NCERT Solutions for Class XI Physics

Chapter-5
NCERT Physics Class 11

1. Give the magnitude and direction of the net force acting on
(a) a drop of rain falling down with a constant speed,
(b) a cork of mass 10 g floating on water,
(c) a kite skilfully held stationary in the sky,
(d) a car moving with a constant velocity of 30 km/h on a rough road,
(e) a high-speed electron in space far from all material objects, and free of electric and magnetic fields.

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

2. A pebble of mass 0.05 kg is thrown vertically upwards. Give the direction and magnitude of the net force on the pebble,
(a) during its upward motion,
(b) during its downward motion,
(c) at the highest point where it is momentarily at rest. Do your answers change if the pebble was thrown at an angle of 45° with the horizontal direction?
Ignore air resistance.

2. According to the Newton's second law of motion:
$F = m \times a$
Where,
'F' is the net force acting on an object.
'm' is the mass of the object.
'a' is the acceleration of the object.

Given,

Mass of the pebble 'm'= 0.05 kg

a = acceleration due to gravity = 10 m/s^2

In all the three cases A, B and C the only force acting on the pebble is that of gravitational force in the downward direction. Irrespective of the motion of an object, The acceleration due to gravity always acts downwards.

The magnitude of the force due to gravity will be,

$F = 0.05\ kg \times 10\ m/s^2 = 0.5\ N$

Thus, the net force acting on the pebble ignoring the air resistance in upward or downward motion is 0.5 N and this gravitational force always acts downwards towards the centre of the earth.

The only difference if a pebble is thrown at an angle of 45° with the horizontal is the change in its velocity as it travels all the way up where the vertical velocity becomes zero at the highest peak but the horizontal velocity remains. The acceleration due to gravity is still acting constantly downwards in this case too and ignoring the air resistance. Thus, the net force still remains the same.

3. Give the magnitude and direction of the net force acting on a stone of mass 0.1 kg,

(a) just after it is dropped from the window of a stationary train,

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

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

(d) lying on the floor of a train which is accelerating with 1 m s^{-2}, the stone being at rest relative to the train. Neglect air resistance throughout.

3. According to the Newton's second law of motion:

$F = m \times a$

Where,

'F' is the magnitude of the force acting on an object.

'm' is the mass of the object.

'a' is the acceleration of the object.

Given,

Mass of the stone, m = 0.1 kg

Acceleration due to gravity is taken as 'g' = 10 m/s^2

When the train is stationary the net force acting on it is only due to gravitational force.

Thus, the magnitude of the force is

$F = m \times a = m \times g$

$= 0.1\ kg \times 10\ m/s^2$

F = 1 N

Therefore, the net force acting on the stone will be due to gravitation which is always in the downward direction.

When the train is moving with a constant velocity. The rate of change of velocity i.e. acceleration is zero. Thus, there is no net force acting on the stone in the horizontal direction.

The only force that acts is in vertical direction i.e. gravitational force with the magnitude,

$F = m \times a = m \times g$
$= 0.1 \text{ kg} \times 10 \text{m/s}^2$
$F = 1 \text{ N}$
Therefore, the net force acting on the stone is of the magnitude 1 N acting in the vertically downward direction.
When the stone leaves the train, the net force acting on it just after it has left does not consist of horizontal force as the force due to train stops acting on it the instant it leaves the train. According to Newton's first law of motion, the force acting on a body at an instant depends on that instant.
The net force acting on the stone is given only by acceleration due to gravity.
$F = m \times a = m \times g$
$= 0.1 \text{ kg} \times 10 \text{m/s}^2$
$F = 1$ N acting in the downward direction.
Therefore, the net force acting on the stone is of the magnitude 1 N acting in the vertically downward direction.
Given,
Acceleration of the train, 'a' = 1 m/s^2
When the stone is lying on the floor of the train the weight of the stone is balanced by the normal reaction of the floor. The vertical forces vanish and only the horizontal force remains which is due to the acceleration of the train.
Thus the net force acting on the stone will be in the same direction as the train,
The magnitude of the net force is,
$F = ma$
$\Rightarrow F = 0.1 \text{ m/s}^2 \times 1 \text{ kg} = 0.1 \text{ N}$
Therefore, the net force acting on the stone is of the magnitude 1 N acting in the same direction as the train.

4. One end of a string of length l is connected to a particle of mass m and the other to a small peg on a smooth horizontal table. If the particle moves in a circle with speed v the net force on the particle (directed towards the centre) is:

(i) T, (ii) $T - \frac{mv^2}{l}$

(iii) $T + \frac{mv^2}{l}$ (iv) 0

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

4. (i) T
When a particle connected to a string revolves in a circular path around a centre, the centripetal force is provided by the tension produced in the string. Hence, in the given case, 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 50 N is applied to a body of mass 20 kg moving initially with a speed of 15 ms^{-1}. How long does the body take to stop?

5. The Newton's second law of motion states that,

$F = m \times a$

$\Rightarrow a = F / m$

Where,

F is the force on the body,

m is the mass of the body and

a is the acceleration of the body.

Given,

$F = -50$ N

The negative sign is because the force applied to the body is retarding and acts in the opposite direction to the motion of the body.

m= 20 kg

Thus the acceleration is

$$a = -\frac{50\text{ N}}{20\text{ kg}} = -2.5\ \text{m/s}^2$$

The first equation of motion at time t, can be written as,

$v = u + at$

where,

v is the final velocity,

u is the initial velocity,

a is the acceleration of the body.

For the body to stop the final velocity must be equal to zero, thus the equation becomes,

$$t = -\frac{u}{a} = \frac{-15}{-2.5} = 6\text{ sec}$$

Ans: the total time taken by the body to come to rest is 6 seconds.

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

6. 0.18 N; in the direction of motion of the body

Mass of the body, m = 3 kg

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

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

Time, t = 25 s

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

$v = u + at$

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

$$= \frac{3.5-2}{25} = \frac{1.5}{25} = 0.06\ \text{m/s}^2$$

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

$F = ma$

$= 3 \times 0.06 = 0.18$ N

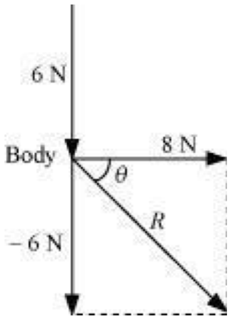
Since the application of force does not change the direction of the body, the net force acting on the body is in the direction of its motion.

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

7. 2 m/s^2, at an angle of 37° with a force of 8 N

Mass of the body, m = 5 kg

The given situation can be represented as follows:



The resultant of two forces is given as:

$$R = \sqrt{(8)^2 + (-6)^2} = \sqrt{64 + 36} = 10N$$

θ is the angle made by R with the force of 8 N

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

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

As per Newton's second law of motion, the acceleration (a) of the body is given as:

F = ma

$$\therefore a = \frac{F}{m} = \frac{10}{5} = 2m/s^2$$

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

8. The first equation of motion is given as :

v = u + at …….(i)

where,

v is the final speed of the body,

u is the initial speed of the body,

a is the acceleration of the body.

t is the time taken by the body.

Given,

Mass of the three wheeler, M = 400 kg

Mass of the driver, m = 65 kg

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

Final speed of the three wheeler, v = 0 km/h

Time taken by the vehicle to completely stop, t = 4 sec

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

From equation (i), $a = \frac{v - u}{t}$

$$\Rightarrow a = \frac{(0-10)\,m/s}{4\,sec} = -2.5\,m/s^2$$

Here, the negative sign indicates that the body is retarding and the velocity of the system is decreasing with the time.

From Newton's second law of motion, the magnitude of the force is given as,

F = (M + m) × a

= 465 kg × (–2.5 m/s^2) = –1162.5 N

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

The average retarding force on the vehicle is 1162.5 N

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

9. Mass of the rocket, m = 20,000 kg

Initial acceleration, a = 5 m/s2

Acceleration due to gravity, g = 10 m/s^2

Using Newton's second law of motion, the net force (thrust) acting on the rocket is given by the relation:

F – mg = ma

F = m (g + a)

= 2000 × (10 + 5) = 20000 × 15 = 3 × 105 N

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

10. Given,

Mass of the body, m = 0.40 kg

Initial speed of the body, u = 10 m/s

Force acting on the body, F = -8 N

The force is negative because it acts in the opposite direction i.e. south to the motion of the body i.e. north.

Time for which the force acts on the body, t =30 s

According to the second law of motion, the acceleration of the body is:

$$a = \frac{F}{m} = \frac{-8\,N}{0.40\,kg} = -20\,m/s^2$$

The third equation of motion is given as,

$$s = ut + \frac{1}{2}at^2 \quad n..(i)$$

Where,

's' is the position of the body,

'u' is the initial speed of the body,
'a' is the acceleration of the body and
't' is the time.
Given,

1. <u>At t=-5 s</u>
   The acceleration of the body is zero since the force was applied starting t=0
   u = 10 m/s
   using equation (i) we get,
   s =10 m/s × (–5 sec)
   ⇒ s= –50 m
2. <u>At t= 25s</u>
   Acceleration , a' = -20 m/s^2 and
   u = 10 m/s
   using equation (i) we get,
   $$s = 10\frac{m}{s} \times 25\,s + \frac{1}{2} \times \left(-20\frac{m}{s^2}\right) \times (25\,s)^2$$
   $\Rightarrow s = 250\ m - 6250\ m = -6000\ m$
3. At t=100 s
   We divide this time period in two parts with displacements s' and s",
   • The first part is time 0<t≤30s,
   Given,
   Acceleration of the body, a = -20 m/s^2
   u = 10 m/s
   The displacement travelled by the body using equation (i) during this time t' is,
   $$s' = 10\frac{m}{s} \times 30s + \frac{1}{2} \times \left(-20\frac{m}{s^2}\right) \times (30\,s)^2$$
   $\Rightarrow s' = 300\ m - 9000\ m = -8700\ m$

The displacement travelled by the body till t=30 s , s'=-8700 m
• The second part is 30s < t ≤ 100s,
Given,
Acceleration of the body = 0
The final velocity for the first part is the initial velocity for the second part, From the first equation of motion, The final velocity after t=30 s is,
v = u + at
⇒ v = 10 m/s + (–20) m/s^2 × 30 s = –590 m/s
Thus, velocity of the body after 30 sec= –590 m/s
For, motion between 30 s to 100 s, i.e. t = 70 s, we use equation (i):
s" = v t + 0
⇒ s" = – 590 m/s × 70 s = – 41300 m
Thus, s = s'+ s" = – 8700 m – 41300 m
⇒ s = – 50000 m

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

11. (a) 22.36 m/s, at an angle of 26.57° with the motion of the truck

(b) 10 m/s^2

Initial velocity of the truck, u = 0

Acceleration, a = 2 m/s^2

Time, t = 10 s

As per the first equation of motion, final velocity is given as:

v = u + at

= 0 + 2 × 10 = 20 m/s

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

At t = 11 s, the horizontal component (v_x) of velocity, in the absence of air resistance, remains unchanged, i.e., v_x = 20 m/s

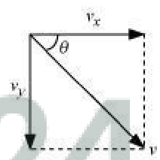
The vertical component (v_y) of velocity of the stone is given by the first equation of motion as:

$vy = u + a_y \delta t$

Where, δt = 11 – 10 = 1 s and $a_y = g = 10\ m/s^2$

$\therefore v_y = 0 + 10 \times 1 = 10$ m/s

The resultant velocity (v) of the stone is given as:



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

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

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

Let θ be the angle made by the resultant velocity with the horizontal component of velocity, v_x

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

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

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

= 26.57°

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. Hence, the acceleration of the stone is 10 m/s2 and it acts vertically downward.

12. A bob of mass 0.1 kg hung from the ceiling of a room by a string 2 m long is set into oscillation. The speed of the bob at its mean position is 1 m s^{-1}. What is the trajectory of the bob if the string is cut when the bob is (a) at one of its extreme positions, (b) at its mean position.

12. (a) The velocity of the bob at the extreme positions becomes zero because the kinetic energy becomes zero. Thus, there is no horizontal velocity.

The net force just after it has been cut at extreme positions is just gravitational force which always acts vertically downward.Thus, the bob will fall vertically downwards to the ground if the string is cut at the extreme positions.

(b) Given,

The speed of the bob at the mean position is 1 m/s.

The kinetic energy is thus maximum here and the direction of the velocity is tangential to the arc traced by the oscillating bob. Thus, if it is cut at the mean position then it will follow a projectile path due to the presence of the horizontal velocity.

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

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

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

(c) upwards with a uniform acceleration of 5 m s^{-2}.

What would be the readings on the scale in each case?

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

13. Mass of the man, m = 70 kg

Acceleration, a = 0

Using Newton's second law of motion, we can write the equation of motion as:

$R - mg = ma$

Where, ma is the net force acting on the man.

As the lift is moving at a uniform speed, acceleration a = 0

$\therefore$ R = mg

$= 70 \times 10 = 700$ N

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

Mass of the man, m = 70 kg

Acceleration, a = 5 m/s^2 downward

Using Newton's second law of motion, we can write the equation of motion as:

$R + mg = ma$

$R = m(g - a)$

$= 70\,(10 - 5) = 70 \times 5$

$= 350$ N

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

Mass of the man, m = 70 kg

Acceleration, a = 5 m/s^2 upward

Using Newton's second law of motion, we can write the equation of motion as:

$R - mg = ma$

$R = m(g + a)$

$= 70\,(10 + 5) = 70 \times 15$

$= 1050$ N

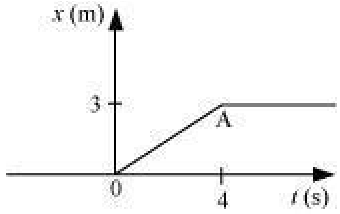
$\therefore$ Reading on the weighing scale = $\frac{1050}{g} = \frac{1050}{10} = 105\text{kg}$

When the lift moves freely under gravity, acceleration a = g
Using Newton's second law of motion, we can write the equation of motion as:
R + mg = ma
R = m(g – a)
= m(g – g) = 0

$\therefore$ Reading on the weighing scale = $\frac{0}{g} = 0\,\text{kg}$

The man will be in a state of weightlessness.

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



14. For the particle with the trajectory as shown in the graph, the force on the particle,

(A) For t < 0

We can observe from the graph that the line displaying the position of the particle is coinciding with the x axis, i.e. There is no displacement and hence no net force on the body before t=0.

(B) For t >4 s

We can observe that the position-time graph attains a constant value after t=4, this means that the displacement is not changing, it has a constant value of 3 m and thus the particle is at rest. Thus the net force on the body is zero.

For 0<t<4 s

We can observe that the position-time graph has a constant slope at the given time. The velocity is thus constant and so the acceleration is zero. The net force acting on the particle is thus zero.

(C) From the second Newton's law of motion, Impulse, 'I' is defined as the change in the momentum of an object.

I = mv-mu = m(v-u)
Where ,
'm' is the mass of the particle
'v' is the final velocity of the particle
'u' is the initial velocity of the particle.
At t=0
Given,
Mass of the particle ,m = 4 kg
Initial velocity of the particle, u= 0

Final velocity of the particle can be obtained by calculating the slope of the position-time graph at t =4 s

$\Rightarrow v = \frac{3}{4}\, m/s$

Therefore,

$I = 4\, kg \times \left(\frac{3}{4} - 0\right) m/s$

$\Rightarrow$ I = 3 kg m/s

At t=4 s

Given,

Mass of the particle, m = 4 kg

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

Final velocity of the particle can be obtained by calculating the slope of the position-time graph after t =4, i.e. v = 0

Therefore,

$I = 4\, kg \times \left(0 - \frac{3}{4}\right) m/s$

$\Rightarrow I = -3\, kg\, m/s$

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

15. The Newton's second law of motion is defined as,

F = m× a

$\Rightarrow$ a = F / m

Where

'a' is the acceleration of the system

'F' is the force applied

'm' is the mass of the system.

Given,

Horizontal force applied on the body, F = 600 N

Mass of the body A, m_A = 10 kg

Mass of the body B, m_B = 20 kg

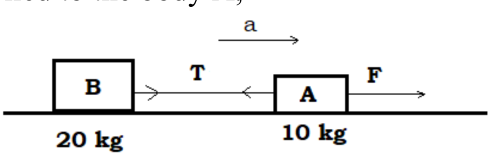
The mass of the system, M = $m_A + m_B$ = 10 +20 kg = 30 kg

Thus, the acceleration 'a' of the system is given as,

$a = \frac{F}{m} = \frac{600\, N}{30 kg} = 20\, m/s^2$

$\Rightarrow a = 20\, m/s^2$

When the force is applied to the body A,



Using the newton's second law of motion, The equation of motion is given as,

$F - T = m_A a$

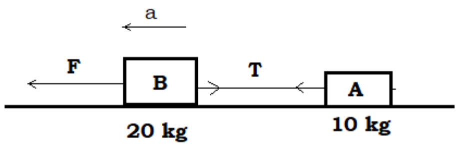
$\Rightarrow T = F - m_A a$

$\Rightarrow T = 600\text{ N} - 10\text{ kg} \times 20\text{ m/s}^2$

$\Rightarrow T = 600\text{ N} - 200\text{ N} = 400\text{ N}$

Tension when the force is applied on body A is 400 N.

When the force is applied to the body B



Using the newton's second law of motion, The equation of motion is given as,

$F - T = m_B a$

$\Rightarrow T = F - m_B a$

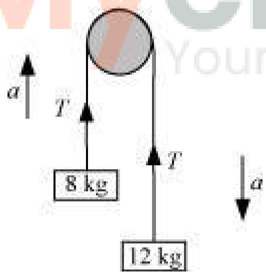
$\Rightarrow T = 600\text{ N} - 20\text{ kg} \times 20\text{ m/s}^2$

$\Rightarrow T = 600\text{ N} - 400\text{ N} = 200\text{ N}$

Tension when the force is applied on body B is 200 N.

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

16. The given system of two masses and a pulley can be represented as shown in the following figure:



Smaller mass, $m_1 = 8$ kg

Larger mass, $m_2 = 12$ kg

Tension in the string = T

Mass m_2, owing to its weight, moves downward with acceleration a, and mass m1 moves 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:

$T - m_1 g = ma$ …………………… (i)

For mass m2: The equation of motion can be written as:

$m_2 g - T = m_2 a$ ………………….… (ii)

Adding equations (i) and (ii), we get:

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

$\therefore a = \left(\dfrac{m_2 - m_1}{m_1 + m_2}\right)g$ … (iii)

$$=\left(\frac{12-8}{12+8}\right)\times 10=\frac{4}{20}\times 10=2\text{m/s}^2$$

Therefore, the acceleration of the masses is 2 m/s^2.

Substituting the value of a in equation (ii), we get:

$$m_2g-T=m_2\left(\frac{m_2-m_1}{m_1+m_2}\right)g$$

$$T=\left(m_2-\frac{m_2^2-m_1m_2}{m_1=m_2}\right)g$$

$$=\left(\frac{2m_1m_2}{m_1+m_2}\right)g$$

$$=\left(\frac{2\times 12\times 8}{12+8}\right)\times 10$$

$$=\frac{2\times 12\times 8}{20}\times 10=96\text{N}$$

Therefore, the tension in the string is 96 N.

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

17. We suppose,

Mass of the parent nucleus as M and the mass of two daughter nuclei as m_1 and m_2.

The final velocities of the respective two daughter nuclei after disintegration as v_1, v_2 respectively.

Since, the parent nucleus before disintegration was at rest,

Initial momentum of the system i.e. parent nucleus = 0

Final momentum of the system i.e. daughter nuclei = $m_1v_1+m_2v_2$

According to the law of conservation of linear momentum:

Total initial momentum = Total final momentum

Therefore,

$0 = m_1v_1+m_2v_2$

$\Rightarrow v_1 = -(m_1/m_2) \times v_2$

The negative sign indicates that both the velocities of the daughter nuclei are in opposite directions.

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

18. Mass of each ball = 0.05 kg

Initial velocity of each ball = 6 m/s

Magnitude of the initial momentum of each ball, p_i = 0.3 kg m/s

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

Final momentum of each ball, p_f = –0.3 kg m/s

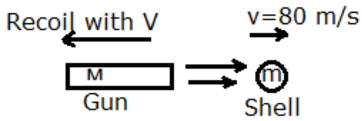
Impulse imparted to each ball = Change in the momentum of the system

$= p_f - p_i$

= –0.3 – 0.3 = –0.6 kg m/s

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

19. The initial velocity of both the gun and the shell system is zero
The initial momentum of the system = 0
Given,
Mass of the gun, M = 100 kg
Mass of the shell, m =0.02 kg
Final speed of the muzzle of the shell, v = 80 m/s
We suppose the recoil speed of the gun to be V.
The final momentum of the system = mv – MV
The negative sign is because the direction of motion of gun and shell is opposition to each other.



According to the law of conservation of linear momentum:
Total initial momentum = Total final momentum
Therefore,
0 = mv – MV

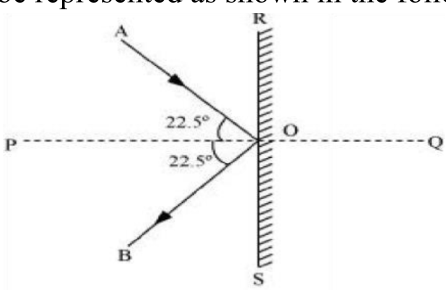
$$\Rightarrow V = \frac{mv}{M}$$

$$\Rightarrow V = \frac{0.02\ \text{kg} \times 80\ \text{m/s}}{100\ \text{kg}} = 0.016 \text{m/s}$$

Ans: The recoil speed of the gun is 0.016 m/s

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

20. The given situation can be represented as shown in the following figure.



Where,
AO = Incident path of the ball
OB = Path followed by the ball after deflection
∠AOB = Angle between the incident and deflected paths of the ball = 45°
∠AOP = ∠BOP = 22.5° = θ
Initial and final velocities of the ball = v

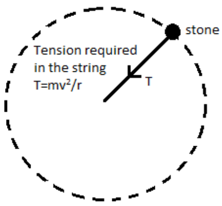
Horizontal component of the initial velocity = vcos θ along RO
Vertical component of the initial velocity = vsin θ along PO
Horizontal component of the final velocity = vcos θ along OS
Vertical component of the final velocity = vsin θ along OP
The horizontal components of velocities suffer no change. The vertical components of velocities are in the opposite directions.
∴Impulse imparted to the ball = Change in the linear momentum of the ball
= mv cos θ – (–mv cos θ)
= 2mv cos θ
Mass of the ball, m = 0.15 kg
Velocity of the ball, v = 54 km/h = 15 m/s
∴ Impulse = 2 × 0.15 × 15 cos 22.5° = 4.16 kg m/s

21. A stone of mass 0.25 kg tied to the end of a string is whirled round in a circle of radius 1.5 m with a speed of 40 rev./min in a horizontal plane. What is the tension in the string? What is the maximum speed with which the stone can be whirled around if the string can withstand a maximum tension of 200 N?

21. The angular velocity of the stone in circular motion is given as,

$$\omega = \frac{v}{r} = 2\pi n$$

where,
'v' is the linear velocity
'r' is the radius of the circle.
'n' is the number of revolutions per second
The centripetal force for the stone is provided by the tension T of the string,



The centripetal force 'F_c' can be given as

$$F_c = \frac{mv^2}{r} = m\omega 2r = m(2\pi n)^2 r$$

And F_c = Tension in the string
Where, m
Given,
Mass of the stone, m= 0.25 kg
Radius of the circle, r= 1.5 m
Number of the revolution per second, $n = \frac{40 \text{ rev}}{60 \text{ sec}}$

$$\Rightarrow n = \frac{2}{3} \text{rps}$$

Thus,

$$T = F_c = 0.25\text{ kg} \times 1.5\text{ m} \times \left(2 \times 3.14 \times \frac{2}{3}\text{ rps}\right)^2$$

$\Rightarrow T = 6.57\text{ N}$

Ans: The tension in the string is 6.57 N

Given,

The maximum tension that the string can withstand is, T' =200 N

$$T' = \frac{mv'^2}{r}$$

$$\Rightarrow v' = \left(\frac{T' \times r}{m}\right)^{\frac{1}{2}}$$

Where, v' is the maximum velocity of the stone

$$\Rightarrow v' = \left(\frac{200\text{ N} \times 1.5\text{ m}}{0.25\text{ kg}}\right)^{\frac{1}{2}} = \sqrt{1200} = 34.64\text{ m/s}$$

Ans: The maximum speed of the stone is 34.64 m/s

22. If, in Exercise 5.21, the speed of the stone is increased beyond the maximum permissible value, and the string breaks suddenly, which of the following correctly describes the trajectory of the stone after the string breaks:

(a) the stone moves radially outwards,

(b) the stone flies off tangentially from the instant the string breaks,

(c) the stone flies off at an angle with the tangent whose magnitude depends on the speed of the particle?

22. Option (b) is correct.

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

23. Explain why

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

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

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

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

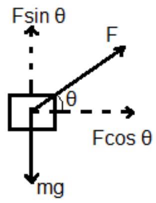
23. a. The Newton's third law of motion explains that to move forward and equal and opposite reaction force is acted on the ground. If the horse pushes the ground with some force, the ground in turn exerts equal and opposite force on the feet of the horse. This reaction force is the reason for the motion of the horse. An empty space does not have a surface for friction and thus no reaction force.

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

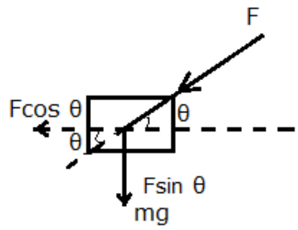
b. When a speeding bus suddenly stops, the feet of the passengers are still in the contact with bus, which suddenly comes to rest. Whereas, according to Newton's first law of motion, the upper body of the passengers which is not in contact with the bus, continues to be in motion.

As a result, the passenger's upper body is thrown forward while the lower body comes to halt with the bus.

c. When we pull a lawn mower, a force at some angle is applied on it. The vertical component is in the upward direction. This upward component reduces the effective weight of the mower, thus making it easier to pull.



Whereas, when we push a lawn mower, a force acting at some angle is applied on it, the vertical components is in the downward direction and act thus, increases the effective weight of the land mower.



Due to the less effective weight in the first case, the land mower is easier to pull than push.

d. According to the second law of motion, we have the equation of motion as,

$F = ma = m\frac{\Delta v}{\Delta t}$

Where
'F' is the force experienced by the cricketer as he catches the ball.
'm' is the mass of the ball
'Δt' is the short time of the impact with the hand of cricketer.
We can thus see from the equation that impact force is inversely proportional to the impact time, Thus, if the impact is for a shorter period of time then the force will be large.
It also shows that the force experienced by the cricketer decreases with the increase in the impact time.
Therefore, the cricketer moves his hand backward while taking a catch to increase the impact time, and hence decrease the impact force on his hand and prevent it from getting hurt.