CLASS – 11

WORKSHEET- LAWS OF MOTION

A. LAWS OF MOTION

(1 Marks Questions)

1. Action and reaction are equal and opposite. Why cannot they cancel each other?

Sol. Action and reaction force pairs don't cancel because they act on different objects. Forces can cancel only if they act on the same object.

2. Physical independance of force is a consequence of

(a) first law of motion (b) second law of motion

(c) third law of motion (d) all of these laws.

Ans. (c)

3. A ball is travelling with uniform translatory motion. This means that

(a) it is at rest.

(b) the path can be a straight line or circular and the ball travels with uniform speed.

(c) all parts of the ball have the same velocity (magnitude and direction) and the velocity is constant.

(d) the centre of the ball moves with constant velocity and the ball spins about its centre uniformly.

Ans. (c)

(2 Marks Questions)

4. State Newton's second law of motion. Show that it gives a measure of force. Hence define 1N force

Sol. **Newton's second law of motion** is closely related to Newton's first law of motion. It mathematically states the cause and effect relationship between force and changes in motion. Newton's second law of motion is more quantitative and is used extensively to calculate what happens in situations involving a force.

The rate of change in linear momentum of a body is directly proportional to the external force applied on the body and this change takes place always in the direction of the applied force, i.e. $\vec{F} \propto \frac{d\vec{p}}{dt}$ or $\vec{F} = k\frac{d\vec{p}}{dt} = k\frac{d(m\vec{v})}{dt}$

For body of constant mass, $\vec{F} = km\frac{d\vec{v}}{dt} = km\vec{a}$ (since $\vec{a} = d\vec{v}/dt$)

In SI units, k = 1.

5. State that Newton's second law of motion is the real law of motion.

Sol. Same as 8.
As both first and third laws of motion are contained in the second law , we can say that Newton's second law is the real law of motion.

6. State Newton's third law of motion. Derive the law of conservation of linear momentum from it.

Sol. Newton's third law states that when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction. The third law is also known as the law of action and reaction.

Consider two bodies of mass m_1 and m_2 moving with initial velocity u_1 and u_2 respectively. The two bodies collide with each other for a time interval 't'. The velocity after collision be v_1 & v_2 respectively. Let F_{12} be the force applied by m_1 on m_2 and F_{21} be the force applied by m_2 on m_1.

Momentum of mass m_1 before collision = $m_1 u_1$
Momentum of mass m_2 before collision = $m_2 u_2$
Momentum of mass m_1 after collision = $m_1 v_1$
Momentum of mass m_2 after collision = $m_2 v_2$
Impulse = force × time = change in momentum
For mass m_1 : $F_{12}\, t = m_1 v_1 - m_1 u_1$ …………….(1)
For mass m_2: $F_{21} t = m_2 v_2 – m_2 u_2$ ……………..(2)
Adding equation (1) & (2)
$F_{12}\, t + F_{21} t = (m_1 v_1 - m_1 u_1) + (m_2 v_2 – m_2 u_2)$
$(F_{12} + F_{21})\, t = (m_1 v_1 + m_2 v_2) - (m_1 u_1 + m_2 u_2)$
According to Newton's third law: $F_{12} = - F_{21}$
$F_{12} + F_{21} = 0$
$(m_1 v_1 + m_2 v_2) = (m_1 u_1 + m_2 u_2)$
Final momentum = Initial momentum
Hence momentum is conserved.

(3 Marks Questions)

7. Explain, why
(a) The passengers are thrown forward from their seats, when a speeding bus tops suddenly.

Sol. The lower part of the body of passengers (which is in contact with the bus) comes to rest, but because of inertia, the upper part of the body tends to keep on moving. As a result of it, the rider falls forward.
(b) Does a cricketer moves his hand backwards while holding a catch?

Sol. As we know that impulse = force × time = change in linear momentum.

By moving his hands in backward direction cricketer allows a longer time for his hands to stop the ball. As a result, the balls exerts a smaller force on his hands and hands are not injured.

(c) Is the boat pushed away when a man jumps out of the boat?

Sol. According to Newton's third law of motion, for every action, there is an equal and opposite reaction. When the man jumps from a boat, he applies force on the boat due to which boat moves backward. An equal force is exerted by the boat on the man which helps the man to jump out of the boat.

(5 Marks Questions)

8. State and explain the Newton's second law of motion. Hence deduce first and third law of motion from second law of motion. A piece of work is floating on water. What is the net force acting on it?

Sol. Second law: The rate of change in linear momentum of a body is directly proportional to the external force applied on the body and this change takes place always in the direction of the applied force, i.e. $\vec{F} \propto \frac{d\vec{p}}{dt}$ or $\vec{F} = k\frac{d\vec{p}}{dt} = k\frac{d(m\vec{v})}{dt}$

For body of constant mass, $\vec{F} = km\frac{d\vec{v}}{dt} = km\vec{a}$ (since $\vec{a} = d\vec{v}/dt$)

In SI units, k = 1. So, $\vec{F} = m\vec{a}$.

Derivation of first law from second law:

According to Newton's second law of motion the force acting on the body is F = ma

If no external force is applied, then F = 0, ma = 0

i.e. when external force is zero, there will be no acceleration in the body. That means body at rest will remain at rest and body in motion will keep moving along the same straight line which is the explanation of first law of motion.

Derivation of third law form second law:

Let two bodies A and B interact mutually in isolated system with each other.

Let $\vec{F}_{BA}$ = force exerted by A on B

$\frac{d\vec{p}_B}{dt}$ = rate of change of momentum of B.

$\vec{F}_{AB}$ = force exerted on A by B

$\frac{d\vec{p}_A}{dt}$ = Rate of change of momentum of A

According to 2nd law of motion,

$\vec{F}_{BA} = \frac{d\vec{p}_B}{dt}$ and $\vec{F}_{AB} = \frac{d\vec{p}_A}{dt}$

$\therefore \vec{F}_{BA} + \vec{F}_{AB} = \frac{d\vec{p}_B}{dt} + \frac{d\vec{p}_A}{dt} = \frac{d}{dt}(\vec{p}_B + \vec{p}_A)$

If external force = 0 then $\frac{d\vec{p}}{dt} = 0$

i.e. $\frac{d}{dt}(\vec{p}_B + \vec{p}_A)$

So, $\vec{F}_{BA} + \vec{F}_{AB} = 0$

$\vec{F}_{BA} = -\vec{F}_{AB}$ which is nothing but Newton's third law of motion.

Net force on the cork is zero because net downward force is equal to upthrust.

B. LINEAR MOMENT AND INERTIA

(1 Marks Questions)

1. Define impulse.

Sol. Impulse in Physics is a term that is used to describe or quantify the effect of force acting over time to change the momentum of an object. It is represented by the symbol J and usually expressed in Newton-seconds or kg m/s.

2. Which one of the following statements is not true?

(a) The same force for the same time causes the same change in momentum for different bodies.

Sol. The same force of same time causes the same change in momentum for different bodies. This statement is correct because when a force is applied on a body then it produces a change in momentum of that body, so the same force applied for the same duration of time will produce the same change in momentum of that body.

(b) The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction the force acts

Sol. The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts. This statement is also true as evident from the following relation. F=dp/dt .The change in momentum is also in the same direction as the force.

(c) A greater opposing force is needed to stop a heavy body than a light body in the same time, if they are moving with the same speed.

Sol. A greater opposing force is needed to stop a heavy body than a light body in the same times, if they are moving with the same speed. Out of a heavy body and a light body moving with same speed, the heavier body will have greater momentum, so, the heavier body requires a greater opposing force to stop than a lighter body. So, this statement is also true.

(d) The greater the change in the momentum in a given time, the lesser is the force that needs to be applied.

Sol. The greater the change in momentum in a given time, the lesser is the force that needs to be applied. Since the force and change in momentum are directly proportional to each other, so in order to produce a large change in momentum in a given time, a large force will be required. Therefore, this statement is wrong.

Hence, the correct answer is option D.

So, the correct answer is “Option D”.

3. A cricket ball of mass 150 g has an initial velocity $\vec{u} = 1\,(3\hat{i} + 4\hat{j})\,m\,s^{-1}$ and a final velocity $\vec{v} = -(3\hat{i} + 4\hat{j})\,m\,s^{-1}$ after being hit. The change in momentum (final momentum-initial momentum) is (in kg m s^{1})

(a) zero (b) $-(0.45\hat{i} + 0.6\hat{j})$ (c) $-(0.9\hat{i} + 1.2\hat{j})$ (d) $-5(\hat{i} + \hat{j})$.

Ans. (c)

4. In the previous problem the magnitude of the momentum transferred during the hit is

(a) Zero (b) 0.75 kg m s^{-1} (c) 1.5 kg m s^{-1} (d) 14 kg m s^{-1}.

Ans. (c)

5. Conservation of momentum in a collision between particles can be understood from

(a) conservation of energy. (b) Newton’s first law only.

(c) Newton’s second law only. (d) both Newton’s second and third law.

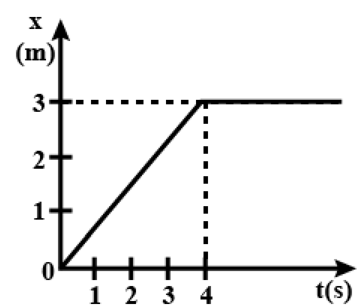
Sol. (d)

From the FBD

$T\sin 45° = F$ and $T\cos 45° = 50$

Therefore F = 50N

6. The position time graph of a body of mass 2 kg is as given in Figure. What is the impulse on the body at t = 0 s and t = 4 s.



Sol. Here, m = 2 k g

As is clear from position time graph in At t = 0 , x = 0 body is at rest . Therefore impulse of body (at t=0)=0

From t = 0 t=0 to t = 4 t=4 s position time graph of body is a st line with positive slope. The body moves with a uniform velocity.

Beyond t = 4s position time graph is parallel to time axis Therefore, body comes to rest
Now initial vel of body (v) = tan θ = 3/ 4 m / s ;final vel of body (υ) = 0 (υ)=0
∴ Impulse (at t = 4 s) = Change in momentum
= m (v − u) = 2 (0 – 3/4) = − 3/2 k g m s^{-1}

(2 Marks Questions)

7. A cricketer lowers his hands to catch the ball safely. Explain, why?

Sol. As we know that impulse = force × time = change in linear momentum.
By moving his hands in backward direction cricketer allows a longer time for his hands to stop the ball. As a result, the balls exerts a smaller force on his hands and hands are not injured.

8. Prove impulse-momentum theorem.

Sol. According to Newton's second law of motion, external force = Rate of change of momentum
$\vec{F} = \frac{d\vec{p}}{dt} \Rightarrow \vec{F}dt = d\vec{p}$ …(i)
Let momentum change for $\vec{p}_1$ to $\vec{p}_2$ in the time interval 0 to t.
The equation (i) becomes, $\int_0^t \vec{F}.dt = \int_{\vec{p}_1}^{\vec{p}_2} d\vec{p} = \vec{p}_2 - \vec{p}_1$ …(ii)
And as we know $\int_0^t \vec{F}.dt = \text{Impulse} = \vec{J}$
From equation (ii) and (iii), $\vec{J} = \vec{p}_2 - \vec{p}_1$
i.e. the impulse of force is equal to the total change in momentum produced by the force.

9. 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 M be the mass of the nucleus at rest. Suppose it disintegrates into two smaller nuclei of masses m_1 and $m_2$which move with velocities v_1 and v_2 respectively.
Therefore momentum before disintegration = M × 0 = 0
Momentum after disintegration = $m_1v_1 + m_2v_2$
According to the law of conservation of momentum, $m_1v_1 + m_2 v_2 = 0$
Or $v_2 = -\frac{m_2}{m_1}.v_1$
As the masses m_1 and m_2 cannot be negative, the above equation shows v_1 and v_2 must have opposite sings i.e. the two products must move in opposite directions.

10. 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?

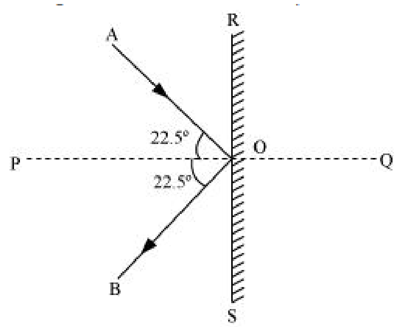
Sol. Mass of shell, m = 0.02kg, mass of gun, M = 100kg, speed of shell, v = 80ms^{-1}
Let V be the recoil speed of the gun. According to law fo conservation of momentum
Initial momentum = Final momentum
Or 0 = mv + MV

Or V = $-\frac{mv}{MV} = -\frac{0.02\times80}{100}$ = - 0.016 ms^{-1}

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

11. 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.



The horizontal components of velocity are to be considered for imparting impulse as vertical components are in the same direction thus impulse in the vertical direction is zero.

The impulse is given by a change in momentum.

Initial momentum = $-mv\cos\Theta$

Final momentum = $mv\cos\Theta$

Thus impulse is $= mv\cos\Theta - (-mv\cos\Theta) = 2mv\cos\Theta$

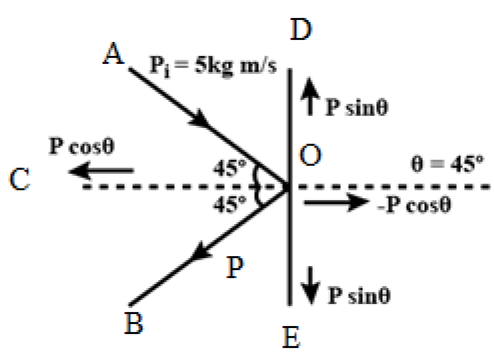
or $= 2\times0.15\times15\ \cos22.5^\circ$

or $= 4.16\ Kg\ m/s$

(3 Marks Questions)

12. A ball moving with am momentum of 5 kg ms^{-1} strikes against a wall at an angle of 45° and is refracted at the same angle. Calculate the change in momentum.

Sol.



Initial momentum is along AO. It has two rectangular components:

p cos 45° along CO and p sin 45° along DO. Final momentum p is along OB. It has two rectangular components: p cos 45° along OC and p sin 45° along OE

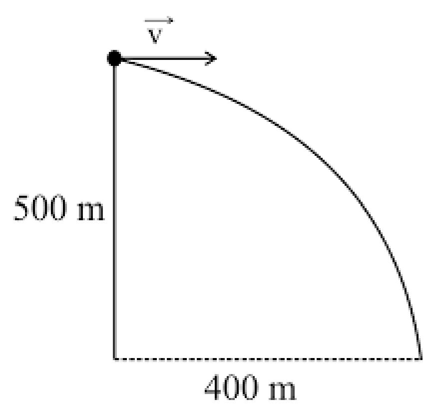
Change in momentum along vertical direction = final momentum – initial momentum
= p sin 45° - p sin 45° = 0
Change in momentum along horizontal direction
= - p cos 45° - p cos 45° = - 2p cos 45° = - 2 × 5 × $\frac{1}{\sqrt{2}}$ = 2 × 5 × 0.707 = - 7.01 kg ms^{-1}
Negative sign indicates that the direction of change in momentum is away from the wall.

13. A hammer of mass 1kg moving with a speed of 6 ms^{-1} strikes a wall and comes to rest in 0.1s. Calculate (a) the impulse of force (b) the retardation of the hammer, and (c) the retarding force that stops the hammer.

Sol. Mass of hammer, m = 1kg; initial velocity, u = 6ms^{-1}; Final velocity, v = 0 and t = 0.1s
(a) Impulse = Ft = m(v – u) = 1(0 – 6) = - 6Ns
(b) Retardation of the hammer = $\frac{F}{m} = \frac{60}{1}$ = 60 ms^{-2}
(c) Retarding force that stops the hammer, F = $\frac{\text{impulse}}{\text{time}} = \frac{6}{0.1}$ = 60N.

14. A 100kg gun fires a ball of 1kg horizontally from a cliff of height 500m. It falls on the ground at a distance of 400m from the bottom of the cliff. Find the recoil velocity of the gun. (acceleration due to gravity = 10 ms^{-2}).

Sol. Given mass of gun, M = 100kg; mass of the shell. M = 1kg; recoil velocity of gun = v; horizontal distance covered by ball, x = 400m;
Vertical distance covered by ball, y = 500m
U_x = ?, a_x = 0, a_y = g = 10ms^{-2}, u_y = 0, t = ?



Motion along y axis, y = $u_y t + ½ a_y t^2$
⇒500 = 0 × t + ½ × (10)t^2
⇒ 5t^2 = 500 ⇒ t = 10s
Motion along x axis, x = $u_x t + ½ a_x t^2$
⇒ 400 = u_x(10) + ½ × 0 ×10^2
⇒ 10u_x = 400 ⇒ u_x = 40ms^{-1}
Now applying conservation of momentum principle before and after firing
M × 0 + m × 0 = - Mv + mu_x

$\Rightarrow v = \frac{mu_x}{M} = \frac{2\times40}{100} = 0.4\ ms^{-1}$

15. Why does a gun recoil on firing? What is recoil velocity? Find the expression for it.

Sol. It recoils due to conservation of momentum of system.

When you fire a bullet from the gun, the gun experience a force in the backward direction. Because of this force, the gun attains a velocity in the backward direction. This velocity is known as **recoil velocity**.

Initial momentum of gun = Final momentum of gun

$0 = m_1v_1 + m_2v_2$

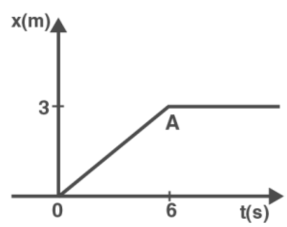
$v_2 = -(m_1v_1) / m_2$

(-ve sign because velocity of gun is in opposite direction of bullet)

Recoil velocity = $-v_2 = (m_1v_1) / m_2$

Where m_1 and m_2 are masses of bullet and gun respectively v_1 and v_2 are velocity of bullet and gun respectively.

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

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

(ii) Before t = 0, the particles is at rest, so u = 0

After t = 0, the particle has a constant velocity, v = slope of OA = ¾ ms^{-1}

Therefore at t = 0,

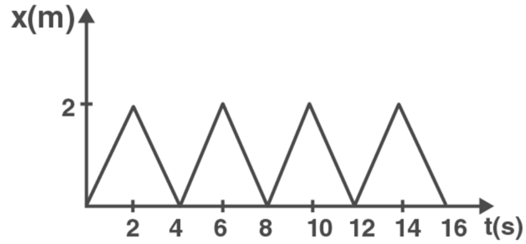
Impulse = change in momentum = m(v – u) = 4(3/4 – 0) = 3kg ms^{-1}

Before t = 0,. The p[article has a constant velocity, u = slope of OA = ¾ ms^{-1}

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

At t= 4s, impulse = n(v – u) = 4(0 – ¾) = 3kg ms^{-1}.

17. 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?



Sol. Figure shows that (i) the direction of motion of the particle changes after every 2 sec and (ii) in both directions, the particle moves with a uniform speed.

Before t = 2s, velocity of the particle, u = slope of x-t graph

= $\frac{(20-)\text{cm}}{(2-0)\text{s}} = 1\text{cms}^{-1} = 0.01\text{ms}^{-1}$

After t = 2as, velocity of the particle, v = $\frac{(0-2)\text{cm}}{(4-2)\text{s}} = 1\text{cms}^{-1} = -0.01\text{ms}^{-1}$

Mass of particle, m = 0.04kg

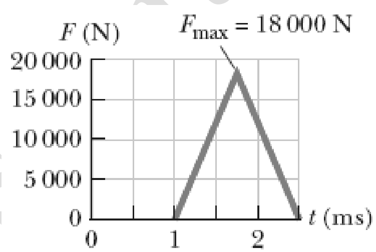
At t= 2s, magnitude of the impulse = change in momentum = m(u – v)

= 0.04[0.01 – (- 0.01)] $\text{kgms}^{-1} = 8 \times 10^{-4}\ \text{kgms}^{-1}$

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

(5 Marks Questions)

18. Figure shows an estimated force time graph for a base ball struck by a bat.



From this curve, determine (i) impulse delivered to the ball (ii) force exerted on the ball (iii) the maximum force on the ball.

Sol. (i) Impulse = Area ABC – ½ × 18000 × (2.5 – 1) = 1.35 ×10^4 kg ms^{-1}.

(ii) Force = $\frac{\text{Impulse}}{\text{Time}} = \frac{1.35\times10^4}{(2.5-1)}$ = 9000N

(iii) Maximum force = 18000N.

C. EQUILIBRIUM OF A BODY

(1 Marks Questions)

1. The magnitude of the net force acting on a car moving with a constant velocity of 30 km/h is

(a) 15N (b) 20N (c) 30N (d) zero

Ans. (d)
Since the car is moving with a constant velocity, the net force on the car is zero.

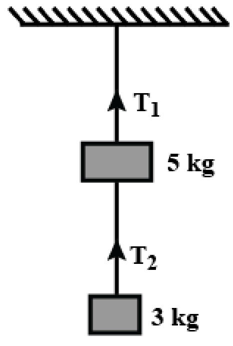
2. The quantity which remains conserved in rocket repulsion
(a) Impulse (b) Force (c) Momentum (d) Acceleration
Ans. (c)

3. A body subjected to three concurrent forces is found to be in equilibrium. The resultant of any two forces.
(a) is equal to third force (b) is opposite to third force
(c) is collinear with the third force (d) all of these
Ans. (d)

4. What is the condition for equilibrium of an object?
Sol. The equilibrium condition of an object exists when Newton's first law is valid. An object is in equilibrium in a reference coordinate system when all external forces (including moments) acting on it are balanced. This means that the net result of all the external forces and moments acting on this object is zero.

(2 Marks Questions)

5. Two masses of 5 kg and 3 kg are suspended with help of massless inextensible strings as shown in Figure. Calculate T_1 and T_2 when whole system is going upwards with acceleration = 2 m s^2 (use g = 9.8 m s^{-2}).



Sol. $m_1 = 5$ kg, $m_2 = 3$ kg, g = 9.8 m/s^2
Force on mass m_1,
$T_1 - T_2 - m_1 g = m_1 a$
$T_1 - T_2 - 5g = 5a$
$T_1 - T_2 = 59.0$ N
Force on mass m_2
$T_2 - m_2 g = m_2 a$
$T_2 = m_2 (g + a) = 3(9.8+2)$

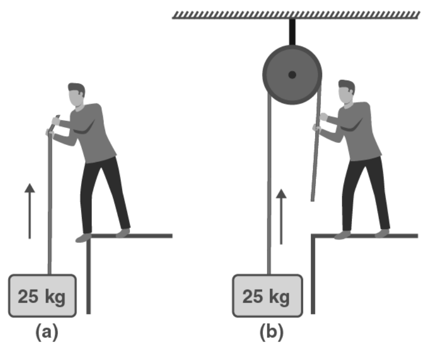
$T_2 = 35.4$
$T_1 = T_2 + 59.0$
or $T_1 = 35.4 + 59.0 = 94.4$ N

(3 Marks Questions)

6. 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.

Sol. (a) force on 7^{th} coin = force due to 3 coins on its top = 3mg
(b) force on the 7^{th} coin by 8^{th} coin = masses of 8^{th}, 9^{th}, 10^{th} coins × g = 3mg
(c) reaction on 6^{th} coin on 7^{th} coin = force on the 6^{th} coin due to 7^{th} coin = 4mg

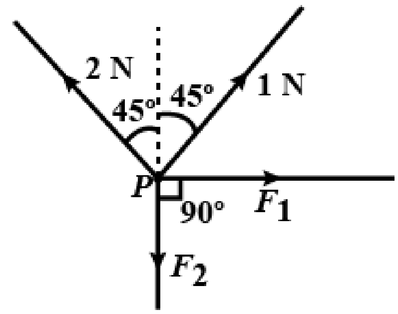
7. A block of mass 25 kg is raised by a 50 kg man in two different ways as shown in Fig. What is the action on the floor by the man in the two cases? If the floor yields to a normal force of 700 N, which mode should the man adopt to lift the block without the floor yielding?



Sol. In mode (a) the man applies force equal to 25kg wt in the upward direction. According to Newton's third law of motion, there will be downward force of reaction on the floor.
Therefore, total action on the floor buy the man = 50kg wt 25 kg wt = 75 kg wt
= 75 × 9.8N = 735N
In mode (b), the man applies a downward force equal to 25 kg wt. According to Newton's third law, the reaction will be in the upward direction.
Therefore action on the floor by the man = 50 kg wt - 25 kg wt = 25 kg wt
= 25 × 9.8N = 245N
As the floor yields to a downward force of 700N, so the man should adopt mode (b).

(5 Marks Questions)

8. There are four forces acting at a point P produced by strings as shown in Figure, which is at rest. Find the forces F_1 and F_2.



D. ACCELERATED MOTION

(1 Marks Questions)

1. A body under the action of a force $\vec{F} = 6\hat{i} - \hat{j}$ N acquires an acceleration of 5 ms^{-2}. The mass of the body is

   (a) 2kg (b) 5kg (c) 4kg (d) 6kg

Ans. (a)

Mass of the body is, m=F/a=10N/5ms^{-2}=2kg.

2. Give the magnitude and direction of the net force acting on

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

Sol. As the raindrop is falling with a constant speed, so its acceleration a will be 0. As the force acting on a particle is given by , so the net force acting on the rain drop will be 0.

   (b) a cork of mass 10 g floating on water

Sol. When a cork floats on water, two forces will act on it. One of them is the weight of the cork acting vertically downwards and the other is the upthrust by water acting vertically upwards. As the cork is floating on water, so the two forces acting on it balance each other. Hence the net force acting on the cork will be 0.

   (c) a kite skillfully held stationary in the sky

Sol. As the kite is held stationary, so by Newton's first law of motion, the algebraic sum of forces acting on the kite is zero.

(d) a car moving with a constant velocity of 30 km/h on a rough road

Sol. When a car moves on a rough road, three forces will act on it, its weight acting vertically downwards, the normal reaction by the road acting on it vertically upwards. These two forces balance each other. The third force will be the frictional force acting opposite to the motion of the car. As the car is moving with a constant velocity, so its acceleration will be zero. Hence the net force acting on the car will be 0.

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

Sol. Since, the high-speed electron is free from all material objects and no electric field and magnetic field acts on it. So, the net force acting on it will be 0.

3. 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

Sol. (a) When the pebble moves vertically upwards, the net force on the pebble is given by: F = Mg = 0.05 x 9.8 = 0.49 N (vertically downwards) (

b) In this case, the net force on the pebble is F = Mg = 0.49 N (vertically downwards)

(c) Even in this case, the net force is F = Mg = 0.49 N (vertically downwards)

If the pebble was thrown at an angle of 45° with horizontal, the pebble will have components of velocity along horizontal and vertical. These components of velocity along horizontal or along vertical do not lead to any force on the pebble. Therefore, if the pebble were thrown at some angle with the horizontal, the answer in case (a), (b) and (c) will not change.

4. 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

Sol. 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 × 10 = 1 N

Acceleration due to gravity always acts in the downward direction.

(b) just after it is dropped from the window of a train running at a constant velocity of 36 km/h

Sol. 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.

(c) just after it is dropped from the window of a train accelerating with1 m s^{-2}

Sol. 1 N; vertically downward

It is given that the train is accelerating at the rate of 1 m/s^2 .Therefore, the net f orce acting on the stone, F' = ma = 0.1 × 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) 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.

Sol. 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 × 1 = 0.1

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. Given

F=50N, M=20kg, u=15m/s, v=0

As F=ma

a=50/20=2.5m/s^2

Since the retarding is negative so -2.5 m/s^2

Time=

v=u+at =0-15/-2.5=6s

Ans2 F=ma

50=20×0-15/t

50=20×-15/t

50/20×-15=1/t

-6 s=t or t = 6s

6. A person of mass 50 kg stands on a weighing scale on a lift. If the lift is descending with a downward acceleration of 9 m s^{-2}, what would be the reading of the weighing scale? (g = 10 m s^{-2})

Sol. The apparent weight would decrease on the weighing scale if the lift is descending with an acceleration 'a'.

Thus, W' = R = (mg – ma)

= m (g – a)

Due to reaction force, apparent weight by the lift on the weighing scale would be,

W' = 50 (10 – 9) =50 N

Thus, the reading of the weighing scale would be

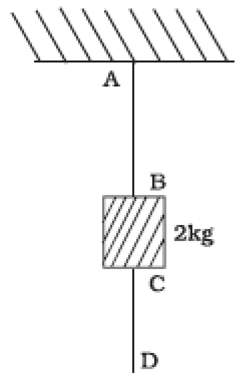
$$\frac{R}{g} = \frac{50}{10} = 5kg$$

(2 Marks Questions)

7. An astronaut accidently gets separated out of his small spaceship accelerating in inter-stellar space at a constant rate of 100 ms^{-2}. What is the acceleration of the astronaut the instant after he is outside the spaceship?

Sol. Assuming that there are no nearby stars to exert gravitational force and the small spaceship exerts negligible gravitational force on the astronaut, then moment he gets out of the ship, there is no external force on him. By the first law of motion, the acceleration of the astronaut is zero.

8. A mass of 2kg is suspended with thread AB (Figure). Thread CD of the same type is attached to the other end of 2 kg mass. Lower thread is pulled gradually, harder and harder in the downward direction so as to apply force on AB. Which of the threads will break and why?



Sol. Thread AB breaks down we pull the lower thread slowly then upper thread would break. This is because already the upper thread is having tension due to weight of the 2 kg mass. Addition tension is applied to this thread by pulling. Hence chances are more for upper thread to get broken first.

9. In the above given problem if the lower thread is pulled with a jerk, what happens?

Sol. In this case as pulling with jerk is given now more chances for second thread to get broken As sudden impact is given to the hanging mass then due to conservation of momentum the mass would go upwards instantly and tension would be more on the lower thread and it gets broken first.

(3 Marks Questions)

10. A bus starts from rest accelerating uniformly with 4 ms^{-2}. At t = 10s, a stone is dropped out of a window of the bus 2m high. What are the (i) magnitude of velocity and (ii) acceleration of the stone at 10.2s? Take g = 10 ms^{-2}.

Sol. (i) Horizontal velocity of the bus or the stone at t = 10s is

$v_x = u + at = 0 + 4 \times 10 = 40ms^{-1}$

For vertical motion of the stone, u =0, a = g = 10ms^{-2}, t = 10.2 – 10 = 0.2s
Therefore $v_y = 0 + 10 \times 0.2 = 2ms^{-1}$
Magnitude of the resultant velocity of the stone is

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{40^2 + 2^2} = \sqrt{1604} = 40.04ms^{-1}.$$

(ii) After the stone is dropped its acceleration along horizontal is zero. It has only a vertical acceleration of 10ms^{-2}.

11. A body of mass m moves along X-axis such that its position coordinate at any instant t is $x = at^4 - bt^3 + ct$, where a, b, and c are constants. What is the force acting on the particle at any instant t?

Sol. Position coordinates, $x = at^4 - bt^3 + ct$
Velocity = $dx/dt = 4at^3 - 3bt^2 + c$
Acceleration = $d^2x/dt^2 = d/dt(4at^3 - 3bt^2 + c) = 12at^2 - 6bt$
Force = Mass × acceleration = $m(12at^2 - 6bt)$

12. A truck starts from rest and rolls down a hill with constant acceleration. It travels a distance of 400m in 20s. Calculate the acceleration and the force acting on it if its mass is 7 metric tons.

Sol. As $s = ut + ½ at^2$
So, $400 = 0 + ½ a(20)^2$
Or $a = 2ms^{-2}$ and $F = ma = 7000\times2 = 14000N$.

13. A 70kg man in sea is being lifted by a helicopter with the help of a rope which can bear a maximum tension of 100 kg wt. With what maximum acceleration the helicopter should rise so that the rope may not break? Take g = 9.8 ms^{-2}.

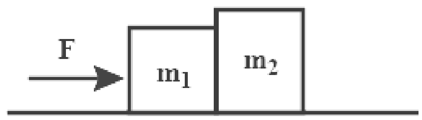
Sol. Given- T = 100 kg-wt = 1000 Nm
= 70 kg
Solution- Let a be the required acceleration.
Then, for maximum tension, ma = T – mg
70a = 1000 - 70×10
70a = 300
a = 4.286 m/s^2
Therefore, maximum acceleration without breaking the rope is 4.286 m/s^2 or 4.2 ms^2

14. Fuel is consumed at the rate of 50 g per second in a rocket. The exhaust gases are rejected at the rate of 5×10^5 cms^{-1}. What is the thrust experienced by the rocket?

Sol. F = ma
m=0.05
$a = 5 \times 10^3$ m/s^2

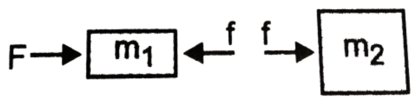
$F = 0.05 \times 5\times10^3 = 250$ N = thrust

15. Two blocks of masses m_1 and m_2 in contact lie on a horizontal smooth surface as shown in fig. The blocks are pushed by a force F. If the two blocks are always in contact, what is the force at their common interface?



Sol. From Newton's second law, the common acceleration produced in the system will be

$a = \frac{F}{m_1+m_2}$



If the block of mass m_1 exerts force f on block of mass m_2, then the force of reaction on block of mass m_1 will be equal and opposite to f. These forces are shown in free body diagrams of figure. As the block of mass m_2 has acceleration a, so

$f = m_2 a = \frac{m_2 F}{m_1+m_2}$

16. 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?

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

As v – u +at

So, 3.5 = 2 +a × 25

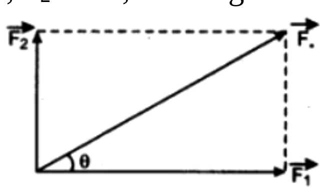
Or $a = \frac{3.5-2}{25} = 0.06\ ms^{-2}$

Force F = ma = 3 × 0.06 = 0.18N.

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

17. 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. As shown in figure, F_1 – 8N, F_2 – 6N, m = 5kg



The magnitude of the resultant force, $F = \sqrt{F_1^2 + F_2^2} = \sqrt{8^2 + 6^2}$ = 10N

Them magnitude of the acceleration produced, a = F/m = 10/5 = 2ms^{-2}.

If the force F makes angle θ with F_1 then, cos θ = F_1/F = 8/10 \ 0.8

θ = $\cos^{-1}(0.8)$ = 36.87° with the 8N force.

18. 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.

Sol. Here $u = 36kmh^{-1} = 10ms^{-1}$, $v = 0$, $t = 4s$, $m = 400+65 = 465kg$

As $v = u + at$

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

Magnitude of the retarding force on the vehicle is $F = ma = 465\times 2.5 = 1162.5N$.

19. 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?

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

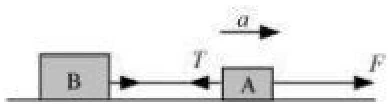
(b) At the mean position, the bob has a horizontal velocity. If the string is cut, it will fall along a parabolic path under the effect of gravity.

20. 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?

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

Let T be the tension in the string and a be the acceleration produced in the system, in the direction of applied force F. Then $a = \frac{F}{m_1+m_2} = \frac{600}{10+20} = 20ms^{-2}$

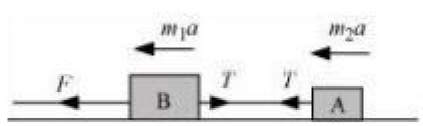
(i) Suppose the pull F is applied on the body B of mass 20kg as shown in figure.



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

$T_1 = m_1a = 10 \times 20 = 200N$.

(ii) When the pull F is applied on body A of mass 10 kg (fig), tension in the string wil be



$T_2 = m_2a = 20\times20 = 400N$

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

21. 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. Her $m = 8kg$, $M = 12kg$, $g = 10ms^{-2}$

From the derivation of connected motion, we have

$a = \frac{\mathbf{M-m}}{\mathbf{M+m}}.\mathbf{g} = \frac{\mathbf{12-8}}{\mathbf{12+8}} \times \mathbf{10}$ = $2ms^{-2}$
$T = \frac{\mathbf{2Mm}}{\mathbf{M+m}}.\mathbf{g} = \frac{\mathbf{2\times12\times8}}{\mathbf{12+8}} \times \mathbf{10}$ = 96N.

22. 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?

Sol. Here u = $15ms^{-1}$, v = 0, t = 1s, A = $10^{-2}m^2$
Density of water = 1000 kgm^{-3}
m = mass of water gushed out per second
$= \frac{\mathbf{Volume\times density}}{\mathbf{Time}} = \frac{\mathbf{Area\times distance\times density}}{\mathbf{Time}}$
= Area × velocity × density = Aυρ = 10^{-2} × 15 × 1000 = 150kg
Force exerted by the wall on water, F = ma = $m\left(\frac{\mathbf{v-u}}{\mathbf{t}}\right) = \mathbf{150} \times \frac{\mathbf{0-15}}{\mathbf{1}}$ = - 2250N
Force exerted on the w all by the impact of water, F' = - F = 2250 N

(5 Marks Questions)

23. (a) A person of mass m is standing in a lift. Find his apparent weight when the lift is (i) moving upward with uniform acceleration a (ii) moving downward with uniform acceleration a(<g) (iii) falls freely
(b) Explain why, it is easier to pull a lawn mover than to push it.
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24. 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.

Sol. We take south to north as the positive direction. Then u -= $+10ms^{-1}$ (due north), F = - 8N (due south), t = 30s, m = 0.4kg.
A = F/m = -8/40 = - $20ms^{-2}$
(i) At t = 5s, no force acts on the particle.
Therefore x = ut = 10 × (-5) = - 50m

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

$x = ut + ½ at^2 = 10 × 25 - ½ × 20 × (25)^2 = 250 – 6250 = -6000m = - 6$ km

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

Therefore distance covered during first 30s is

$x_1 = ut + ½ at^2 = 10 − 20 × (30)^2 = - 8700m$

Velocity acquired at t = 30s will be v = u + at = 10 – 20 × 30 = - 590 ms^{-1}

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

x_2 = vt = - 590 Ú 70 = - 41300m

Therefore position of the particle at t = 30s is $x_1 + x_2$ = - 8700 – 41300 = - 50000m = -50km

25. 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?

Sol. Mass of man standing on a weighting scale is m = 70kg. SO actual weight of man, mg = 70g

(a) When lift is moving upwards with a uniform speed, v = 10m/s

In this case, acceleration a = 0

Therefore net force on the man is R – mg = ma; where R is the reaction force read by the weighting machine and is the apparent weight of man.

If a = 0 the R – mg = 0 or R = mg = 70g

= 70 × 9.8 = 686N

(b) When lift is moving downward with a uniform acceleration of 5m/s^2, the net downward force on the man is mg – R = ma

Therefore apparent weight, R = m(g – a) = 70(9.8 – 5) = 336N

(c) When lift freely falling under gravity then acceleration is equal to acceleration due to gravity, i.e. a = g

Then net downward force on the man is R = m(g – a) = m(g – g) = 0

Therefore apparent weight, R = 0.

26. 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

Sol. Mass of helicopter, M = 1000kg, mass of the crew and passengers, m = 300kg

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

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

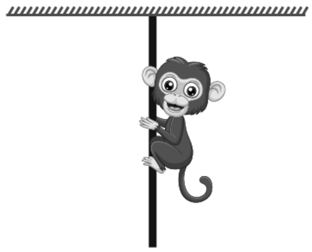
F = apparent weigth = m(g +a) = 300(10+15) = 7500N vertically downwards

(b) Action of the rotor of the helicopter on the surrounding air = apparent weight of the helicopter, crew and passengers

= (M+m)(g+a) = (1000+300)(10+15) = 32500N, vertically downwards

(c) Force on the helicopter due to the surrounding air is equal and opposite to the action of the rotor of the helicopter on the surrounding air.
So, force on surrounding air = 32500 N vertically upwards.

27. 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).



Sol. Mass of the monkey = 40kg.
(a) When a monkey climbs u=p with an acceleration of 6 ms^{-2}, the tension T in the siring must be greater than the weight of the monkey, i.e., T = mg = ma
= 40(10+6) = 640N > 600N
Therefore the rope will break.
(b) When the monkey climbs down with an acceleration a = 4ms^{-2}
So, mg – T = ma or T = m(g – a) = 40(10 – 4)
Or T = 240N < 640 N
Therefore rope will not break.
(c) When monkey climbs up with a uniform speed i.e. a = 0
So, T = mg = 400N<600N
Hence rope will not break
(d) When the monkey fall down the rope nearly freely under gravity i.e. a = g
So, T = T = m(g – a) = m(g – g) = 0
Hence the rope will not break.

E. FRICTION

(1 Marks Questions)

1. Define angle of friction.

Sol. Angle made by the resultant of normal reaction and limiting friction with the normal reaction is called the angle of friction. The coefficient of static friction is equal to the tangent of the angle of friction.

2. A book is lying on the table. What is the angle between the action of the book a on the table and the reaction of the table on the book?
(a) 0° (b) 45° (c) 90° (d) 180°

Ans. (a)

3. Why are tyres made of rubber not of steel?

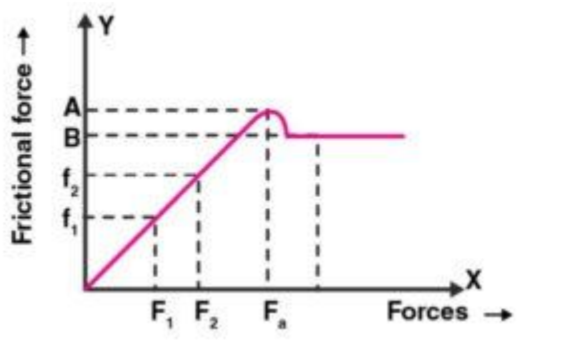
Sol. For making tyres for vehicles, we require a type of material which can be made into tyre shape easily. Iron is a lot harder than the rubber and requires more force and effort. Since rubber can be given a circular shape much more easily than iron, the car tyres are made of rubber and not of iron.

4. In a tug of war, the team that pushes harder against the ground wins. Why?

Sol. The ground is pushing back equally hard, but since the two teams are pushing against the ground with different forces, then the team that pushes harder against the ground will have the greater horizontal force and they will have greater net force--making them the winner.

5. A block placed on a rough horizontal surface is pulled by a horizontal force F. Let f be the force applied by the rough surface on the block. Plot a graph of f versus F.

Sol. F_1 is the force exerted on the heavy box, which is equal to F_1 and is resisted by the lesser frictional force f_1. F = Fs, which is the maximum static frictional force, is required for the box to move. On the y-axis, this force corresponds to the frictional force fs.
When F_k-F_s is applied to the body and it begins to move, the frictional force diminishes, resulting in reduced friction.



(2 Marks Questions)

6. Sand is thrown on tracks covered with snow. Why?

Sol. When tracks are covered with snow, there is considerable reduction fo frictional force. So the driving is not safe. When sand is thrown on the snow covered tracks, the frictional force increases. So safe driving is possible.

7. It is difficult to move a cycle along a road with its brakes on. Explain.

Sol. When the cycle is moved with brakes on, the wheels can only skid. So, the friction is sliding in nature. Since the sliding friction is greater than rolling friction, therefore, it is difficult to move a cycle with its brakes on.

8. Why do we slip on a rainy day?

Sol. On a rainy day, the wet ground becomes very smooth. The friction between our feet and the ground is greatly reduced. It causes us to slip.

9. A horse has to apply more force to start a cart than to keep it moving. Why?

Sol. During the first few steps of his motion, the horse has to work against the limiting friction and once the cart starts moving, the horse has to work against kinetic friction which is less than limiting friction.

10. It is difficult to push a box full of clothes than an empty box. Explain.

Sol. From Newton's second law of motion,

Force, $F = m \times a$ where ma and a are the mass and acceleration of the box

Since acceleration of the box is nearly constant

Therefore $F \propto n$

Since mass of box full of clothes is more than an empty box, so it is difficult to push the box filled with clothes.

11. Why is friction called self-adjusting force?

Sol. The force of friction (f) increases with increase in the applied force (F) till it is near the maximum value called limiting value of friction. The force of friction upto the maximum value is static friction because the body remains at rest position till then. With further increase in the applied force, the frictional force decreases to become constant. This value of frictional force is called dynamic friction of kinetic friction. Thus force of friction adjust itself with applied force.

12. Proper inflation of tyres of vehicles saves fuel. Why?

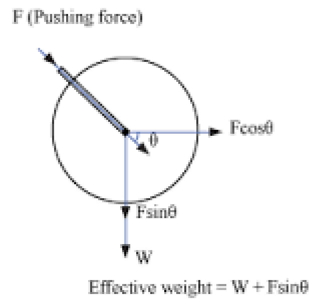
Sol. When the tyre is properly inflated, the area of contact between the tyre and the found is reduced. This reduces rolling friction. Consequently the automobile covers greater distance for the same quantity of fuel consumed.

13. How does friction help in walking? Explain.

Sol. When we walk we press our feet against the ground slantingly in the backward direction. It is the reaction of the ground on our feet in the forward direction, arising due to friction between the two which helps us to walk.

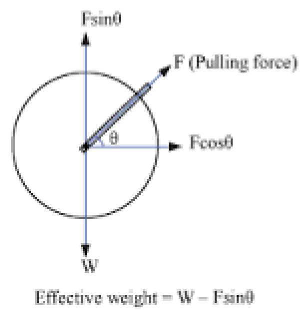
14. Use component of force, show that it is easier to pull a lawn roller than to push it.

Sol. While pushing:



Normal reaction force, R = mg + F sin θ

While pulling:



R = F sin θ

Normal reaction, R = mg – F sin θ

So the normal reaction in case of pulling is less than the normal reaction while pushing the lawn roller. Therefore it is easier to pull the lawn roller than pushing it.

(3 Marks Questions)

15. A scooter weighs 120 kg f. Brakes are applied so that wheels stop rolling and start skidding. Find the force of friction is the coefficient of friction is 0.4.

Sol. Here R = weight of scooter = 120kg f, $\mu = 0.4$

Therefore $f = \mu R = 0.4\times120 = 45$ kg f.

16. A suitcase is gently dropped on a conveyor belt moving at 3 m/s. If the coefficient of friction between the belt and the suitcase is 0.5, how far will the suitcase move on the belt before coming to rest?

Sol. Here, $u = 3\ m\ s^{-1}$, $\mu = 0.5$, s = ? $a = -\mu g = -0.5 \times 9.8 = -4.9\ m/s^{2}$

From $v^2 - u^2 = 2as$

$s = v^2 - u^2/2a = 0 - 3^2/\ 2(-4.9) = 0.92$ m

17. A block of mass 2kg rests on a plane inclined at an angle of 30° with the horizontal. The coefficient of friction between the block and the surface is 0.7. What will be the frictional force acting on the block?

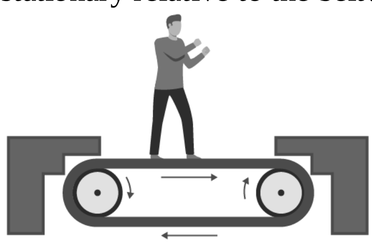
Sol. Here $f = \mu R = \mu\, mg \cos\theta = 0.7 \times 2 \times 9.8 \cos 30° = 0.7 \times 9.8 \times 0.866 = 11.9N$

18. State laws of friction.

Sol. There are five laws of friction and they are:

- The friction of the moving object is proportional and perpendicular to the normal force.
- The friction experienced by the object is dependent on the nature of the surface it is in contact with.
- Friction is independent of the area of contact as long as there is an area of contact.
- Kinetic friction is independent of velocity.
- The coefficient of static friction is greater than the coefficient of kinetic friction.

19. 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.)



Sol. As the man is standing stationary w.r.t. the belt, so, acceleration of the man = acceleration of the belt = a = $2ms^{-2}$

Mass of man, m = 65kg, net force on the man = ma = 65×1 = 65N

Given coefficient of friction, $\mu = 0.2$

Therefore limiting friction, $f = \mu R = \mu mg$

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

$ma' = f = \mu mg =$

So, $a' = \mu g = 0.2 \times 9.8 = 1.96\ ms^{-2}$

20. 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.

Sol. Mass of block, m = 15kg, $\mu_s = 0.18$, a = 0.5 ms^{-2}, t = 20s

Maximum value of the static friction, $f_{ms} = \mu_s R = \mu_s mg = 0.18 \times 15 \times 9.8 = 26.46N$

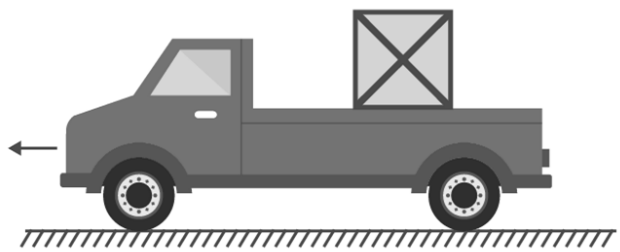
Force acting on the block during the accelerated motion, $F = ma = 15 \times 0.5 = 7.5N$

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

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

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

21. 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).



Sol. Mass of the box, m = 40kg, acceleration of truck, a = 2ms^{-2}, distance of the box from the rear end, s = 5m, coefficient of friction, $\mu = 0.15$

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

Motion of the box is opposed by the frictional force, $f = \mu R = \mu mg$

So, net force on the box in the back ward direction is

$F' = F - f = ma - \mu mg = m(a - \mu g) = 40(2 - 0.05 \times 9.8) = 21.2N$

Acceleration produced in the box in the backward direction,

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

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

$s = ut + 182\ a't^2$ or $5 = 0 \times t + ½ \times 0.53 \times t^2$ or $t^2 = \frac{5\times2}{0.53} = \frac{10}{0.53}$

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

$s' = ½\ at^2 = ½ \times 2 \times \frac{10}{0.53} = 18.57m.$

(5 Marks Questions)

22. Define the terms static friction, limiting friction and kinetic friction. Draw the graph between friction and applied force on any object and show static friction, limiting friction and kinetic friction in graph.

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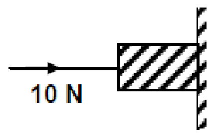
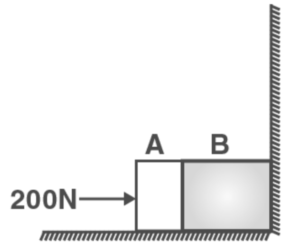
23. (a) Draw a graph to show the variation of force of friction with the applied force.
(b) Define angle of repose and deduce the relation with coefficient of static friction.
(c) A horizontal force of 10N is necessary to just hold a block stationary against the wall. Find the weight of the block if coefficient of friction between the block and wall is 0.2.



24. 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.



Sol. Mass of body A, m_A = 5kg, mass of body B, m_B = 10kg
Coefficient of friction, μ = 0.15, applied force, P = 200N
(a) Force on limiting friction is f = μR = $\mu(m_1 + m_2)g$ = 0.15(5+10)×9.8 = 22.05N (towards left)
When a force of 200N is applied, the net force exerted on the portion is
P' = O – f = 200 – 22.05 = 177.95 (towards right)
Reaction of the partition = 177.95N (towards left)
(b) Force on limiting friction on body A is
$f_1 = \mu m_1 g$ = 0.15×5×9.8 = 7.35ZN
Net force exerted by body A on body B = P_1 = P = f_1 = 200 – 7..5 = 192.65 (towards right)
Reaction of body B on A = 192.65N (towards left)
When the partition is removed: The system of the two bodies moves under the action of the net force. P' = 177.95N
Acceleration produced in the system, a = $\frac{P'}{m_1+m_2} = \frac{177.95}{5+10}$ = 11.86ms^{-2}
Force producing motion in the body A = m_2a = 5 × 11.86 = 59.3N
Net force exerted by A on B after the removal of partition= P_1 = 59.3 = 19.65 – 59.3 = 133.35 (towards right)
Reaction of the body by B on A = 133.5N (towards left)

F. CIRCULAR DYNAMICS

(1 Marks Questions)

1. What happens to a stone tied to the end of a string and whirled in a circle if the string suddenly breaks?

Sol. When the string breaks, the centripetal force stops to act. Due to inertia, the stone continues to move along the tangent to circular path. So, the stone flies off tangentially to the circular path.

2. 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

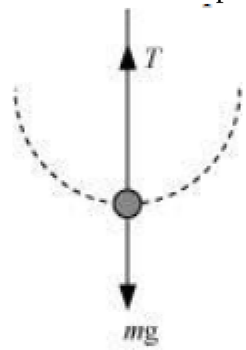
Ans. (i)
The net force on the particle directed towards the centre is T. This provides the necessary centripetal force to the particle moving in the circle.

3. 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).

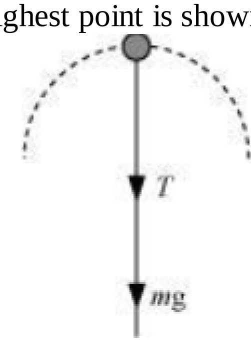
	Lowest Point	Highest Point
(a)	$mg - T_1$	$mg + T_2$
(b)	$mg + T_1$	$mg - T_2$
(c)	$mg + T_1 - (mv_1^2)/R$	$mg - T_2 + (mv_1^2)/R$
(d)	$mg - T_1 - (mv_1^2)/R$	$mg + T_2 + (mv_1^2)/R$

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. The free body diagram of the stone at the lowest point is shown in the following figure.



According to Newton's second law of motion, the net force acting on the stone at this point is equal to the centripetal force, i.e.,
$F_{net} = T - mg = mv_1^2/R$.......................(i) Where, v_1 = Velocity at the lowest point The free body diagram of the stone at the highest point is shown in the following figure.



Using Newton's second law of motion, we have:
$T + mg = mv_2^2/R$.......................(ii) Where, v_2 = Velocity at the highest point
It is clear from equations (i) and (ii) that the net force acting at the lowest and the highest points are respectively (T – mg) and (T + mg).

4. Why are mountain roads generally made winding upwards rather than going straight up?

Sol. Mountain roads rarely go straight up the slope. Reason: Slope of mountains are large, therefore more chances of vehicle to slip from roads.

(2 Marks Questions)

5. A cyclist riding at a speed of $14\sqrt{3}$ ms^{-1} takes a turn around a circular road of radius $20\sqrt{3}$m. What is the inclination to the vertical?

Sol. $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right) = \tan^{-1}\left(\frac{(14\sqrt{3})^2}{20\sqrt{3}\times 9.8}\right) = \tan^{-1}(\sqrt{3}) = 60°$

6. An aero-plane travelling at a speed of 500 kmh^{-1} tilts at an angle of 30°as it makes a turn. What is the radius of the curve?

Sol. Here, v = 500 kmh^{-1}, $= \frac{500\times 1000}{60\times 60}$ m/s $= \frac{500}{36}$ m/s =

$\theta = 30°$, r = ?

From $\tan\theta = \left(\frac{v^2}{rg}\right)$, $r = \left(\frac{v^2}{g\tan\theta}\right)$

$r = \frac{500}{36} \times \frac{5000}{36\times 9.8\tan 30°} = \frac{25\times 10^6\sqrt{3}}{36\times 36\times 9.8} = 3.41\times 10^3$m

7. Why does a cyclist bend inwards while riding along a curved road?

Sol. A cyclist bends inwards because then the horizontal component of the normal reaction of the ground provides the necessary centripetal force for going along the curved road.

8. 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?

Sol. Convert speed of aircraft in SI units :

$$V = 720\ Km/h = 720 \times \frac{5}{18} = 200\ m/s$$

We are familiar with the following relation :

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

or

$$r = \frac{v^2}{g\tan\Theta}$$

or

$$= \frac{200^2}{10\times\tan 15°}$$

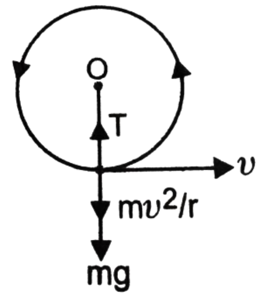
or

$$= 14925.37\ m = 14.9\ Km$$

(3 Marks Questions)

9. A child revolves a stone of mass 0.5kg tied to the end of the string of length 40cm in a vertical circle. The speed of the stone at the lowest point of the circle is 3 ms^{-1}. Calculate the tension in the string at this point.

Sol.



From figure, T = mg = $\frac{mv^2}{r}$ or T = $m\left(\frac{v^2}{r} + g\right) = 0.5\left(\frac{3^2}{0.40} + 9.8\right)$ = 16.15N.

10. 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?

Sol. Here m = 0.25kg, r = 1.2m, v = 40rev min^{-1} = 40rev $(60s)^{-1}$ = 2/3 rps
$\omega = 2\pi v = 2\pi \times 2/3 = 4\pi/3\ rads^{-1}$
Tension in the string = centripetal force
Or $T = mr\omega^2 = 0.25 \times 1.5\,(4\pi/3)^2 = 6.6N$
(i) Given T_{max} = 200N
As $\frac{mv_{max}^2}{r} = T_{max}$
So, $v_{max} = \sqrt{\frac{T_{max} \times r}{m}} = \sqrt{\frac{200 \times 1.5}{0.25}} = 34.6\ ms^{-1}$

11. If in previous question, 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?

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

12. 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?

Sol. Here r= 30m, v = $54kmh^{-1} = 15ms^{-1}$, m = 10^6kg
The centripetal force required for the purpose is provided by the lateral thrust by the outer rail on the flanges of the wheels. BY Newton's third law of motion, the train exerts an equal and opposite thrust on the outer rail causing its wear and tear

$\tan\theta = \frac{v^2}{rg} = \frac{(15)^2}{30\times9.8}$ = 0.7653

Therefore angle of banking, θ = 37.4°.

13. A disc revolves with a speed of 33 1/3 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 disc? (take g = 9.8 ms^{-2})

Sol. Here v = $33\frac{1}{3}\,\text{rpm} = \frac{100}{3}\,\text{rpm} = \frac{100}{3\times60}\,\text{rps}$

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

r = 15cm, μ = 0.15

The coin will revolved with the disc if the force of friction is enough to provide the necessary centripetal force, i.e. $mr\omega^2 \le \mu mg$ or $r \le \frac{\mu g}{\omega^2}$

Now $\frac{\mu g}{\omega^2} = \frac{0.5\times9.8}{\left(\frac{220}{63}\right)^2}$ = 0.12m = 12cm

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

(5 Marks Questions)

14. What is meant by banking of roads? What is the need for banking of a road? Obtain an expression for the maximum speed with which a vehicle can safely negotiate a curved road banked at an angle θ. The coefficient of friction between the wheels and the road is μ.

Sol. Same as 16.

15. (a) Why are circular roads banked? Deduce an expression for the angle of banking.
(b) A 1000 kg car rounds a curve on a flat road of radius 50m at a speed of 50 km/h (14m/s). Will the car make the turn or will it skid if the coefficient of friction is 0.60? Justify?

Sol. (a) Banking of roads is the phenomenon in which the outer edges of curved roads are raised above the inner edge to provide the required centripetal force to the vehicles in order for them to take a safe turn.

If any vehicle of mass m is moving with velocity v on the banked road with radius r and g is the acceleration due to gravity, then the angle of banking 'θ' can be represented as

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

(b) The centripetal force needed to make the vehicle turn is

Fc = m v^2 / r, m = mass of the car = 1000 kg, v = speed of the car = 15 m/s, r = radius of the turn = 50 m

Then

Fc = 1000 x 15^2 / 50 = 4500 N

This force must be supplied by the friction between tires and road surface. The frictional force is

Ff = u m g

u = coefficient of static friction = 0.6, m = mass of the car = 1000 kg. g = gravity acceleration = 9.8 m/s²

Then

Ff = 0.6 x 1000 x 9.8 = 5880 N

The frictional force is more than sufficient to keep the car turning, so the car will not skid.

16 Define banking of roads. Also derive an expression for maximum safe velocity of a vehicle on a banked road having coefficient of friction μ. It is easier to roll a barrel than to pull it along the road. Why?

Sol. Banking of roads is defined as the phenomenon in which the outer edges are raised for the curved roads above the inner edge to provide the necessary centripetal force to the vehicles so that they take a safe turn.

Balancing the forces in vertical direction, $N \cos \theta = mg$…..(1)

In horizontal direction net force towards centre is $N \sin \theta$

This net force towards centre act as centripetal force which is equal to mv^2/R

Therefore, $N \sin \theta = mv^2/R$ ….(2)

By taking the ratio of equation (2) and (1), we get

$\tan \theta = v^2/Rg$

$v = \sqrt{Rg\tan\theta}$

This is the safe speed of the car when the banked road is frictionless.

It is easier to roll a barrel than to pull it along the road because rolling friction is smaller than the sliding friction.

G. CASE STUDY

1. Reference Frames: We define the position of a body in terms of a frame of reference. Rest and motion are relative, there is nothing like absolute rest or absolute motion. The position or state of motion of a body may appear different from different frames of reference. For example, the passengers and everything else in a moving trains are at rest in a reference frame situated in the train but they are in motion in a reference frame situated on the platform. Similarly a stone dropped by a passenger from the window of a railway carriage in uniform motion appears to him to fall vertically downwards but to a person outside the carriage, it appears to follow a parabolic path.

   Newton's first law of motion does not hold in all frames of reference; it holds only for inertial frames of reference. An inertial reference frame is a frame which moves with a constant velocity.

(i) A reference frame attached to the earth
(a) is an inertial frame by definition
(b) cannot be an inertial frame because the earth is revolving round the sun.
(c) is an inertial frame because Newton's laws of motion are applicable in this frame
(d) cannot be an inertial frame because the earth is rotating its own axis.

Sol. The velocity of the earth changes with time (due to a change in its direction) as it revolves round the sun. Therefore a frame attached to the earth is accelerated. Accelerated frames and rotating frames of reference are not inertial frames. Hence the correct choices are b and d.

(ii) Which of the following observers are inertial?
(a) a child revolving in a merry go round.
(b) a driver in a car moving with a constant velocity.
(c) a pilot in an aircraft which is taking off
(d) a passenger in a train which is slowing down to a stop.

Sol. The observers in a, c and d are all accelerating. Hence are non inertial, only the driver in b is inertial since his motion is not accelerated.

(iii) Choose the correct statement from the following:
(a) an internal frame is non accelerating (b) an inertia frame is non rotating
(c) a reference frame moving at a constant velocity with respect to an inertial frame is also an inertial frame
(d) Newton's laws of motion hold for both inertial and non-inertial frames.

Sol. The correct choices are a, b and c.

G. ASSERTION REASON TYPE QUESTIONS

(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false **(d) If both assertion and reason are false**
(e) If assertion is false but reason is true

1. Assertion: Aeroplanes always fly at low altitudes.
Reason: According to Newton's third law of motion, for every action there is an equal and opposite reaction.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion.
The wings of the aeroplane push the external air backward and the aeroplane move forward by reaction of pushed air. At low altitudes, density of air is high and as aeroplane gets sufficient force to move forward.

2. Assertion: A cyclist always bends inwards while negotiating a curve.
Reason: By bending, cyclist lowers his centre of gravity.

Ans. (b) Both assertion and reason are true but reason is not the correct explanation of assertion.

In fact, the cyclist bends inward by an angle θ in order to generate a force necessary for circular motion. If R represents the reaction of the ground then R may be resolved into two components horizontal and vertical. The vertical component R cos θ balances the weight mg of the cyclist and the horizontal component R sin θ provides the necessary centripetal force for circular motion.

3. Assertion: In the case of free fall of the lift, the man will feel weightlessness.
Reason: In free falling, acceleration of lift is equal to acceleration due to gravity.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion.
For downward accelerated motion of the lift, apparent weight R = m(g – a). For free fall a =-g, then R = m(g – g) = 0, i.e. the man will feel weightlessness.

4. Assertion: A player lowers his hands while catching a cricket ball.
Reason: The time of catch increases when cricketer lowers his hand while catching a ball.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion.
According to law of conservation of linear momentum, the momentum of the ball remains constant. As we know that, impulse = F ×t = change in momentum of ball = constant, therefore, when the time of catch (t) increases, F decreases i.e. hands of the player are not hurt much.

5. Assertion: A table cloth can be pulled from a table without dislodging the dishes
Reason: To every action there is an equal and opposite reaction.

Ans. (b) Both assertion and reason are true but reason is not the correct explanation of assertion.
According to law of inertia (Newton's first law), when cloth is pulled form a table, the cloth come in state of motion but dishes remains stationary due to inertia. Therefore if we pull the cloth from table the dishes remains stationary.

G. CHALLENGING PROBLEMS

1. 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?

Sol. At the highest point fo the death well, the normal rection R fo the walls fo the chamnber acts downwards. The centripetal force is provided by his weight mg and the normal reaction R
Therefore $mv^2.r = R + mg$
The motorcyclist dies not fall down due to the balancing of these forces, for minimum speed, at the highest point, R = 0 so that
$mv_{min}^2 = mg$
or $v_{min} = \sqrt{\mathbf{rg}} = \sqrt{\mathbf{25 \times 9.8}}$ = 15.65 ms^{-1}

2. 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?

Sol. Here r= 3m, μ = 0.15, v = 200rpm = 200/60 rps

$\omega = 2\pi v = 2 \times \times \frac{22}{7} \times \frac{200}{60} = \frac{400}{7}$ rads^{-1}

The horizontal reaction, R of the wall on the man provides the necessary centripetal force, $R = mv^2/r = mr\omega^2$ [since $v = r\omega$]

The frictional force f acting vertically upwards balances the weight of the man. The man will remain struck to the wall and the floor is removed, if $f \leq \mu R$

Or $mg \leq \mu mr\omega^2$ [since f = mg]

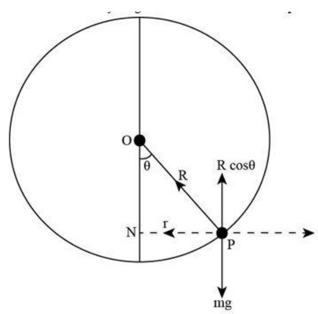
Or $g \leq \mu r\omega^2$ or $\omega^2 \geq g/\mu r$

The minimum rotational speed of the cylinder is

$\omega_{min} = \sqrt{\frac{g}{\mu r}} = \sqrt{\frac{9.8}{0.15\times3}} = \sqrt{21.78} = 4.7$ rads^{-1}

3. 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 $\omega \leq \sqrt{g / R}$. What is the angle made by the radius vector joining the centre to the bead with the vertically downward direction for $\omega = \sqrt{2g/ R}$? Neglect friction.

Sol.



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

$mr\omega2 = N \sin\theta$ ....(ii)

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

Form equation (i), $mg = mR\omega^2 \cos\theta$

or, $\cos\theta = \{g\}/\{R\omega^2\}$ ...(iii)

As $|\cos\theta| \leq 1$, therefore bead will remain at its lowermost point for

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

hen $\omega = \sqrt{\{2g/R\}}$, from eqn (iii)

$\cos\theta = g/R \sqrt{\{R/2g\}} = 1/2$ or $\theta = 60°$

SPACE FOR ROUGH WORK

SPACE FOR NOTES