Laws of Motion

Chapter 4

1. **Give the magnitude and direction of the net force acting on**
   a) a drop of rain falling down with a constant speed,

Ans: The net force is zero.
As the speed of the rain drop falling down is constant, its acceleration is zero.
Therefore, from Newton's second law of motion, the net force acting on the rain drop is zero.

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

Ans: The net force is zero.
It is known that the weight of a cork floating on water acts downward.
The weight of the cork is balanced by buoyant force exerted by the water in the upward direction.
Therefore, no net force acts on the floating cork.

c) a kite skilfully held stationary in the sky,

Ans: The net force is zero.
The kite is stationary in the sky indicates that it is not moving.
Therefore, from Newton's first law of motion, the net force acting on the kite is zero.

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

Ans: The net force is zero.
As the car is moving with constant velocity, its acceleration is zero.
Therefore, from Newton's second law of motion, net force acting on the car is equal to zero.

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

Ans: The net force is zero.
As the high speed electron is free from influence of all the fields, no net force acts on the electron.

2. **A pebble of mass 0.05kg is thrown vertically upwards. Ignore air resistance and give the direction and magnitude of the net force on the pebble,**
   a) during its upward motion,

Ans: It is known that,

Acceleration due to gravity always acts downward irrespective of the direction of motion of an object. The only force that acts on the pebble thrown vertically upward during its upward motion is the gravitational force.
From Newton's second law of motion: $F = m \times a$
Where,
F is the net force
m is the mass of the pebble, $m = 0.05kg$
a is the acceleration due to gravity, $a = g = 10 m/s^{-2}$
$\Rightarrow F = 0.05 \times 10 = 0.5N$
Therefore, the net force on the pebble is $0.5N$ and this force acts in the downward direction.

b) during its downward motion,
Ans: The only force that acts on the pebble during its downward motion is the gravitational force.
Therefore, the net force on the pebble in its downward direction is same as in upward direction i.e., $0.5N$ and this force acts in the downward direction.

c) at the highest point where it is momentarily at rest. Do your answers change if the pebble was thrown at an angle of 45° with the horizontal direction?
Ans: When the pebble is thrown at an angle of 45° with the horizontal, it will have both the horizontal and vertical components of velocity.
At the highest point, only the vertical component of velocity becomes zero. However, the pebble will have the horizontal component of velocity throughout its motion. This component of velocity produces no effect on the net force acting on the pebble.
Therefore, the net force on the pebble is $0.5N$.

3. Neglect air resistance throughout and give the magnitude and direction of the net force acting on a stone of mass $0.1kg$,
a) just after it is dropped from the window of a stationary train,
Ans: It is given that,
Mass of the stone, $m = 0.1kg$
Acceleration of the stone, $a = g = 10 m/s^2$
From Newton's second law of motion,
The net force acting on the stone is $F = ma = mg$
$\Rightarrow F = 0.1 \times 10 = 1N$
It is known that acceleration due to gravity always acts in the downward direction.
Therefore, the magnitude of force is $1N$ and its direction is vertically downward.

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

Ans: It is given that,

The train is moving with a constant velocity.

Therefore, its acceleration is zero in the direction of its motion, i.e. in the horizontal direction.

Thus, no force is acting on the stone in the horizontal direction.

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

Therefore, the magnitude of force is 1N and its direction is vertically downward.

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

Ans: It is given that,

The train is accelerating at the rate of 1ms^{-2}.

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

This force is acting in the horizontal direction. Now, when the stone is dropped, the horizontal force 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 i.e., $F = mg = 1\text{N}$.

Therefore, the magnitude of force is 1N and its direction is vertically downward.

d) lying on the floor of a train which is accelerating with 1ms^{-2}, the stone being at rest relative to the train.

Ans: It is known that,

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, $a = 1\text{ms}^{-2}$

The net force acting on the stone will be in the direction of motion of the train.

Magnitude: $F = ma = 0.1 \times 1 = 0.1\text{N}$

Therefore, the magnitude of force is 0.1N and its direction is in 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) $\mathbf{T - \frac{mv^2}{l}}$ **,**

(iii) $\mathbf{T + \frac{mv^2}{l}}$**,**

(iv) 0

$\mathbf{T}$ **is the tension in the string. [Choose the correct alternative].**

Ans: (i) T

The centripetal force of a particle connected to a string revolving in a circular path around a centre is provided by the tension produced in the string.

Therefore, the net force on the particle is the tension T, i.e.,

$$F = T = \frac{mv^2}{l}$$

Where F is the net force acting on the particle.

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

Ans: It is given that,

Retarding force, $F = -50N$

Mass of the body, $m = 20kg$

Initial velocity of the body, $u = 15m/s$

Final velocity of the body, $v = 0$

From Newton's second law of motion,

The acceleration (a) produced in the body: $F = ma$

$$\Rightarrow -50 = 20 \times a$$

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

From the first equation of motion,

The time (t) taken by the body to come to rest: $v = u + at$

$$\Rightarrow 0 = 15 + (-2.5)t$$

$$\Rightarrow t = \frac{-15}{-2.5} = 6s$$

Therefore, the time taken by the body to stop is $6s$.

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

Ans: It is given that,

Mass of the body, $m = 3kg$

Initial speed of the body, $u = 2m/s$
Final speed of the body, $v = 3.5m/s$
Time, $t = 25s$
From the first equation of motion,
The acceleration (a) produced in the body: $v = u + at$

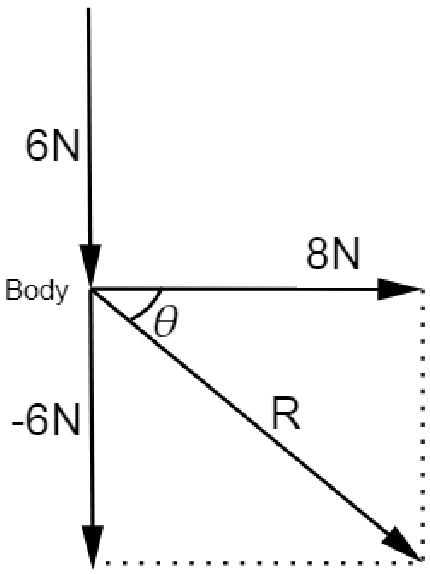
$$\Rightarrow a = \frac{v - u}{t}$$

$$\Rightarrow a = \frac{3.5 - 2}{25} = \frac{1.5}{25} = 0.6ms^{-2}$$

From Newton's second law of motion,
Force, $F = ma$
$\Rightarrow F = 3 \times 0.06 = 0.18N$
As the application of force does not change the direction of the body, the net force acting on the body is in the direction of its motion.
Therefore, the magnitude of force is $0.18N$ and direction is along the direction of motion.

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

Ans: It is given that,
Mass of the body, $m = 5kg$
Representation of given data:



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Resultant of two forces $8N$ and $6N$, $R = \sqrt{(8)^2 + (-6)^2}$

$$\Rightarrow R = \sqrt{64 + 36}$$

$\Rightarrow R = 10N$

Angle made by R with the force of $8N$

$$\theta = \tan^{-1}\left(\frac{-6}{8}\right) = -36.87^\circ$$

The negative sign indicates that θ is in the clockwise direction with respect to the force of magnitude $8N$.

From Newton's second law of motion,

The acceleration (a) produced in the body: $F = ma$

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

Therefore, the magnitude of acceleration is $2ms^{-2}$ and direction is 37° with a force of $8N$.

8. The driver of a three-wheeler moving with a speed of $36km/h$ sees a child standing in the middle of the road and brings his vehicle to rest in $4.0s$ just in time to save the child. What is the average retarding force on the vehicle? The mass of the three-wheeler is $400kg$ and the mass of the driver is $65kg$.

Ans: It is given that,

Initial speed of the three-wheeler, $u = 36\ km/h$

Final speed of the three-wheeler, $v = 0m/s$

Time, $t = 4s$

Mass of the three-wheeler, $m = 400kg$

Mass of the driver, $m' = 65kg$

Total mass of the system, $M = 400 + 65 = 465kg$

From the first law of motion,

The acceleration (a) of the three-wheeler can be calculated from: $v = u + at$

$$\Rightarrow a = \frac{v-u}{t} = \frac{0-10}{4}$$

$\Rightarrow a = -2.5m/s^2$

The negative sign indicates that the velocity of the three-wheeler is decreasing with time.

From Newton's second law of motion,

The net force acting on the three-wheeler can be calculated as: $F = ma$

$\Rightarrow F = 465 \times (-2.5)$

$\Rightarrow F = -1162.5N$

The negative sign indicates that the force is acting against the direction of motion of the three-wheeler.

Therefore, the average retarding force on the vehicle is $-1162.5N$.

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

Ans: It is known that,

Mass of the rocket, $m = 20,000\text{kg}$

Initial acceleration, $a = 5\text{ms}^{-2}$

Acceleration due to gravity, $g = 10\text{ms}^{-2}$

By using Newton's second law of motion,

The net force (thrust) acting on the rocket can be written as:

$F - mg = ma$

$\Rightarrow F = m(g + a)$

$\Rightarrow F = 20000(10 + 5) = 20000 \times 15$

$\Rightarrow F = 3 \times 10^5\,\text{N}$

Therefore, the initial thrust(force) of the blast is $3 \times 10^5\,\text{N}$.

10. A body of mass 0.40kg moving initially with a constant speed of 10ms^{-1} subject to a constant force of 8.0N directed towards the south for 30s. Take the instant the force is applied to be $t = 0$, the position of the body at that time to be predict its position at $t = -5\text{ s},\ 25\text{ s},\ 100\text{ s}$.

Ans: It is given that,

Mass of the body, $m = 0.40\,\text{kg}$

Initial speed of the body, $u = 10\text{m/s}$ due north

Force acting on the body, $F = -8.0\text{N}$

Acceleration produced in the body, $a = \dfrac{F}{m}$

At $t = 0$

$\Rightarrow a = \dfrac{-8}{0.4} = -20\text{ms}^{-2}$

At $t = -5\text{s}$

Acceleration, $a' = 0$ and $u = 10\text{m/s}$

$s = ut + \dfrac{1}{2}a't^2$

$\Rightarrow s = 10 \times (-5) = -50\text{m}$

At $t = 25\text{s}$

Acceleration, $a = -20\text{ms}^{-2}$ and $u = 10\text{m/s}$

$s' = ut' + \dfrac{1}{2}a(t')^2$

$\Rightarrow s' = 10 \times (25) + \frac{1}{2} \times (-20)(25)^2$

$\Rightarrow s' = 250 + (-6250)$

$\Rightarrow s' = -6000\text{m}$

At $t = 100\text{s}$

For $0 \le t \le 30\text{s}$, $a = -20\text{ms}^{-2}$ and $u = 10\text{m/s}$

$s_1 = ut + \frac{1}{2}at^2$

$\Rightarrow s_1 = 10 \times 30 + \frac{1}{2} \times (-20) \times (30)^2$

$\Rightarrow s_1 = 300 - 9000$

$\Rightarrow s_1 = 8700\text{m}$

For $30\text{s} \le t \le 100\text{s}$

First equation of motion: $v = u + at$

$\Rightarrow v = 10 + (-20) \times 30$

$\Rightarrow v = -590\text{ms}^{-1}$

Velocity of body after $30\text{s} = -590\text{m/s}$

For motion between 30s to 100s i.e., in 70s

$s_2 = vt + \frac{1}{2}a't^2$

$s_2 = -590 \times 70 = -41300\text{m}$

Total distance, $s'' = s_1 + s_2$

$\Rightarrow s'' = -8700 + (-41300) = -50000\text{m}$

Therefore, the position of the body at $t = -5\text{s}$ is -50m at $t = 25\text{s}$ is -6000m and at $t = 100\text{s}$ is $-50,000\text{m}$.

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

a) velocity, and

Ans: It is given that,

Initial velocity of the truck, $u = 0$ (Initially at rest)

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

Time, $t = 10\text{s}$

From first equation of motion: $v = u + at$

$\Rightarrow v = 0 + 2 \times 10 = 20\text{m/s}$

Therefore, the final velocity of the truck and the stone is 20m/s.

At $t = 11\text{s}$:

The horizontal component (v_x) of velocity, in the absence of air resistance, remains unchanged, i.e. $v_x = 20m/s$.

The vertical component of velocity (v_y) of the stone is given by the first equation of motion as:

$v_y = u + a_y \delta t$

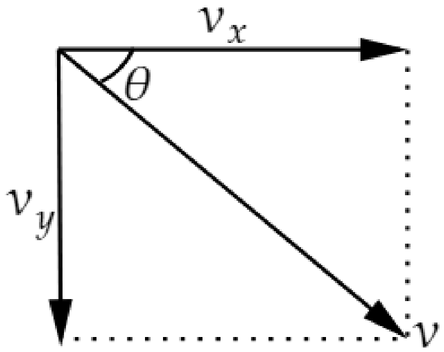
Where,

$\delta t = 11 - 10 = 1s$

$a = g = 10m/s^2$

$\Rightarrow v_y = 0 + 10 \times 1 = 10 m/s^2$

The resultant velocity (v) of the stone is:



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

$\Rightarrow v = \sqrt{20^2 + 10^2} = \sqrt{400 + 100}$

$\Rightarrow v = \sqrt{500} = 22.36m/s$

Consider θ as the angle made by the resultant velocity with the horizontal component of velocity, v_x.

$\Rightarrow \tan\theta = \left(\frac{v_y}{v_x}\right)$

$\Rightarrow \theta = \tan^{-1}\left(\frac{v_y}{v_x}\right)$

$\Rightarrow \theta = \tan^{-1}\left(\frac{10}{20}\right)$

$\Rightarrow \theta = \tan^{-1}(0.5)$

$\Rightarrow \theta = 26.57^\circ$

Therefore, the magnitude of resultant velocity is $22.36 m/s$ making an angle of 26.57° with the horizontal component of velocity.

b) acceleration of the stone at $t = 11s$?

Ans: When the stone is dropped from the truck, the horizontal force acting on it becomes zero. However, the stone continues to move under the influence of gravity. Therefore, the acceleration of the stone is $10ms^{-2}$ and it acts vertically downward.

12. A bob of mass $0.1kg$ hung from the ceiling of a room by a string $2m$ long is set into oscillation. The speed of the bob at its mean position is $1ms^{-2}$. What is the trajectory of the bob if the string is cut when the bob is

a) at one of its extreme positions,

Ans: If the string is cut when the bob is at one of its extremes then the bob will fall vertically on the ground.

Therefore, at the extreme position, the velocity of the bob becomes zero.

b) at its mean position.

Ans: If the string is cut when the bob is at its mean position then the bob will trace a projectile path having the horizontal components of velocity only.

The direction of this velocity is tangential to the arc formed by the oscillating bob.

At the mean position, the velocity of the bob is $1m/s$.

Therefore, it will follow a parabolic path.

13. What would be the readings on the scale of a man of mass $70kg$ stands on a weighing scale in a lift which is moving

a) upwards with a uniform speed of $10ms^{-1}$,

Ans: It is given that,

Mass of the man, $m = 70kg$

Acceleration, $a = 0$ (uniform speed)

From Newton's second law: $R - mg = ma$

Where,

ma is the net force acting on the man.

$\Rightarrow R - 70 \times 10 = 0$

$\Rightarrow R = 700N$

Reading on the weighing scale $= \frac{700}{g} = \frac{700}{10} = 70kg$

Therefore, the mass of the man, $m = 70kg$

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

Ans: Acceleration, $a = 5m/s^2$ downward

From Newton's second law: $R = m(g - a)$

$\Rightarrow R = 70(10 - 5) = 70 \times 5$

$\Rightarrow R = 350N$

Reading on the weighing scale $= \frac{350}{g} = \frac{350}{10} = 35kg$

Therefore, the mass of the man, $m = 35kg$

c) upwards with a uniform acceleration of $5ms^{-2}$.

Ans: Acceleration, $a = 5m/s^2$ upward

From Newton's second law: $R = m(g+a)$

$\Rightarrow R = 70(10+5) = 70 \times 15$

$\Rightarrow R = 1050N$

Reading on the weighing scale $= \frac{1050}{g} = \frac{1050}{10} = 105kg$

Therefore, the mass of the man, $m = 105kg$

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

Ans: When the lift moves freely under gravity,

Acceleration, $a = g = 10ms^{-2}$

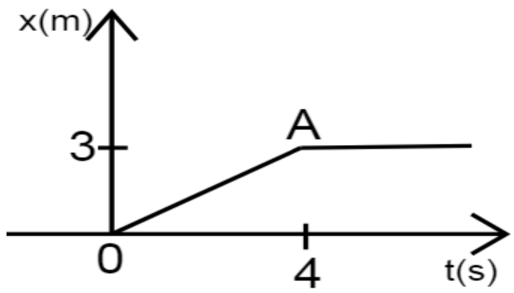
From Newton's second law: $R = m(g-a)$

$\Rightarrow R = 70(10-10) = 0$

Reading on the weighing scale $= \frac{0}{g} = \frac{0}{10} = 0kg$

Therefore, the man will be in a state of weightlessness.

14. Figure shows the position-time graph of a particle of mass $4kg$. Consider one-dimensional motion only and find the



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a) force on the particle for $t < 0, t > 4s, 0 < t < 4s$?

Ans: For $t < 0$:

From the given graph, it is observed that the position of the particle is coincident with the time axis. It indicates that the displacement of the particle in this time interval is zero.

Therefore, the force acting on the particle is zero.

For $t > 4s$:

From the given graph, it is observed that the position of the particle is parallel to the time axis. It indicates that the particle is at rest at a distance of $3m$ from the origin.

Therefore, no force acts on the particle.

For $0 < t < 4$:

From the given position-time graph, it is observed that it has a constant slope. Thus, the acceleration produced in the particle is zero.

Therefore, the force acting on the particle is zero.

b) impulse at $t = 0$ and $t = 4s$?

Ans: At $t = 0$:

$\text{Impulse} = \text{Change in momentum} = mv - mu$

Mass of the particle, $m = 4kg$

Initial velocity of the particle, $u = 0$

Final velocity of the particle, $v = \frac{3}{4} m/s$

Impulse $= 4\left(\frac{3}{4} - 0\right) = 3kgms^{-1}$

At $t = 4s$:

Initial velocity of the particle, $u = \frac{3}{4} m/s$

Final velocity of the particle, $v = 0$

$\text{Impulse} = 4\left(0 - \frac{3}{4}\right) = -3kgms^{-1}$

Therefore, the impulse at $t = 0$ is $3kgms^{-1}$ and at $t = 4s$ is $-3kgms^{-1}$.

15. Two bodies of masses 10kg and 20kg respectively kept on a smooth, horizontal surface are tied to the ends of a light string. What is the tension in the string if a horizontal force $F = 600N$ is applied along the direction of string to

a) A,

Ans: It is given that,

Horizontal force, $F = 600N$

Mass of body A, $m_1 = 10kg$

Mass of body B, $m_2 = 20kg$

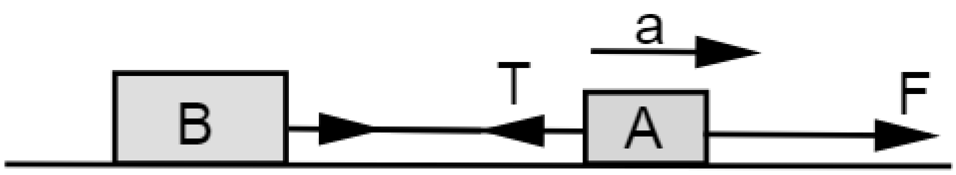
Total mass of the system, $m = m_1 + m_2 = 30kg$

From Newton's second law of motion,

The acceleration (a) produced in the system is: $F = ma$

$$\Rightarrow a = \frac{F}{m} = \frac{600}{30} = 20ms^{-2}$$

When force F is applied on body A:



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The equation of motion can be written as: $F - T = ma$

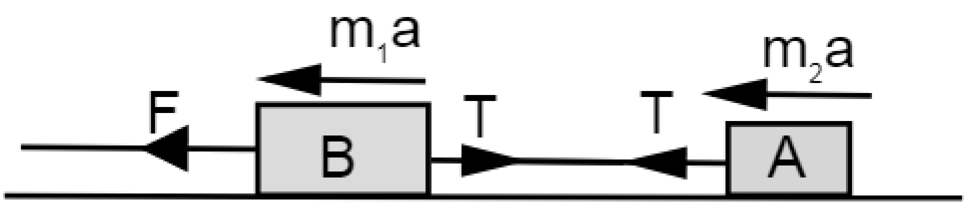
$\Rightarrow T = F - m_1 a$

$\Rightarrow T = 600 - 10 \times 20 = 400N$

Therefore, the tension in the string is $400N$.

b) B along

Ans: When force F is applied on body B:



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The equation of motion can be written as: $F - T = m_2 a$

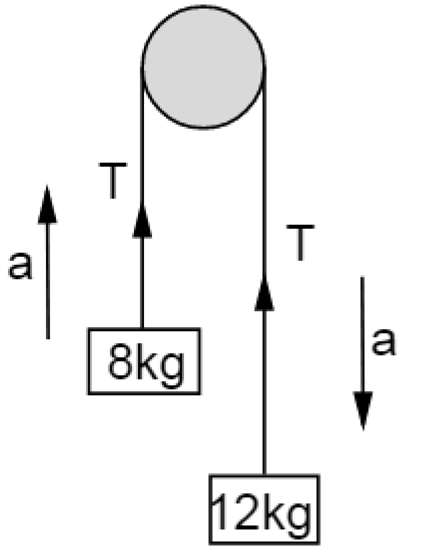
$\Rightarrow T = F - m_2 a$

$\Rightarrow T = 600 - 20 \times 20 = 200N$

Therefore, the tension in the string is $200N$.

16. Two masses $8kg$ and $12kg$ 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.

Ans: The given system of two masses and a pulley are represented in the following figure:



Smaller mass, $m_1 = 8kg$
Larger mass, $m_2 = 12kg$
Tension in the string $= T$
Mass m_2, owing to its weight, moves downward with acceleration a, and mass moves m_1 upward.

Applying Newton's second law of motion to the system of each mass:

For mass m_1:

The equation of motion can be written as: $T - m_1 g = ma \quad ....(1)$

For mass m_2:

The equation of motion can be written as: $m_2 g - T = m_2 a \quad ....(2)$

Adding equations (1) and (2), we get:

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

$$\Rightarrow a = \left(\frac{m_2 - m_1}{m_2 + m_1}\right)g \quad ....(3)$$

$$\Rightarrow a = \left(\frac{12-8}{12+8}\right)\times 10 = \frac{4}{20}\times 10$$

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

Thus, the acceleration of the masses is $2ms^{-2}$. Substituting the value of a in equation (2):

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

$$\Rightarrow T = \left(m_2 - \frac{m_2^2 - m_1 m_2}{m_2 + m_1}\right)g$$

$$\Rightarrow T = \left(\frac{2m_1 m_2}{m_1 + m_2}\right)g$$

$$\Rightarrow T = \left(\frac{2\times12\times8}{12+8}\right)\times10$$

$$\Rightarrow T = 96N$$

Thus, the tension in the string is $96N$.

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

Ans: Consider m, m_1 and m_2 as the respective masses of the parent nucleus and the two daughter nuclei. The parent nucleus is at rest.

Initial momentum of the system (parent nucleus) $= 0$

Let v_1 and v_2 be the respective velocities of the daughter nuclei having masses m_1 and m_2.

Total linear momentum of the system after disintegration $= m_1v_1 + m_2v_2$

From the law of conservation of momentum:

Total initial momentum $=$ Total final momentum

$$\Rightarrow 0 = m_1v_1 + m_2v_2$$

$$\Rightarrow m_1v_1 = -m_2v_2$$

$$\Rightarrow v_1 = \frac{-m_2v_2}{m_1}$$

The negative sign indicates that the fragments of the parent nucleus move in directions opposite to each other.

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

Ans: It is given that,

Mass of each ball $= 0.05kg$

Initial velocity of each ball $= 6m/s$

Magnitude of the initial momentum of each ball, $p_i = 0.3kgms^{-1}$

After collision, the balls change their directions of motion without changing the magnitudes of their velocity.

Final momentum of each ball, $p_f = -0.3kgms^{-1}$

Impulse imparted to each ball $=$ Change in the momentum of the system

$$\Rightarrow Impulse = p_f - p_i$$

$$\Rightarrow Impulse = -0.3 - 0.3 = -0.6kgms^{-1}$$

The negative sign indicates that the impulses imparted to the balls are opposite in direction.

19. A shell of mass 0.020kg is fired by a gun of mass 100kg. If the muzzle speed of the shell is 80ms^{-1} , what is the recoil speed of the gun?

Ans: It is given that,

Mass of the gun, $M = 100\text{kg}$

Mass of the shell, $m = 0.020\text{kg}$

Muzzle speed of the shell, $v = 80\text{m/s}$

Recoil speed of the gun $= V$.

Both the gun and the shell are at rest initially.

Initial momentum of the system $= 0$

Final momentum of the system $= mv - MV$

Here, the negative sign appears because the directions of the shell and the gun are opposite to each other.

From the law of conservation of momentum:

$$\text{Final momentum} = \text{Initial momentum}$$

$$mv - MV = 0$$

$$\Rightarrow V = \frac{mv}{M}$$

$$\Rightarrow V = \frac{0.020 \times 80}{100 \times 1000} = 0.016\text{m/s}$$

Therefore, the recoil speed of the gun is 0.016m/s.

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

Ans: The given situation can be represented as:

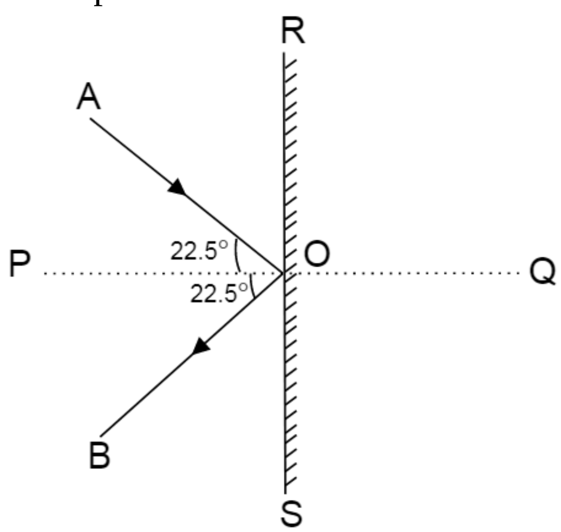


Image source: Self-created

Where,

$AO =$ Incident path of the ball
$OB =$ Path followed by the ball after deflection
$\angle AOB =$ Angle between the incident and deflected paths of the ball $= 45^\circ$
$\angle AOB = \angle BOP = 22.5^\circ = \theta$
Initial and final velocities of the ball $= v$
Horizontal component of the initial velocity $= v\cos\theta$ along RO
Vertical component of the initial velocity $= v\sin\theta$ along PO
Horizontal component of the final velocity $= v\cos\theta$ along OS
Vertical component of the final velocity $= v\sin\theta$ along OP
The horizontal components of velocities suffer no change. The vertical components of velocities are in the opposite directions.
It is known that, Impulse imparted to the ball $=$ Change in the linear momentum of the ball.
$\text{Impulse} = mv\cos\theta - (-mv\cos\theta) = 2mv\cos\theta$
It is given that,
Mass of the ball, $m = 0.15kg$
Velocity of the ball, $v = 54km/h = 54 \times \frac{5}{18} = 15m/s$
$\text{Impulse} = 2 \times 0.15 \times 15 \cos 22.5^\circ = 4.16kgms^{-1}$
Therefore, impulse imparted to the ball is $4.16kgms^{-1}$.

21. A stone of mass $0.25kg$ tied to the end of a string is whirled round in a circle of radius $1.5m$ with a speed of $40rev./min$ 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 $200N$?

Ans: It is given that,
Mass of the stone, $m = 0.25kg$
Radius of the circle, $r = 1.5m$
Number of revolution per second, $n = \frac{40}{60} = \frac{2}{3} rps$
Angular velocity, $\omega = \frac{v}{r} = 2\pi n$ ....(1)
The centripetal force for the stone is provided by the tension T , in the string, i.e., $T = F_{Centripetal}$

$$\Rightarrow \frac{mv^2}{r} = mr\omega^2 = mr(2\pi n)^2$$

$$\Rightarrow F_{Centripetal} = 0.25 \times 1.5 \times \left(2 \times 3.14 \times \frac{2}{3}\right)^2$$

$$\Rightarrow F_{Centripetal} = 6.57N$$

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

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

$$\Rightarrow v_{max} = \sqrt{\frac{T_{max} \times r}{m}}$$

$$\Rightarrow v_{max} = \sqrt{\frac{200 \times 1.5}{0.25}}$$

$$\Rightarrow v_{max} = \sqrt{1200} = 34.64m/s$$

Thus, the maximum speed of the stone is $34.64m/s$.

22. If, in Exercise 21, the speed of the stone is increased beyond the maximum permissible value, and the string breaks suddenly, which of the following correctly describes the trajectory of the stone after the string breaks:
(i) the stone moves radially outwards,
(ii) the stone flies off tangentially from the instant the string breaks,
(iii) the stone flies off at an angle with the tangent whose magnitude depends on the speed of the particle?

Ans: (ii)

From the first law of motion, the direction of velocity vector is tangential to the path of the stone at that instant. So, if the string breaks, the stone will move in the direction of the velocity at that instant.

Therefore, the stone will fly off tangentially from the instant the string breaks.

23. Explain why

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

Ans: In order to pull a cart, a horse pushes the ground backward with some force.

The ground in turn exerts an equal and opposite reaction force upon the feet of the horse.

This reaction force causes the horse to move forward. An empty space is devoid of any such reaction force.

Hence, a horse cannot pull a cart and run in empty space.

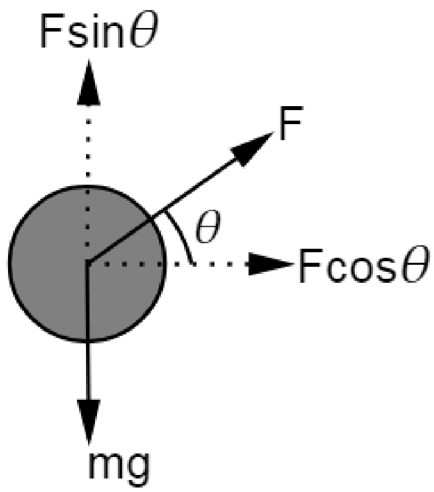
b) passengers are thrown forward from their seats when a speeding bus stops suddenly,

Ans: If a speeding bus stops suddenly, the lower portion of a passenger's body, which is in contact with the seat, suddenly comes to rest. However, the upper portion tends to remain in motion (as per the first law of motion).

So, the passenger's upper body is thrown forward in the direction in which the bus was moving.

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

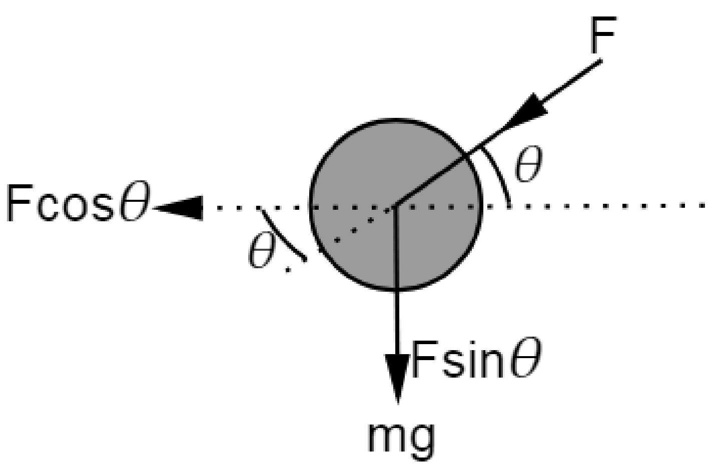
Ans: While pulling a lawn mower, a force at an angle θ is applied on it, as shown in the following figure:



.

The vertical component of this applied force acts upward. This reduces the effective weight of the mower.

While pushing a lawn mower, a force at an angle θ is applied on it, as shown in the following figure:



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

As the effective weight of the lawn mower is lesser in the first case, pulling the lawn mower is easier than pushing it.

From Newton's second law of motion: $F = ma = m\frac{\Delta v}{\Delta t}$ ....(1)

Where,

$F =$ Stopping force experienced by the cricketer as he catches the ball

$m =$ Mass of the ball

$t =$ Time of impact of the ball with the hand

From equation (1) it can be observed that the impact force is inversely proportional to the impact time, i.e., $F < \frac{1}{\Delta t}$ ....(2)

Equation (2) shows that the force experienced by the cricketer decreases if the time of impact increases and vice versa.

Therefore, it is easier to pull a lawn mower than to push it.

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

Ans: While taking a catch, a cricketer moves his hand backward so as to increase the time of impact Δt. This in turn results in the decrease in the stopping force, thereby preventing the hands of the cricketer from getting hurt.

Therefore, a cricketer moves his hands backwards while holding a catch.