the applied force acts upwards. This reduces the effective weight of the lawnmower. When the lawn mower is pushed, the vertical component acts in the

direction of the weight of the mower. Therefore, there is an increase in the weight of the mower. So, it is easier to pull a lawnmower than to push it.

4. When the batsman hits the ball, the ball will have a large momentum. When he moves his hands backwards the time of impact is increased contact, so the force is reduced.

24. Figure 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?



Solution:

This graph could be of a ball rebounding between two walls separated by a distance of 2 cm. The ball rebounds between the walls every 2 seconds with a uniform velocity.

Velocity = displacement/ time = $(2 \times 10^{-2})/2 = 0.01$ m/s

Initial momentum = mu = $0.04 \times 0.01 = 4 \times 10^{-4}$ kgm/s

Final momentum = mv = $0.04 \times (-0.01) = -4 \times 10^{-4}$ kgm/s

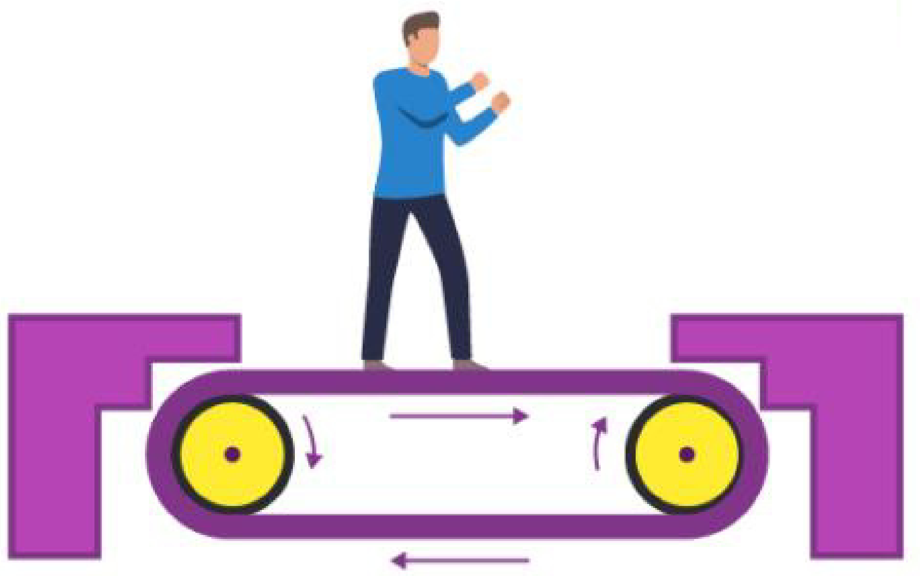
Magnitude of impulse = Change in momentum

$= (4 \times 10^{-4}) - (-4 \times 10^{-4}) = 8 \times 10^{-4}$ kgm/s

The time between two consecutive impulses is 2 sec, so the ball receives an impulse every 2 seconds.

25. Figure 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, up to what acceleration of the belt can the man continue to be stationary relative to the belt? (Mass of the man = 65 kg.)



Solution:

Here acceleration of conveyor belt a = 1 ms^{-2},

Coefficient of static friction, μ_s= 0.2

mass of man, m = 65 kg

Net Force = ma = 65 x 1 = 65N

This net force is due to the friction between the belt and the man

Maximum static friction = μ_s N

Beyond that, the man starts moving relative to the belt as per the pseudo force

At maximum static friction

$\mu_s N = \mu_s .mg = ma_{max}$

$a_{max}= \mu s\ g = 0.2 \times 10 = 2\ m/s^2$

26. A stone of mass m tied to the end of a string is revolving in a vertical circle of radius R. The net force 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)	$mg + T_1 - (m v_1^2) / R$	$mg - T_2 + (m v_1^2) / R$
(d)	$mg - T_1 - (m v_1^2) / R$	$mg + T_2 + (m v_1^2) / R$

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.

Solution:

(a)

The net force at the lowest point is ($mg - T_1$) and the net force at the highest point is ($mg + T_2$). Therefore option (a) is correct.

Since mg and T_1 are in mutually opposite directions at the lowest point and mg and T_2 are in the same direction at the highest point.

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

(a) force on the floor by the crew and passengers,

(b) the action of the rotor of the helicopter on surrounding air

(c) force on the helicopter due to the surrounding air

Solution:

Mass of helicopter = 1000 kg

Crew and passengers weight = 300 kg

Vertical acceleration, a = 15 ms^{-2} and g = 10 ms^{-2}

The total mass of the system, m_i = 1000 + 300 = 1300 Kg

(a)Force on the floor of the helicopter by the crew and passengers

R – mg = ma

= m (g+a)

= m (g + a) = 300 (10 + 15) N = 7500 N

(b)Action of the rotor of the helicopter on surrounding air is due to the mass of the helicopter and the passengers.

R' – m_ig = m_ia

R' = m_i (g+a)

= 1300 x (10 + 15) = 32500 N

This force acts vertically downwards

(c)Force on the helicopter due to the surrounding air is the reaction of the force applied by the rotor on the air. As action and reaction are equal and opposite, therefore, the force of reaction, F = 32500 N. This force acts vertically upwards.

28. A stream of water flowing horizontally with a speed of 15 m/s pushes 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 that it does not rebound?

Solution:

Speed of water flowing, v= 15 m/s

Cross-sectional area of the tube, A= 10^{-2} m^2

In one second, the distance travelled is equal to the velocity v

Density of water, ρ = 1000 kgm^{-3}

Mass of water hitting the wall per second = ρ x A x v

= 1000 kgm^{-3} x 10^{-2} m^2 x 15 m/s = 150 kg/s

Force exerted on the wall because of the impact of water = momentum loss of water per second

= Mass x velocity

= 150 kg/s x 15 m/s = 2250 N

29. Ten one rupee coins are put on top of one another on a table. Each coin has a mass of m kg. Give the magnitude and direction of

(a) the force on the 7th coin (counted from the bottom) due to all coins above it.

(b) the force on the 7th coin by the eighth coin and

(c) the reaction of the sixth coin on the seventh coin.

Solution:

(a) The force on the 7th coin is due to the weight of the three coins kept above it.

Weight of one coin is mg. So the weight of three coins is 3mg

Force exerted on the 7th coin is (3mg)N and the force acts vertically downwards.

(b) The eighth coin is already under the weight of two coins above it and it has its own weight too. Hence the force on the 7th coin due to the 8th coin will be the same as the force on the 7th coin by the three coins above it.

Therefore, the force on the 7th coin by the 8th coin is (3mg)N and the force act vertically downwards.

(c) The sixth coin is under the weight of four coins above it and experiences a downward force due to the four coins.

The total downward force on the 6th coin is 4mg

Applying Newton's third law of motion, the 6th coin will exert a reaction force upwards. Therefore, the force exerted by the 6th coin on the 7th coin is equal to 4mg and acts in the upward direction.

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

Solution:

The speed of the aircraft executing the horizontal loop = 720 km/h = 720 x (5/18) = 200 m/s

The angle of banking = 15°

$\tan\theta = v^2/rg$, we have

$r = v^2/g\tan\theta = (200 \times 200)/(10 \times \tan 15^0) = (200 \times 200)/ (10 \times 0.2679) = 14931$ m

31. A train runs along an unbanked circular track of radius of 30 m at a speed of 54 km/h. The mass of the train is 10^6 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?

Solution:

Radius of the track = 30 m

Velocity of the train = 54 km/h = 54 x (5/18) = 15 m/s

Mass of the train = 10^6kg

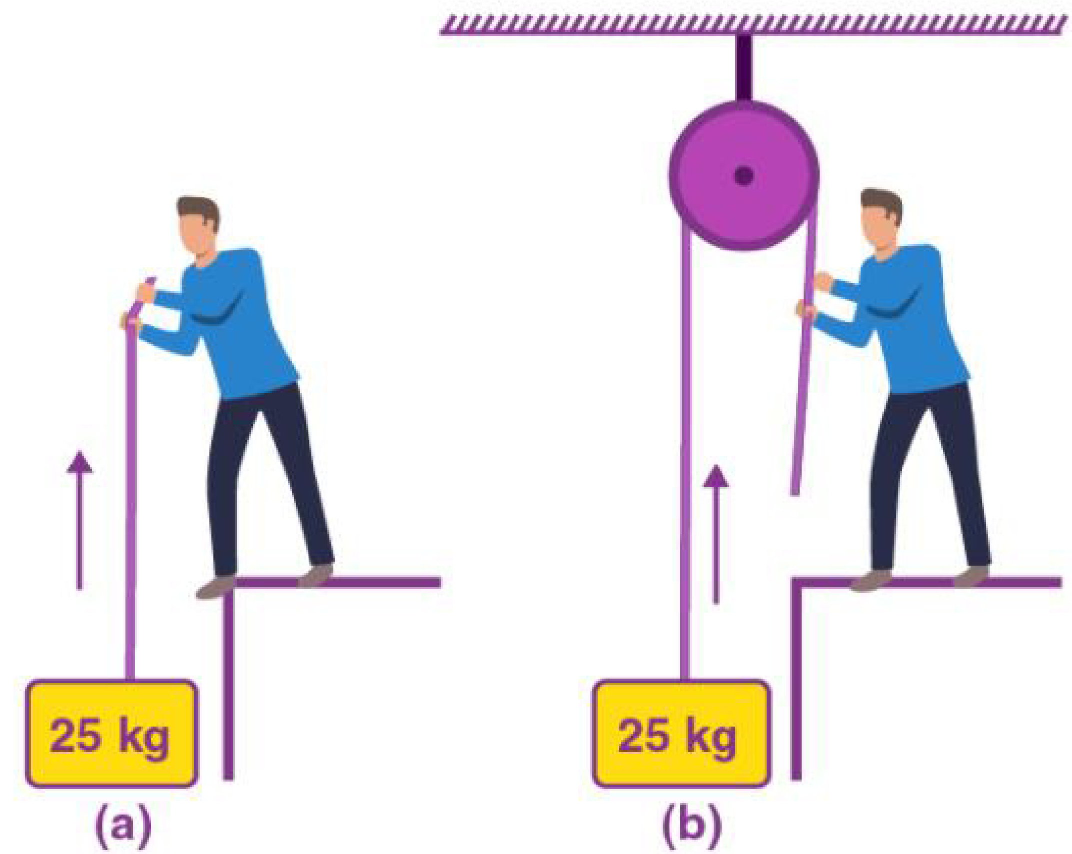
The required centripetal force is provided by the force of lateral friction due to the rails on the wheels of the train

The angle of banking required to prevent wearing out of the rails

$\tan\theta = v^2/rg = (15 \times 15)/ (30 \times 10) = 0.75$

$\theta = \tan^{-1} (0.75) = 37^0$

32. A block of mass 25 kg is raised by a 50 kg man in two different ways as shown in Fig. 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?



Solution:

Mass of the block = 25 kg

Mass of the man = 50 kg

Acceleration due to gravity = 10 m/s^2

Weight of the block, F = 25 x 10 = 250 N

Weight of the man, W = 50 x 10 = 500 N

In the 1st case, the man lifts the block directly by applying an upward force of 250 N (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.

= 500 N + 250 N = 750 N.

In the 2nd case, the man applies a downward force of 25 kg wt. According to Newton's third law of motion, the reaction is in the upward direction.

In this case, action on the floor by the man

= 500 N – 250 N= 250 N.

Therefore, man should adopt the second method.

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

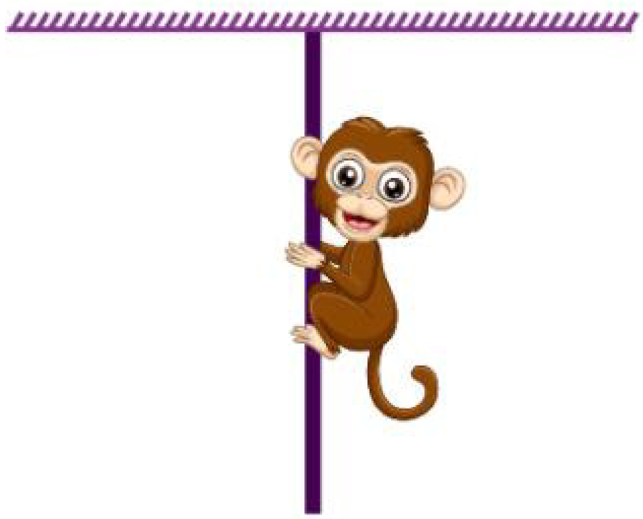
(a) climbs up with an acceleration of 6 ms^{-2}

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

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

(d) falls down the rope nearly freely under gravity?

(Ignore the mass of the rope).



Solution:

Mass of the monkey = 40 kg

Maximum tension the rope can withstand, T_{max}= 600 N

(a) When the monkey climbs up with an acceleration of 6m/s2,

Tension T – mg = ma

T = m (g+a)

T = 40 (10 + 6)

= 640 N

Since T > Tmax, the rope will break

(b) When the monkey climbs down with the acceleration of $4 m/s^2$

mg – T = ma

T = mg – ma = m (g – a)

= 40 (10 – 4) = 240 N

Since $T < T_{max}$, the rope will not break

(c) When the monkey climbs with a uniform speed 5m/s. The acceleration will be zero. The equation of motion is

T – mg = ma

T – mg = 0

T = mg = 40 x 10 = 400 N

Since $T < T_{max}$, the rope will not break

(d) When the monkey falls freely, the acceleration of the monkey will be equal to the acceleration due to gravity

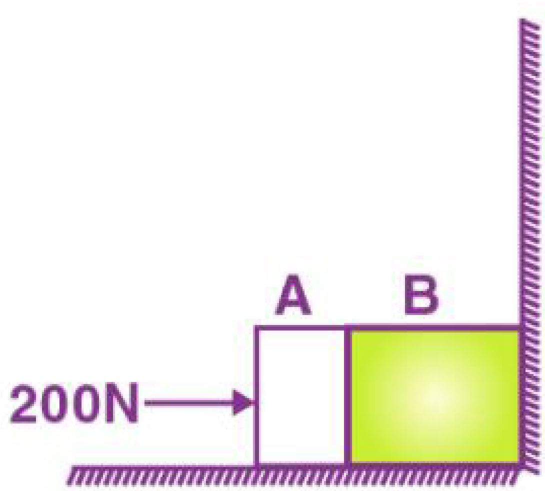
The equation of motion is written as

mg + T = mg

T = m(g-g) = 0

Since $T < T_{max}$, the rope will not break

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 200 N 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 solution to (b) change, when the bodies are in motion? Ignore the difference between μ_s and μ_k.



Solution:

Mass of the body, m_A = 5 Kg

Mass of the body, m_B = 10 kg

Applied Force = 200 N

Coefficient of friction between the bodies and the table μ_s = 0.15

(a) The force of friction is given by the relation:

$f_s = \mu(m_A + m_B)g$

= 0.15 (5 + 10) x 10

= 1.5 x 15 = 22.5 N, towards left

Therefore, the net force on the partition is 200 – 22.5 = 177. 5 N rightward

According to Newton's third law, action and reaction are in the opposite direction

Therefore, the reaction of the partition will be 177.5 N, in the leftward direction

(b) Force of friction on mass A

$F_A = \mu m_A g$

= 0.15 x 5 x 10 = 7.5 N leftward

The net force exerted by mass A on mass B = 200 – 7.5 = 192.5 N rightwards

An equal amount of reaction force will be applied on mass A by B, i.e., 192.5 N acting leftward

When the wall is removed, the two bodies move in the direction of the applied force

The net force acting on the moving system = 177. 5 N

The equation of motion for the system of acceleration a, can be written as

Net force = $(m_A + m_B)$ a

a = Net force/ $(m_A + m_B)$

= 177.5/ (5 + 10) = 177. 5/15 = 11. 83 m/s^2

Net force causing mass A to move

$F_A = m_A$ a = 5 x 11.83 = 59. 15 N

Net force exerted by the mass A on mass B= 192.5 – 59.15= 133. 35 N

This force acts in the direction of motion. As per Newton's third law of motion, an equal amount of force will be exerted by mass B on mass A, i.e., 133.3N, acting opposite to the direction of motion.

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 ms^{-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.

Solution:

Mass of the block = 15 kg

Coefficient of static friction between the block and the trolley, p= 0.18

Acceleration of the trolley = 0.5 m/s^2

(a) Force experienced by block, F = ma = 15 x 0.5 = 7.5 N, this force acts in the direction of motion of the trolley

Force of friction, F_f= p mg = 0.18 x 15 x 10 = 27 N

Force experienced by the block will be less than the friction. So the block will not move. So, for a stationary observer on the ground, the block will be stationary.

(b) The observer moving with the trolley has an accelerated motion. He forms a non-inertial frame in which Newton's laws of motion are not applicable. The trolley will be at rest for the observer moving with the trolley

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. 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 size of the box).

Solution:

Force experienced by box, F = ma = 40 x 2 = 80 N

Frictional force F_f = μmg = 0.15 x 40 x 10 = 60 N

Net force = F – F_f = 80 – 60 = 20 N

Backward acceleration produced in the box, a =20/40(Net Force/m)

a = 0.5 ms^{-2}

If t is time taken by the box to travel s =5 metre and fall off the truck then from

$S = ut + 1/2\ at^2$

$5 = 0 \times t + (½) \times 0.5\ t^2$

$t = \sqrt{(5×2/0.5)} = 4.47$ s

If the truck travel a distance x during this time, then again from

$S = ut + 1/2\ at^2$

$x = 0 \times 4.47 + (½) \times 2(4.47)^2 = 19.98$ m

37. A disc revolves with a speed of 33⅓ rpm 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 coefficient of friction between the coins and record is 0.15, which of the coins will revolve with the record?

Solution:

Speed of revolution of the disc = 33 ⅓ rpm= 100/3 rpm= 100/ (3 x 60) rps = 5/9 rps

$\omega = 2\pi v = 2 \times (22/7) \times (5/9) = 220/63$ rad/s

The coins revolve with the disc, the centripetal force is provided by the frictional force $mv^2/r \le \mu mg$ ——– (1)

As $v = r\omega$, equation (1) becomes $mr\omega^2/r \le \mu mg$

$r \le \mu g/\omega^2 = (0.15 \times 10)/(220/63)^2 = 12$ cm

For coin A, r = 4 cm

The condition (r≤ 12) is satisfied for coin placed at 4cm, so coin A will revolve with the disc

For coin B, r = 14 cm

The condition (r≤ 12) is not satisfied for the coin placed at 14cm, so coin B will not revolve with the disc.

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 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?

Solution:

When the motorcyclist is at the uppermost point of the death-well, the normal reaction R on the motorcyclist by the ceiling of the chamber acts downwards. His weight mg also acts downwards. The outward centrifugal force acting on the motorcyclist is balanced by these two forces.

$R + mg = mv^2/r$ ——— (1)

Here, v is the velocity of the motorcyclist

m is the mass of the motorcyclist and the motorcycle

Because of the balance between the forces, the motorcyclist does not fall

The minimum speed required at the uppermost position to perform a vertical loop is given by the equation (1) when R = 0

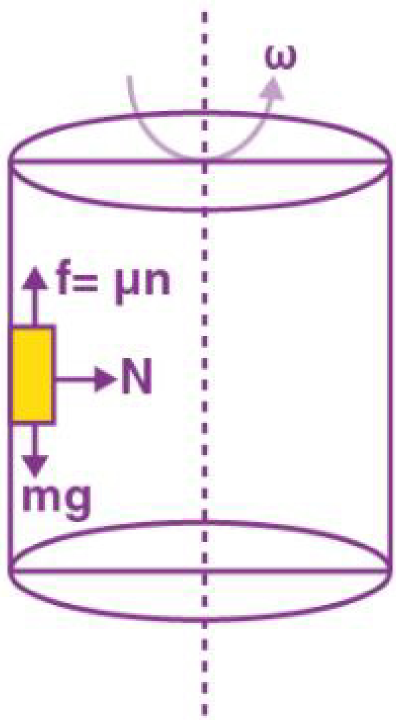
$mg = mv^2_{min}/r$

$V^2_{min} = gr$

$V_{min} = \sqrt{10} \times 25 = 15.8$ m/s

39. A 70 kg man stands in contact against the inner wall of a hollow 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?

Solution:



Mass of the man, m = 70 kg

Radius of the drum, r = 3 m

Coefficient of friction between the wall and his clothing, μ = 0.15

Number of revolution of hollow cylindrical drum = 200 rev/min= 200/60 = 10/3 rev/s

The centripetal force required is provided by the normal N of the wall on the man

$N = mv^2/R = m\omega^2R$

When the floor revolves, the man sticks to the wall of the drum. Hence, the weight of the man (mg) acting downward is balanced by the frictional force acting vertically upwards.

The man will not fall if mg ≤ limiting frictional force f_e (μN)

$mg \le \mu N$

$mg \le \mu\ (m\omega^2 R)$

$\omega^2 \ge g/R\mu$

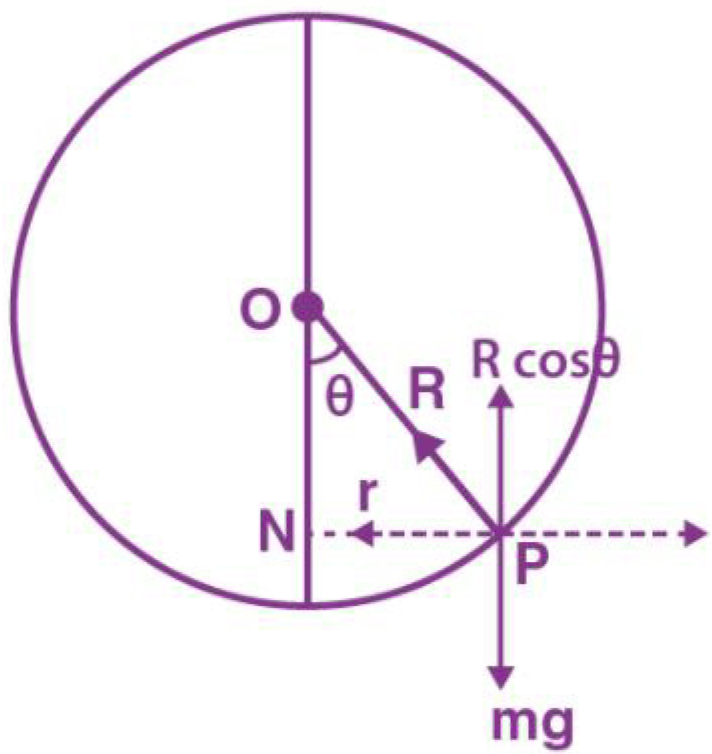
Therefore, for minimum rotational speed of the cylinder

$\omega^2 = g/R\mu = 10/(0.15 \times 3) = 22.\ 2$

$\omega = \sqrt{22.2} = 4.7$ rad/s

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 ω ≤ √g / R . What is the angle made by the radius vector joining the centre to the bead with the vertically downward direction for ω = √2g/ R? Neglect friction.

Solution:



Let θ be the angle made by the radius vector joining the bead and the centre of the wire with the downward direction. Let, N be the normal reaction

$mg = N \cos\theta$ ——(1)

$mr\omega^2 = N \sin\theta$ —— (2)

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

$mR\omega^2 = N$

Substituting the value of N in (1)

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

(or) $\cos \theta = g/R\omega^2$ ———(3)

As $|\cos\theta| \leq 1$ the bead will remain at the lowermost point

$g/R\omega^2 \leq 1$ or $\omega \leq \sqrt{g/R}$

For $\omega = \sqrt{2g/R}$, equation (3) becomes

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

$\cos \theta = (g/R) (R/2g) = ½$

$\theta = 60^0$