Concept Notes on Laws of Motion for NEET

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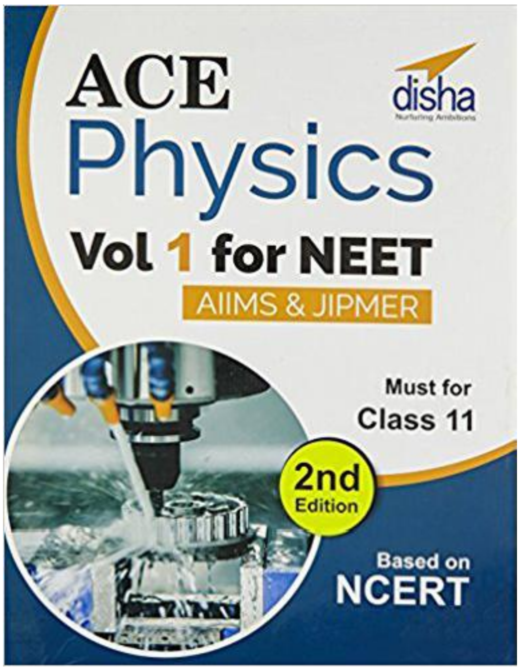

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5 Laws of Motion

ARISTOTLE'S FALLACY

According to Aristotelian law an external force is required to keep a body in motion. However an external force is required to overcome the frictional forces in case of solids and viscous forces in fluids which are always present in nature.

LINEAR MOMENTUM (p)

Linear momentum of a body is the quantity of motion contained in the body. Momentum $\vec{p} = m\vec{v}$

It is a vector quantity having the same direction as the direction of the velocity. Its **SI unit** is kg ms^{-1}.

NEWTON'S LAWS OF MOTION

First law : *A body continues to be in a state of rest or of uniform motion, unless it is acted upon by some external force to change its state*.

Newton's first law gives the qualitative definition of force according to which *force is that external cause which tends to change or actually changes the state of rest or motion of a body*.

Newton's first law of motion is the same as **law of inertia** given by Galileo.

Inertia *is the inherent property of all bodies because of which they cannot change their state of rest or of uniform motion unless acted upon by an external force*.

Second law : *The rate of change of momentum of a body is directly proportional to the external force applied on it and the change takes place in the direction of force applied*.

$$i.e., \quad \vec{F} = \frac{d\vec{p}}{dt} = \frac{md\vec{v}}{dt} = m\vec{a}$$

This is the equation of motion of constant mass system. For variable mass system such as rocket propulsion

$$\vec{F} = \frac{d(m\vec{v})}{dt}$$

$$\text{And,} \quad \vec{F} = \frac{m(d\vec{v})}{dt} + \vec{v}\frac{dm}{dt}$$

The **SI unit** of force is newton. (One newton force is that much force which produces an acceleration of $1ms^{-2}$ in a body of mass 1 kg.

The **CGS unit** of force is dyne. ($1N = 10^5$ dyne)

The gravitational unit of force is kg-wt (kg-f) or g-wt (g-f)

$$1\,kg\text{-}wt\,(kg\text{-}f) = 9.8\,N, \qquad 1\,g\text{-}wt\,(g\text{-}f) = 980\,dyne$$

Third law : *To every action there is an equal and opposite reaction*. For example – walking , swimming , a horse pulling a cart etc.

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

Action and reaction act on different bodies and hence cannot balance each other. Action and reaction occur simultaneously. Forces always occur in pairs.

EQUILIBRIUM OF A PARTICLE

A body is said to be in equilibrium when no net force acts on the body.

$$i.e., \ \Sigma\vec{F} = 0$$

Then $\Sigma F_x = 0$, $\Sigma F_y = 0$ and $\Sigma F_z = 0$

Stable equilibrium : If a body is slightly displaced from equilbrium position, it has the tendency to regain its original position, it is said to be in stable equilibrium.

In this case, *P.E. is minimum.* $\left(\frac{d^2u}{dr^2} = +ve\right)$

So, the *centre of gravity is lowest*.

Unstable equilibrium : If a body, after being displaced from the equilibrium position, moves in the direction of displacement, it is said to be in unstable equilibrium.

In this case, *P.E. is maximum.* $\left(\frac{d^2u}{dr^2} = -ve\right)$

So, the *centre of gravity is highest*.

Neutral equilibrium : If a body, after being slightly displaced from the equilibrium position has no tendency to come back or to move in the direction of displacement the equilibrium is known to be neutral.

In this case, *P.E. is constant* $\left(\frac{d^2u}{dr^2} = constant\right)$

The *centre of gravity remains at constant height*.

EXERCISE 5.1

Solve following problems with the help of above text and examples :

1. Swimming is possible on account of
(a) Newton's first law of motion
(b) Newton's second law of motion
(c) Newton's third law of motion
(d) Newton's law of gravitation

2. Inertia is that property of a body by virtue of which the body is
(a) unable to change by itself the state of rest
(b) unable to change by itself the state of uniform motion
(c) unable to change by itself the direction of motion
(d) All of the above

3. An object will continue moving uniformly when
(a) the resultant force on it is increasing continuously
(b) the resultant force is at right angles to its rotation
(c) the resultant force on it is zero
(d) the resultant force on it begins to decrease

4. A man getting down a running bus falls forward because
(a) of inertia of rest, road is left behind and man reaches forward
(b) of inertia of motion upper part of body continues to be in motion in forward direction while feet come to rest as soon as they touch the road.
(c) he leans forward as a matter of habit
(d) of the combined effect of all the three factors stated in (a), (b) and (c).

5. A man is at rest in the middle of a pond of perfectly smooth ice. He can get himself to the shore by making use of Newton's
(a) first law (b) second law
(c) third law (d) All of the above

6. A cannon after firing recoils due to
(a) conservation of energy
(b) backward thrust of gases produced
(c) Newton's third law of motion
(d) Newton's first law of motion

7. Newton's second law measures the
(a) acceleration (b) force
(c) momentum (d) angular momentum

8. We can derive Newton's
(a) second and third laws from the first law
(b) first and second laws from the third law
(c) third and first laws from the second law
(d) All the three laws are independent of each other

9. A jet plane moves up in air because
(a) the gravity does not act on bodies moving with high speeds
(b) the thrust of the jet compensates for the force of gravity
(c) the flow of air around the wings causes an upward force, which compensates for the force of gravity
(d) the weight of air whose volume is equal to the volume of the plane is more than the weight of the plane

10. When a body is stationary
(a) there is no force acting on it
(b) the force acting on it is not in contact with it
(c) the combination of forces acting on it balances each other
(d) the body is in vacuum

ANSWER KEY

1. (c) 2. (d) 3. (c) 4. (b) 5. (c) 6. (c) 7. (b) 8. (c) 9.(b) 10.(c)

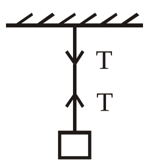
COMMON FORCES IN MECHANICS

1. Weight : It is the force with which the earth attracts a body and is called force of gravity, For a body of mass m, where acceleration due to gravity is g, the weight

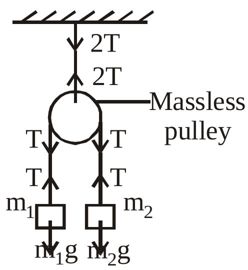
$$W = mg$$

2. Tension : The force exerted by the ends of a loaded/stretched string (or chain) is called tension. The tension has a sense of pull at its ends.

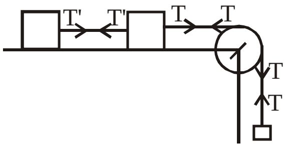
Case 1

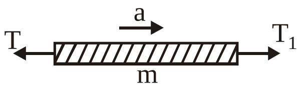


Case 2



Case 3





$T_1 - T = ma$

If $m = 0$, $T_1 = T$

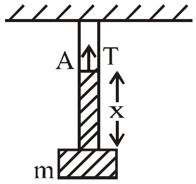
i.e tension is same

The tension in a string remains the same throughout the string if

(a) string is massless,

(b) pulley is massless or pulley is frictionless

Case 4 : String having mass



Let the total mass of the string be M and length be L. Then mass per unit length is $\frac{M}{L}$

Let x be the distance of the string from the mass m. Then the mass of the shaded portion of string is $\left(\frac{M}{L} \times x\right)$

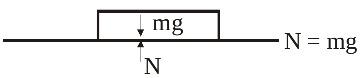
If the string is at rest then the tension T has to balance the wt of shaded portion of string and weight of mass m.

$$\therefore T = \left(m + \frac{M}{L}x\right)g$$

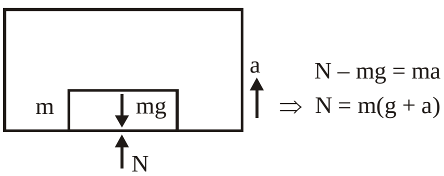
$\Rightarrow$ as x increases, the tension increases. Thus tension is non-uniform in a string having mass.

3. **Normal force :** It measures how strongly one body presses the other body in contact. It acts normal to the surface of contact.

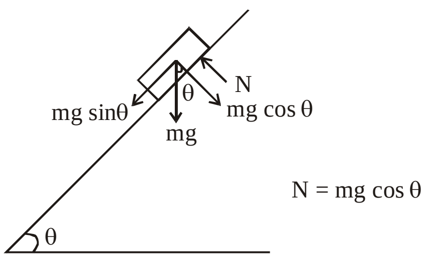
Case 1



Case 2



Case 3



4. **Spring force :** If an object is connected by spring and spring is stretched or compressed by a distance x, then restoring force on the object $F = -kx$

   where k is a spring contact on force constant.

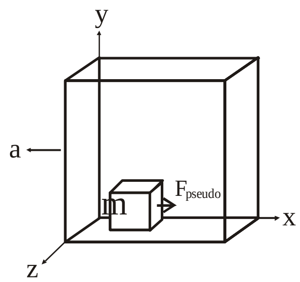
5. **Frictional force :** It is a force which opposes relative motion between the surfaces in contact. $f = \mu N$

   This will be discussed in detail in later section.

6. **Pseudo force :** If a body of mass m is placed in a non-inertial frame having aceleration $\vec{a}$, then it experiences a Pseudo force acting in a direction opposite to the direction of $\vec{a}$.

$$\vec{F}_{pseudo} = -m\vec{a}$$

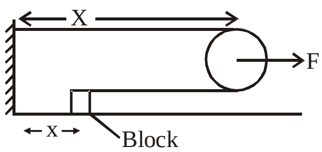
   Negative sign shows that the pseudo force is always directed in a direction opposite to the direction of the acceleration of the frame.



CONSTRAINT MOTION :

When the motion of one body is dependent on the other body, the relationship of displacements, velocities and accelerations of the two bodies are called constraint relationships.

Case 1 Pulley string system :



Step 1 : Find the distance of the two bodies from fixed points.

Step 2 : The length of the string remain constant. (We use of this condition)

Therefore $X + (X - x) = \text{constant} \Rightarrow 2X - x = \text{constant}$

$$\Rightarrow \quad 2\frac{dX}{dt} - \frac{dx}{dt} = 0 \quad \Rightarrow \quad 2\frac{dX}{dt} = \frac{dx}{dt}$$

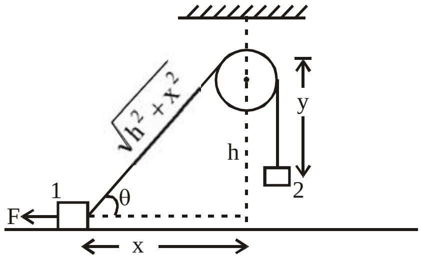
$$\Rightarrow \quad 2V_p = v_B \left[\because \frac{dX}{dt} = V_p = \text{velocity of pulley} \quad \frac{dx}{dt} = v_B = \text{velocity of block}\right]$$

Again differentiating we get, $2a_p = a_B$

$$\left[a_p = \frac{dVp}{dt} \text{and } a_B = \frac{dv_B}{dt}\right]$$

a_p = acceleration of pulley, a_B = acceleration of block

Case 2 Here $\sqrt{h^2+x^2}+y=\text{constt.}$ On differentiating w.r.t 't'

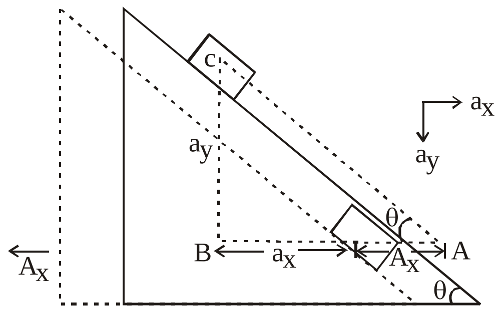


[Negative sign with dy/dt shows that with increase in time, y decreases]

$$\frac{1\times 2x}{2\sqrt{h^2+x^2}}\frac{dx}{dt}-\frac{dy}{dt}=0 \Rightarrow \cos\theta\,(v_1-v_2)=0$$

$$\left[\because \cos\theta=\frac{x}{\sqrt{h^2+x^2}}\right]$$

Case 3 Wedge block system : Thin lines represents the condition of wedge block at t = 0 and dotted lines at t = t



A_x = acceleration of wedge towards left
a_x, a_y = acceleration of block as shown

From ΔABC, $\tan\theta=\dfrac{a_y}{a_x+A_x}$

Frame of Reference :

Reference frames are co-ordinate systems in which an event is described.

There are two types of reference frames

(a) **Inertial frame of reference**: These are frames of reference in which Newton's laws hold good. These frames are at rest with each other or which are moving with uniform speed with respect to each other.
All reference frames present on surface of Earth are supposed to be inertial frame of reference.

(b) **Non – inertial frame of reference**: Newton's law do not hold good in non-inertial reference frame.
All accelerated and rotatory reference frames are non – inertial frame of reference. Earth is a non-intertial frame.

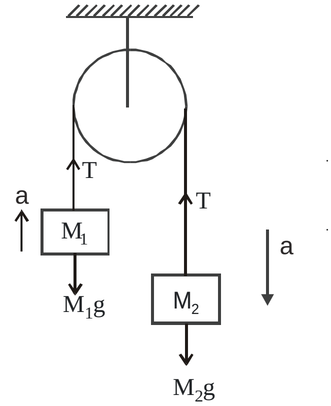
Note : When the observer is in non-inertial reference frame a pseudo force is applied on the body under observation.

Free Body Diagram (FBD) :

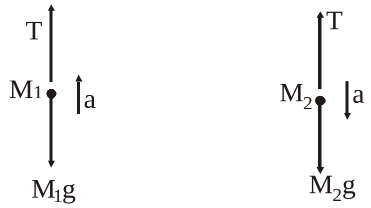
Free body diagram of a mass is a separate diagram of that mass. All forces acting on the mass are sketched. A FBD is drawn to visualise the direct forces acting on a body.

Case 1 : Masses M_1 and M_2 are tied to a string, which goes over a frictionless pulley

(a) **If $M_2 > M_1$ and they move with acceleration a**



FBD of M_1, FBD of M_2



$T-M_1g=M_1a$ $\qquad M_2g-T=M_2a$

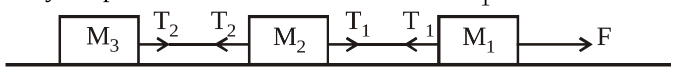
where T is the tension in the string. It gives

$$a=\frac{M_2-M_1}{M_1+M_2}g \text{ and } T=\frac{2M_1M_2}{M_1+M_2}g$$

(b) **If the pulley begins to move with acceleration f, downwards**

$$\vec{a}=\frac{M_2-M_1}{M_1+M_2}(\vec{g}-\vec{f}) \text{ and } \vec{T}=\frac{2M_1M_2}{M_1+M_2}(\vec{g}-\vec{f})$$

Case 2 : Three masses M_1, M_2 and M_3 are connected with strings as shown in the figure and lie on a frictionless surface. They are pulled with a force F attached to M_1.

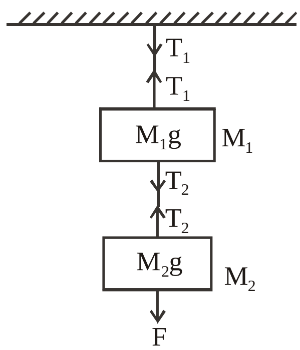


The forces on M_2 and M_3 are as follows

$$T_1=\frac{M_2+M_3}{M_1+M_2+M_3}F \text{ and } T_2=\frac{M_3}{M_1+M_2+M_3}F\,;$$

Acceleration of the system is $a=\dfrac{F}{M_1+M_2+M_3}$

Case 3 : Two blocks of masses M_1 and M_2 are suspended vertically from a rigid support with the help of strings as shown in the figure. The mass M_2 is pulled down with a force F.



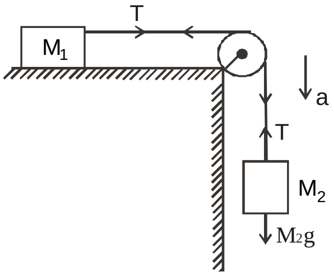
The tension between the masses M_1 and M_2 will be

$$T_2 = F + M_2 g$$

Tension between the support and the mass M_1 will be

$$T_1 = F + (M_1 + M_2)g$$

Case 4 : Two masses M_1 and M_2 are attached to a string which passes over a pulley attached to the edge of a horizontal table. The mass M_1 lies on the frictionless surface of the table.



Let the tension in the string be T and the acceleration of the system be a. Then

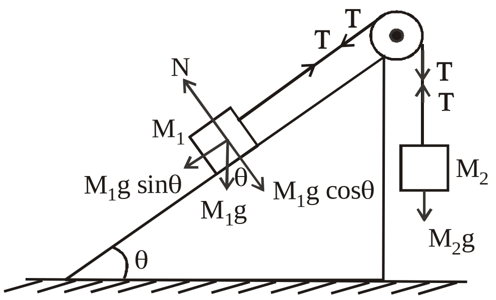
$T = M_1 a$ ...(1)

$M_2 g - T = M_2 a$ ...(2)

Adding eqns. (1) and (2), we get

$$a = \left[\frac{M_2}{M_1 + M_2}\right] g \text{ and } T = \left[\frac{M_1 M_2}{M_1 + M_2}\right] g$$

Case 5 : Two masses M_1 and M_2 are attached to the ends of a string, which passes over a frictionless pulley at the top of the inclined plane of inclination θ. Let the tension in the string be T.



(i) **When the mass M_1 moves upwards with acceleration a**.

From the FBD of M_1 and M_2,

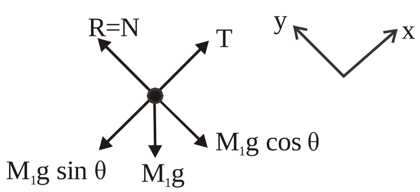
$T - M_1 g \sin\theta = M_1 a$ ...(1)

$M_2 g - T = M_2 a$ ...(2)

Solving eqns. (1) and (2) we get,

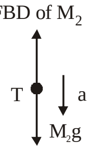
$$a = \left[\frac{M_2 - M_1 \sin\theta}{M_1 + M_2}\right] g$$

FBD of mass M_1



$$T = \left[\frac{M_2 M_1}{M_1 + M_2}\right] \frac{g}{(1+\sin\theta)}$$

FBD of M_2



(ii) **When the mass M_1 moves downwards with acceleration a**.

Equation of motion for M_1 and M_2,

$M_1 g \sin\theta - T = M_1 a$ ...(1)

$T - M_2 g = M_2 a$ ...(2)

Solving eqns. (1) and (2) we get,

$$a = \left[\frac{M_1 \sin\theta - M_2}{M_1 + M_2}\right] g;\ T = \left[\frac{M_2 M_1}{M_1 + M_2}\right] \frac{g}{(1+\sin\theta)}$$

(a) If $(M_2/M_1 = \sin\theta)$ then the system does not accelerate.

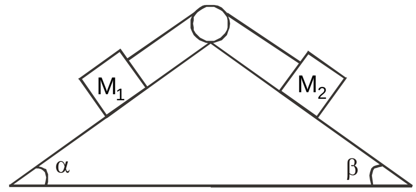
(b) Changing position of masses, does not affect the tension. Also, the acceleration of the system remains unchanged.

(c) If $M_1 = M_2 = M$ (say), then

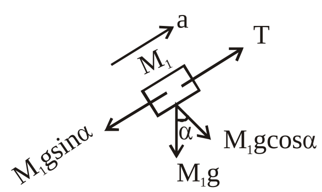
$$a = \left(\cos\frac{\theta}{2} - \sin\frac{\theta}{2}\right)^2 \left(\frac{g}{2}\right);\ T = \left(\cos\frac{\theta}{2} + \sin\frac{\theta}{2}\right)^2 \left(\frac{Mg}{2}\right)$$

Case 6 : Two masses M_1 and M_2 are attached to the ends of a string over a pulley attached to the top of a double inclined plane of angle of inclination α and β.

Let M_2 move downwards with acceleration a and the tension in the string be T then



<u>FBD of M_1</u>

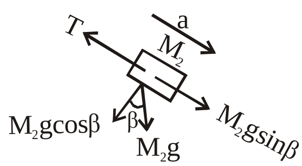


Equation of motion for M_1

$T - M_1 g \sin\alpha = M_1 a$

or $T = M_1 g \sin\alpha + M_1 a$ ...(1)

<u>FBD of M_2</u>



Equation of motion for M_2

$M_2 g \sin\beta - T = M_2 a$

or $T = M_2 g \sin\beta - M_2 a$ ...(2)

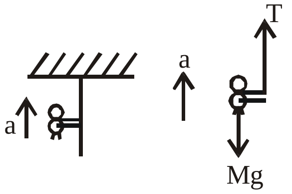
Using eqn. (1) and (2) we get,

$M_1 g \sin\alpha + M_1 a = M_2 g \sin\beta - M_2 a$

Solving we get,

$$a = \frac{(M_2 \sin\beta - M_1 \sin\alpha) g}{M_1 + M_2} \text{ and } T = \frac{M_1 M_2 g}{M_1 + M_2}[\sin\beta + \sin\alpha]$$

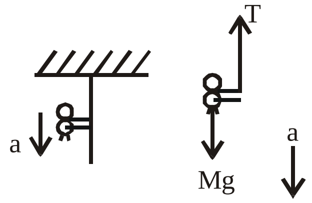
Case 7 : A person/monkey climbing a rope



(a) A person of mass M climbs up a rope with acceleration a. The tension in the rope will be M(g+a).

$T - Mg = Ma \Rightarrow T = M(g + a)$

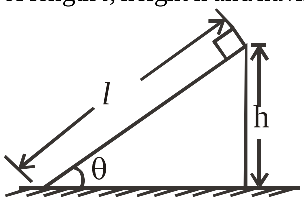
(b) If the person climbs down along the rope with acceleration a, the tension in the rope will be M(g–a).



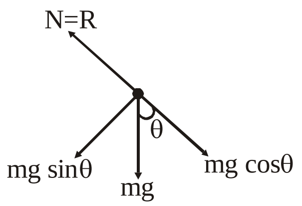
$Mg - T = Ma \Rightarrow T = M(g - a)$

(c) When the person climbs up or down with uniform speed, tension in the string will be Mg.

Case 8 : A body starting from rest moves along a smooth inclined plane of length *l*, height h and having angle of inclination θ.



FBD of body



(where N=R is normal reaction applied by plane on the body of mass m)

For downward motion, along the inclined plane,

$mg \sin\theta = ma \Rightarrow a = g \sin\theta$

By work-energy theorem loss in P.E. = gain in K.E.

$$\Rightarrow mgh = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{2gh}$$

Also, from the figure, $h = \ell \sin\theta$. $\therefore\ v = \sqrt{2gh} = \sqrt{2g\ell\sin\theta}$

(a) Acceleration down the plane is $g\sin\theta$.

(b) Its velocity at the bottom of the inclined plane will be $\sqrt{2gh} = \sqrt{2g\ell\sin\theta}$

(c) Time taken to reach the bottom will be

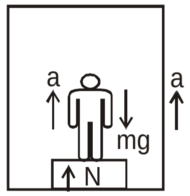
$$t = \left(\frac{2\ell}{g\sin\theta}\right)^{1/2} = \left(\frac{2h}{g\sin^2\theta}\right)^{1/2} = \frac{1}{\sin\theta\left(\frac{g}{2h}\right)^{1/2}} = \frac{1}{\sin\theta}\sqrt{\frac{2h}{g}}$$

(d) If angles of inclination are θ_1 and θ_2 for two inclined planes

Keeping the length constant then $\dfrac{t_1}{t_2} = \left(\dfrac{\sin\theta_2}{\sin\theta_1}\right)^{1/2}$

Case 9 : Weight of a man in a lift :

(i) **When lift is accelerated upward :** In this case the man also moves in upward direction with an acceleration $\vec{a}$.



Then from Newton' second law

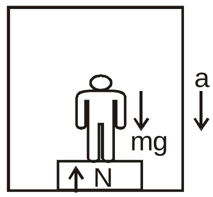
$N - mg = ma$ or $N = m(g + a)$

or $W_{app} = m(g + a) = W_o(1 + a/g)$ (as W = mg)

Where W_{app} is apparent weight of the man in the lift, W_o is the real weight, N is the reaction of lift on the man. It is clear that $N = W_{app}$

When the lift moves upward and if we measure the weight of the man by any means (such as spring balance) then we observe more weight (i.e., W_{app}) than the real weight (W_o) $W_{app} > W_o$

(ii) **When lift is accelerated downward :** In this case from Newton's second law



$mg - N = ma$

or $N = m(g - a) = W_o(1 - a/g)$

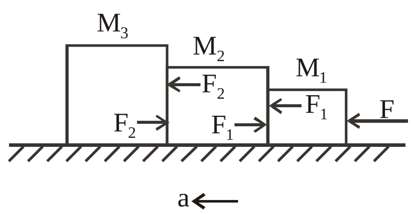
or $W'_{app} = W_o(1 - a/g)$ $\{\because W_o = mg\}$

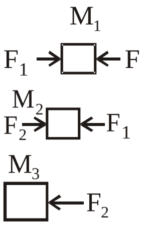
If we measure the weight of man by spring balance, we observe deficiency because $W_{app} < W_o$.

(iii) **When lift is at rest or moving with constant velocity :** From Newton's second law $N - mg = 0$ or $N = mg$

In this case spring balance gives the true weight of the man.

Case 10 : Three masses M_1, M_2 and M_3 are placed on a smooth surface in contact with each other as shown in the figure. A force F pushes them as shown in the figure and the three masses move with acceleration a,





$\Rightarrow F - F_1 = m_1 a$ ...(i)

$\Rightarrow F_1 - F_2 = m_2 a$ ...(ii)

$\Rightarrow F_2 = M_3\, a$ ...(iii)

Adding eqns. (i), (ii) and (iii) we get, $a = \dfrac{F}{M_1 + M_2 + M_3}$

$$\Rightarrow F_2 = \frac{M_3 F}{M_1 + M_2 + M_3} \text{ and } F_1 = \frac{(M_2 + M_3)F}{M_1 + M_2 + M_3}$$

Keep in Memory

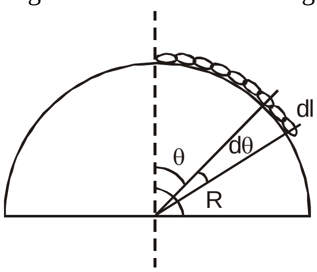
1. When a man jumps with load on his head, the apparent weight of the load and the man is zero.
2. (i) If a person sitting in a train moving with uniform velocity throws a coin vertically up, then coin will fall back in his hand.
   (ii) If the train is uniformly accelerated, the coin will fall behind him.
   (iii) If the train is retarded uniformly, then the coin will fall in front of him.

Example 1.

A chain of length ℓ is placed on a smooth spherical surface of radius R with one of its ends fixed at the top of the sphere. What will be the acceleration a of each element of the chain when its upper end is released? It is assumed that the length of chain $\ell < \left(\pi \dfrac{R}{2}\right)$.

Solution :

Let m be the mass of the chain of length ℓ. Consider an element of length $d\ell$ of the chain at an angle θ with vertical,



From figure, $d\ell = R\, d\theta$;

Mass of the element,

$$dm = \frac{m}{\ell} d\ell \text{ ; or } dm = \frac{m}{\ell}.R\, d\theta$$

Force responsible for acceleration, $dF = (dm) g \sin\theta$;

$$dF = \left(\frac{m}{\ell} R\, d\theta\right)(g \sin\theta) = \frac{mgR}{\ell} \sin\theta\, d\theta$$

Net force on the chain can be obtained by integrating the above relation between 0 to α, we have

$$F = \int_0^\alpha \frac{mg\,R}{\ell} \sin\theta\, d\theta = \frac{mg\,R}{\ell}(-\cos\theta)_0^\alpha = \frac{mg\,R}{\ell}[1 - \cos\alpha]$$

$$= \frac{mg\,R}{\ell}\left[1 - \cos\frac{\ell}{R}\right];$$

$$\therefore \text{ Acceleration, } a = \frac{F}{m} = \frac{gR}{\ell}\left(1 - \cos\frac{\ell}{R}\right).$$

Example 2.

Having gone through a plank of thickness h, a bullet changed its velocity from u to v. Find the time of motion of the bullet in the plank, assuming the resistance force to be proportional to the square of the velocity.

Solution :

Given force F= $-k\,v^2$, where k is a constant. Negative sign shows that the force is retarding one. Now, force = rate of change of momentum = m dv/d t ;

$$\frac{mdv}{dt} = -kv^2 \text{ or } mdv/v^2 = -kdt \text{ ;}$$

Integrating it within the conditions of motion i.e. as time changes from o to t, the velocity changes from u to v, we have

$$m\int_u^v \frac{dv}{v^2} = -k\int_0^t dt \text{ ;} \qquad \text{or } -m\left(\frac{1}{v}\right)_u^v = -kt$$

$$\text{or} \quad t = \frac{m}{k}\left(\frac{u - v}{uv}\right) \qquad \text{....(i)}$$

$$\text{Also, } F = m\frac{dv}{dt} = m\frac{dv}{ds}\frac{ds}{dt} = -kv^2$$

$$\text{or } \frac{dv}{v} = -\frac{k}{m} d\,s. \text{ ;} \qquad \left(\because \frac{ds}{dt} = v\right) \text{ ; Integrating it,}$$

$$\text{we get } \int_u^v \frac{dv}{v} = -\frac{k}{m}\int_0^h ds \qquad \text{or } (\log_e v)_u^v = -\frac{k}{m}(s)_o^h$$

$$\text{or } \log_e v - \log_e u = \frac{-k}{m}(h - 0) = -\frac{kh}{m}$$

$$\text{or } k = \frac{m}{h}\log_e(u/v)$$

Putting this value in eq^n. (i), we get

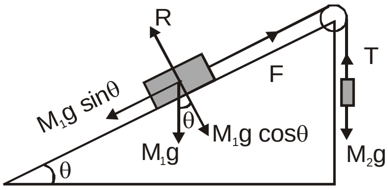
$$t = \frac{m(u - v)/uv}{(m/h)\log_e(u/v)} = \frac{h(u - v)}{uv\,\log_e(u/v)}$$

Example 3.

A wire of mass 9.8×10^{-3} kg per metre passes over a frictionless pulley fixed on the top of an inclined frictionless plane which makes an angle of 30º with the horizontal. Masses M_1 and M_2 are tied at the two ends of the wire. The mass M_1 rests on the plane and mass M_2 hangs freely vertically downwards. The whole system is in equilibrium. Now a transverse wave propagates along the wire with a velocity of 100 ms^{-1}. Find M_1 and M_2.

Solution :

Resolving M_1g into rectangular components, we have M_1g sin 30º acting along the plane downwards, and M_1g cos30º acting perpendicular to the plane downwards. The situation has been shown in fig.



Let T be the tension in the wire and R be the reaction of plane on the mass M_1. Since the system is in equilibrium, therefore,

$T = M_1g \sin 30^\circ$ ...(i)

and $R = M_1g \cos 30^\circ$ ...(ii)

$T = M_2g$ ...(iii)

From eq^n. (i) and (iii) we have

$T = M_1g \sin 30^\circ = M_2g$ ...(iv)

Velocity of transverse wave, $v = \sqrt{\dfrac{T}{m}}$,

where m is the mass per unit length of the wire.

$\therefore\ v^2 = T/m$, or $T = v^2m = (100)^2 \times (9.8 \times 10^{-3}) = 98N$

From eq^n. (iii), $M_2 = T/g = 98/9.8 = 10$kg.

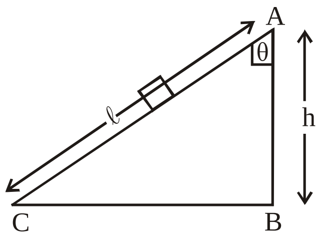
From eq^n. (iv), $M_1 = 2M_2 = 2 \times 10 = 20$kg.

Example 4.

A block slides down a smooth inclined plane to the ground when released at the top, in time t second. Another block is dropped vertically from the same point, in the absence of the inclined plane and reaches the ground in t/2 second. Then find the angle of inclination of the plane with the vertical.

Solution :

If θ is the angle which the inclined plane makes with the vertical direction, then the acceleration of the block sliding down the plane of length ℓ will be g cosθ.



Using the formula, $s = ut + \frac{1}{2}at^2$, we have $s = \ell$, u = 0, t = t and a = g cos θ.

so $\ell = 0 \times t + \frac{1}{2} g\cos\theta\, t^2 = \frac{1}{2}(g\cos\theta)t^2$ ...(i)

Taking vertical downward motion of the block, we get

$h = 0 + \frac{1}{2}g(t/2)^2 = \frac{1}{2}gt^2/4$ ...(ii)

Dividing eq^n. (ii) by (i), we get

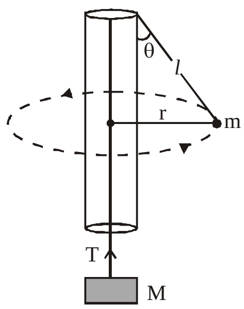
$$\frac{h}{\ell} = \frac{1}{4\cos\theta} \quad [\because \cos\theta = h/\ell]$$

or $\cos\theta = \frac{1}{4\cos\theta}$; or $\cos^2\theta = \frac{1}{4}$; or $\cos\theta = \frac{1}{2}$

or θ = 60º

Example 5.

A large mass M and a small mass m hang at the two ends of a string that passes through a smooth tube as shown in fig. The mass m moves around a circular path in a horizontal plane. The length of the string from mass m to the top of the tube is l, and θ is the angle the string makes with the vertical. What should be the frequency (ν) of rotation of mass m so that mass M remains stationary?



Solution :

Tension in the string T = Mg.

Centripetal force on the body = $mr\omega^2 = mr(2\pi\nu)^2$. This is provided by the component of tension acting horizontally i.e. T sinθ (= Mg sinθ).

$\therefore\ mr(2\pi\nu)^2 = Mg\sin\theta = Mgr/l$. or $\nu = \frac{1}{2\pi}\sqrt{\frac{Mg}{ml}}$

Example 6.

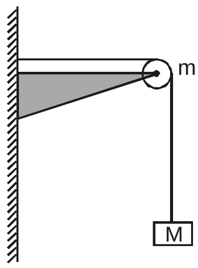
A string of negligible mass going over a clamped pulley of mass m supports a block of mass M as shown in fig. The force on the pulley by the clamp is given by

(a) $\sqrt{2}$ Mg

(b) $\sqrt{2}$ mg

(c) $[\sqrt{(M+m)^2 + m^2}]\,g$

(d) $[\sqrt{(M+m)^2 + M^2}]\,g$



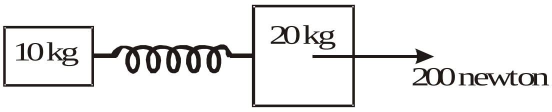
Solution : (c)

Force on the pulley by the clamp = resultant of T = (M + m)g and mg acting along horizontal and vertical respectively

$\therefore\ F = \sqrt{[(M+m)g]^2 + (mg)^2} = [\sqrt{(M+m)^2 + m^2}]g$

Example 7.

The masses of 10 kg and 20 kg respectively are connected by a massless spring in fig. A force of 200 newton acts on the 20 kg mass. At the instant shown, the 10 kg mass has acceleration 12 m/sec^2. What is the acceleration of 20 kg mass?



Solution :

Force on 10 kg mass = 10 × 12 = 120 N

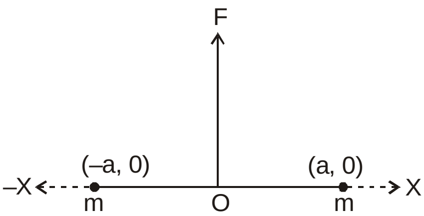
The mass of 10 kg will pull the mass of 20 kg in the backward direction with a force of 120 N.

$\therefore$ Net force on mass 20 kg = 200 – 120 = 80 N

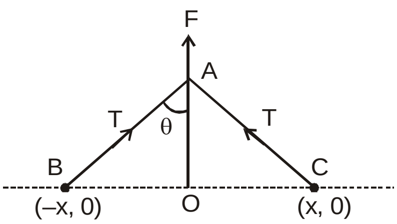
Its acceleration $a = \dfrac{\text{force}}{\text{mass}} = \dfrac{80\,N}{20\,kg} = 4\,m/s^2$

Example 8.

Two masses each equal to m are lying on X-axis at (–a, 0) and (+ a, 0) respectively as shown in fig. They are connected by a light string. A force F is applied at the origin and along the Y-axis. As a result, the masses move towards each other. What is the acceleration of each mass? Assume the instantaneous position of the masses as (– x, 0) and (x, 0) respectively



Solution :



From figure F = 2 T cos θ or T = F/(2 cos θ)

The force responsible for motion of masses on X-axis is T sin θ

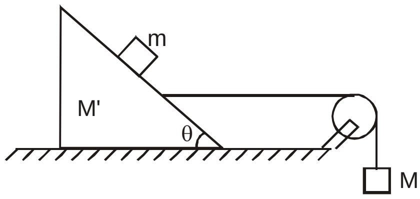
$$\therefore ma = T\sin\theta = \frac{F}{2\cos\theta}\times\sin\theta$$

$$= \frac{F}{2}\tan\theta = \frac{F}{2}\times\frac{OB}{OA} = \frac{F}{2}\times\frac{x}{\sqrt{(a^2-x^2)}}$$

so, $$a = \frac{F}{2m}\times\frac{x}{\sqrt{(a^2-x^2)}}$$

Example 9.

Find the mass M of the hanging block in figure which will prevent smaller block from slipping over the triangular block. All surfaces are frictionless and the string and the pulley are light.



Solution :

Since m does not slip on M' (relative velocity of m w.r.t. M' is zero)

$\therefore$ M', m will move with same acceleration as that of M.

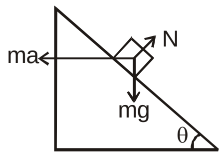
Since surfaces are smooth

$\therefore$ frictional force is zero

Net force = Mg = (M + M' + m) a

$$\therefore a = \frac{Mg}{M + M' + m} \qquad ....(1)$$

Now let us see m, w.r.t. M'



Downward acceleration of m on slope = 0

$\therefore$ N – ma sin θ + mg cos θ = 0 ....(2)

(net $\perp$ force = 0)

and mg sin θ – ma cos θ = 0 ....(3)

[$\because$ net force along slope = 0]

From eq^n. (3) g sin θ = a cos θ or a = g tan θ ....(4)

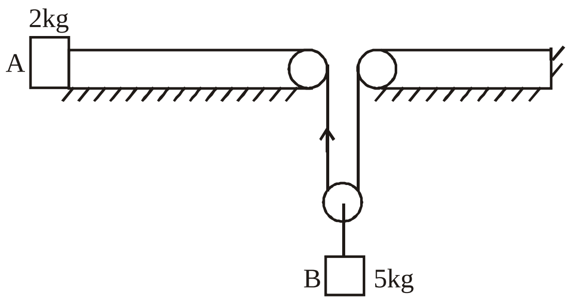
From eq^n. (4) and (1),

we have $\tan\theta = \dfrac{M}{M + M' + m} \Rightarrow M\cot\theta = M + M' + m$

$$\Rightarrow M = \frac{M' + m}{\cot\theta - 1}$$

Example 10.

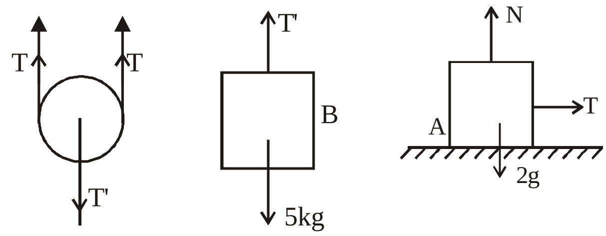
Find the acceleration of block A and B. Assume pulley is massless.



Solution :

If acceleration of B is a, then acceleration of A is 2a, since A moves twice the distance moved by B

T' – (T +T) = 0 (since pulley is massless)



$\Rightarrow T' = 2T$ ....(1)

$5g - T' = 5a$ (for 5 kg block)

$\Rightarrow 5g - 2T = 5a$ ....(2)

$T = 2 \times (2a) = 4a$ ....(3) (for 2 kg block)

From equations (2) and (3),

$5g - (2 \times 4a)$

$$a = \frac{5g}{13}$$

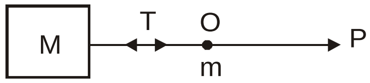
$$a_A = 2a = \frac{10g}{13}\ ;\ \ a_B = a = \frac{5g}{13}$$

Example 11.

A block of mass M is pulled along horizontal frictionless surface by a rope of mass m. Force P is applied at one end of rope. Find the force which the rope exerts on the block.

Solution :

The situation is shown in fig



Let a be the common acceleration of the system. Here

T = M a for block

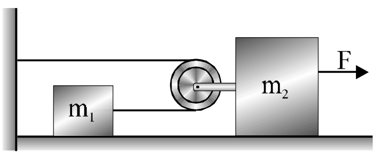
P – T = m a for rope

$$\therefore P - Ma = ma \text{ or } P = a(M+m) \text{ or } a = \frac{P}{(M+m)}$$

$$\therefore T = \frac{MP}{(M+m)}$$

Example 12.

In the system shown below, friction and mass of the pulley are negligible. Find the acceleration of m_2 if m_1 = 300 g, m_2 = 500 g and F = 1.50 N



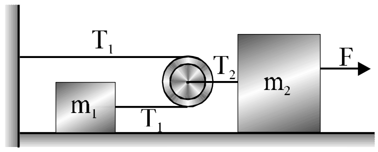
Solution :

When the pulley moves a distance d, m_1 will move a distance 2d. Hence m_1 will have twice as large an acceleration as m_2 has.

For mass m_1, $T_1 = m_1(2a)$ ...(1)

For mass m_2, $F - T_2 = m_2(a)$ ...(2)

Putting $T_1 = \frac{T_2}{2}$ in eq^n. (1) gives $T_2 = 4m_1a$



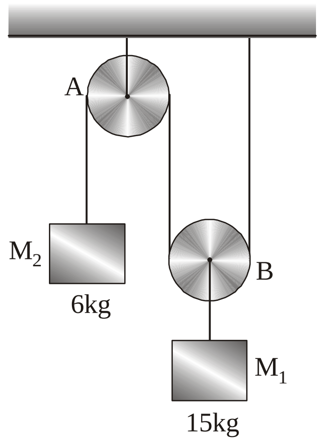
Substituting value of T_2 in equation (2),

$F = 4m_1a + m_2a = (4m_1 + m_2)a$

$$\text{Hence } a = \frac{F}{4m_1 + m_2} = \frac{1.50}{4(0.3)+0.5} = 0.88 \text{ m/s}^2$$

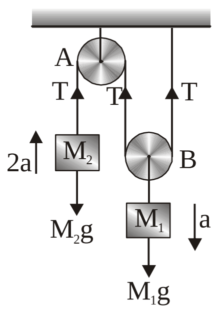
Example 13.

A mass of 15 kg and another of mass 6 kg are attached to a pulley system as shown in fig. A is a fixed pulley while B is a movable one. Both are considered light and frictionless. Find the acceleration of 6 kg mass.



Solution :

Tension is the same throughout the string. It is clear that M_1 will descend downwards while M_2 rises up. If the acceleration of M_1 is a downwards, M_2 will have an acceleration '2a' upward.



Now, $M_1g - 2T = M_1a$

$T - M_2g = M_2.2a$

or $M_1g - 2M_2g = a(M_1 + 4M_2)$

$$\Rightarrow a = \frac{M_1 - 2M_2}{M_1 + 4M_2}g = \frac{15-12}{15-24}g = \frac{3}{39}g$$

$$\therefore a = \frac{g}{13}$$

$$\therefore \text{ acceleration of 6 kg mass} = 2a = \frac{2g}{13}$$

EXERCISE 5.2

Solve following problems with the help of above text and examples :

1. Tension in the cable supporting an elevator, is equal to the weight of the elevator. From this, we can conclude that the elevator is going up or down with a
   (a) uniform velocity (b) uniform acceleration
   (c) variable acceleration (d) either (b) or (c)
2. The force exerted by the floor of an elevator on the foot of a person standing there, is more than his weight, if the elevator is
   (a) going down and slowing down
   (b) going up and speeding up
   (c) going up and slowing down
   (d) either (a) or (b)
3. A reference frame attached to earth cannot be an inertial frame because
   (a) earth is revolving around the sun
   (b) earth is rotating about its axis
   (c) Newton's laws are applicable in this frame
   (d) both (a) and (b)
4. When an elevator cabin falls down, the cabin and all the bodies fixed in the cabin are accelerated with respect to
   (a) ceiling of elevator (b) floor of elevator
   (c) man standing on earth
   (d) man standing in the cabin
5. A particle is found to be at rest when seen from frame S_1 and moving with a constant velocity when seen from another frame S_2. Mark out the possible option.
   (a) S_1 is inertial and S_2 is non-inertial frame
   (b) both the frames are non-inertial
   (c) both the frames are inertial
   (d) either (b) or (c).
6. The tension in the cable of 1000 kg elevator is 1000 kg wt, the elevator
   (a) is ascending upwards
   (b) is descending downwards
   (c) may be at rest or accelerating
   (d) may be at rest or in uniform motion
7. Consider an elevator moving downwards with an acceleration a. The force exerted by a passenger of mass m on the floor of the elevator is
   (a) ma (b) ma – mg
   (c) mg – ma (d) mg + ma
8. If an elevator is moving vertically up with an acceleration a, the force exerted on the floor by a passenger of mass M is
   (a) Ma (b) Mg
   (c) M (g – a) (d) M (g + a)
9. You are on a frictionless horizontal plane. How can you get off if no horizontal force is exerted by pushing against the surface?
   (a) By jumping
   (b) By spitting or sneezing
   (c) by rolling your body on the surface
   (d) By running on the plane
10. Pulling a roller is easier than pushing because
    (a) when we pull a roller, the vertical component of the pulling force acts in the direction of weight
    (b) the vertical component of the pulling force acts in the opposite direction of weight
    (c) force of friction is in opposite direction
    (d) it is possible in the case of roller only

ANSWER KEY

1. (a) 2. (b) 3. (d) 4. (c) 5. (d) 6. (d) 7. (c) 8. (d) 9. (b) 10. (b)

LAW OF CONSERVATION OF LINEAR MOMENTUM

A system is said to be isolated, when no external force acts on it. For such isolated system, the linear momentum $(\vec{P} = m\vec{v})$ *is constant i.e., conserved.*

The linear momentum is defined as

$$\vec{P} = m\vec{v} \qquad .....(1)$$

where $\vec{v}$ is the velocity of the body, whose mass is m. The direction of $\vec{P}$ is same as the direction of the velocity of the body. It is a vector quantity. From Newton's second law,

$$\vec{F}_{ext.} = \frac{d}{dt}(m\vec{v}) = \frac{d}{dt}\vec{P} \qquad .....(2)$$

i.e., time rate of change in momentum of the body is equal to total external force applied on the body.

If $\vec{F}_{ext.} = 0 \Rightarrow \frac{d}{dt}(\vec{P}) = 0$ or $\vec{P}$ = constant .....(3)

This is called **law of conservation of momentum**.

Now let us consider a rigid body consisting of a large number of particles moving with different velocities, then total linear momentum of the rigid body is equal to the summation of individual linear momentum of all particles

i.e., $\sum_{i=1}^{n} \vec{p}_i = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + ...\vec{p}_n$

or $\vec{P}_{total} = \sum_{i=1}^{n} \vec{p}_i = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + ... + \vec{p}_n$

where $\vec{p}_1, \vec{p}_2 ....\vec{p}_n$ are individual linear momentum of first, second and nth particle respectively.

If this rigid body is isolated i.e., no external force is applied on it, then $\vec{P}_{total}$ = constant (from Newton's second law).

Further we know that internal forces (such as intermolecular forces etc.) also act inside the body, but these can only change individual linear momentum of the particles (i.e., p_1, p_2.........), but their total momentum $\vec{P}_{total}$ remains constant.

Gun Firing a Bullet

If a gun of mass M fires a bullet of mass m with velocity v. Then from law of conservation of momentum, as initially bullet & gun are at rest position i.e., initial momentum is zero, so final momentum (gun + bullet) must also be zero.

Since on firing, the bullet moves with velocity $\vec{v}_b$ in forward direction, then from Newton's third law, the gun moves in backward direction $\vec{v}_g$. So,

Initial momentum = final momentum

$$0 = \underset{\text{Momentum of bullet}}{m\vec{v}_b} + \underset{\text{Momentum of gun}}{M\vec{V}_g} \quad \therefore \overrightarrow{V_g} = \frac{-m\overrightarrow{v_b}}{M}$$

(–ve sign shows that the vel. of gun will have the opposite direction to that of bullet)

IMPULSE

According to Newton's second law the rate of change of momentum of a particle is equal to the total external force applied on it (particle) i.e.,

$$\frac{d\vec{P}}{dt} = \vec{F}_{ext} \qquad ...(i)$$

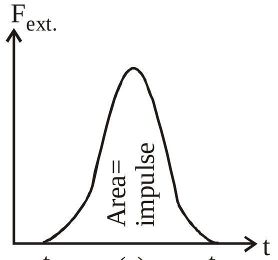
$$\text{or } d\vec{P} = \vec{F}_{ext}.dt \text{ or } \Delta\vec{P} = \vec{P}_f - \vec{P}_i = \int_{t_i}^{t_f} \vec{F}_{ext}.dt \qquad ...(ii)$$

Where $\vec{P}_i$ is momentum of the particle at initial time t_i and when we apply some external force $\vec{F}_{ext}$ its final momentum is $\vec{P}_f$ at time t_f. The quantity $\vec{F}_{ext} \cdot dt$ on R.H.S in equation (ii) is called the **impulse.**

We can write equation (ii) as

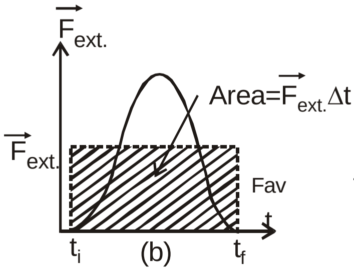
$$I = \int_{t_i}^{t_f} \vec{F}_{ext}.dt = \Delta\vec{P} \qquad ...(iii)$$

So, *the impulse of the force* $\vec{F}_{ext}$ *is equal to the change in momentum of the particle. It is known as* **impulse momentum theorem.**



(a)

Force vary with time and impulse is area under force versus time curve



(b)

Force constant with time i.e., $\vec{F}_{ext.}$ *constant with time (shown by horizontal line) and it would give same impulse to particle in time* $\Delta t = t_f - t_i$ *as time varying force described.*

It is a vector quantity having a magnitude equal to the area under the force-time curve as shown in fig. (a). In this figure, it is assumed that force varies with time and is non-zero in time interval $\Delta t = t_f - t_i$. Fig.(b) shows the time averaged force $\vec{F}_{ext.}$ i.e., it is constant in time interval Δt, then equation (iii) can be written as

$$I = \vec{F}_{ext.}\int_{t_i}^{t_f} dt = \vec{F}_{ext.}(t_f - t_i) \qquad I = \vec{F}_{ext.}\Delta t \qquad ...(iv)$$

The direction of impulsive vector I is same as the direction of change in momentum. Impulse I has same dimensions as that of momentum i.e, $[MLT^{-1}]$

Rocket propulsion (A case of system of variable mass) : It is **based on principle of conservation of linear momentum**.

In rocket, the fuel burns and produces gases at high temperature. These gases are ejected out of the rocket from nozzle at the backside of rocket and the ejecting gas exerts a forward force on the rocket which accelerates it.

Let the gas ejects at a rate $r = -\frac{dM}{dt}$ and at constant velocity u w.r.t. rocket then from the conservation of linear momentum $\frac{dv}{dt} = \frac{ru}{M} = \frac{ru}{M_0 - rt}$ where $M = M_0$ - rt and M_0 is mass of rocket with fuel and solving this equation, we get $v = u \log_e\left(\frac{M_0}{M_0 - rt}\right)$

where v = velocity of rocket w.r.t. ground.

Example 14.

Two skaters A and B approach each other at right angles. Skater A has a mass 30 kg and velocity 1 m/s and skater B has a mass 20 kg and velocity 2 m/s. They meet and cling together. Find the final velocity of the couple.

Solution :

Applying principle of conservation of linear momentum,

$$p = \sqrt{p_1^2 + p_2^2}; (m_1 + m_2)v = \sqrt{(m_1v_1)^2 + (m_2v_2)^2}$$

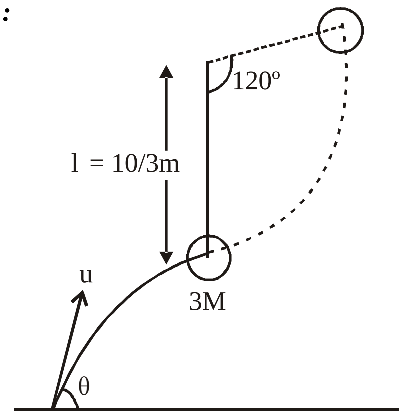
$$(30 + 20)v = \sqrt{(30 \times 1)^2 + (20 \times 2)^2} = 50$$

$$v = \frac{50}{50} = 1\ m/s$$

Example 15.

A bullet of mass M is fired with a velocity of 50 m/sec at an angle θ with the horizontal. At the highest point of its trajectory, it collides head on with a bob of mass 3M suspended by a massless string of length 10/3 m and gets embedded in the bob. After the collision, the string moves to an angle of 120º. What is the angle θ ?

Solution :



Vel. of bullet at highest point of path = 50 cos θ
From law of conservation of linear momentum,

$$MV\cos\theta = (3M + M)V' \text{ or } V' = \frac{V\cos\theta}{4} = \frac{50\cos\theta}{4}$$

$$\text{Again, } \frac{1}{2}(M+3M)V'^2 = (M+3M)g\ell(1-\cos 120^\circ)$$

$$\frac{V'^2}{2} = g\ell\left(1+\frac{1}{2}\right) \text{ or } V' = \sqrt{3g\ell}\ ;$$

$$\therefore\ \frac{50\cos\theta}{4} = \sqrt{3\times10\times\frac{10}{3}} = 10$$

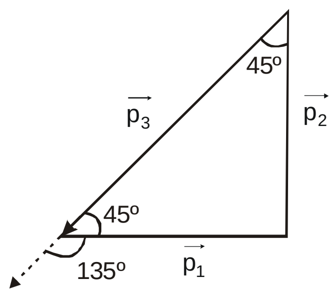
$$\Rightarrow \cos\theta = \frac{4}{5}\ \ \therefore\ \theta = \cos^{-1}\frac{4}{5}$$

Example 16.

A body of mass 5 kg which is at rest explodes into three fragments with masses in the ratio 1 : 1 : 3. The fragments with equal masses fly in mutually perpendicular directions with speeds of 21 m/sec. What will be the velocity of the heaviest fragment?

Solution :

Momentum of first body
$p_1 = 1 \times 21 = 21$ kg × m /sec.
Momentum of second body, $p_2 = 1 \times 21 = 21$ kg × m/sec.
Momentum of third body $p_3 = 3V$ kg × m/sec



According to law of conservation of liner momentum, Initial momentum = zero ∴ final momentum = 0

$$\therefore\ \vec{p_1} + \vec{p_2} + \vec{p_3} = 0$$

$$|\vec{p_3}| = \sqrt{(21)^2 + (21)^2} = 21\sqrt{2}$$

$$\therefore\ 3V = 21\sqrt{2} \text{ or } V = 7\sqrt{2} = 9.8\ \text{m/sec}.$$

And it is at an angle of 135º with the direction of $\vec{p_1}$.

Example 17.

A hammer of mass M strikes a nail of mass m with velocity of u m/s and drives it 's' meters in to fixed block of wood. Find the average resistance of wood to the penetration of nail.

Solution :

Applying the law of conservation of momentum,

$$m u = (M + m) v_0 \Rightarrow v_0 = \left(\frac{M}{m+M}\right)u$$

There acceleration a can be obtained using the formula ($v^2 = u^2 + 2as$).

Here we have $0 - v_0^2 = 2as$ or $a = v_0^2/2s$

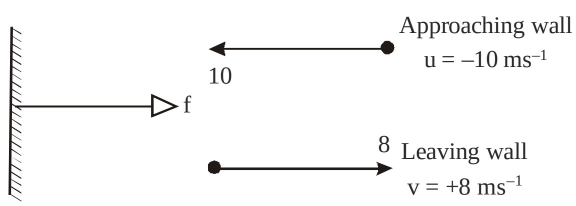
$$\therefore\ a = \left(\frac{M}{m+M}\right)^2 \frac{u^2}{2s}$$

$$\text{Resistance} = (M + m)\,a = \left(\frac{M^2}{m+M}\right)\frac{u^2}{2s}$$

Example 18.

A ball of mass 0.5 kg is thrown towards a wall so that it strikes the wall normally with a speed of 10 ms^{-1}. If the ball bounces at right angles away from the wall with a speed of 8ms^{-1}, what impulse does the wall exert on the ball ?

Solution :



Taking the direction of the impulse J as positive and using

$$J = mv - mu$$

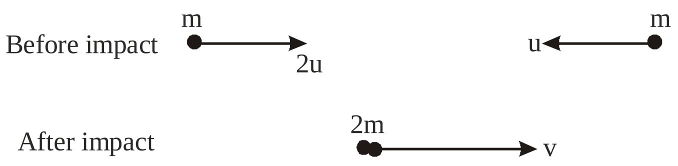
we have $J = \frac{1}{2}\times 8 - \frac{1}{2}(-10) = 9$ N-s

Therefore the wall exerts an impulse of 9 N-s on the ball.

Example 19.

Two particles, each of mass m, collide head on when their speeds are 2u and u. If they stick together on impact, find their combined speed in terms of u.

Solution :



Using conservation of linear momentum (in the direction of the velocity 2u) we have

$$(m)(2u) - mu = 2m \times V \Rightarrow V = \frac{1}{2}u$$

The combined mass will travel at speed u/2.
(Note that the momentum of the second particle before impact is negative because its sense is opposite to that specified as positive.)

EXERCISE 5.3

Solve following problems with the help of above text and examples :

1. A machine gun of mass M fires n bullets per second. The mass and speed of each bullet is m and v respectively. The force exerted on the machine gun is
(a) zero (b) mvn
(c) Mvn (d) Mvn/m

2. A body whose momentum is constant must have constant
(a) velocity (b) force
(c) acceleration (d) All of the above

3. Rocket works on the principle of
(a) conservation of mass
(b) conservation of linear momentum
(c) conservation of energy
(d) conservation of angular momentum

4. A bullet of mass 10 gm is fired from a gun of mass 1 kg. If the recoil velocity is $5\ ms^{-1}$, the velocity of muzzle is
(a) $0.05\ ms^{-1}$ (b) $5\ ms^{-1}$
(c) $50\ ms^{-1}$ (d) $500\ ms^{-1}$

ANSWER KEY

1. (b) 2. (a) 3. (b) 4. (d)

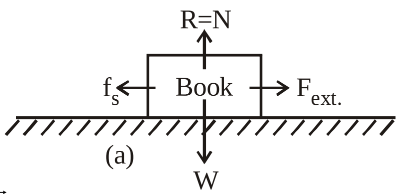
FRICTION

When a body is in motion on a rough surface, or when an object moves through water (i.e., viscous medium), then velocity of the body decreases constantly even if no external force is applied on the body. This is due to **friction.**

So "*an opposing force which comes into existence, when two surfaces are in contact with each other and try to move relative to one another, is called friction*".

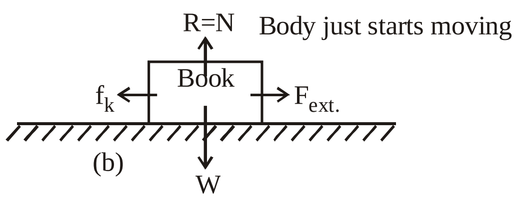
Frictional force acts along the common surface between the two bodies in such a direction so as to oppose the relative movement of the two bodies.

(a) The force of static friction f_s between book and rough surface is opposite to the applied external force $F_{ext.}$ The force of static friction $f_s = \vec{F}_{ext}$.



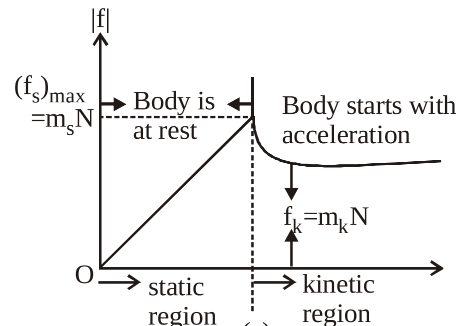
(a)

(b) When $\vec{F}_{ext}$. exceeds the certain maximum value of static friction, the book starts accelerating and during motion Kinetic frictional force is present.



(b)

(c) *A graph $\vec{F}_{ext}$. versus | f | shown in figure. It is clear that* $f_{s,\ ,max} > f_k$



(c)

Fig.(a) shows a book on a horizontal rough surface. Now if we apply external force $\vec{F}_{ext.}$, on the book, then the book will remain stationary if $\vec{F}_{ext.}$ is not too large. If we increase $\vec{F}_{ext.}$ then frictional force f also increase up to $(f_s)_{max}$ (called maximum force of static friction or limiting friction) and $(f_s)_{max} = \mu_s N$. At any instant when $\vec{F}_{ext.}$ is slightly greater than $(f_s)_{max}$ then the book moves and accelerates to the right.

Fig.(b) when the book is in motion, the retarding frictional force become less than, $(f_s)_{max}$

Fig.(c) $(f_s)_{max}$ is equal to $\mu_k N$. When the book is in motion, we call the retarding frictional force as the force of kinetic friction f_k.

Since $f_k < (f_s)_{max}$, so it is clear that, we require more force to start motion than to maintain it against friction.

By experiment one can find that $(f_s)_{max}$ and f_k are proportional to normal force N acting on the book (by rough surface) and depends on the roughness of the two surfaces in contact.

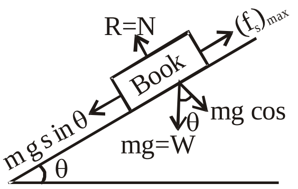
Note :

(i) The force of static friction between any two surfaces in contact is opposite to $\vec{F}_{ext.}$ and given by $f_s \le \mu_s N$ and $(f_s)_{max} = \mu_s N$ (when the body just moves in the right direction).
where N = W = weight of book and μ_s is called coefficient of static friction, f_s is called force of static friction and $(f_s)_{max}$ is called *limiting friction or maximum value of static friction.*

(ii) The force of kinetic friction is opposite to the direction of motion and is given by $f_k = \mu_k N$
where μ_k is coefficient of kinetic friction.

(iii) The value of μ_k and μ_s depends on the nature of surfaces and μ_k is always less then μ_s.

Friction on an inclined plane : Now we consider a book on an inclined plane & it just moves or slips, then by definition



$$(f_s)_{max} = \mu_s R$$

Now from figure, $f_{s,max}$ = mg sin θ and R = mg cosθ

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

where angle θ is called the **angle of friction** or **angle of repose**

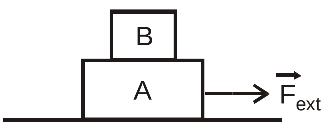
Some facts about friction :

(1) The force of kinetic friction is less than the force of static friction and the force of rolling friction is less than force of kinetic friction i.e.,

$$f_r < f_k < f_s \quad \text{or} \quad \mu_{rolling} < \mu_{kinetic} < \mu_{static}$$

hence it is easy to roll the drum in comparison to sliding it.

(2) Frictional force does not oppose the motion in all cases, infact in some cases the body moves due to it.



In the figure, book B moves to the right due to friction between A and B. If book A is totally smooth (i.e., frictionless) then book B does not move to the right. This is because of no force applies on the book B in the right direction.

Laws of limiting friction :

(i) The force of friction is independent of area of surfaces in contact and relative velocity between them (if it is not too high).

(ii) The force of friction depends on the nature of material of surfaces in contact (i.e., force of adhesion).
μ depends upon nature of the surface. It is independent of the normal reaction.

(iii) The force of friction is directly proportional to normal reaction i.e., F ∝ N or F = mn.

While solving a problem having friction involved, follow the given methodology

Check
(a) F_{app}
(b) Limiting friction (f_l)

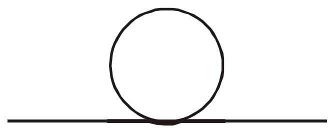
→ If $F_{app} < f_l$
Body does not move and
F_{app} = frictional force

→ If $F_{app} = f_l$
Body is on the verge of movement if the body is initially at rest
Body moves with constant velocity

→ If $F_{app} > f_l$
Body moves with an acceleration
$F_{app} - f_l$ = m.a in the line of action of frictional force

Rolling Friction :

The name rolling friction is a misnomer. Rolling friction has nothing to do with rolling. Rolling friction occurs during rolling as well as sliding operation.



Cause of rolling friction : When a body is kept on a surface of another body it causes a depression (an exaggerated view shown in the figure). When the body moves, it has to overcome the depression. This is the cause of rolling friction.

Note : Rolling friction will be zero only when both the bodies incontact are rigid. Rolling friction is very small as compared to sliding friction. Work done by rolling friction is zero

CONSERVATIVE AND NON-CONSERVATIVE FORCES

If work done on a particle is zero in complete round trip, the force is said to be conservative. The gravitational force, electrostatics force, elastic force etc., are conservative forces. On the other hand *if the work done on a body is not zero during a complete round trip, the force is said to be non-conservative*. The frictional force, viscous force etc. are non-conservative forces.

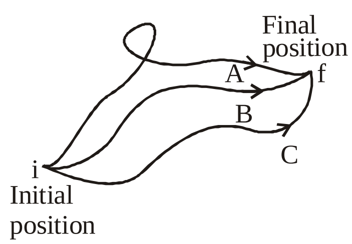


Figure shows three processes A, B and C by which we can reach from an initial position to final position. If force is conservative, then work done is same in all the three processes i.e., independent of the path followed between initial and final position.

If force is non conservative then work done from i to f is different in all three paths A,B and C.

Hence it is clear that *work done in conservative force depends only on initial & final position irrespective of the path followed between initial & final position. In case of non-conservative forces the work done depends on the path followed between initial and final position.*

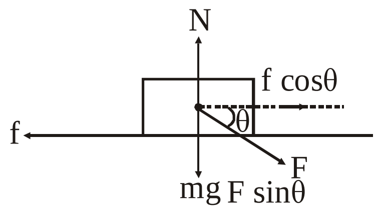
We can say also that there is no change in kinetic energy of the body in complete round trip in case of conservative force. While in case of non conservative forces, when a body return to its initial position after completing the round trip, the kinetic energy of the body may be more or less than the kinetic energy with which it starts.

Example 20.

Pushing force making an angle θ to the horizontal is applied on a block of weight W placed on a horizontal table. If the angle of friction is ϕ, then determine the magnitude of force required to move the body.

Solution :

The various forces acting on the block are shown in fig.



Here,

$\mu = \tan\phi = \dfrac{f}{N}$; or f = N tanϕ ...(i)

The condition for the block just to move is

$F\cos\theta = f = N\tan\phi$ ...(ii)

and $F\sin\theta + W = N$ ...(iii)

From (ii) and (iii),

$F\cos\theta = (W + F\sin\theta)\tan\phi = W\tan\phi + F\sin\theta\tan\phi$;

or $F\cos\theta - F\sin\theta\sin\phi/\cos\phi = W\sin\phi/\cos\phi$

or $F(\cos\theta\cos\phi - \sin\theta\sin\phi) = W\sin\phi$;

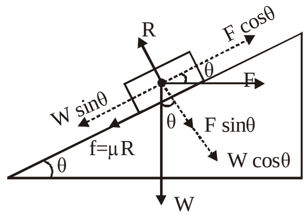
or $F\cos(\theta + \phi) = W\sin\phi$ or $F = W\sin\phi / \cos(\theta + \phi)$

Example 21.

An object of weight W is resting on an inclined plane at an angle θ to the horizontal. The coefficient of static friction is μ. Find the horizontal force needed to just push the object up the plane.

Solution :

The situation is shown in fig.



Let F be the horizontal force needed to just push the object up the plane. From figure $R = W\cos\theta + F\sin\theta$

Now $f = \mu R = \mu[W\cos\theta + F\sin\theta]$ ...(1)

Further, $F\cos\theta = W\sin\theta + f$ ...(2)

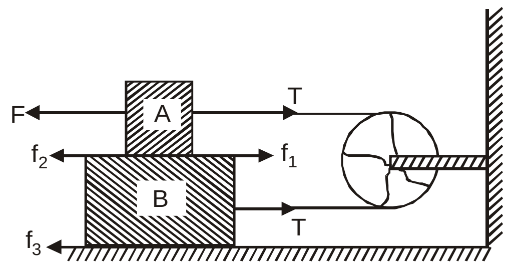
$F\cos\theta = W\sin\theta + \mu[W\cos\theta + F\sin\theta]$

$F\cos\theta - \mu F\sin\theta = W\sin\theta + \mu W\cos\theta$

$$\therefore \quad F = \frac{W(\sin\theta + \mu\cos\theta)}{(\cos\theta - \mu\sin\theta)}$$

Example 22.

A block A of mass m_1 rests on a block B of mass m_2. B rests on fixed surface. The coefficient of friction between any two surfaces is μ. A and B are connected by a massless string passing around a frictionless pulley fixed to the wall as shown in fig. With what force should A be dragged so as to keep both A and B moving with uniform speed?



Solution :

The situation is shown in fig.

Let F be the horizontal force applied on A.

For block A, $F = T + f_1 = T + \mu m_1 g$ .....(1)

($\because$ Block A moves towards left, frictional force f_1 acts towards right)

For block B, $f_B = f_2 + f_3$

($\because$ Block B moves towards right, frictional forces f_2 and f_3 acts towards left).

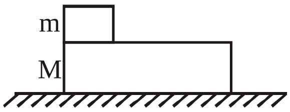
$T = \mu m_1 g + \mu(m_1 + m_2)g = \mu g(2m_1 + m_2)$ ...(2)

From eqns. (1) and (2), we get

$F = \mu g(2m_1 + m_2) + \mu m_1 g$ or $F = \mu g(3m_1 + m_2)$

Example 23.

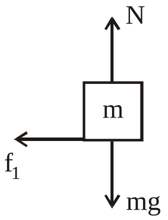
Figure shows a small block of mass m kept at the left hand of a larger block of mass M and length ℓ. The system can slide on a horizontal road. The system is started towards right with an initial velocity v. The friction coefficient between road and bigger block is μ and between the block is $\mu/2$. Find the time elapsed before the smaller block separates from the bigger block.

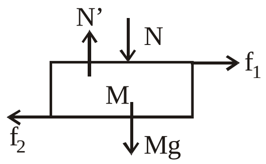


Solution :

Make free body diagram of m

Take right as the positive direction. Let $a_{1/g}$ be the acceleration of m w.r.t. ground.





$$a_{1/g} = \frac{-f_1}{m} \qquad \left[\because f_1 = \frac{\mu}{2}mg\right]$$

$$\Rightarrow a_{1/g} = \frac{-\mu g}{2} \qquad ...(1)$$

$N' = N + Mg$ and $N' = (m + M)g$ ...(2)

$f_2 = \mu N' = \mu(m+M)g$ ...(3)

$$a_{2/g} = \frac{-(f_2 - f_1)}{M}$$

[$\because$ $a_{2/g}$ is acceleration of M w.r.t. ground]

$$= \frac{-\{\mu(m+M)g - \mu/2\,mg\}}{M} = -\mu g\left[1 + \frac{m}{2M}\right]$$

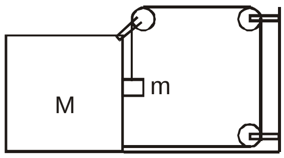
$a_{1/2}$ = acceleration of m w.r.t. to M $= a_{1/g} - a_{2/g}$

$$= -\frac{\mu g}{2} + \mu g\left[1 + \frac{m}{2M}\right] = \mu g\left[-\frac{1}{2} + 1 + \frac{m}{2M}\right] = \mu g\frac{[m+M]}{2M}$$

Now $\ell = \frac{1}{2}a_{1/2}t^2 \Rightarrow t = \sqrt{\frac{4M\ell}{(M+m)\mu g}}$

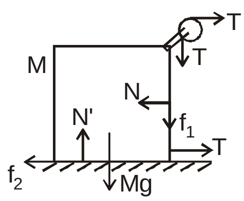
Example 24.

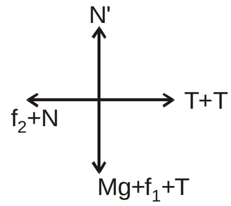
Find the acceleration of the block of mass M in the situation of figure. The coefficient of friction between the two blocks is μ_1 and between the bigger block and the ground is μ_2.



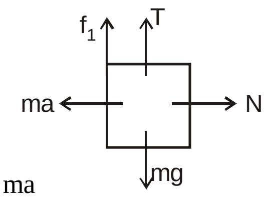
Solution :

We make free body diagram of mass M and m separately, Let acceleration of M be a, then acceleration of m w.r.t. M will be 2a since m moves twice the distance moved by m





Now see m w.r.t. M



$\therefore$ $N = ma$ ...(1)

$f_1 = \mu_1 N = \mu_1 ma$ ...(2)

$mg - f_1 - T = m(2a) \Rightarrow mg = \mu_1 ma + T + 2ma$

$\Rightarrow mg - T = (2 + \mu_1)ma$ ...(3)

or $T = mg - (2 + \mu_1)ma$ ...(4)

for M, $N' = Mg + f_1 + T = Mg + \mu ma + T$ ...(5)

and $2T - (f_2 + N) = Ma$

$\Rightarrow 2T - \mu_2(N') - N = Ma$ ...(6)

$\Rightarrow 2T - \mu_2(Mg + \mu_1 ma + T) - ma = Ma$

[Using eq^{ns}.(5) and (6)]

$\Rightarrow (2 - \mu_2)T = m_2 Mg + \mu_1\mu_2 ma + (M + m)a$ ...(7)

Solving equation (4) and (7), we get

$$a = \frac{[2m - \mu_2(M+m)]g}{M + m[5 + 2(\mu_1 - \mu_2)]}$$

EXERCISE 5.4

Solve following problems with the help of above text and examples :

1. Which of the following statements about friction is true?
(a) Friction can be reduced to zero
(b) Frictional force cannot accelerate a body
(c) Frictional force is proportional to the area of contact between the two surfaces
(d) Kinetic friction is always greater than rolling friction

2. Which of the following is a self adjusting force?
(a) Static friction (b) Limiting friction
(c) Dynamic friction (d) Sliding friction

3. The force required to just move a body up the inclined plane is double the force required to just prevent the body from sliding down the plane. The coefficient of friction is μ. The inclination θ of the plane is
(a) $\tan^{-1}\mu$ (b) $\tan^{-1}(\mu/2)$
(c) $\tan^{-1} 2\mu$ (d) $\tan^{-1} 3\mu$

4. If μ_s, μ_k and μ_r are coefficients of static friction, sliding friction and rolling friction, then

(a) $\mu_s < \mu_k < \mu_f$ (b) $\mu_k < \mu_r < \mu_s$
(c) $\mu_r < \mu_k < \mu_s$ (d) $\mu_r = \mu_k = \mu_s$

5. A 30 kg block rests on a rough horizontal surface. A force of 200 N is applied on the body. The block acquires a speed of 4 m/sec, starting from rest, in 2 seconds. What is the value of coefficient of friction?

(a) $10/\sqrt{3}$ (b) $\sqrt{3}/10$
(c) 0.47 (d) 0.185

6. A block is at rest on an inclined plane making an angle α with the horizontal. As the angle α of the inclination is increased, the block just starts slipping when the angle of inclination becomes θ. Then the coefficient of static friction between the block and the surface of the inclined plane is

(a) $\sin\theta$ (b) $\cos\theta$
(c) $\tan\theta$ (d) independent of θ

7. Which of the following statements is correct, when a person walks on a rough surface?

(a) The frictional force exerted by the surface keeps him moving
(b) The force which the man exerts on the floor keeps him moving
(c) The reaction of the force which the man exerts on floor keeps him moving
(d) None of these

8. It is difficult to move a cycle with brakes on because

(a) rolling friction opposes motion on road
(b) sliding friction opposes motion on road
(c) rolling friction is more than sliding friction
(d) sliding friction is more than rolling friction

ANSWER KEY

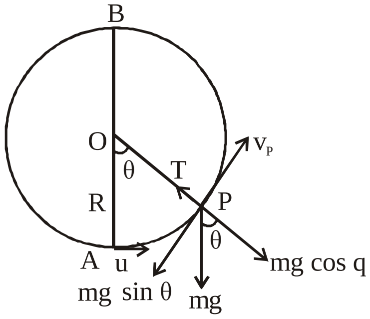
1. (d) 2. (a) 3. (d) 4. (c) 5. (c) 6. (c) 7. (c) 8. (d)

CASES OF CIRCULAR MOTIONS

Motion in a Vertical Circle :

Let us consider a particle of mass m attached to a string of length R let the particle be rotated about its centre O.

At t = 0 the particle start with velocity u from the point A (lowest point of vertical circle) and at time t its position is P. Then the tension at point P is given by



$$T_P - mg\cos\theta = \frac{mv_P^2}{R} \text{ or } T_P = mg\cos\theta + \frac{mv_P^2}{R} \qquad ...(1)$$

So tension at point A (lowest point of vertical circle) is

$$T_A - mg = \frac{mv_A^2}{R} \qquad (\because \theta = 0^\circ) \qquad ...(2)$$

and tension at point B (highest point of vertical circle) is

$$T_B + mg = \frac{mv_B^2}{R} \qquad (\because \theta = 180^\circ) \qquad ...(3)$$

Where $\frac{\mathbf{mv^2}}{\mathbf{r}}$ **is centripetal force** required for the particle to move in a vertical circle.

Now from law of conservation of energy

$$\frac{1}{2}mv_A^2 - \frac{1}{2}mv_B^2 = 2mgR$$

$$\text{or, } v_A^2 - v_B^2 = 4gR \qquad ...(4)$$

(change in kinetic energy of particle)

= (change in potential energy of particle)

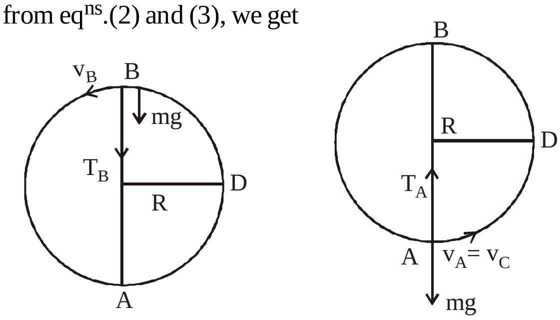
or

(loss in kinetic energy of the particle) = (gain in potential energy)

In conservative force system (such as gravity force) the mechanical energy (i.e., kinetic energy + potential energy) must be constant.

Total energy will be constant

Now from eq[ns].(2) and (3), we get



$$T_A - T_B = 2mg + \frac{m}{R}(V_A^2 - V_B^2) = 2mg + \frac{m}{R}(4gR)$$

$$\Rightarrow \quad T_A - T_B = 6mg \qquad ...(5)$$

$$\text{or} \quad T_A = T_B + 6mg \qquad ...(6)$$

So it is clear from eq^n. (6) that tension in string at lowest point of vertical circle is greater then the tension at highest point of vertical circle by 6mg.

Condition to complete a vertical circle :

If we reduce the velocity v_A in equation (2), then T_A will be reduce and at some critical velocity v_c, T_B will be zero, then put $T_B = 0$ and $v_B = v_C$ in equation (3) and we obtain

$$v_C = v_B = \sqrt{gR} \qquad ...(7)$$

In this condition the necessary centripetal force at point B is provided by the weight of the particle [see again equation (3)] then from equation (4), we get

$$v_A^2 - gR = 4gR \Rightarrow v_A = \sqrt{5gR} \qquad ...(8)$$

then the tension at the point A will be

$$T_A = mg + \frac{m(5gR)}{R} = 6mg \qquad ...(9)$$

Hence if we rotate a particle in a vertical circle and tension in string at highest point is zero, then the tension at lowest point of vertical circle is 6 times of the weight of the particle.

Some Facts of Vertical Motion :

(i) The body will complete the vertical circle if its velocity at lowest point is equal to or greater then $\sqrt{5gR}$

(ii) The body will oscillate about the lowest point if its velocity at lowest point is less then $\sqrt{2gR}$. This will happen when the velocity at the halfway mark, i.e.

$$v_D = 0 \quad \left[\because \frac{1}{2} m v_A^2 = mgR\right]$$

(iii) The string become slack and fails to describe the circle when its velocity at lowest point lies between $\sqrt{2gR}$ to $\sqrt{5gR}$

Example 25.

A mass m is revolving in a vertical circle at the end of a string of length 20 cm. By how much does the tension of the string at the lowest point exceed the tension at the topmost point?

Solution :

The tension T_1 at the topmost point is given by,

$$T_1 = \frac{m v_1^2}{20} - m g$$

Centrifugal force acting outward while weight acting downward

The tension T_2 at the lowest point, $T_2 = \frac{m v_2^2}{20} + m g$

Centrifugal force and weight (both) acting downward

$$T_2 - T_1 = \frac{m v_2^2 - m v_1^2}{20} + 2 m g \, ; \quad v_1^2 = v_2^2 - 2 g h \text{ or}$$

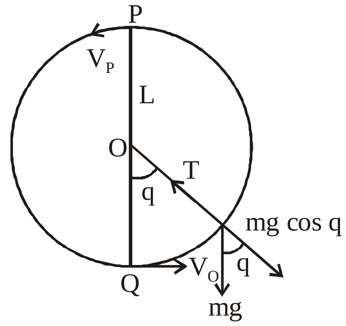
$$v_2^2 - v_1^2 = 2 g (40) = 80 g$$

$$\therefore \quad T_2 - T_1 = \frac{80 m g}{20} + 2 m g = 6 \ m g$$

Example 26.

A stone of mass 1 kg tied to a light inextensible string of length L = (10/3) m is whirling in a circular path of radius L in a vertical plane. If the ratio of the maximum to the minimum tension in the string is 4 and g = 10 m/s^2, then find the speed of the stone at the highest point of the circle.

Solution :



The tension T in the string is given by

$$T_{max} = m\left[g + \frac{v_Q^2}{L}\right] \text{ and } T_{min} = m\left[-g + \frac{v_P^2}{L}\right]$$

According to the given problem

$$\frac{g + (v_Q^2 / L)}{-g + (v_P^2 / L)} = 4 \quad \text{or} \quad g + \frac{v_Q^2}{L} = -4g + 4\frac{v_P^2}{L}$$

$$\text{or} \quad g + \frac{v_P^2 + 4 g L}{L} = -4g + 4\frac{v_P^2}{L}$$

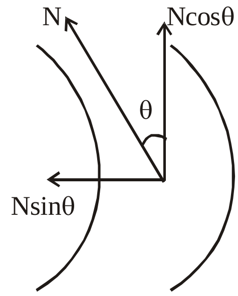
L = (10/3) m and g = 10 m/s^2 (given)

Solving we get v_P = 10 m/s.

Negotiating a Curve :

Case of cyclist

To safely negotiate a curve of radius r, a cyclist should bend at an angle θ with the vertical.



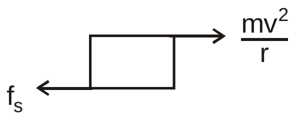
Which is given by $\tan\theta = \frac{v^2}{rg}$. Angle θ is also called as **angle of banking**.

$$N \sin\theta = \frac{mv^2}{r} \text{ and } N\cos\theta = mg$$

Case of car on a levelled road

A vehicle can safely negotiate a curve of radius r on a rough level road when coefficient of sliding friction is related to the velocity as $\mu_s \ge \frac{v^2}{rg}$.

Now consider a case when a vehicle is moving in a circle, the centrifugal force is $\frac{mv^2}{r}$ whereas m is mass of vehicle, r = radius of circle and v is its velocity.



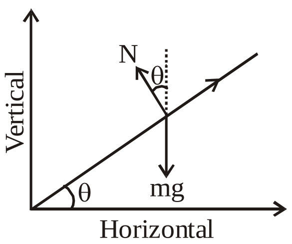
The frictional force is static since wheels are in rolling motion because point of contact with the surface is at rest

$$\therefore f_s = \frac{mv^2}{r} \qquad f_s \le f_{max} = \mu_s mg$$

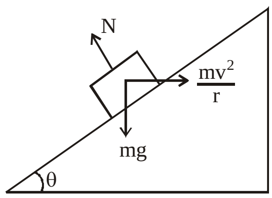
$$\frac{mv^2}{r} \le \mu_s mg \text{ or } \mu_s \ge \frac{v^2}{rg}$$

Case of banking of road (frictionless)

A vehicle can safely negotiate a curve of radius r on a smooth (frictionless) road, when the angle θ of banking of the road is given by $\tan\theta = \frac{v^2}{rg}$.



When the banked surface is smooth, the force acting will be gravity and normal force only.



Balancing forces

$$N\cos\theta = mg \qquad ...(1)$$

$$N\sin\theta = \frac{mv^2}{r} \qquad ...(2)$$

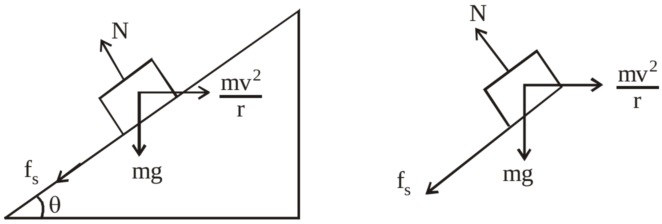
$$\frac{v^2}{rg} = \tan\theta \qquad ...(3)$$

Case of banking of road (with friction)

The maximum velocity with which a vehicle can safely negotiate a curve of radius r on a rough inclined road is given by

$v^2 = \frac{rg(\mu + \tan\theta)}{1 - \mu\tan\theta}$; where μ is the coefficient of friction of the rough surface on which the vehicle is moving, and θ is the angle of inclined road with the horizontal.

Suppose a vehicle is moving in a circle of radius r on a rough inclined road whose coefficient of friction is $\frac{\mu}{M}$ and angle of banking is θ.



Let velocity of object (vehicle) be V.

If we apply pseudo force on body, centrifugal force is $\frac{mv^2}{r}$ when v is max. and friction force will be acting down the slope.

Balancing the force horizontally, $\frac{mv^2}{r} = f_s\cos\theta + N\sin\theta$ ...(1)

Balancing the force vertically,

$$N\cos\theta = f_s\sin\theta + mg \qquad ...(2)$$

when v = maximum, $f = f_{max} = f_s = \mu N$ ...(3)

From eq^n. (2),

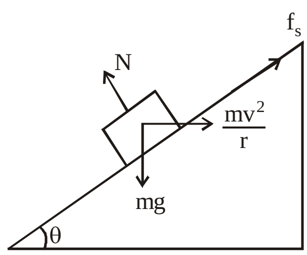
$$N\cos\theta = \mu N\sin\theta + mg \Rightarrow N(\cos\theta - \mu\sin\theta) = mg$$

$$\text{or } N = \frac{mg}{\cos\theta - \mu\sin\theta}$$

From eq^{ns}.(1) and (3), $\frac{mv^2}{r} = \frac{\mu mg\cos\theta + mg\sin\theta}{\cos\theta - \mu\sin\theta}$

$$\Rightarrow \frac{mv^2}{r} = \frac{mg(\mu + \tan\theta)}{1 - \mu\tan\theta} \Rightarrow v_{max}^2 = rg\frac{(\mu + \tan\theta)}{1 - \mu\tan\theta}$$

Now in the case of minimum velocity with which body could move in a circular motion, the direction of friction will be opposite to that one in maximum velocity case.



$$\text{and } v_{min}^2 = rg\left(\frac{\mu - \tan\theta}{1 + \mu\tan\theta}\right)$$

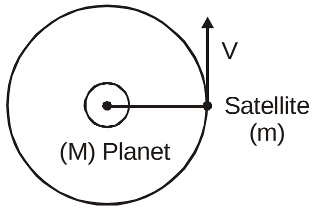
Keep in Memory

1. Whenever a particle is moving on the circular path then there must be some external force which will provide the necessary centripetal acceleration to the particle.

For examples :

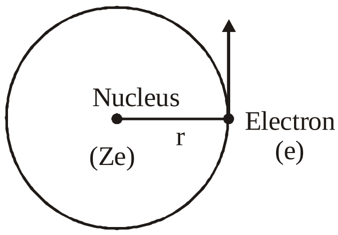
(i) Motion of satellite around a planet : Here the centripetal force is provided by the gravitational force.

i.e. $\frac{GMm}{r^2} = \frac{mv^2}{r}$



(ii) Motion of electron around the nucleus : Here the required centripetal force is provided by the Coulombian force

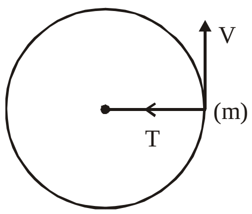
i.e. $\frac{1}{4\pi\varepsilon_o}\frac{(ze)(e)}{r^2} = \frac{mv^2}{r}$



(iii) Motion of a body in horizontal and vertical circle: Here the centripetal force is provided by the tension.

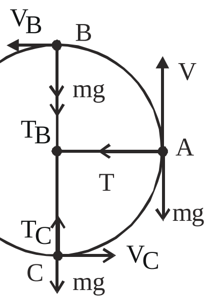
Horizontal circle

$T = \frac{mv^2}{r}$



Vertical circle

At point A, $T_A = \frac{mv_A{}^2}{r}$;

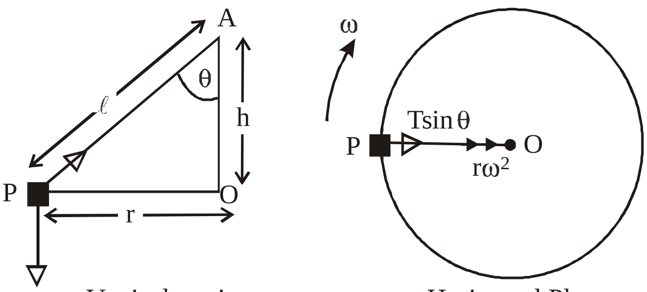


At point B, $T_B + mg = \frac{mv_B{}^2}{r}$

And at point C, $T_C - mg = \frac{mv_C{}^2}{r}$

CONICAL PENDULUM

Consider an inextensible string of length ℓ which is fixed at one end, A. At the other end is attached a particle P of mass m describing a circle with constant angular velocity ω in a horizontal plane.



Vertical section Horizontal Plane

As P rotates, the string AP traces out the surface of a cone. Consequently the system is known as a conical pendulum.

Vertically, $T\cos\theta = mg$ ... (1)

Horizontally, $T\sin\theta = mr\omega^2$ ... (2)

In triangle AOP, $r = \ell\sin\theta$ ... (3)

and $h = \ell\cos\theta$ ... (4)

Several interesting facts can be deduced from these equations :

(a) It is impossible for the string to be horizontal.

This is seen from eq^n. (1) in which $\cos\theta = \frac{mg}{T}$ cannot be zero. Hence θ cannot be 90°.

(b) The tension is always greater than mg.

This also follows from eq^n. (1) as $\cos\theta < 1$ (θ is acute but not zero). Hence, $T > mg$

(c) The tension can be calculated without knowing the inclination of the string since, from eq^n. (2) and (3)

$T\sin\theta = m\ell\sin\theta\,\omega^2 \Rightarrow T = m\ell\omega^2$

(d) The vertical depth h of P below A is independent of the length of the string since from eq^n. (1) and (4)

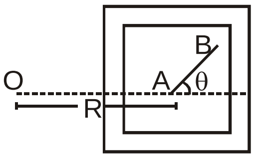
$$T\frac{h}{\ell} = mg \Rightarrow T = \frac{\ell mg}{h} \quad \text{but} \quad T = m\ell\omega^2$$

Therefore $m\ell\omega^2 = \frac{m\ell g}{h} \Rightarrow h = \frac{g}{\omega^2}$

which is independent of ℓ.

Example 27.

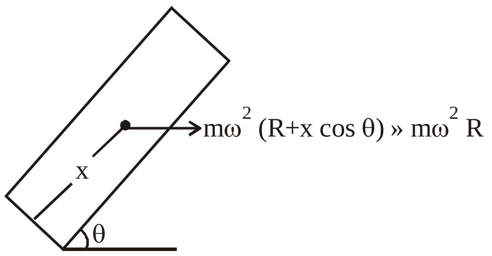
A table with smooth horizontal surface is fixed in a cabin that rotates with a uniform angular velocity ω in a circular path of radius R. A smooth groove AB of length L (<<R) is made on the surface of the table. The groove makes an angle θ with the radius OA of the circle in which a particle is kept at the point A in the groove and is released to move along AB. Find the time taken by the particle to reach the point B.



Solution :

Now let us take the cabin as reference frame. Since it is accelerated we have to use pseudo force to apply Newton's second law.

Here R >> L ' $m\omega^2 (R + x\cos\theta) \approx m\omega^2 R$



Since groove is smooth (friction is zero)

$\therefore$ Component of $m\omega^2R$ in the direction of groove is the net force (rest is balanced by normal force)

Let a' is acceleration in the direction of groove

$\therefore$ $a' = \omega^2 R\cos\theta$

$\therefore L = \frac{1}{2}a't^2 \Rightarrow t = \sqrt{\frac{2L}{\omega^2 R\cos\theta}}$

Example 28.

A particle of mass m is moving in a circular path of constant radius r such that its centripetal acceleration a_c is varying with time t as $a_c = k^2rt^2$, where k is a constant. Determine the power delivered to the particle by the forces acting on it.

Solution :

Here tangential acceleration also exists which requires power. Given that centripetal acceleration

$a_c = k^2rt^2$ also, $a_c = v^2/r$;

$\therefore$ $v^2/r = k^2rt^2$ or $v^2 = k^2r^2t^2$ or $v = k\,r\,t$;

Tangential acceleration, $a = \frac{dv}{dt} = kr$

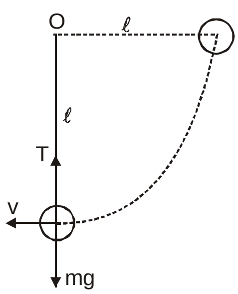
Now, force $F = ma = mkr$;

So, power, $P = Fv = mkr \times krt = mk^2r^2t$.

Example 29.

The string of a pendulum is horizontal. The mass of the bob is m. Now the string is released. What is the tension in the string in the lowest position?

Solution :



Let v be the velocity of the bob at the lowest position. In this position, The P.E. of bob is converted into K.E. Hence,

$$mg\ell = \frac{1}{2}mv^2 \quad \text{or} \quad v^2 = 2g\ell \qquad ...(1)$$

If T be the tension in the string, then

$$T - mg = \left(\frac{mv^2}{\ell}\right) \qquad ...(2)$$

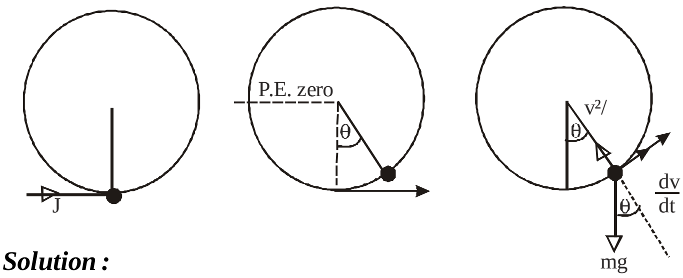
From eq^{ns}. (1) and (2).

$T - mg = 2mg$ or $T = 3mg$

Example 30.

A light rod of length ℓ is free to rotate in vertical plane about one end. A particle of mass m is attached to the other end.

When the rod is hanging at rest vertically downward, an impulse is applied to the particle so that it travels in complete vertical circles. Find the range of possible values of the impulse and the tangential acceleration when the rod is inclined at 60° to the downward vertical.



Solution :

First, using impulse = change in momentum we have

$J = mu$ .... (1)

Using conservation of mechanical energy gives

$$\frac{1}{2}mu^2 - mg\ell = \frac{1}{2}mv^2 - mg\ell\cos\theta \qquad .... (2)$$

Applying Newton's law tangentially gives

$$-mg\sin\theta = m\frac{dv}{dt} \qquad .... (3)$$

If the particle is to describe complete circles,

$v > 0$; $\theta = 180°$

When $\theta = 180°$, eq^n. (2) gives

$$v^2 = u^2 - 2g\ell + 2g\ell\cos 180° \Rightarrow v^2 = u^2 - 4g\ell$$

But $v > 0$ therefore, $u^2 > 4g\ell \Rightarrow u > 2\sqrt{g\ell}$

(u cannot be negative)

Hence, from eq^n. (1) $J > 2m\sqrt{g\ell}$

When θ = 60°, equation (3) becomes $mg\frac{\sqrt{3}}{2} = m\frac{dv}{dt}$

So the tangential acceleration is $g\sqrt{3}/2$

EXERCISE 5.5

Solve following problems with the help of above text and examples :

1. On a railway curve the outside rail is laid higher than the inside one so that resultant force exerted on the wheels of the rail car by the tops of the rails will
(a) have a horizontal inward component
(b) be vertical
(c) equilibriate the centripetal force
(d) be decreased

2. A car moving on a horizontal road may be thrown out of the road in taking a turn
(a) by the gravitational force
(b) due to the lack of proper centripetal force
(c) due to the rolling frictional force between the tyre and road
(d) due to the reaction of the ground

3. A cyclist taking turn bends inwards while a car passenger taking the same turn is thrown outwards. The reason is
(a) car is heavier than cycle
(b) car has four wheels while cycle has only two
(c) difference in the speed of the two
(d) cyclist has to counteract the centrifugal force while in the case of car only the passenger is thrown by this force

4. A car sometimes overturns while taking a turn. When it overturns, it is
(a) the inner wheel which leaves the ground first
(b) the outer wheel which leaves the ground first
(c) both the wheel leave the ground simultaneously
(d) either wheel will leave the ground first

5. A tachometer is a device to measure
(a) gravitational pull (b) speed of rotation
(c) surface tension (d) tension in a spring

6. A particle moves in a circle with a uniform speed. When it goes from a point A to a diametrically opposite point B, the momentum of the particle changes by $\vec{p}_A - \vec{p}_B = 2$ kg m/s $(\hat{j})$ and the centripetal force acting on it changes by $\vec{F}_A - \vec{F}_B = 8N\ (\hat{i})$ where $\hat{i}, \hat{j}$ are unit vectors along X and Y axes respectively. The angular velocity of the particle is
(a) dependent on its mass
(b) 4 rad/sec
(c) $\frac{2}{\pi}$ rad/sec (d) 16π rad/sec

7. A car takes a circular turn with a uniform speed u. If the reaction at inner and outer wheels be denoted by R_1 and R_2, then
(a) $R_1 = R_2$ (b) $R_1 < R_2$
(c) $R_1 > R_2$ (d) None of these

8. A piece of stone is thrown from the top of a tower with a horizontal speed of $10\sqrt{3}$ m/s. It is found that at a point P along the path, the velocity vector of the stone makes an angle of 30º with the horizontal. The point P is reached in time t which is given by ($g = 10\ m/s^2$)
(a) 1 sec (b) $\sqrt{3}$ sec
(c) 2 sec (d) $2\sqrt{3}$ sec

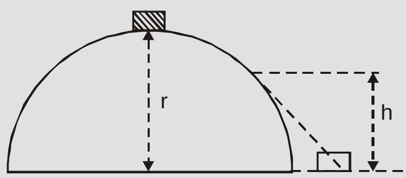
9. A block of mass m at the end of a string is whirled round in a vertical circle of radius R. The critical speed of the block at the top of its swing below which the string would slacken before the block reaches the top is
(a) $R g$ (b) $(R g)^2$
(c) R/g (d) $\sqrt{R g}$

10. A sphere is suspended by a thread of length ℓ. What minimum horizontal velocity has to be imparted to the sphere for it to reach the height of the suspension?
(a) $g\ \ell$ (b) $2\ g\ \ell$
(c) $\sqrt{g\ell}$ (d) $\sqrt{2g\ell}$

11. A particle rests on the top of a hemisphere of radius R. Find the smallest horizontal velocity that must be imparted to the particle if it is to leave the hemisphere without sliding down is
(a) $\sqrt{gR}$ (b) $\sqrt{2gR}$
(c) $\sqrt{3gR}$ (d) $\sqrt{5gR}$

12. A body of mass m is rotated in a vertical circle of radius r. The minimum velocity of the body at the topmost position for the string to remain just stretched is
(a) $\sqrt{2gr}$ (b) $\sqrt{gr}$
(c) $\sqrt{3gr}$ (d) $\sqrt{5gr}$

13. A small body of mass m slides down from the top of a hemisphere of radius r. The surface of block and hemisphere are frictionless.



The height at which the body lose contact with the surface of the sphere is

(a) (3/2) r (b) (2/3) r
(c) (1/2) g r^2 (d) $v^2/2g$

14. A particle of mass m is describing a circular path of radius r with uniform speed. If L is the angular momentum of the particle about the axis of the circle, the kinetic energy of the particle is given by

(a) L^2/mr^2 (b) $L^2/2mr^2$
(c) $2L^2/mr^2$ (d) $mr^2 L$

15. A car is travelling with linear velocity v on a circular road of radius r. If it is increasing its speed at the rate of 'a' metre/sec^2, then the resultant acceleration will be

(a) $\sqrt{\left\{\frac{v^2}{r^2}-a^2\right\}}$ (b) $\sqrt{\left\{\frac{v^4}{r^2}+a^2\right\}}$

(c) $\sqrt{\left\{\frac{v^4}{r^2}-a^2\right\}}$ (d) $\sqrt{\left\{\frac{v^2}{r^2}+a^2\right\}}$

16. An automobile of mass m is crossing over a convex upwards over bridge with a speed v. If the radius of the bridge is r, the thrust on the bridge at the highest point will be

(a) $mg+\frac{mv^2}{r}$ (b) $mg-\frac{mv^2}{r}$

(c) $\frac{m^2 v^2 g}{r}$ (d) $\frac{v^2 g}{r}$

17. The coefficient of friction between the rubber tyres and the road way is 0.25. The maximum speed with which a car can be driven round a curve of radius 20 m without skidding is (g = 9.8 m/s^2)

(a) 5 m/s (b) 7 m/s
(c) 10 m/s (d) 14 m/s

18. A bucket tied at the end of a 1.6 m long string is whirled in a vertical circle with constant speed. What should be the minimum speed so that the water from the bucket does not spill when the bucket is at the highest position?

(a) 4 m/sec (b) 6.25 m/sec
(c) 16 m/sec (d) None of these

19. A can filled with water is revolved in a vertical circle of radius 4 metre and the water just does not fall down. The time period of revolution will be

(a) 1 sec (b) 10 sec
(c) 8 sec (d) 4 sec

20. A motor cyclist moving with a velocity of 72 km per hour on a flat road takes a turn on the road at a point where the radius of curvature of the road is 20 metres. the acceleration due to gravity is 10m/sec^2. In order to avoid skidding, he must not bend with respect to the vertical plane by an angle greater than

(a) $\theta = \tan^{-1} 6$ (b) $\theta = \tan^{-1} 2$
(c) $\theta = \tan^{-1} 25.92$ (d) $\theta = \tan^{-1} 4$

21. The kinetic energy K of a particle moving along a circle of radius R depends on the distance covered s as K = a s^2. The force acting on the particle is

(a) $2as^2/R$ (b) $2as[1 + (s^2/R^2)]^{1/2}$
(c) 2 a s (d) $2aR^2/s$

22. A train is moving with a speed of 36 km/hour on a curved path of radius 200 m. If the distance between the rails is 1.5 m, the height of the outer rail over the inner rail is

(a) 1 m (b) 0.5 m
(c) 0.75 m (d) 0.075 m

23. A mass m is revolving in a vertical circle at the end of a string of length 20 cm. By how much does the tension of the string at the lowest point exceed the tension at the topmost point?

(a) 2 m g (b) 4 m g
(c) 6 m g (d) 8 m g

24. The string of a pendulum of length ℓ is displaced through 90° from the vertical and released. Then the minimum strength of the string in order to withstand the tension as the pendulum passes through the mean position is

(a) 3 m g (b) 4 m g
(c) 5 m g (d) 6 m g

25. A particle is moving along a circular path with a uniform speed. Through what angle does its angular velocity change when it completes half of the circular path?

(a) 0° (b) 45°
(c) 180° (d) 360°

ANSWER KEY

1. (a)	2. (b)	3. (d)	4. (a)	5. (b)	6. (b)		7. (b)	8. (a)	9.(d)	10. (d)	11.(a)
12.(b)	13.(b)	14. (b)	15.(b)	16. (b)	17. (b)	18. (a)	19. (d)	20. (b)	21. (a)	22. (d)	23. (c)
24. (a)	25. (a)										

Exercise-1 | NCERT Based Questions

Very Short / Short Answer Questions

1. Two objects having different masses have same momentum. Which one of them will move faster?

2. At which place on earth, the centripetal force is maximum?

3. Can a body in linear motion be in equilibrium?

4. Why are curved roads generally banked?

5. The two ends of a spring-balance are pulled each by a force of 10 kg-wt. What will be the reading of the balance?

6. Why is it easier to maintain the motion than to start it?

7. What is the angle of friction between two surfaces in contact, if coefficient of friction is $1/\sqrt{3}$?

8. Explain how proper inflation of tyres saves fuel?

9. In a circus in the game of swing, the man falls on a net after leaving the swing but he is not injured, why?

10. State the laws of limiting friction. Hence define coefficient of friction.

11. Derive a relation between angle of friction and angle of repose.

12. Derive the maximum angle by which a cyclist can bend while negotiating a curved path.

Long Answer Questions

13. State Newton's second law of motion. How does it help to measure force. Also state the units of force.

14. A uniform rod is made to lean between a rough vertical wall and the ground. Show that the least angle at which the rod can be leaned without slipping is given by

$$\theta = \tan^{-1}\left(\frac{1-\mu_1\mu_2}{2\mu_2}\right)$$

where μ_1 and μ_2 stand for the coefficient of friction between (i) the rod and the wall and (ii) the rod and the ground.

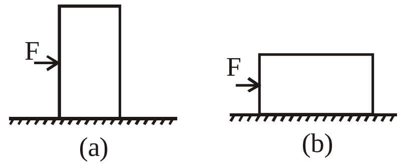
15. Name a varying mass system. Derive an expression for velocity of propulsion of a rocket at any instant.

16. A force produces an acceleration of 16 m/s^2 in a body of mass 0.5 kg, and an acceleration of 4 m/s^2 in another body. If both the bodies are fastened together, then what is the acceleration produced by that force?

17. A gun weighing 10 kg fires a bullet of 30 g with a velocity of 330 m/s. With what velcotiy does the gun recoil? What is the resultant momentum of the gun and the bullet before and after firing?

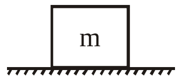
Multiple Choice Questions

18. A rectangular block is placed on a rough horizontal surface in two different ways as shown, then



(a) friction will be more in case (a)
(b) friction will be more in case (b)
(c) friction will be equal in both the cases
(d) friction depends on the relations among its dimensions.

19. A block of mass m is placed on a smooth horizontal surface as shown. The weight (mg) of the block and normal reaction (N) exerted by the surface on the block



(a) form action-reaction pair
(b) balance each other
(c) act in same direction
(d) both (a) and (b)

20. Centripetal force :
(a) can change speed of the body.
(b) is always perpendicular to direction of motion
(c) is constant for uniform circular motion.
(d) all of these

21. When a horse pulls a cart, the horse moves down to
(a) horse on the cart.
(b) cart on the horse.
(c) horse on the earth.
(d) earth on the horse.

22. The force of action and reaction
(a) must be of same nature
(b) must be of different nature
(c) may be of different nature
(d) may not have equal magnitude

23. A body is moving with uniform velocity, then
(a) no force must be acting on the body.
(b) exactly two forces must be acting on the body
(c) body is not acted upon by a single force.
(d) the number of forces acting on the body must be even.

24. The direction of impulse is
(a) same as that of the net force
(b) opposite to that of the net force
(c) same as that of the final velocity
(d) same as that of the initial velocity

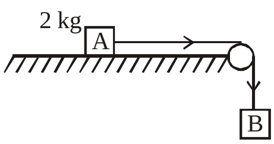
25. A monkey is climbing up a rope, then the tension in the rope
(a) must be equal to the force applied by the monkey on the rope
(b) must be less than the force applied by the monkey on the rope.
(c) must be greater than the force applied by the monkey on the rope.
(d) may be equal to, less than or greater the force applied by the monkey on the rope.

Exercise-2 | Past Competition MCQs

1. A player caught a cricket ball of mass 150 g moving at a rate of 20 m/s. If the catching process is completed in 0.1s, the force of the blow exerted by the ball on the hand of the player is equal to **[CBSE PMT 2001]**
(a) 150 N (b) 3 N
(c) 30 N (d) 300 N

2. A block of mass *m* is placed on a smooth wedge of inclination θ. The whole system is accelerated horizontally so that the block does not slip on the wedge. The force exerted by the wedge on the block (g is acceleration due to gravity) will be **[CBSE PMT 2004]**
(a) mg/cos θ (b) mg cos θ
(c) mg sin θ (d) mg

3. The coefficient of static friction, μ_s, between block A of mass 2 kg and the table as shown in the figure is 0.2. What would be the maximum mass value of block B so that the two blocks do not move? The string and the pulley are assumed to be smooth and massless. (g = 10 m/s^2) **[CBSE PMT 2004]**



(a) 0.4 kg (b) 2.0 kg
(c) 4.0 kg (d) 0.2 kg

4. A body under the action of a force $\vec{F} = 6\,\hat{i} - 8\,\hat{j} + 10\,\hat{k}$, acquires an acceleration of 1 m/s^2. The mass of this body must be **[CBSE-PMT 2009]**
(a) 10 kg (b) 20 kg
(c) $10\sqrt{2}$ kg (d) $2\sqrt{10}$ kg

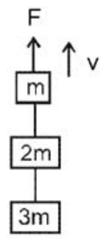
5. A conveyor belt is moving at a constant speed of 2m/s. A box is gently dropped on it. The coefficient of friction between them is μ = 0.5. The distance that the box will move relative to belt before coming to rest on it taking g = 10 ms^{-2}, is **[CBSE-PMT 2011 M]**
(a) 1.2 m (b) 0.6 m (c) zero (d) 0.4 m

6. A body of mass M hits normally a rigid wall with velocity V and bounces back with the same velocity. The impulse experienced by the body is **[CBSE-PMT 2011 S]**
(a) MV (b) 1.5 MV (c) 2 MV (d) zero

7. A person of mass 60 kg is inside a lift of mass 940 kg and presses the button on control panel. The lift starts moving upwards with an acceleration 1.0 m/s^2. If g = 10 ms^{-2}, the tension in the supporting cable is **[CBSE-PMT 2011 M]**
(a) 8600 N (b) 9680 N
(c) 11000 N (d) 1200 N

8. The upper half of an inclined plane of inclination θ is perfectly smooth while lower half is rough. A block starting from rest at the top of the plane will again come to rest at the bottom, if the coefficient of friction between the block and lower half of the plane is given by **[NEET 2013]**
(a) $\mu = \dfrac{2}{\tan\theta}$ (b) $\mu = 2\tan\theta$
(c) $\mu = \tan\theta$ (d) $\mu = \dfrac{1}{\tan\theta}$

9. Three blocks with masses m, 2 m and 3 m are connected by strings as shown in the figure. After an upward force F is applied on block m, the masses move upward at constant speed v. What is the net force on the block of mass 2m?
(g is the acceleration due to gravity) **[NEET 2013]**
(a) 2 mg
(b) 3 mg
(c) 6 mg
(d) zero



10. An explosion breaks a rock into three parts in a horizontal plane. Two of them go off at right angles to each other. The first part of mass 1 kg moves with a speed of 12 ms^{-1} and the second part of mass 2 kg moves with speed 8 ms^{-1}. If the third part flies off with speed 4 ms^{-1} then its mass is **[NEET 2013]**
(a) 5 kg (b) 7 kg
(c) 17 kg (d) 3 kg

11. If a body looses half of its velocity on penetrating 3 cm in a wooden block, then how much will it penetrate more before coming to rest? **[AIEEE 2002]**
(a) 1 cm (b) 2 cm
(c) 3 cm (d) 4 cm.

12. Speeds of two identical cars are *u* and 4*u* at a specific instant. The ratio of the respective distances in which the two cars are stopped from that instant is **[AIEEE 2002]**
(a) 1 : 1 (b) 1 : 4
(c) 1 : 8 (d) 1 : 16.

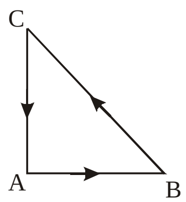
13. A light string passing over a smooth light pulley connects two blocks of masses m_1 and m_2 (vertically). If the acceleration of the system is $g/8$, then the ratio of the masses is **[AIEEE 2002]**

(a) 8 : 1 (b) 9 : 7
(c) 4 : 3 (d) 5 : 3.

14. A spring balance is attached to the ceiling of a lift. A man hangs his bag on the spring and the spring reads 49 N, when the lift is stationary. If the lift moves downward with an acceleration of $5 m/s^2$, the reading of the spring balance will be **[AIEEE 2003]**

(a) 24 N (b) 74 N
(c) 15 N (d) 49 N

15. Three forces start acting simultaneously on a particle moving with velocity, $\vec{v}$. These forces are represented in magnitude and direction by the three sides of a triangle ABC (as shown). The particle will now move with velocity **[AIEEE 2003]**



(a) less than $\vec{v}$
(b) greater than $\vec{v}$
(c) $|\vec{v}|$ in the direction of the largest force BC
(d) $\vec{v}$, remaining unchanged

16. A marble block of mass 2 kg lying on ice when given a velocity of 6 m/s is stopped by friction in 10 s. Then the coefficient of friction is (Take g = 10 ms^{-2}) **[AIEEE 2003]**

(a) 0.06 (b) 0.03
(c) 0.04 (d) 0.01

17. A rocket with a lift-off mass 3.5×10^4 kg is blasted upwards with an initial acceleration of 10m/s^2. Then the initial thrust of the blast is **[AIEEE 2003]**

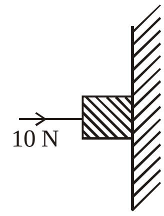
(a) 3.5×10^5 N (b) 7.0×10^5 N
(c) 14.0×10^5 N (d) 1.75×10^5 N

18. A light spring balance hangs from the hook of the other light spring balance and a block of mass M kg hangs from the former one. Then the true statement about the scale reading is **[AIEEE 2003]**

(a) the scale of the lower one reads M kg and of the upper one zero
(b) the reading of the two scales can be anything but the sum of the reading will be M kg
(c) both the scales read M/2 kg each
(d) both the scales read M kg each

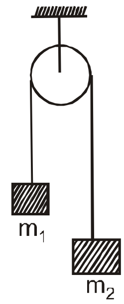
19. A horizontal force of 10 N is necessary to just hold a block stationary against a wall. The coefficient of friction between the block and the wall is 0.2. The weight of the block is **[AIEEE 2003]**

(a) 2 N
(b) 100 N
(c) 50 N
(d) 20 N



20. Two masses $m_1 = 5kg$ and $m_2 = 4.8kg$ tied to a string are hanging over a light frictionless pulley. What is the acceleration of the masses when left free to move ? $(g = 9.8 m/s^2)$ **[AIEEE 2004]**

(a) $5\ m/s^2$
(b) $9.8\ m/s^2$
(c) $0.2\ m/s^2$
(d) $4.8\ m/s^2$



21. A block rests on a rough inclined plane making an angle of 30° with the horizontal. The coefficient of static friction between the block and the plane is 0.8. If the frictional force on the block is 10 N, the mass of the block (in kg) is (take $g = 10\ m/s^2$) **[AIEEE 2004]**

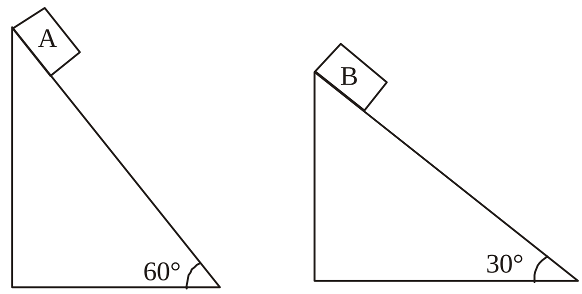
(a) 1.6 (b) 4.0
(c) 2.0 (d) 2.5

22. A given object takes n times as much time to slide down a 45° rough incline as it takes to slide down a perfectly smooth 45° incline. The coefficient of kinetic friction between the object and incline is given by **[AIEEE 2005]**

(a) $\left(1-\frac{1}{n^2}\right)$ (b) $\frac{1}{1-n^2}$

(c) $\sqrt{\left(1-\frac{1}{n^2}\right)}$ (d) $\sqrt{\left(\frac{1}{1-n^2}\right)}$

23. Two fixed frictionless inclined planes making an angle 30° and 60° with the vertical are shown in the figure. Two blocks A and B are placed on the two planes. What is the relative vertical acceleration of A with respect to B ? **[AIEEE 2010]**

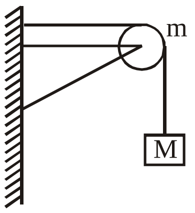


(a) $4.9\ ms^{-2}$ in horizontal direction
(b) $9.8\ ms^{-2}$ in vertical direction
(c) Zero
(d) $4.9\ ms^{-2}$ in vertical direction

24. Two cars of masses m_1 and m_2 are moving in circles of radii r_1 and r_2, respectively. Their speeds are such that they make complete circles in the same time t. The ratio of their centripetal acceleration is **[AIEEE 2012]**

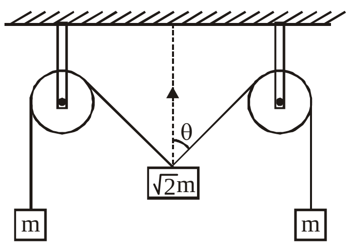
(a) $m_1r_1 : m_2r_2$ (b) $m_1 : m_2$
(c) $r_1 : r_2$ (d) $1 : 1$

25. A string of negligible mass going over a clamped pulley of mass m supports a block of mass M as shown in the figure. The force on the pulley by the clamp is given by **[IIT JEE 2001 S]**



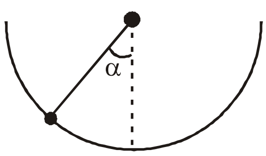
(a) $\sqrt{2}Mg$ (b) $\sqrt{2}mg$
(c) $\sqrt{[(M+m)^2+m^2]}g$ (d) $\sqrt{[(M+m)^2+M^2]}g$

26. The pulleys and strings shown in the figure are smooth and of negligible mass. For the system to remain in equilibrium. The angle θ should be **[IIT JEE 2001]**



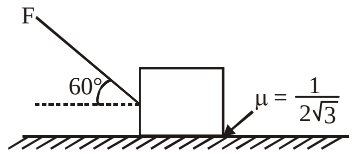
(a) 0° (b) 30°
(c) 45° (d) 60°

27. An insect crawls up a hemispherical surface very slowly, (fig). The coefficient of friction between the insect and the surface is 1/3. If the line joining the center of the hemispherical surface to the insect makes an angle α with the vertical, the max. possible value of α is given by **[IIT JEE 2001 S]**



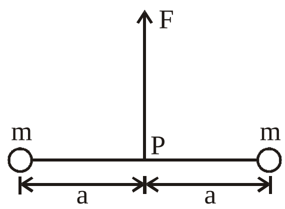
(a) cot α = 3 (b) sec α = 3
(c) cosec α = 3 (d) None

28. A force F is applied to a block of mass $2\sqrt{3}$ kg as shown in the diagram. What should be the maximum value of force so that the block does not move ? **[IIT JEE 2003]**



(a) 10 N (b) 20 N
(c) 30 N (d) 40 N

29. Two particles of mass m each are tied at the ends of a light string of length 2a. The whole system is kept on a frictionless horizontal surface with the string held tight so that each mass is at a distance 'a' from the center P (as shown in the figure). Now, the mid-point of the string is pulled vertically upwards with a small but constant force F. As a result, the particles move towards each other on the surface. The magnitude of acceleration, when the separation between them becomes 2x, is **[IIT JEE 2004]**



(a) $\frac{F}{2m}\frac{a}{\sqrt{a^2-x^2}}$ (b) $\frac{F}{2m}\frac{x}{\sqrt{a^2-x^2}}$

(c) $\frac{F}{2m}\frac{x}{a}$ (d) $\frac{F}{2m}\frac{\sqrt{a^2-x^2}}{x}$

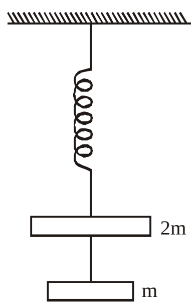
30. The string between blocks of mass m and 2m is massless and inextensible. The system is suspended by a massless spring as shown. If the string is cut, find the magnitudes of accelerations of mass 2m and m (immediately after cutting). **[IIT JEE 2006]**

(a) g, g

(b) g, $\frac{g}{2}$

(c) $\frac{g}{2}$, g

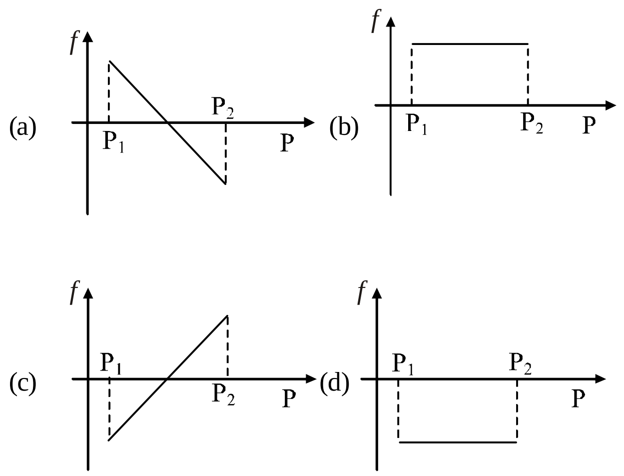
(d) $\frac{g}{2}$, $\frac{g}{2}$



31. A block of base 10 cm × 10 cm and height 15 cm is kept on an inclined plane. The coefficient of friction between them is $\sqrt{3}$. The inclination θ of this inclined plane from the horizontal plane is gradually increased from 0°. Then **[IIT-JEE 2009]**

(a) at $\theta = 30°$, the block will start sliding down the plane
(b) the block will remain at rest on the plane up to certain θ and then it will topple
(c) at $\theta = 60°$, the block will start sliding down the plane and continue to do so at higher angles
(d) at $\theta = 60°$, the block will start sliding down the plane and on further increasing θ, it will topple at certain θ

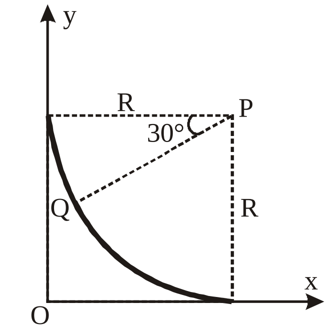
32. A block of mass m is on an inclined plane of angle θ. The coefficient of friction between the block and the plane is μ and $\tan\theta > \mu$. The block is held stationary by applying a force P parallel to the plane. The direction of force pointing up the plane is taken to be positive. As P is varied from $P_1 = mg(\sin\theta - \mu\cos\theta)$ to $P_2 = mg(\sin\theta + \mu\cos\theta)$, the frictional force f versus P graph will look like **[IIT-JEE 2010]**



Paragraphs for Questions 33 and 34

A small block of mass 1 kg is released from rest at the top of a rough track. The track is a circular arc of radius 40 m. The block slides along the track without toppling and a frictional force acts on it in the direction opposite to the instantaneous velocity. The work done in overcoming the friction up to the point Q, as shown in the figure below, is 150 J.

(Take the acceleration due to gravity, $g = 10\ ms^{-2}$)



33. The magnitude of the normal reaction that acts on the block at the point Q is **[JEE Adv. 2013]**

(a) 7.5 N (b) 8.6 N
(c) 11.5 N (d) 22.5 N

34. The speed of the block when it reaches the point Q is **[JEE Adv. 2013]**

(a) $5\ ms^{-1}$ (b) $10\ ms^{-1}$
(c) $10\sqrt{3}\ ms^{-1}$ (d) $20\ ms^{-1}$

35. A bob of mass m, suspended by a string of length l_1, is given a minimum velocity required to complete a full circle in the vertical plane. At the highest point, it collides elastically with another bob of mass m suspended by a string of length l_2, which is initially at rest. Both the strings are mass-less and inextensible. If the second bob, after collision acquires the minimum speed required to complete a full circle in the vertical plane, the ratio $\frac{l_1}{l_2}$ is **[JEE Adv. 2013]**

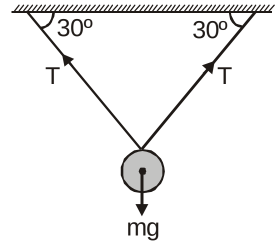
(a) 3 (b) 5
(c) 6 (d) 8

Exercise-3 | Conceptual & Applied MCQs

1. An object of mass 10 kg moves at a constant speed of $10\ ms^{-1}$. A constant force, that acts for 4 sec on the object, gives it a speed of $2\ ms^{-1}$ in opposite direction. The force acting on the object is

(a) –3 N (b) –30 N
(c) 3 N (d) 30 N

2. A solid sphere of 2 kg is suspended from a horizontal beam by two supporting wires as shown in fig. Tension in each wire is approximately ($g = 10\ ms^{-2}$)



(a) 30 N
(b) 20 N
(c) 10 N
(d) 5 N

3. A body of mass 4 kg moving on a horizontal surface with an initial velocity of 6 ms^{-1} comes to rest after 3 seconds. If one wants to keep the body moving on the same surface with the velocity of 6 ms^{-1}, the force required is
(a) Zero (b) 4 N
(c) 8 N (d) 16 N

4. A toy gun consists of a spring and a rubber dart of mass 16 g. When compressed by 4 cm and released, it projects the dart to a height of 2 m. If compressed by 6 cm, the height achieved is
(a) 3m (b) 4m
(c) 4.5m (d) 6m

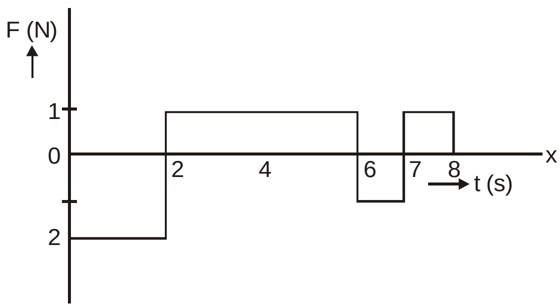
5. A player stops a football weighting 0.5 kg which comes flying towards him with a velocity of 10m/s. If the impact lasts for 1/50th sec. and the ball bounces back with a velocity of 15 m/s, then the average force involved is
(a) 250 N (b) 1250 N
(c) 500 N (d) 625 N

6. A car travelling at a speed of 30 km/h is brought to a halt in 4 m by applying brakes. If the same car is travelling at 60 km/h, it can be brought to halt with the same braking power in
(a) 8m (b) 16m
(c) 24m (d) 32m

7. A uniform rope of length L resting on a frictionless horizontal surface is pulled at one end by a force F. What is the tension in the rope at a distance ℓ from the end where the force is applied.
(a) F (b) F (1 + ℓ/L)
(c) F/2 (d) F (1 – ℓ/L)

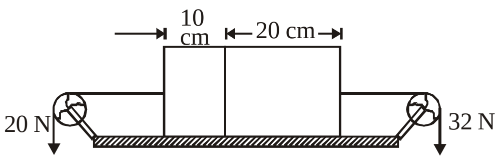
8. A machine gun has a mass 5 kg. It fires 50 gram bullets at the rate of 30 bullets per minute at a speed of 400 ms^{-1}. What force is required to keep the gun in position?
(a) 10 N (b) 5 N
(c) 15 N (d) 30 N

9. A force time graph for the motion of a body is shown in Fig. Change in linear momentum between 0 and 8s is



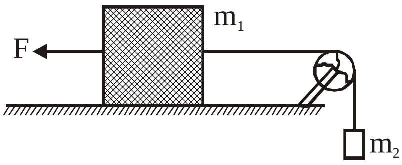
(a) zero (b) 4 N-s
(c) 8 Ns (d) None of these

10. Fig. shows a uniform rod of length 30 cm having a mass of 3.0 kg. The strings shown in the figure are pulled by constant forces of 20 N and 32 N. All the surfaces are smooth and the strings and pulleys are light. The force exerted by 20 cm part of the rod on the 10 cm part is



(a) 20 N (b) 24 N
(c) 32 N (d) 52 N

11. A constant force F = $m_2g/2$ is applied on the block of mass m_1 as shown in fig. The string and the pulley are light and the surface of the table is smooth. The acceleration of m_1 is



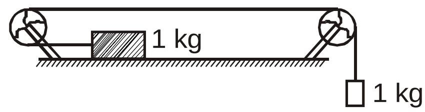
(a) $\frac{m_2 g}{2(m_1+m_2)}$ towards right

(b) $\frac{m_2 g}{2(m_1-m_2)}$ towards left

(c) $\frac{m_2 g}{2(m_2-m_1)}$ towards right

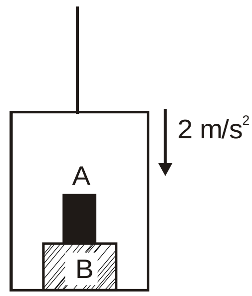
(d) $\frac{m_2 g}{2(m_2-m_1)}$ towards left

12. Consider the system shown in fig. The pulley and the string are light and all the surfaces are frictionless. The tension in the string is (take g = 10 m/s^2)



(a) 0 N (b) 1 N
(c) 2 N (d) 5 N

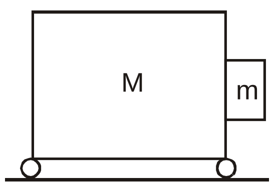
13. The elevator shown in fig. is descending with an acceleration of 2 m/s^2. The mass of the block A = 0.5 kg. The force exerted by the block A on block B is



(a) 2 N
(b) 4 N
(c) 6 N
(d) 8 N

14. Two blocks of masses 2 kg and 1 kg are placed on a smooth horizontal table in contact with each other. A horizontal force of 3 newton is applied on the first so that the block moves with a constant acceleration. The force between the blocks would be
(a) 3 newton (b) 2 newton
(c) 1 newton (d) zero

15. A cart of mass M has a block of mass m attached to it as shown in fig. The coefficient of friction between the block and the cart is μ. What is the minimum acceleration of the cart so that the block m does not fall?



(a) μg
(b) g/μ
(c) μ/g
(d) M μg/m

16. A rocket has a mass of 100 kg. Ninety percent of this is fuel. It ejects fuel vapors at the rate of 1 kg/sec with a velocity of 500 m/sec relative to the rocket. It is supposed that the rocket is outside the gravitational field. The initial upthrust on the rocket when it just starts moving upwards is

(a) zero (b) 500 newton
(c) 1000 newton (d) 2000 newton

17. A particle of mass m moving eastward with a speed v collides with another particle of the same mass moving northward with the same speed v. The two particles coalesce on collision. The new particle of mass 2m will move in the north-external direction with a velocity :

(a) v/2 (b) 2v
(c) $v/\sqrt{2}$ (d) None of these

18. A spring is compressed between two toy carts of mass m_1 and m_2. When the toy carts are released, the springs exert equal and opposite average forces for the same time on each toy cart. If v_1 and v_2 are the velocities of the toy carts and there is no friction between the toy carts and the ground, then :

(a) $v_1/v_2 = m_1/m_2$ (b) $v_1/v_2 = m_2/m_1$
(c) $v_1/v_2 = -m_2/m_1$ (d) $v_1/v_2 = -m_1/m_2$

19. A man weighing 80 kg is standing on a trolley weighing 320 kg. The trolley is resting on frictionless horizontal rails. If the man starts walking on the trolley along the rails at a speed of one metre per second, then after 4 seconds, his displacement relative to the ground will be :

(a) 5 metres (b) 4.8 metres
(c) 3.2 metres (d) 3.0 metres

20. Starting from rest, a body slides down a 45° inclined plane in twice the time it takes to slide down the same distance in the absence of friction. The coefficient of friction between the body and the inclined plane is:

(a) 0.33 (b) 0.25
(c) 0.75 (d) 0.80

21. A ball of mass 0.5 kg moving with a velocity of 2 m/sec strikes a wall normally and bounces back with the same speed. If the time of contact between the ball and the wall is one millisecond, the average force exerted by the wall on the ball is :

(a) 2000 newton (b) 1000 newton
(c) 5000 newton (d) 125 newton

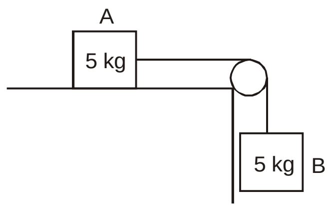
22. The mass of the lift is 100 kg which is hanging on the string. The tension in the string, when the lift is moving with constant velocity, is ($g = 9.8\ m/sec^2$)

(a) 100 newton (b) 980 newton
(c) 1000 newton (d) None of these

23. In the question , the tension in the strings, when the lift is accelerating up with an acceleration 1 m/sec^2, is

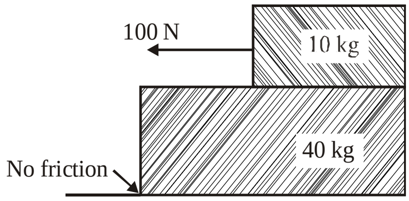
(a) 100 newton (b) 980 newton
(c) 1080 newton (d) 880 newton

24. A block of mass 5 kg resting on a horizontal surface is connected by a cord, passing over a light frictionless pulley to a hanging block of mass 5 kg. The coefficient of kinetic friction between the block and the surface is 0.5. Tension in the cord is : ($g = 9.8\ m/sec^2$)



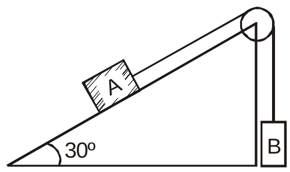
(a) 49 N (b) Zero
(c) 36.75 N (d) 2.45 N

25. A 40 kg slab rests on frictionless floor as shown in fig. A 10 kg block rests on the top of the slab. The static coefficient of friction between the block and slab is 0.60 while the kinetic friction is 0.40. The 10 kg block is acted upon by a horizontal force of 100 N. If $g = 9.8\ m/s^2$, the resulting acceleration of the slab will be:



(a) 0.98 m/s^2 (b) 1.47 m/s^2
(c) 1.52 m/s^2 (d) 6.1 m/s^2

26. Two blocks are connected over a massless pulley as shown in fig. The mass of block A is 10 kg and the coefficient of kinetic friction is 0.2. Block A slides down the incline at constant speed. The mass of block B in kg is:



(a) 3.5 (b) 3.3
(c) 3.0 (d) 2.5

27. Two trolleys of mass m and 3m are connected by a spring. They were compressed and released at once, they move off in opposite direction and come to rest after covering a distance S_1, S_2 respectively. Assuming the coefficient of friction to be uniform, ratio of distances $S_1 : S_2$ is :

(a) 1 : 9 (b) 1 : 3
(c) 3 : 1 (d) 9 : 1

28. A particle of mass 10 kg is moving in a straight line. If its displacement, x with time t is given by $x = (t^3 - 2t - 10)$ m, then the force acting on it at the end of 4 seconds is

(a) 24 N (b) 240 N
(c) 300 N (d) 1200 N

29. A particle of mass m is moving with velocity v_1, it is given an impulse such that the velocity becomes v_2. Then magnitude of impulse is equal to

(a) $m(\vec{v}_2 - \vec{v}_1)$ (b) $m(\vec{v}_1 - \vec{v}_2)$
(c) $m \times (\vec{v}_2 - \vec{v}_1)$ (d) $0.5m(\vec{v}_2 - \vec{v}_1)$

30. A force of 10 N acts on a body of mass 20 kg for 10 seconds. Change in its momentum is

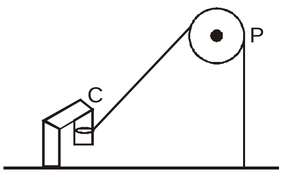
(a) 5 kg m/s (b) 100 kg m/s
(c) 200 kg m/s (d) 1000 kg m/s

31. When forces F_1, F_2, F_3 are acting on a particle of mass m such that F_2 and F_3 are mutually perpendicular, then the particle remains stationary. If the force F_1 is now removed then the acceleration of the particle is

(a) F_1/m (b) F_2F_3/mF_1

(c) $(F_2 - F_3)/m$ (d) F_2/m

32. One end of massless rope, which passes over a massless and frictionless pulley P is tied to a hook C while the other end is free. Maximum tension that the rope can bear is 360 N. With what value of maximum safe acceleration (in ms^{-2}) can a man of 60 kg moves downwards on the rope? [Take $g = 10\ ms^{-2}$]



(a) 16 (b) 6

(c) 4 (d) 8

33. Two mass m and 2m are attached with each other by a rope passing over a frictionless and massless pulley. If the pulley is accelerated upwards with an acceleration 'a', what is the value of T?

(a) $\frac{g+a}{3}$ (b) $\frac{g-a}{3}$

(c) $\frac{4m(g+a)}{3}$ (d) $\frac{m(g-a)}{3}$

34. A uniform chain of length 2 m is kept on a table such that a length of 60 cm hangs freely from the edge of the table. The total mass of the chain is 4 kg. What is the work done in pulling the entire chain on the table ?

(a) 12 J (b) 3.6 J

(c) 7.2 J (d) 1200 J

35. A mass is hanging on a spring balance which is kept in a lift. The lift ascends. The spring balance will show in its readings

(a) an increase

(b) a decrease

(c) no change

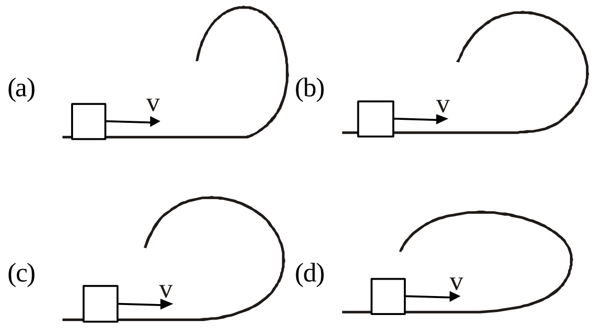
(d) a change depending on its velocity

36. A block of mass 0.1kg is held against a wall applying a horizontal force of 5 N on the block. If the coefficient of friction between the block and the wall is 0.5, the magnitude of the frictional force acting on the block is:

(a) 2.5 N (b) 0.98 N

(c) 4.9 N (d) 0.49 N

37. A small block is shot into each of the four tracks as shown below. Each of the tracks rises to the same height. The speed with which the block enters the track is the same in all cases. At the highest point of the track, the normal reaction is maximum in



38. A particle starts sliding down a frictionless inclined plane. If S_n is the distance traveled by it from time t = n – 1 sec to t = n sec, the ratio S_n/S_{n+1} is

(a) $\frac{2n-1}{2n+1}$ (b) $\frac{2n+1}{2n}$

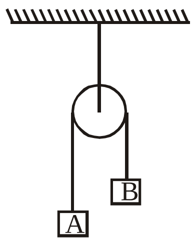
(c) $\frac{2n}{2n+1}$ (d) $\frac{2n+1}{2n-1}$

39. A block is kept on a inclined plane of inclination θ of length ℓ. The velocity of particle at the bottom of inclined is (the coefficient of friction is μ)

(a) $[2g\ell(\mu\cos\theta - \sin\theta)]^{1/2}$ (b) $\sqrt{2g\ell(\sin\theta - \mu\cos\theta)}$

(c) $\sqrt{2g\ell(\sin\theta + \mu\cos\theta)}$ (d) $\sqrt{2g\ell(\cos\theta + \mu\sin\theta)}$

40. Blocks A and B of masses 15 kg and 10 kg, respectively, are connected by a light cable passing over a frictionless pulley as shown below. Approximately what is the acceleration experienced by the system?



(a) $2.0\ m/s^2$

(b) $3.3\ m/s^2$

(c) $4.9\ m/s^2$

(d) $9.8\ m/s^2$

41. A 50 kg ice skater, initially at rest, throws a 0.15 kg snowball with a speed of 35 m/s. What is the approximate recoil speed of the skater?

(a) 0.10 m/s (b) 0.20 m/s

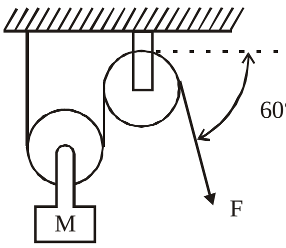
(c) 0.70 m/s (d) 1.4 m/s

42. Block A is moving with acceleration A along a frictionless horizontal surface. When a second block, B is placed on top of Block A the acceleration of the combined blocks drops to 1/5 the original value. What is the ratio of the mass of A to the mass of B?

(a) 5 : 1 (b) 1 : 4

(c) 3 : 1 (d) 2 : 1

43. A force F is used to raise a 4-kg mass M from the ground to a height of 5 m.



What is the work done by the force F? (Note : sin 60° = 0.87; cos 60° = 0.50. Ignore friction and the weights of the pulleys)

(a) 50 J (b) 100 J
(c) 174 J (d) 200 J

44. A 5000 kg rocket is set for vertical firing. The exhaust speed is 800 m/s. To give an initial upward acceleration of 20 m/s^2, the amount of gas ejected per second to supply the needed thrust will be (Take g = 10 m/s^2)

(a) 127.5 kg/s (b) 137.5 kg/s
(c) 155.5 kg/s (d) 187.5 kg/s

45. A bullet is fired from a gun. The force on the bullet is given by $F = 600 - 2 \times 10^5 t$

Where, F is in newtons and t in seconds. The force on the bullet becomes zero as soon as it leaves the barrel. What is the average impulse imparted to the bullet?

(a) 1.8 N-s (b) Zero
(c) 9 N-s (d) 0.9 N-s

46. A 4000 kg lift is accelerating upwards. The tension in the supporting cable is 48000 N. If $g = 10\,ms^{-2}$ then the acceleration of the lift is

(a) $1\ ms^{-2}$ (b) $2\ ms^{-2}$
(c) $4\ ms^{-2}$ (d) $6\ ms^{-2}$

47. A 0.1 kg block suspended from a massless string is moved first vertically up with an acceleration of $5ms^{-2}$ and then moved vertically down with an acceleration of $5ms^{-2}$. If T_1 and T_2 are the respective tensions in the two cases, then

(a) $T_2 > T_1$
(b) $T_1 - T_2 = 1\,N$, if $g = 10\,ms^{-2}$
(c) $T_1 - T_2 = 1\,kg\,f$
(d) $T_1 - T_2 = 9.8N$, if $g = 9.8\ ms^{-2}$

48. A rifle man, who together with his rifle has a mass of 100 kg, stands on a smooth surface and fires 10 shots horizontally. Each bullet has a mass 10 g and a muzzle velocity of 800 ms^{-1}. The velocity which the rifle man attains after firing 10 shots is

(a) $8\ ms^{-1}$ (b) $0.8\ ms^{-1}$
(c) $0.08\,ms^{-1}$ (d) $-0.8\ ms^{-1}$

49. The coefficient of friction between two surfaces is 0.2. The angle of friction is

(a) $\sin^{-1}(0.2)$ (b) $\cos^{-1}(0.2)$
(c) $\tan^{-1}(0.1)$ (d) $\cot^{-1}(5)$

50. A force $\vec{F} = 8\hat{i} - 6\hat{j} - 10\hat{k}$ newton produces an acceleration of 1 ms^{-2} in a body. The mass of the body is

(a) 10 kg (b) $10\sqrt{2}$ kg
(c) $10\sqrt{3}$ kg (d) 200 kg

51. A block of mass 4 kg rests on an inclined plane. The inclination to the plane is gradually increased. It is found that when the inclination is 3 in 5, the block just begins to slidedown the plane. The coefficient of friction between the block and the plane is

(a) 0.4 (b) 0.6
(c) 0.8 (d) 0.75.

52. A bird is in a wire cage which is hanging from a spring balance . In the first case, the bird sits in the cage and in the second case, the bird flies about inside the cage. The reading in the spring balance is

(a) more in the first case
(b) less in first case
(c) unchanged
(d) zero in second case.

53. A rider on a horse back falls forward when the horse suddenly stops. This is due to

(a) inertia of horse
(b) inertia of rider
(c) large weight of the horse
(d) losing of the balance

54. A ball of mass m is thrown vertically upwards. What is the rate at which the momentum of the ball changes?

(a) Zero
(b) mg
(c) Infinity
(d) Data is not sufficient.

55. A body of mass 1 kg moving with a uniform velocity of $1ms^{-1}$. If the value of g is $5\,ms^{-2}$, then the force acting on the frictionless horizontal surface on which the body is moving is

(a) 5 N (b) 1 N
(c) 0 N (d) 10N

56. A body of mass 2 kg is placed on a horizontal surface having kinetic friction 0.4 and static friction 0.5. If the force applied on the body is 2.5 N, then the frictional force acting on the body will be [g = 10 ms^{-2}]

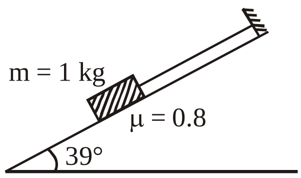
(a) 8 N (b) 10 N
(c) 20 N (d) 2.5 N

57. A bag of sand of mass m is suspended by a rope. A bullet of mass $\frac{m}{20}$ is fired at it with a velocity v and gets embedded into it. The velocity of the bag finally is

(a) $\frac{v}{20} \times 21$ (b) $\frac{20v}{21}$

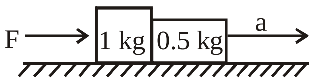
(c) $\frac{v}{20}$ (d) $\frac{v}{21}$

58. For the arrangement shown in the Figure the tension in the string is [Given : $\tan^{-1}(0.8) = 39°$]



(a) 6 N (b) 6.4 N
(c) 0.4 N (d) zero.

59. A 1 kg block and a 0.5 kg block move together on a horizontal frictionless surface . Each block exerts a force of 6 N on the other. The block move with a uniform acceleration of



(a) $3\,ms^{-2}$ (b) $6\,ms^{-2}$

(c) $9\,ms^{-2}$ (d) $12\,ms^{-2}$

60. A body of mass 32 kg is suspended by a spring balance from the roof of a vertically operating lift and going downward from rest. At the instant the lift has covered 20 m and 50 m, the spring balance showed 30 kg and 36 kg respectively. Then the velocity of the lift is

(a) decreasing at 20 m, and increasing at 50 m
(b) increasing at 20m and decreasing at 50 m
(c) continuously decreasing at a steady rate throughout the journey
(d) constantly increasing at constant rate throughout the journey.

61. An object at rest in space suddenly explodes into three parts of same mass. The momentum of the two parts are $2p\hat{i}$ and $p\hat{j}$. The momentum of the third part

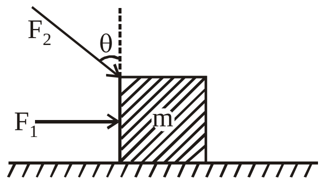
(a) will have a magnitude $p\sqrt{3}$
(b) will have a magnitude $p\sqrt{5}$
(c) will have a magnitude p
(d) will have a magnitude 2p.

62. A triangular block of mass M with angles 30°, 60°, and 90° rests with its 30°–90° side on a horizontal table. A cubical block of mass m rests on the 60°–30° side. The acceleration which M must have relative to the table to keep m stationary relative to the triangular block assuming frictionless contact is

(a) g (b) $\frac{g}{\sqrt{2}}$

(c) $\frac{g}{\sqrt{3}}$ (d) $\frac{g}{\sqrt{5}}$

63. A block of mass m on a rough horizontal surface is acted upon by two forces as shown in figure. For equilibrium of block the coefficient of friction between block and surface is



(a) $\frac{F_1 + F_2 \sin\theta}{mg + F_2 \cos\theta}$ (b) $\frac{F_1 \cos\theta + F_2}{mg - F_2 \sin\theta}$

(c) $\frac{F_1 + F_2 \cos\theta}{mg + F_2 \sin\theta}$ (d) $\frac{F_1 \sin\theta - F_2}{mg - F_2 \cos\theta}$

64. A weight W rests on a rough horizontal plane. If the angle of friction be θ, the least force that will move the body along the plane will be

(a) $W \cos\theta$ (b) $W \cot\theta$
(c) $W \tan\theta$ (d) $W \sin\theta$

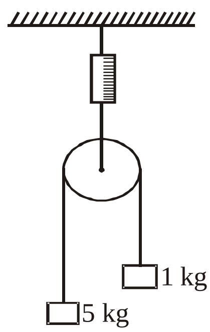
65. A trailer of mass 1000 kg is towed by means of a rope attached to a car moving at a steady speed along a level road. The tension in the rope is 400 N. The car starts to accelerate steadily. If the tension in the rope is now 1650 N, with what acceleration is the trailer moving ?

(a) $1.75\,ms^{-2}$ (b) $0.75\,ms^{-2}$
(c) $2.5\,ms^{-2}$ (d) $1.25\,ms^{-2}$

66. A rocket of mass 5000 kg is to be projected vertically upward. The gases are exhausted vertically downwards with velocity $1000\,ms^{-2}$ with respect to the rocket. What is the minimum rate of burning the fuel so as to just lift the rocket upwards against gravitational attraction ?

(a) $49\,kg\,s^{-1}$ (b) $147\,kg\,s^{-1}$
(c) $98\,kg\,s^{-1}$ (d) $196\,kg\,s^{-1}$

67. In the figure a smooth pulley of negligible weight is suspended by a spring balance. Weight of 1 kg f and 5 kg f are attached to the opposite ends of a string passing over the pulley and move with acceleration because of gravity, During their motion, the spring balance reads a weight of



(a) 6 kg f
(b) less then 6 kg f
(c) more than 6 kg f
(d) may be more or less then 6 kg f

68. A particle moves so that its acceleration is always twice its velocity. If its initial velocity is 0.1 ms^{-1}, its velocity after it has gone 0.1 m is

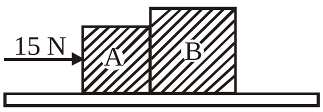
(a) 0.3 ms^{-1} (b) 0.7 ms^{-1}
(c) 1.2 ms^{-1} (d) 3.6 ms^{-1}

69. An object is resting at the bottom of two strings which are inclined at an angle of 120° with each other. Each string can withstand a tension of 20N. The maximum weight of the object that can be supported without breaking the string is

(a) 5 N (b) 10 N
(c) 20 N (d) 40 N

70. On a smooth plane surface (figure) two block A and B are accelerated up by applying a force 15 N on A. If mass of B is twice that of A, the force on B is

(a) 30 N (b) 15 N
(c) 10 N (d) 5 N



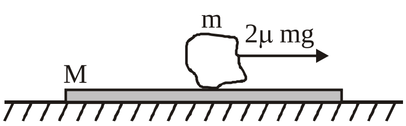
71. A 10 kg stone is suspended with a rope of breaking strength 30 kg-wt. The minimum time in which the stone can be raised through a height 10 m starting from rest is (Take $g = 10 N/kg$)

(a) 0.5 s (b) 1.0 s
(c) $\sqrt{2/3}$ s (d) 2 s

72. A ball of mass 0.4 kg thrown up in air with velocity 30 ms^{-1} reaches the highest point in 2.5 second . The air resistance encountered by the ball during upward motion is

(a) 0.88 N (b) 8800N
(c) 300 dyne (d) 300 N.

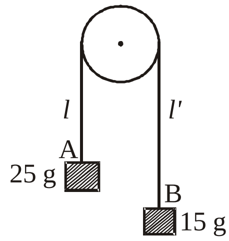
73. A plate of mass M is placed on a horizontal of frictionless surface (see figure), and a body of mass m is placed on this plate. The coefficient of dynamic friction between this body and the plate is μ . If a force 2μ mg is applied to the body of mass m along the horizontal, the acceleration of the plate will be



(a) $\frac{\mu m}{M} g$ (b) $\frac{\mu m}{(M+m)} g$

(c) $\frac{2\mu m}{M} g$ (d) $\frac{2\mu m}{(M+m)} g$.

74. In the system shown in figure, the pulley is smooth and massless, the string has a total mass 5g, and the two suspended blocks have masses 25 g and 15 g. The system is released from state $\ell = 0$ and is studied upto stage $\ell' = 0$ During the process, the acceleration of block A will be



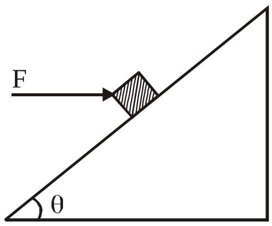
(a) constant at $\frac{g}{9}$

(b) constant at $\frac{g}{4}$

(c) increasing by factor of 3

(d) increasing by factor of 2

75. A horizontal force F is applied on back of mass m placed on a rough inclined plane of inclination θ . The normal reaction N is



(a) $mg\cos\theta$ (b) $mg\sin\theta$
(c) $mg\cos\theta - F\cos\theta$ (d) $mg\cos\theta + F\sin\theta$

76. The coefficient of friction between the rubber tyres and the road way is 0.25. The maximum speed with which a car can be driven round a curve of radius 20 m without skidding is ($g = 9.8 m/s^2$)

(a) 5 m/s (b) 7 m/s
(c) 10 m/s (d) 14 m/s

77. A bucket tied at the end of a 1.6 m long string is whirled in a vertical circle with constant speed. What should be the minimum speed so that the water from the bucket does not spill when the bucket is at the highest position?

(a) 4 m/sec (b) 6.25 m/sec
(c) 16 m/sec (d) None of the above

78. A cane filled with water is revolved in a vertical circle of radius 4 meter and the water just does not fall down. The time period of revolution will be

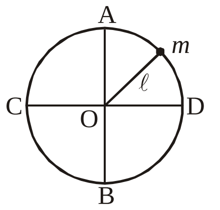
(a) 1 sec (b) 10 sec
(c) 8 sec (d) 4 sec

79. A circular road of radius r in which maximum velocity is v, has angle of banking

(a) $\tan^{-1}\left(\frac{v^2}{rg}\right)$ (b) $\tan^{-1}\left(\frac{rg}{v^2}\right)$

(c) $\tan^{-1}\left(\frac{v}{rg}\right)$ (d) $\tan^{-1}\left(\frac{rg}{v}\right)$

80. A small sphere is attached to a cord and rotates in a vertical circle about a point O. If the average speed of the sphere is increased, the cord is most likely to break at the orientation when the mass is at



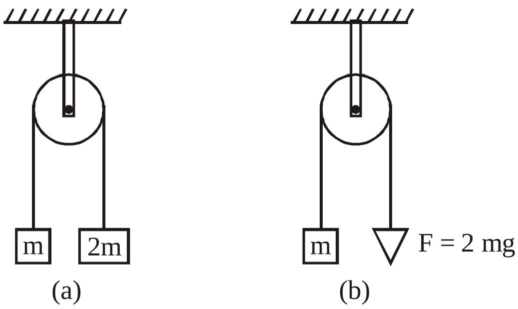
(a) bottom point B (b) the point C
(c) the point D (d) top point A

81. A person with his hand in his pocket is skating on ice at the rate of 10m/s and describes a circle of radius 50 m. What is his inclination to vertical : ($g = 10$ m/sec^2)
(a) $\tan^{-1}(½)$ (b) $\tan^{-1}(1/5)$
(c) $\tan^{-1}(3/5)$ (d) $\tan^{-1}(1/10)$

82. When the road is dry and the coefficient of the friction is μ, the maximum speed of a car in a circular path is 10 ms^{-1}. If the road becomes wet and $\mu' = \frac{\mu}{2}$, what is the maximum speed permitted?
(a) 5 ms^{-1} (b) 10 ms^{-1}
(c) $10\sqrt{2}$ ms^{-1} (d) $5\sqrt{2}$ ms^{-1}

83. The minimum velocity (in ms^{-1}) with which a car driver must traverse a flat curve of radius 150 m and coefficient of friction 0.6 to avoid skidding is
(a) 60 (b) 30
(c) 15 (d) 25

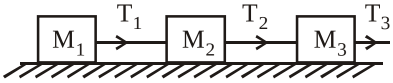
84. Two pulley arrangements of figure given are identical. The mass of the rope is negligible. In fig (a), the mass m is lifted by attaching a mass 2m to the other end of the rope. In fig (b), m is lifted up by pulling the other end of the rope with a constant downward force F = 2mg. The acceleration of m in the two cases are respectively



(a) 3g, g (b) $g/3$, g
(c) $g/3, 2g$ (d) g, $g/3$

85. The linear momentum p of a body moving in one dimension varies with time according to the equating $P = a + bt^2$ where a and b are positive constants. The net force acting on the body is
(a) proportional to t^2
(b) a constant
(c) proportional to t
(d) inversely proportional to t

86. Three blocks of masses m_1, m_2 and m_3 are connected by massless strings, as shown, on a frictionless table. They are pulled with a force $T_3 = 40$ N. If $m_1 = 10$ kg, $m_2 = 6$ kg and $m_3 = 4$kg, the tension T_2 will be



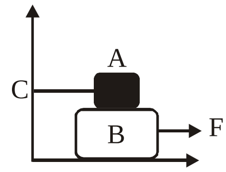
(a) 20 N (b) 40 N
(c) 10 N (d) 32 N

87. In an explosion, a body breaks up into two pieces of unequal masses. In this
(a) both parts will have numerically equal momentum
(b) lighter part will have more momentum
(c) heavier part will have more momentum
(d) both parts will have equal kinetic energy

88. A body of mass 1.0 kg is falling with an acceleration of 10 m/sec^2. Its apparent weight will be ($g = 10$ m/sec^2)
(a) 1.0 kg wt (b) 2.0 kg wt
(c) 0.5 kg wt (d) zero

89. A ball of mass 400 gm is dropped from a height of 5 m. A boy on the ground hits the ball vertically upwards with a bat with an average force of 100 newton so that it attains a vertical height of 20 m. The time for which the ball remains in contact with the bat is ($g = 10$ m/s^2)
(a) 0.12 s (b) 0.08 s
(c) 0.04 s (d) 12 s

90. Block A of weight 100 kg rests on a block B and is tied with horizontal string to the wall at C. Block B is of 200 kg. The coefficient of friction between A and B is 0.25 and that between B and surface is $\frac{1}{3}$. The horizontal force F necessary to move the block B should be ($g = 10$ m/s^2)



(a) 1050 N (b) 1450 N
(c) 1050 N (d) 1250 N

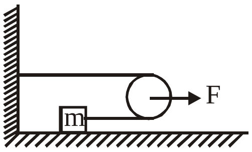
91. An open topped rail road car of mass M has an initial velocity v_0 along a straight horizontal frictionless track. It suddenly starts raising at time t = 0. The rain drops fall vertically with velocity u and add a mass m kg/sec of water. The velocity of car after t second will be (assuming that it is not completely filled with water)
(a) $v_0 + m\frac{u}{M}$ (b) $\frac{mv_0}{M + mt}$
(c) $\frac{Mv_0 + ut}{M + ut}$ (d) $v_0 + \frac{mut}{M + ut}$

92. A ball mass m falls vertically to the ground from a height h_1 and rebounds to a height h_2. The change in momentum of the ball of striking the ground is

(a) $m\sqrt{2}g(h_1+h_2)$ (b) $n\sqrt{2g(m_1+m_2)}$

(c) $mg(h_1-h_2)$ (d) $m(\sqrt{2gh_1}-\sqrt{2gh_2})$

93. In the given figure, the pulley is assumed massless and frictionless. If the friction force on the object of mass m is f, then its acceleration in terms of the force F will be equal to



(a) $(F-f)/m$ (b) $\left(\frac{F}{2}-f\right)/m$

(c) F/m (d) None of these

94. A smooth block is released at rest on a 45° incline and then slides a distance 'd'. The time taken to slide is 'n' times as much to slide on rough incline than on a smooth incline. The coefficient of friction is

(a) $\mu_k = \sqrt{1-\frac{1}{n^2}}$ (b) $\mu_k = 1-\frac{1}{n^2}$

(c) $\mu_s = \sqrt{1-\frac{1}{n^2}}$ (d) $\mu_s = 1-\frac{1}{n^2}$

95. The upper half of an inclined plane with inclination ϕ is perfectly smooth while the lower half is rough. A body starting from rest at the top will again come to rest at the bottom if the coefficient of friction for the lower half is given by

(a) 2 cos ϕ (b) 2 sin ϕ

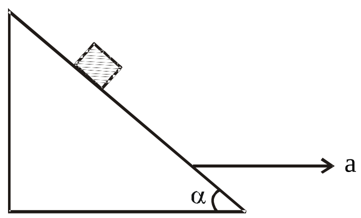
(c) tan ϕ (d) 2 tan ϕ

96. A particle of mass 0.3 kg subject to a force $F = -kx$ with k = 15 N/m . What will be its initial acceleration if it is released from a point 20 cm away from the origin ?

(a) 15 m/s^2 (b) 3 m/s^2

(c) 10 m/s^2 (d) 5 m/s^2

97. A block is kept on a frictionless inclined surface with angle of inclination 'α'. The incline is given an acceleration 'a' to keep the block stationary. Then a is equal to



(a) g cosec α (b) g / tan α

(c) g tan α (d) g

98. Consider a car moving on a straight road with a speed of 100 m/s . The distance at which car can be stopped is [$\mu_k = 0.5$]

(a) 1000 m (b) 800 m

(c) 400 m (d) 100 m

99. A round uniform body of radius R, mass M and moment of inertia I rolls down (without slipping) an inclined plane making an angle θ with the horizontal. Then its acceleration is

(a) $\frac{g\sin\theta}{1-MR^2/I}$ (b) $\frac{g\sin\theta}{1+I/MR^2}$

(c) $\frac{g\sin\theta}{1+MR^2/I}$ (d) $\frac{g\sin\theta}{1-I/MR^2}$

100. A block of mass m is connected to another block of mass M by a spring (massless) of spring constant k. The block are kept on a smooth horizontal plane. Initially the blocks are at rest and the spring is unstretched. Then a constant force F starts acting on the block of mass M to pull it. Find the force of the block of mass m.

(a) $\frac{MF}{(m+M)}$ (b) $\frac{mF}{M}$

(c) $\frac{(M+m)F}{m}$ (d) $\frac{mF}{(m+M)}$

101. A body of mass m = 3.513 kg is moving along the x-axis with a speed of 5.00 ms^{-1}. The magnitude of its momentum is recorded as

(a) 17.6 kg ms^{-1} (b) 17.565 kg ms^{-1}

(c) 17.56 kg ms^{-1} (d) 17.57 kg ms^{-1}

Directions for Qs. (102 to 109) : Read the following passage(s) carefully and answer the questions that follows:

PASSAGE I

A student performs a series of experiments to determine the coefficient of static friction and the coefficient of kinetic friction between a large crate and the floor. The magnitude of the force of static friction is always less than or equal to $\mu_s N$. where μ_s denotes the coefficient of static friction, and *N* denotes the normal force exerted by the floor on the crate:

$$f_s \le \mu_s N$$

Static friction exists only when the crate is not sliding across the floor.

The force of kinetic friction is given by $f_k = \mu_k N$

where μ_k denotes the coefficient of kinetic friction. Kinetic friction exists only when the crate is sliding across the floor.

The create has mass 100 kg. In this situation, the normal force points upward.

Experiment 1

The student pushes horizontally (rightward) on the crate. and gradually increases the strength of this push force. The create does not begin to move until the push force reaches 400 N.

Experiment 2

The student applies a constant horizontal (rightward) push force for 1.0 seconds and measures how far the crate moves during that time interval. In each trial. the crate starts at rest, and the student stops pushing after the 1.0-second interval. The following table summarizes the results.

Trial	*Push force (N)*	*Distance (m)*
1	500	1.5
2	600	1.5
3	700	2.0

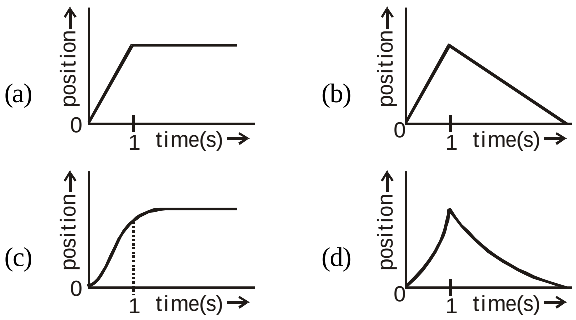
102. The coefficient of static friction between the crate and floor is approximately:
(a) 0.25 (b) 0.40
(c) 0.40 (d) 4.0

103. In experiment 1. when the rightward push force was 50 N. the crate didn't move. Why didn't it move?
(a) The push force was weaker than the frictional force on the crate.
(b) The push force had the same strength as the gravitational force on the crate.
(c) The push force was weaker than the frictional force on the crate.
(d) The push force had the same strength as the frictional force on the crate.

104. The coefficient of kinetic friction between the crate and the floor is approximately:
(a) 0.20 (b) 0.30
(c) 0.40 (d) 0.50

105. In trial 3, what is the crate's speed at the moment the student stops pushing it?
(a) 1.0 m/s (b) 2.0 m/s
(c) 3.0 m/s (d) 4.0 m/s

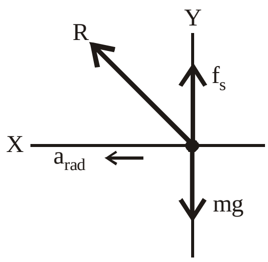
106. For trial 3, which of the following graphs best shows the positions of the crate as a function of time? The student first starts pushing the crate at time t = 0.

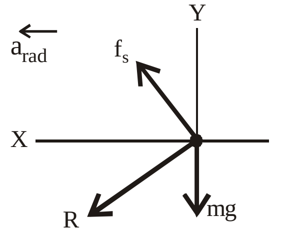


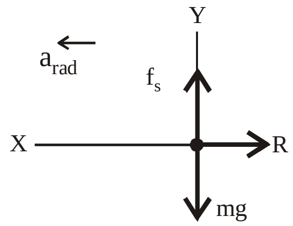
PASSAGE 2

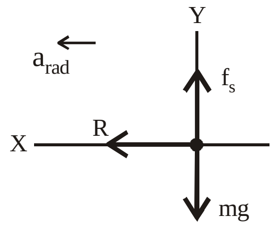
On the ride "spindletop" at the amusement park Six Flags Over Texas, people stood against the inner wall of a hallow vertical cylinder with radius 2.5 m. The cylinder started to rotate, and when it reached a constant rotation rate of 0.60 rev/s, the floor on which people were standing dropped about 0.5 m. The people remained pinned against the wall.

107. Point out the best possible force diagram for a person on this side after the floor has dropped (f_s is force of friction and R is Reaction)

(a)


(b)


(c)


(d)


108. What minimum coefficient of static friction is required if the person on the ride is not to slide downward to the new position of the floor?
(a) 0.28 (b) 0.50
(c) 0.39 (d) 0.01

109. Mark the correct statement/s
(a) Under same conditions a heavy man will fall down
(b) Answer of the above question will depend upon mass of the passenger
(c) Answer of the above question is independent of mass of passenger
(d) For smaller μ_s larger v must be kept to maintain the man in equilibrium

Directions for Qs. (110 to 112) : Each question contains STATEMENT-1 and STATEMENT-2. Choose the correct answer (ONLY ONE option is correct) from the following-
(a) Statement -1 is false, Statement-2 is true
(b) Statement -1 is true, Statement-2 is true; Statement -2 is a correct explanation for Statement-1
(c) Statement -1 is true, Statement-2 is true; Statement -2 is not a correct explanation for Statement-1
(d) Statement -1 is true, Statement-2 is false

110. **Statement -1** : The work done in bringing a body down from the top to the base along a frictionless incline plane is the same as the work done in bringing it down the vartical side.
Statement -2 : The gravitational force on the body along the inclined plane is the same as that along the vertical side.

111. **Statement -1** : On a rainy day, it is difficult to drive a car or bus at high speed.

Statement -2 : The value of coefficient of friction is lowered due to wetting of the surface.

112. **Statement -1** : The two bodies of masses *M* and *m* (*M* > *m*) are allowed to fall from the same height if the air resistance for each be the same then both the bodies will reach the earth simultaneously.

Statement -2 : For same air resistance, acceleration of both the bodies will be same.

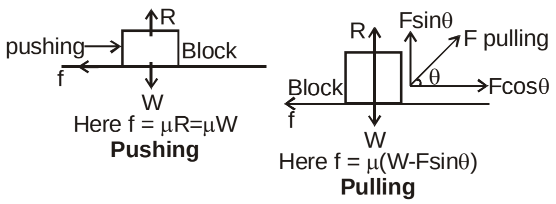
Hints & Solutions

Exercise 5.1

1. (c) When the swimmer push some water in backward direction, then he get some momentum in forward direction from water & starts to swim. This is according to Newton third Law. (action-reaction force)
2. (d) Newton' first law of motion is also called law of inertia as it defines inertia.
3. (c) The body will continue accelerating until the resultant force acting on the body becomes zero.
4. (b) See Newton's first law of motion according to which "the tendency of a body to continue in its state of rest or of uniform motion in a straight line, is called law of inertia".
5. (c) He can come at shore by making use of Newton's third law. In this case man push the ice backward & ice reacts back to the man in forward direction due to friction between ice & man. If friction is very small between him & the ice, then he come out from this pond only by taking very small steps.
6. (c) The gun applied a force F_{12} on the bullet in forward direction & according to Newton's third law bullet applies a reaction force on gun F_{21} in backward direction. But the recoil speed of gun is very low in comparison to bullet due to large mass.
7. (b) $F = \frac{dp}{dt}$
9. (b) When jet plane flies, it ejects gases in back ward direction at very high velocity. From Newton's third law, these gases provides the momentum to jet plane in forward direction plus compensates the force of gravity.
10. (c) From Newton's second law if $\Sigma F_i = 0$ then the body is in translational equilibrium.

Exercise 5.2

1. (a) When tension in the cable is equal to the weight of cable, the system is in equilibrium. It means the system is at rest or moving with uniform velocity.
2. (b) When elevator goes up, then equation of motion is
   $R - mg = ma \Rightarrow R = m(g+a)$ i.e.,
   apparent weight > real weight
   When elevator goes down, then equation of motion is
   $mg - R = ma \Rightarrow R = m(g-a)$ i.e.,
   apparent weight < real weight
3. (d) An inertial frame of reference is one in which law of inertia holds good i.e. Newton's laws of motion are applicable equally. If earth is revolving around the sun or earth is rotating about its axis, then forces are acting on the earth and hence there will be acceleration of earth due to these forces. That is why earth can not be an inertial frame of reference.
4. (c) When an elevator cabin falls down, it is accelerated down with respect to earth i.e. man standing on earth.
5. (d) The observations will be true if both the frames are inertial or non inertial.
6. (d) In this case
   $R = mg \Rightarrow a = 0$
   So elevator may at rest or in uniform motion (either up or down)
7. (c) R = apparent weight = $m(g-a)$
8. (d) R = apparent weight = $m(g+a)$
9. (b) By spitting or sneezing we get a momentum in opposite direction which will help us in getting off the plane. In all other cases we will slip on ice as there is no friction.
10. (b)



Since we required less force in pulling in comparison of pushing it. Hence pulling is easier then pushing.

Exercise 5.3

1. (b) From Newton's second law, the total external applied force on the body is equal to the time rate change of momentum of the body.

$$F = \frac{dp}{dt} = \frac{m(v_2 - v_1)}{t} \quad \text{here } v_1 = 0, v_2 = v$$

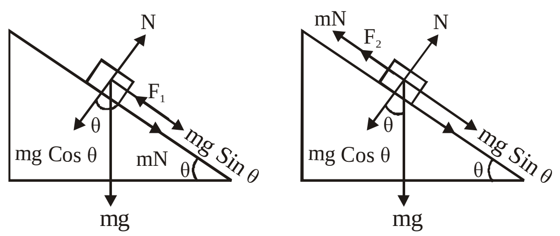
$$\text{so } F = \frac{(mv)}{1/n} = mvn$$

2. (b) It works on the principle of conservation of linear momentum.
3. (a) For a given mass $P \propto V$. If the momentum is constant then its velocity must be constant.
4. (d) $m_G v_G = m_B v_B \rightarrow v_B = \frac{m_G v_G}{m_B} = \frac{1 \times 5}{10 \times 10^{-3}}$

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

Exercise 5.4

1. (d) $\mu_{static} > \mu_{kinetic} > \mu_{rolling}$
2. (a) Static friction is a self adjusting force in magnitude and direction.
3. (d) In case (a) In case (b)



$mg \sin \theta = F_1 - \mu N$

$N = mg \cos \theta$

$\therefore \; mg \sin \theta + \mu \, mg \cos \theta = F_1$

In second case (b)

$\mu N + F_2 = mg \sin \theta$

$\mu \, mg \cos \theta - F_2 = mg \sin \theta$

or $F_2 = mg \sin \theta - \mu mg \cos \theta$

but $F_1 = 2F_2$

therefore $mg \sin \theta + \mu \, mg \cos \theta$

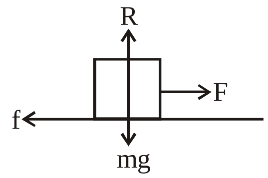
$= 2(mg \sin \theta - \mu \, mg \cos \theta)$

$mg \sin \theta = 3 \mu \, mg \cos \theta$

or $\tan \theta = 3\mu$ or $\theta = \tan^{-1}(3\mu)$

4. (c) $\mu_s > \mu_k > \mu_r$

5. (c)



So equation of motion is $F - f = ma$

where $f = \mu R = \mu Mg = \mu \times 30 \times 9.8 = 294\mu$

Since initial velocity of the body is zero & its velocity increases from zero to 4 m/sec in 2 seconds, so acceleration of the body is

$v = u + at$

$\Rightarrow 4 = 0 + a \times 2$ or $a = 2 \text{ m/sec}^2$

So $F - f = 30 \times 2$

$\Rightarrow 200 - \mu \times 294 = 60$

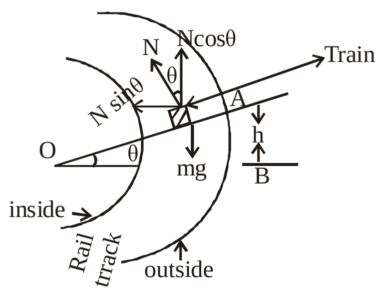
$$\Rightarrow \mu = \frac{140}{294} = 0.476$$

6. (c) θ = Angle of repose $\therefore \; \mu = \tan \theta$.
7. (c) When the men push the rough surface on walking, then surface (from Newton' third Law) applies reaction force in forward direction. It occurs because there is friction between men & surface. If surface is frictionless (such as ice), then it is very difficult to move on it.
8. (d) When brakes are on, the wheels of the cycle will slide on the road instead of rolling there. It means the sliding friction will come into play instead of rolling friction. The value of sliding friction is more than that of rolling friction.

Exercise 5.5

1. (a) If the outside rail is h units higher than inside of rail track as shown in figure then

$N \cos \theta = mg$....................(1)



$$N \sin \theta = \frac{mv^2}{r} \text{ ....(ii)}$$

$$\& \; \tan \theta = \frac{v^2}{rg} \text{ ....(iii)}$$

Where θ is angle of banking of rail track, N is normal reaction exerted by rail track on rail.

It is clear from the equation (i) & (ii) that $N\cos\theta$ balance the weight of the train & $N\sin\theta$ provide the necessary centripetal force to turn.

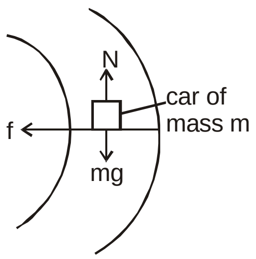
If width of track is ℓ (OB) & h (AB) be height of outside of track from the inside, then

$$\tan\theta = \frac{h}{\ell} = \frac{v^2}{rg} \text{ or } h = \frac{v^2\ell}{rg} \text{ ....(iv)}$$

So it is clear from the above analysis that if we increase the height of track from inside by h metre then resultant force on rail is provided by railway track & whose direction is inwards.

2. (b) It means that car which is moving on a horizontal road & the necessary centripetal force, which is provided by friction (between car & road) is not sufficient.

If μ is friction between car and road, then max speed of safely turn on horizontal road is determined from figure.



$N = mg$ ...(i)

$$f = \frac{mv^2}{r} \text{ ...(ii)}$$

Where f is frictional force between road & car, N is the normal reaction exerted by road on the car. We know that

$f = \mu_s N = \mu_s mg$ ......(iii)

where μ_s is static friction

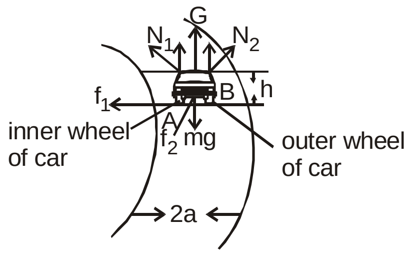
so from eq (ii) & (iii) we have

$$\frac{mv^2}{r} \le \mu_s mg \Rightarrow v^2 \le \mu_s rg \text{ or } v \le \sqrt{\mu_s rg}$$

& $v_{max} = \sqrt{\mu_s rg}$

If the speed of car is greater than v_{max} at that road, then it will be thrown out from road i.e., skidding.

4. (a) The car over turn, when reaction on inner wheel of car is zero, i.e., first the inner wheel of car leaves the ground (where G is C.G of car, h is height of C.G from the ground, f_1 & f_2 are frictional force exerted by ground on inner & outer wheel respectively). The max. speed for no over turning is



$$v_{max} = \sqrt{\frac{gra}{h}}$$

where r is radius of the path followed by car for turn & 2a is distance between two wheels of car (i.e., AB)

6. (b) $\vec{p}_B - \vec{p}_A = m(\vec{v}_B - \vec{v}_A) = mv(\hat{j} + \hat{j})$

$$= 2mv\hat{j} = 2 \text{ kg m/s} \quad \text{....(i)}$$

$$\vec{F}_B - \vec{F}_A = \frac{mv^2}{R}(-\hat{i}) - \frac{mv^2}{R}(+\hat{i})$$

$$= \frac{2mv^2}{R}(-\hat{i}) = 8\,N \quad \text{.....(ii)}$$

Divide (ii) by (i), $\frac{v}{R} = \omega = 4$ rad/s.

7. (b) Due to centrifugal force, the inner wheel will be left up when car is taking a circular turn. Due to this, the reaction on outer wheel is more than that on inner wheel.

8. (a) Here, $u = 10\sqrt{3}$ m/s, t = ? ; $\theta = 30^o$

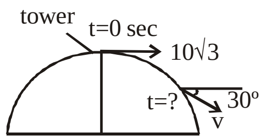
At t = 0, the vertical component of velocity is zero, hence horizontal component of velocity at t = 0 is $10\sqrt{3}$ m/sec

At time t, $v \sin 30^o = 0 + gt$ & $v \cos 30^o = 10\sqrt{3}$

or $\tan\theta = \frac{gt}{v}$

$\therefore gt = u\tan\theta = 10\sqrt{3}\tan 30^o = 10$

t = 10/g = 10/10 = 1 sec.



9. (d) Centripetal acceleration = acceleration due to gravity

$$\frac{v^2}{R} = g \text{ or } v = \sqrt{Rg}$$

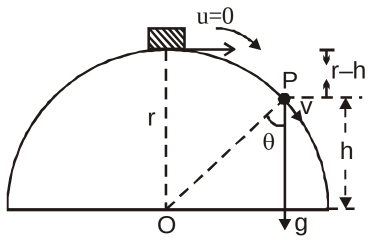
10. (d) $\frac{1}{2}mv^2 = mg\ell$ or $v = \sqrt{(2g\ell)}$

11. (a) The velocity should be such that the centripetal acceleration is equal to the acceleration due to gravity

$$\frac{v^2}{R} = g \text{ or } v = \sqrt{gR}$$

12. (b) $\frac{mv^2}{r} = mg \text{ or } v = \sqrt{gr}$

13. (b) See fig. The body will lose contact when centripetal acceleration becomes equal to the component of acceleration due to gravity along the radius.



Velocity at P, $v = \sqrt{2g(r-h)}$ $(\because \quad v^2 - u^2 = 2gx)$

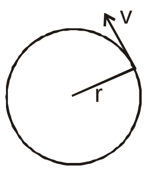
Centripetal acceleration will be v^2/r. It should be equal to the component of g along PO. Hence

$$\frac{v^2}{r} = g\cos\theta \text{ or } \frac{2g(r-h)}{r} = g \times \frac{h}{r}$$

Solving we get, $h = \left(\frac{2r}{3}\right)$

14. (b) Let particle of mass m move in circle of radius r with uniform speed v. Then L is defined as

$$L = mvr \text{ or } \frac{1}{2}mv^2 = \frac{L^2}{2mr^2}$$



15. (b) Centripetal acceleration = v^2/r. It is perpendicular to the increase in speed a which is tangential.

$$\therefore \text{ Resultant acceleration} = \sqrt{\left\{\left(\frac{v^2}{r}\right)^2 + (a^2)\right\}}$$

16. (b) Thrust = weight – centripetal force

17. (b) $\mu mg = mv^2/r$ or $v = \sqrt{\mu g r}$

or $v = \sqrt{(0.25 \times 9.8 \times 20)} = 7 \text{ m/s}$

18. (a) Since water does not fall down, therefore the velocity of revolution should be just sufficient to provide centripetal acceleration at the top of vertical circle. So,

$$v = \sqrt{(gr)} = \sqrt{\{10 \times (1.6)\}} = \sqrt{(16)} = 4 \text{ m/sec.}$$

19. (d) The speed at the highest point must be $v \geq \sqrt{rg}$

Now $v = r\omega = r(2\pi/T)$

$$\therefore r(2\pi/T) \geq \sqrt{rg} \text{ or } T \leq \frac{2\pi r}{\sqrt{rg}} \leq 2\pi\sqrt{\left(\frac{r}{g}\right)}$$

$$\therefore T = 2\pi\sqrt{\left(\frac{4}{9.8}\right)} = 4\,\text{sec}$$

20. (b) $\tan\theta = \frac{v^2}{rg} = \left(\frac{72 \times 1000}{3600}\right)^2 / 20 \times 10 = 2$

21. (a) Since kinetic energy $K = \frac{1}{2}mv^2 = as^2$ (given)

so centripetal force $F_C = \frac{mv^2}{R} = \frac{2as^2}{R}$

22. (d) $\tan\theta = v^2/rg$, $\tan\theta = H/1.5$, $r = 200$ m, $b = 1.5$ m
$v = 36$ km/hour $= 36 \times (5/18) = 10$ m/s.
Putting these values, we get $H = 0.075$ m.

23. (c) The tension T_1 at the topmost point is given by

$$T_1 = \frac{mv_1^2}{20} - mg$$

Centrifugal force acting outward while weight acting downward.

The tension T_2 at the lowest point $T_2 = \frac{mv_2^2}{20} + mg$

Centrifugal force and weight (both) acting downward

$$T_2 - T_1 = \frac{mv_2^2 - mv_1^2}{20} + 2mg$$

$$v_1^2 = v_2^2 - 2gh \text{ or } v_2^2 - v_1^2 = 2g(40) = 80g$$

$$\therefore T_2 - T_1 = \frac{80mg}{20} + 2mg = 6mg$$

24. (a) The velocity at the lowest point is given by $v = \sqrt{(2gr)}$

Further, $T - mg = \frac{mv^2}{r}$ (at lowest point)

$$\therefore T = mg + \frac{mv^2}{r} = mg + \frac{m(2gr)}{r}$$

$$= mg + 2mg = 3mg$$

25. (a) There is no change in the angular velocity, when speed is constant.

Exercise 1 : NCERT Based Questions

1. Object with smaller mass.
2. At the pole
3. Yes
4. To help in providing centripetal force needed for motion of vehicles on the curved road.
5. 10 kg-wt.
6. As the dynamic friction is less than the force of limiting friction.
7. 30°.
16. 3.2 m/s^2
17. – 0.99 m/s zero

18.	(c)	19.	(b)	20.	(b)
21.	(d)	22.	(a)	23.	(c)
24.	(a)	25.	(a)		

Exercise 2 : PAST Competition MCQs

1. (c) $F = \dfrac{m(v-u)}{t} = \dfrac{0.15(0-20)}{0.1} = 30\text{ N}$

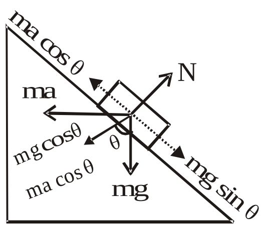
2. (a) $N = m\,a \sin\theta + mg\cos\theta$ ......(1)

also $m\,g \sin\theta = m\,a\cos\theta$ ......(2)

from (2) $a = g\tan\theta$

$\therefore N = mg\dfrac{\sin^2\theta}{\cos\theta} + mg\cos\theta,$

or $N = \dfrac{mg}{\cos\theta}$



3. (a) $m_B g = \mu_s m_A g \quad \{\because m_A g = \mu_s m_A g\}$

$\Rightarrow m_B = \mu_s m_A$

or $m_B = 0.2 \times 2 = 0.4$ kg

4. (c) $\vec{F} = 6\,\hat{i} - 8\,\hat{j} + 10\,\hat{k},$

$|F| = \sqrt{36+64+100} = 10\sqrt{2}$ N $\left(\because F = \sqrt{F_x^2 + F_y^2 + F_z^2}\right)$

$a = 1$ ms^{-2}

$\because F = ma$

$\therefore \quad m = \dfrac{10\sqrt{2}}{1} = 10\sqrt{2}$ kg

5. (d) Frictional force on the box $f = \mu mg$

$\therefore$ Acceleration in the box

$a = \mu g = 5$ ms^{-2}

$v^2 = u^2 + 2as$

$\Rightarrow \quad 0 = 2^2 + 2 \times (5)\,s$

$\Rightarrow s = -\dfrac{2}{5}$ w.r.t. belt

$\Rightarrow$ distance = 0.4 m

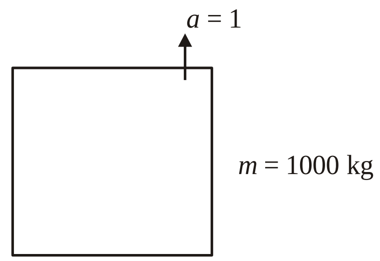
6. (c) Impulse experienced by the body

= change in momentum

= MV – (–MV)

= 2MV.

7. (c)



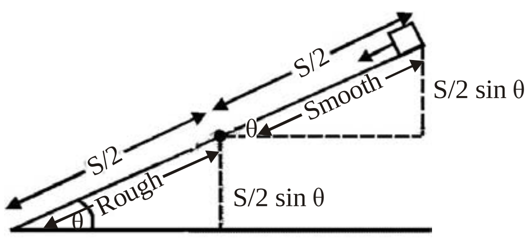
Total mass = (60 + 940) kg = 1000 kg

Let T be the tension in the supporting cable, then

$T - 1000g = 1000 \times 1$

$\Rightarrow T = 1000 \times 11 = 11000$ N

8. (b)



For upper half of inclined plane

$v^2 = u^2 + 2a\,S/2 = 2\,(g\sin\theta)\,S/2 = gS\sin\theta$

For lower half of inclined plane

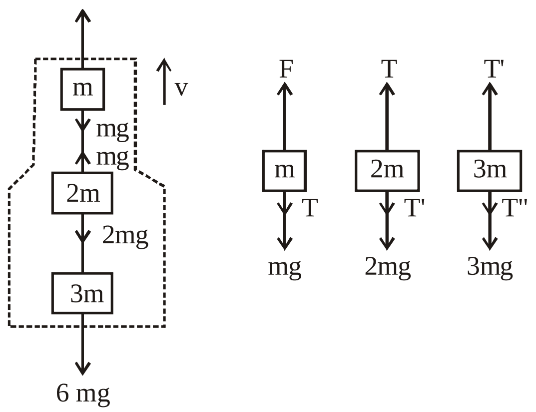
$0 = u^2 + 2\,g\,(\sin\theta - \mu\cos\theta)\,S/2$

$\Rightarrow \; -gS\sin\theta = gS\,(\sin\theta - \mu\cos\theta)$

$\Rightarrow 2\sin\theta = \mu\cos\theta$

$\Rightarrow \mu = \dfrac{2\sin\theta}{\cos\theta} = 2\tan\theta$

9. (d)



From figure

F = 6 mg,

As speed is constant, acceleration a = 0

$\therefore$ 6 mg = 6ma = 0, F = 6 mg

$\therefore$ T = 5 mg , T$'$ = 3 mg

T$''$ = 0

F_{net} on block of mass 2 m

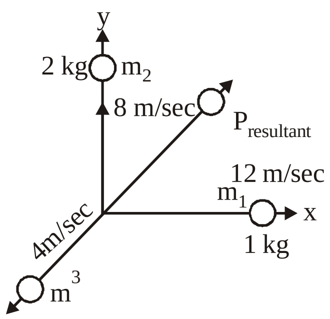
= T – T' – 2 mg = 0

ALTERNATE :

$\because$ v = constant

so, a = 0, Hence, F_{net} = ma = 0

10. (a)



$P_{resultant} = \sqrt{12^2 + 16^2}$

$= \sqrt{144 + 256} = 20$

$m_3 v_3 = 20$ (momentum of third part)

or, $m_3 = \dfrac{20}{4} = 5$ kg

11. (a) Let the initial velocity of the body be v. Hence the final velocity = v/2

Applying $v^2 = u^2 - 2as \Rightarrow \left(\dfrac{v}{2}\right)^2 = v^2 - 2.a.3$

$\Rightarrow a = v^2/8$

In IInd case when the body comes to rest, final velocity

= 0, initial velocity = $\dfrac{v}{2}$

Again, $(0)^2 = \left(\dfrac{v}{2}\right)^2 - 2.\dfrac{v^2}{8}.s$; or s = 1cm

So the extra penetration will be 1 cm.

12. (d) Use $u^2 = 2as$. a is same for both cases.

$s_1 = u^2/2a$; $s_2 = 16u^2/2a = 16s_1 \Rightarrow s_1 : s_2 = 1 : 16$.

13. (b) $a = \dfrac{m_1 - m_2}{m_1 + m_2} g$; $\dfrac{1}{8} = \dfrac{m_1 - m_2}{m_1 + m_2}$

$\Rightarrow m_1 : m_2 = 9 : 7$.

14. (a) Mass $= \dfrac{49}{9.8} = 5$ kg

When lift is moving downward

Apparent weight = 5(9.8 – 5) = 5 × 4.8 = 24 N

15. (d) According to triangle law of forces, the resultant force is zero.

In presence of zero external force, there is no change in velocity.

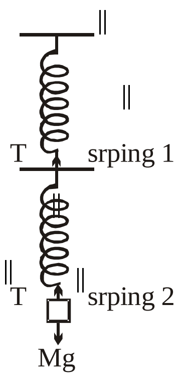
16. (a) $a = \mu g = \dfrac{6}{10}$ [using v = u + at]

$\Rightarrow \mu = \dfrac{6}{10 \times g} = \dfrac{6}{10 \times 10} = 0.06$

17. (a) Thrust = Mass × Acceleration

$= 3.5 \times 10^4 \times 10 = 3.5 \times 10^5$ N

18. (d) Since both springs are very light i.e., mass less. Hence tension T is same in both spring & it is equal to Mg.

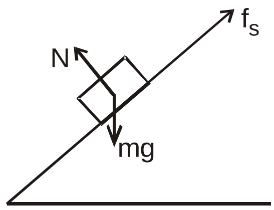


19. (a) mg = μF = 0.2 × 10 = 2N

20. (c) Acceleration $= \left(\dfrac{m_1 - m_2}{m_1 + m_2}\right) g$

$$= \frac{(5-4.8)\times 9.8}{(5+4.8)} \, m/s^2 = 0.2 \; m/s^2$$

21. (c)



mg sinθ $= f_s$ (for body to be at rest)

$\Rightarrow m \times 10 \times \sin 30° = 10$

$\Rightarrow m = 2.0$ kg

22. (a) We have $\sqrt{\dfrac{2s}{g(\sin\theta - \mu\cos\theta)}} = n\sqrt{\dfrac{2s}{g\sin\theta}}$

$$\frac{2s}{g(\sin\theta - \mu\cos\theta)} = \frac{2s \times n^2}{g\sin\theta}$$

here $\theta = 45^o \Rightarrow \dfrac{1}{1-\mu} = n^2$ or $\mu = (1 - 1/n^2)$

23. (a) $mg \sin\theta = ma$

$\therefore a = g \sin\theta$

where a is along the inclined plane

$\therefore$ vertical component of acceleration is $g \sin^2\theta$

$\therefore$ relative vertical acceleration of A with respect to B is

$g(\sin^2 60 - \sin^2 30] = \dfrac{g}{2} = 4.9$ m/s^2

in vertical direction

24. (c) As their period of revolution is same, so it their angualr speed. Centripetal acceleration is circular path, $a = \omega^2 r \cdot$

Thus, $\dfrac{a_1}{a_2} = \dfrac{\omega^2 r_1}{\omega^2 r_2} = \dfrac{r_1}{r_2}$

25. (d) The force on the pulley by the clamp will balance the resultant of the tension forces acting on the pulley (= mg) and the weight of the pulley and block [= (M + m)g]. Hence force on the pulley by the clamp

$= \sqrt{[\{(M+m)g\}^2 + M^2g^2]}$

$= \sqrt{[(M+m)^2 + M^2]}g$

26. (c) If T is the tension in the string , Then

$T = mg$ (For outer masses)

$2T\cos\theta = \sqrt{2}mg$ (For inner mass)

Eliminating T, we get

$2(mg)\cos\theta = \sqrt{2}mg$

or $\cos\theta = 1/\sqrt{2} \Rightarrow \theta = 45°$

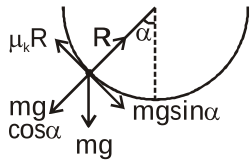
27. (a) From F.B.D of insect

$f = mg \sin\alpha \le \mu_k R$

For max, value of α

$f_{max} = \mu_k R = mg \sin\alpha$ & $R = mg\cos\alpha$

$\Rightarrow \cot\alpha = \dfrac{1}{\mu_k} = 3 \quad (\because \mu_k = 1/3)$



Alternatively :

As is clear from Fig.

$F = mg \sin\alpha$, $R = mg\cos\alpha$

$\dfrac{F}{R} = \tan\alpha$ i.e. $\mu = \tan\alpha = \dfrac{1}{3}$

$\therefore \cot\alpha = 3$

28. (d) Balancing vertical forces, we have

$N = F\sin 60° + mg$

For the block not to move, we must have

$F\cos 60° = \mu N$

i.e., $F\cos 60° = \mu(F\sin 60° + mg)$

$$F\left(\frac{1}{2}\right) = \frac{1}{2\sqrt{3}}\left[F\left(\frac{\sqrt{3}}{2}\right) + (2\sqrt{3})(10)N\right]$$

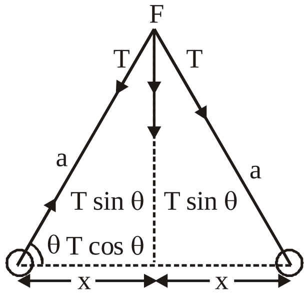
or $F\left(\dfrac{1}{2} - \dfrac{1}{4}\right) = 10N$

or $F = 4 \times 10N = 40N$

29. (b) The acceleration of mass m is due to the force T cos θ

$\therefore T\cos\theta = ma$

$\Rightarrow a = \dfrac{T\cos\theta}{m}$



Also, $F = 2T\sin\theta$

$\Rightarrow \quad T = \dfrac{F}{2\sin\theta}$

From (i) and (ii)

$$a = \left(\frac{F}{2\sin\theta}\right)\frac{\cos\theta}{m} = \frac{F}{2m\tan\theta} = \frac{F}{2m}\frac{x}{\sqrt{a^2 - x^2}}$$

$$\left[\because \tan\theta = \frac{\sqrt{a^2 - x^2}}{x}\right]$$

30. (c) By equilibrium of mass m,

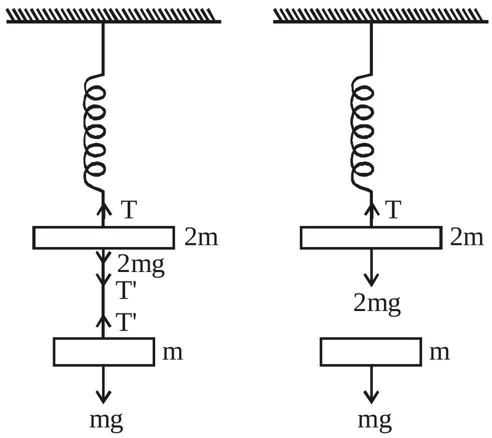
$T' = mg$ ....(i)

By equilibrium of mass 2m,

$T = 2mg - T'$ ....(ii)

From (i) & (ii),

$T = 2mg - mg = mg$ ....(iii)



Situation 1 **Situation 2**

When the string is cut :

For mass m :

$F_{net} = ma_m \Rightarrow mg = ma_m \Rightarrow a_m = g$

For mass 2m :

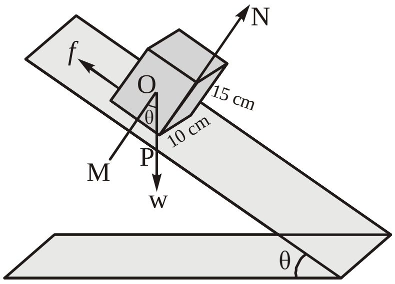
$F_{net} = 2ma_{2m} \Rightarrow 2mg - T = 2ma_{2m}$

$\Rightarrow 2mg - mg = 2ma_{2m} \Rightarrow a_{2m} = \dfrac{g}{2}$

31. (b) For the block to slide, the angle of inclination should be equal to the angle of repose, i.e.,

$\tan^{-1}\mu = \tan^{-1}\sqrt{3} = 60°$. Therefore, option (a) is wrong.

For the block to topple, the condition of the block will be as shown in the figure.



In ΔPOM,

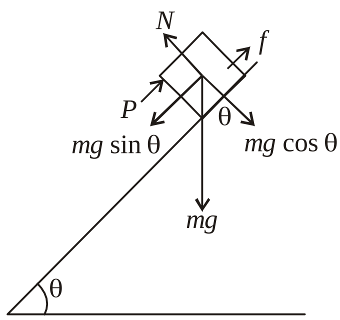
$\theta = \tan\theta = \dfrac{PM}{OM} = \dfrac{5\,\text{cm}}{7.5\,\text{cm}} = \dfrac{2}{3}$

For this, $\theta < 60°$. From this we can conclude that the block will topple at lesser angle of inclination. Thus the block will remain at rest on the plane up to a certain anlgle θ and then it will topple.

32. (a) As $\tan\theta > \mu$, the block has a tendency to move down the incline. Therfore a force *P* is applied upwards along the incline.

Here, at equilibrium $P + f = mg\sin\theta$

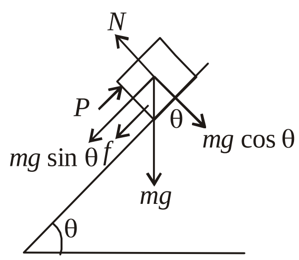
$\Rightarrow f = mg\sin\theta - P$



Now as *P* increases, *f* decreases linearly with respect to *P*.

When $P = mg\sin\theta$, $f = 0$.

When *P* is increased further, the block has a tendency to move upwards along the incline.



Therefore the frictional force acts downwards along the incline.

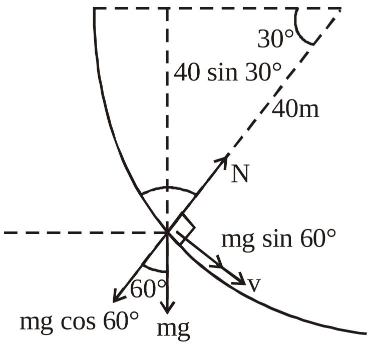
Here, at equilibrium $P = f + mg\sin\theta$

$\therefore \quad f = P - mg\sin\theta$

Now as *P* increases, *f* increases linearly w.r.t *P*.

This is represented by graph (a) .

33. (c)



$$N - mg\cos 60° = \frac{mv^2}{r}$$

$\therefore$ $N = mg\cos 60° + \frac{mv^2}{r}$ ...(1)

Loss in P.E. = mg × 40 sin 30° = 200 J

Work done in over coming friction = 150 J

$\therefore$ K.E. possessed by the particle = 50 J

$\therefore$ $\frac{1}{2}mv^2 = 50J$

$\therefore$ $mv^2 = 100$ J ...(2)

From (1) and (2), $N = 1 \times 10 \times \frac{1}{2} + \frac{100}{40} = 5 + 2.5 = 7.5N$

(a) is the correct option.

34. (a) From (2), $mv^2 = 100$

$\therefore$ $v = 10\ ms^{-1}$

(b) is the correct option.

35. (b) Velocity at the highest point of bob tied to string ℓ_1 is acquired by the bob tied to string ℓ_2 due to elastic head-on collision of equal masses

Therefore $\sqrt{g\ell_1} = \sqrt{5g\ell_2}$

$\therefore \frac{\ell_1}{\ell_2} = 5$

Exercise 3 : Conceptual & Applied MCQs

1. (b) Here $u = 10\ ms^{-1}$, $v = -2\ ms^{-1}$, $t = 4$ s, a = ?

Using $a = \frac{v-u}{t} = \frac{-2-10}{4} = -3\ m/s^2$

$\therefore$ Force, F = ma = 10×(–3) = –30 N

2. (b) 2 T cos 60° = mg

or T = mg = 2×10 = 20 N.

3. (c) Acceleration, $a = \frac{v-u}{t} = \frac{0-6}{3} = -2\ ms^{-2}$

Force = m×a = 4×2 = 8 N

4. (c) If k is the spring factor, then P.E. of the spring compressed by distance x $\left(= \frac{1}{2}kx^2\right)$ will equal to gain in P.E. of the dart (= mgh) i.e. $\frac{1}{2}kx^2 = mgh$

$\therefore$ $\frac{1}{2}k(4)^2 = 16 \times g \times 200$ ....(i)

and $\frac{1}{2}k(6)^2 = 16 \times g \times h$ ...(ii)

On solving, (i) and (ii), we get h = 450 cm = 4.5 m.

5. (d) Here m = 0.5 kg ; u = – 10 m/s ; t = 1/50 s ; v = + 15 ms^{-1}

Force = m (v– u)/t = 0.5 (10 + 15) × 50 = 625 N

6. (b) As, $(1/2)m\,v^2 = Fs$

So $\frac{1}{2}m(30)^2 = F \times 4$ and $\frac{1}{2}m(60)^2 = F \times s$

$\therefore$ $s/4 = (60)^2/(30)^2 = 4$ or $s = 4 \times 4 = 16$ m.

7. (d) Let n be the mass per unit length of rope. Therefore, mass of rope = nL.

Acceleration in the rope due to force F will be a = F/nL.

Mass of rope of length $(L - \ell)$ will be $n(L - \ell)$.

Therefore, tension in the rope of length $(L - \ell)$, is equal to pulling force on it

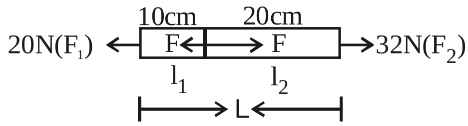
$= n(L - \ell)\,a = n(L - \ell) \times F/nL = F(1 - \ell/L)$

8. (a) Force required $= \frac{\text{change in momentum}}{\text{time taken}}$

$$= \frac{(50 \times 10^{-3} \times 30) \times 400 - (5 \times 0)}{60} = 10\ N$$

9. (a) Change in momentum = Force × time = Area which the force-time curve encloses with time axis.

10. (b)



It is clear $F_2 > F_1$, so rod moves in right direction with an acceleration a, whereas a is given by

$(F_2 – F_1) = mL×a$................(i)

where m is mass of rod per unit length.

Now consider the motion of length l_1 from first end, then

$F – F_1 = ml_1a$..................(ii)

Dividing eq (ii) by (i), we get

$\frac{F - F_1}{F_2 - F_1} = \frac{l_1}{L}$ or $F = (F_2 - F_1) \times \frac{l_1}{L} + F_1$

here $l_1 = 10$ cm., L = 30 cm., $F_1 = 20$ N, $F_2 = 32$N

so F = 24 N

11. (a) Let a be the acceleration of mass m_2 in the downward direction. Then

$T - m_2(g/2) = m_1 a$ ....(i)

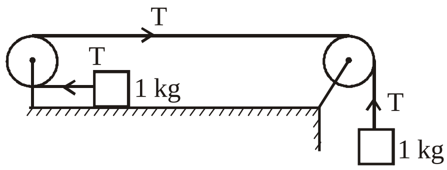
and $m_2 g - T = m_2 a$ ....(ii)

Adding eqs. (1) and (2), we get

$(m_1 + m_2)a = m_2 g - m_2(g/2) = m_2 g/2$

$\therefore$ $a = \frac{m_2 g}{2(m_1 + m_2)}$

12. (d) See fig.



From figure, $1\,g - T = 1\,a$ ...(i)

and $T = 1\,a$ ....(ii)

From eqs. (i) and (ii), we get

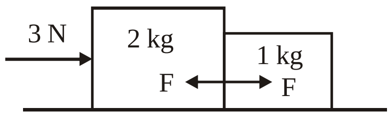
$1g - 1a = 1a$ or $2a = g$

$\therefore\ a = (g/2) = (10/2) = 5\ m/s^2$

So, $T = ma = 1 \times 5 = 5\ N$

13. (b) $R = mg - ma = 0.5 \times 10 - 0.5 \times 2 = 5 - 1 = 4\ N$

14. (c) See fig. Let F be the force between the blocks and a their common acceleration. Then for 2 kg block,

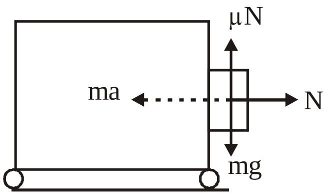


$3 - F = 2\,a$ ...(1)

for 1 kg block, $F = 1 \times a = a$ ....(2)

$\therefore\ 3 - F = 2\,F$ or $3\,F = 3$ or $F = 1$ newton

15. (b) See fig.



If a = acceleration of the cart, then $N = ma$

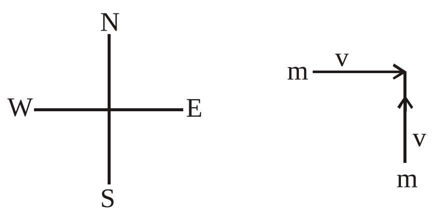
$\therefore\ \mu N = mg$ or $\mu\, ma = mg$ or $a = g/\mu$

16. (b) Initial thrust on the rocket $= \dfrac{\Delta m}{\Delta t} v_{rel}$

$= 500 \times 1 = 500\ N$

where $\dfrac{\Delta m}{\Delta t}$ = rate of ejection of fuel.

17. (c) $p_1 = mv$ northwards, $p_2 = mv$ eastwards



Let p = momentum after collision. Then,

$\vec{p} = \vec{p}_1 + \vec{p}_2$ or $|\vec{p}| = \sqrt{(mv)^2 + (mv)^2}$

$2mv' = mv\sqrt{2}$ or $v' = \dfrac{v}{\sqrt{2}}$ m/sec

18. (c) Applying law of conservation of linear momentum

$m_1v_1 + m_2v_2 = 0,\ \dfrac{m_1}{m_2} = -\dfrac{v_2}{v_1}$ or $\dfrac{v_1}{v_2} = -\dfrac{m_2}{m_1}$

19. (c) Displacement of the man on the trolley

$= 1 \times 4 = 4m$

Now applying conservation of linear momentum

$80 \times 1 + 400\,v = 0$ or $v = -\dfrac{1}{5}$ m/sec.

The distance travelled by the trolley

$= -0.2 \times 4 = -0.8\ m.$

(In opposite direction to the man.)

Thus, the relative displacement of the man with the ground $= (4 - 0.8) = 3.2\ m.$

20. (c) In presence of friction $a = (g \sin\theta - \mu g \cos\theta)$

$\therefore$ Time taken to slide down the plane

$$t_1 = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2s}{g(\sin\theta - \mu\cos\theta)}}$$

In absence of friction $t_2 = \sqrt{\dfrac{2s}{g\sin\theta}}$

Given : $t_1 = 2t_2$

$\therefore\ t_1^2 = 4t_2^2$ or $\dfrac{2s}{g(\sin\theta - \mu\cos\theta)} = \dfrac{2s \times 4}{g\sin\theta}$

$\sin\theta = 4\sin\theta - 4\mu\cos\theta$

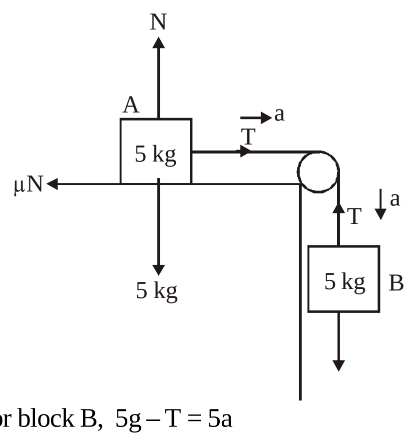
$\mu = \dfrac{3}{4}\tan\theta = \dfrac{3}{4} = 0.75$ (since $\theta = 45°$)

21. (a) $F = \dfrac{mv - (-mv)}{t} = \dfrac{2mv}{t} = \dfrac{2 \times 0.5 \times 2}{10^{-3}} = 2 \times 10^3\,N$

22. (b) $T = m(g + a) = 100(9.8 + 0) = 980\ N$

23. (c) $T = m(g+a) = 100(9.8+1) = 1080N$

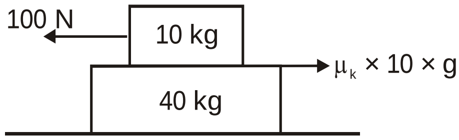
24. (c) For block A, $T - \mu N = 5a$ and $N = 5g$



for block B, $5g - T = 5a$

$\Rightarrow T = 36.75N,\ a = 2.45\ m/sec^2$

25. (a) Force on the slab (m = 40 kg) = reaction of frictional force on the upper block



$\therefore$ $40a = \mu_k \times 10 \times g$ or $a = 0.98$ m/sec^2

26. (b) Considering the equilibrium of B

$-m_Bg + T = m_Ba$

Since the block A slides down with constant speed.

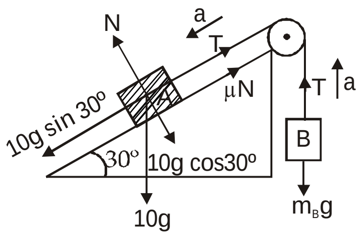
a = 0.

Therefore $T = m_Bg$

Considering the equilibrium of A, we get

$10a = 10g \sin 30° - T - \mu N$

where $N = 10g \cos 30°$



$$\therefore\ 10a = \frac{10}{2}g - T - \mu \times 10g\cos 30°$$

but a = 0, $T = m_Bg$

$$0 = 5g - m_Bg - \frac{0.2\sqrt{3}}{2} \times 10 \times g$$

$\Rightarrow$ $m_B = 3.268 \approx 3.3$ kg

27. (d) $mv_1 + 3mv_2 = 0$ or $\frac{v_1}{v_2} = -3$

Now $\frac{1}{2}mv_1^2 = F.S_1 = \mu.mg.S_1$

$$\frac{1}{2}(3m)v_2^2 = F.S_2 = \mu.3mg.S_2$$

or $\frac{S_1}{S_2} = \frac{v_1^2}{v_2^2} = \frac{9}{1}$

28. (b) m = 10 kg, $x = (t^3 - 2t - 10)$ m

$$\frac{dx}{dt} = v = 3t^2 - 2 \qquad \frac{d^2x}{dt^2} = a = 6t$$

At the end of 4 seconds, a = 6 × 4 = 24 m/s^2

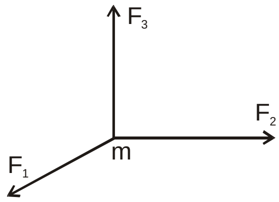
F = ma = 10 × 24 = 240 N

29. (a) Impulse = change in momentum = $m\vec{v}_2 - m\vec{v}_1$

30. (b) Change in momentum = F × t

= 10 × 10 = 100 Ns or 100 kg. m/s

31. (a)

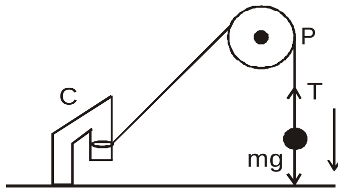


The formula for force is given by $F_1 = ma$

Acceleration of the particle $a = \frac{F_1}{m}$,

because F_1 is equal to the vector sum of F_2 & F_3.

32. (c)



$mg - T = ma$

$$\frac{60 \times 10 - 360}{60} = a$$

$a = 4\ \text{ms}^{-2}$

33. (c) The equations of motion are

$2mg - T = 2ma$

$T - mg = ma \Rightarrow T = 4ma$ & $a = g/3$ so $T = 4mg/3$

If pulley is accelerated upwards with an accleration a, then tension in string is

$$T = \frac{4m}{3}(g + a)$$

34. (b) Mass of over hanging chain $m' = \frac{4}{2} \times (0.6)$kg

Let at the surface PE = 0

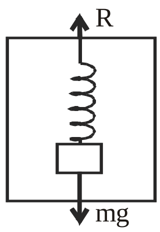
C.M. of hanging part = 0.3 m below the table

$$U_i = -m'gx = -\frac{4}{2} \times 0.6 \times 10 \times 0.30$$

$\Delta U = m'gx = 3.6J$ = Work done in putting the entire chain on the table

35. (a) Let acceleration of lift = a and

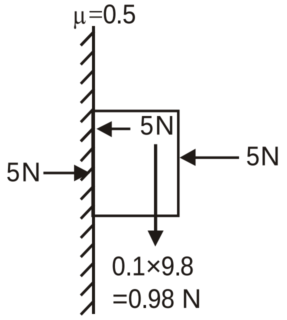
let reaction at spring balance = R



Applying Newton's law

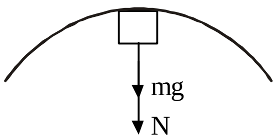
$R - mg = ma \Rightarrow R = m(g+a)$
thus net weight increases,
So reading of spring balance increases.

36. (b) The magnitude of the frictional force f has to balance the weight 0.98 N acting downwards.



Therefore the frictional force = 0.98 N

37. (a) At the highest point of the track, $N + mg = \frac{mv'^2}{r}$



where r is the radius of curvature at that point and v′ is the speed of the block at that point.

Now $N = \frac{mv'^2}{r} - mg$

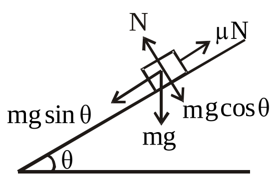
N will be maximum when r is minimum (v′ is the same for all cases). Of the given tracks, (a) has the smallest radius of curvature at the highest point.

38. (a) $S_n = \frac{a}{2}(2n-1)$

$S_{n+1} = \frac{a}{2}(2n+1)$

$\frac{S_n}{S_{n+1}} = \frac{2n-1}{2n+1}$

39. (b) From the F.B.D.
$N = mg\cos\theta$
$F = ma = mg\sin\theta - \mu N$
$\Rightarrow \quad a = g(\sin\theta - \mu\cos\theta)$



Now using, $v^2 - u^2 = 2as$
or, $v^2 = 2 \times g(\sin\theta - \mu\cos\theta)\ell$
(ℓ = length of incline)
or, $v = \sqrt{2g\ell(\sin\theta - \mu\cos\theta)}$

40. (a) Two external forces, F_A and F_B, act on the system and move in opposite direction. Let's arbitrarily assume that the downward direction is positive and that F_A provides downward motion while F_B provides upward motion.
$F_A = (+15\text{ kg})(9.8\text{ m/s}^2) = 147\text{ N}$
and $F_B = (-10\text{ kg})(9.8\text{ m/s}^2) = -98\text{ N}$
$F_{total} = F_A + F_B = 147\text{ N} + (-98\text{ N}) = 49\text{ N}$
The total mass that must be set in motion is
15 kg + 10 kg = 25kg
Since $F_{total} = m_{total}a,\ a = F_{total} / m_{total}$
$= 49\text{ N} / 25\text{ kg} \cong 2\text{ m/s}^2$

41. (a) Momentum is always conserved. Since the skater and snowball are initially at rest, the initial momentum is zero. Therefore, the final momentum after the toss must also be zero.

$P_{skater} + P_{snowball} = 0$

or $m_{skater}v_{skater} + m_{snowball}v_{snowball} = 0$

$v_{skater} = -m_{snowball}v_{snowball} / m_{skater}$

$\frac{= -(0.15\text{kg})(35\text{m/s}) =}{(50\text{kg})} - 0.10\text{m/s}$

The negative sign indicates that the momenta of the skater and the snowball are in opposite directions.

42. (b) Apply Newton's second law
$F_A = F_{AB}$, therefore :
$m_A a_A = (m_A + m_B)a_{AB}$ and $a_{AB} = a_A / 5$
Therefore : $m_A a_A = (m_A + m_B)a_A/5$ which reduces to
$4 m_A = m_B$ or 1 : 4

43. (d) Work is the product of force and distance. The easiest way to calculate the work in this pulley problem is to multiply the net force or the weight *mg* by the distance it is raised: 4 kg x 10 m/s^2 x 5 m = 200 J.

44. (d) **Given :** Mass of rocket (m) = 5000 Kg
Exhaust speed (v) = 800 m/s
Acceleration of rocket (a) = 20 m/s^2
Gravitational acceleration (g) = 10 m/s^2
We know that upward force
F = m (g + a) = 5000 (10 +20)
= 5000 × 30 = 150000 N.
We also know that amount of gas ejected

$$\left(\frac{dm}{dt}\right) = \frac{F}{v} = \frac{150000}{800} = 187.5\text{ kg/s}$$

45. (d) Given $F = 600 - 2\times10^5 t$
The force is zero at time t, given by

$$0 = 600 - 2\times10^5 t$$

$$\Rightarrow \quad t = \frac{600}{2\times10^5} = 3\times10^{-3}\ \text{seconds}$$

$$\therefore \text{ Impulse} = \int_0^t F dt = \int_0^{3\times10^{-3}} (600 - 2\times10^5 t)\, dt$$

$$= \left[600t - \frac{2\times10^5 t^2}{2}\right]_0^{3\times10^{-3}}$$

$$= 600\times3\times10^{-3} - 10^5(3\times10^{-3})^2$$

$$= 1.8 - 0.9 = 0.9\text{Ns}$$

46. (b) $T = m(g+a)$

$48000 = 4000(10+a)$

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

47. (b) $T_1 = m(g+a) = 0.1(10+5) = 1.5\text{N}$

$T_2 = m(g-a) = 0.1(10-5) = 0.5\text{N}$

$\Rightarrow T_1 - T_2 = (1.5-0.5)\text{N} = 1\text{N}$

48. (b) According to law of conservation of momentum,

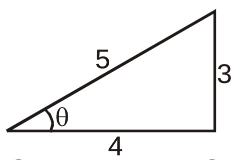
$100v = -\frac{10}{1000}\times10\times800$

ie, $v = 0.8\ \text{ms}^{-1}$.

49. (d) Angle of friction $= \tan^{-1}\mu$

50. (b) $m = \frac{\sqrt{8^2+(-6)^2+(-10)^2}}{1} = 10\sqrt{2}\text{kg}$

51. (d) $\sin\theta = \frac{3}{5}$



$\therefore \tan\theta = \frac{3}{4} \Rightarrow \mu = \tan\theta = \frac{3}{4} = 0.75$

52. (a) Based on Newton's third law of motion.
53. (b) Inertia is resistance to change.
54. (b) The time rate of change of momentum is force.
55. (a) Weight of body = m g = 5 N
56. (d) Limiting friction $= 0.5\times2\times10 = 10\text{N}$

The applied force is less than force of friction, therefore the force of friction is equal to the applied force.

57. (d) Applying law of conservation of momentum

Momentum of bullet = Momentum of sand-bullet system

$$\frac{m}{20}v = \left(m + \frac{m}{20}\right)V = \frac{21}{20}mV$$

58. (d) Here $\tan\theta = 0.8$

where θ is angle of repose

$\theta = \tan^{-1}(0.8) = 39°$

The given angle of inclination is equal to the angle of repose. So the 1 kg block has no tendency to move.

$\therefore\ mg\sin\theta = \text{force of friction}$

$\Rightarrow T = 0$

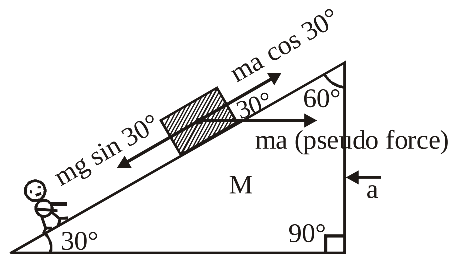
59. (d) For 0.5 kg block, $6 = 0.5\,a$
60. (b) While moving down, when the lift is accelerating the weight will be less and when the lift is decelerating the weight will be more.
61. (b) Total momentum $= 2p\hat{i} + p\hat{j}$

Magnitude of total momentum

$= \sqrt{(2p)^2 + p^2} = \sqrt{5p^2} = \sqrt{5}p$

This must be equal to the momentum of the third part.

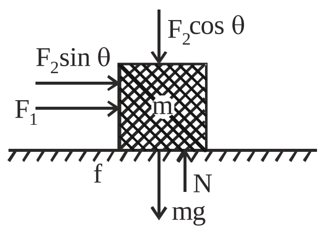
62. (c)



$ma\cos30° = mg\sin30°$

$\therefore a = \frac{g}{\sqrt{3}}$

63. (a) Here, on resolving force F_2 and applying the concept of equilibrium



$N = mg + F_2\cos\theta$, and $f = \mu N$

$\therefore\ f = \mu[mg + F_2\cos\theta]$ ...(i)

Also $f = F_1 + F_2\sin\theta$ ...(ii)

From (i) and (ii)

$\mu[mg + F_2\cos\theta] = F_1 + F_2\sin\theta$

$$\Rightarrow \mu = \frac{F_1 + F_2\sin\theta}{mg + F_2\cos\theta}$$

64. (c) $f = \mu W$

$f = W\tan\theta$ $[\because \mu = \tan\theta]$

65. (d) Here, the force of friction is 400N.

$F_{net} = (1650-400) = 1250N$

$\therefore a = \frac{1250}{1000} = 1.25ms^{-2}$

66. (a) $\frac{dm}{dt} = \frac{mg}{v_r} = \frac{5000\times 9.8}{1000} = 49kg\,s^{-1}$

67. (b) Reading of spring balance

$2T = \frac{4m_1m_2}{m_1+m_2} = \frac{4\times 5\times 1}{6} = \frac{10}{3}$ kgf

68. (a) $a = 2v$ (given)

$\Rightarrow v\frac{dv}{ds} = 2v$

or $dv = 2ds$

$\int_{0.1}^{v} dv = 2[s]_0^{0.1} = 0.2$

$v - 0.1 = 0.2$

$\Rightarrow v = 0.3ms^{-1}$

69. (c) If W is the maximum weight, then

$W = 2T\cos 60°$

or $W = T = 20N$

70. (c) The acceleration of both the blocks $= \frac{15}{3x} = \frac{5}{x}$

$\therefore$ Force on $B = \frac{5}{x}\times 2x = 10$ N

71. (b) The maximum acceleration that can be given is a

$\therefore 30g = 10g + 10a$

$\Rightarrow a = 2g = 20ms^{-2}$

We know that $s = ut + \frac{1}{2}at^2$

$\therefore t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2\times 10}{20}} = 1$ s

72. (a) Let the air resistance be F. Then

$mg + F = ma \Rightarrow F = m[a-g]$

Here $a = \frac{30}{2.5} = 12ms^{-2}$

73. (a) The frictional force acting on M is μmg

$\therefore$ Acceleration $= \frac{\mu mg}{M}$

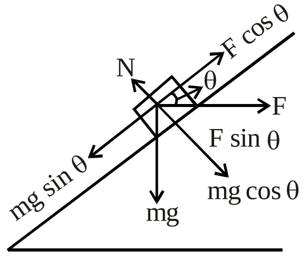
74. (c) Considering the two masses and the rope a system, then

Initial net force $= [25-(15+5)]g = 5g$

Final net force $= [(25+5)-15]g = 15g$

$\Rightarrow$ (acceleration)$_{final}$ = 3 (acceleration)$_{initial}$

75. (d)



From figure $N = mg\cos\theta + F\sin\theta$

76. (b) $\mu mg = mv^2/r$ or $v = \sqrt{\mu g r}$

or $v = \sqrt{(0.25\times 9.8\times 20)} = 7$ m/s

77. (a) Since water does not fall down, therefore the velocity of revolution should be just sufficient to provide centripetal acceleration at the top of vertical circle. So,

$v = \sqrt{(gr)} = \sqrt{\{10\times(1.6)\}} = \sqrt{(16)}$ = 4 m/sec.

78. (d) The speed at the highest point must be $v \geq \sqrt{rg}$

Now $v = r\omega = r(2\pi/T)$

$\therefore r(2\pi/T) > \sqrt{rg}$ or $T < \frac{2\pi r}{\sqrt{rg}} < 2\pi\sqrt{\left(\frac{r}{g}\right)}$

$\therefore T = 2\pi\sqrt{\left(\frac{4}{9.8}\right)} = 4\,sec$

79. (a) From figure,

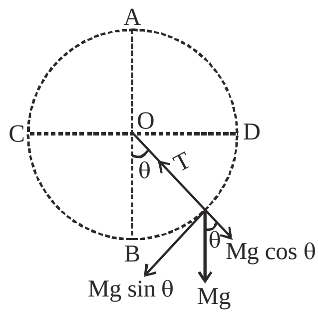
$N\sin\theta = \frac{mv^2}{r}$ .... (i)

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

Dividing, we get

$\tan\theta = \frac{v^2}{rg}$ or $\theta = \tan^{-1}\frac{v^2}{rg}$

80. (a) In the case of a body describing a vertical circle,



$T - mg\cos\theta = \frac{mv^2}{l}$ $\quad T = mg\cos\theta + \frac{mv^2}{l}$

Tension is maximum when $\cos\theta = +1$ and velocity is maximum

Both conditions are satisfied at $\theta = 0^\circ$ (i.e. at lowest point B)

81. (b) Since surface (ice) is frictionless, so the centripetal force required for skating will be provided by inclination of boy with the vertical and that angle is given as

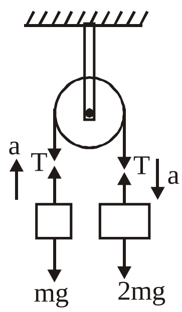
$\tan\theta = \dfrac{v^2}{rg}$ where v is speed of skating & r is radius of circle in which he moves.

82. (d) $v_{max} = \sqrt{\mu gr}$

83. (b) The condition to avoid skidding, $v = \sqrt{\mu rg}$

$= \sqrt{0.6 \times 150 \times 10} = 30$ m/s.

84. (b) Let a and a' be the accelerations in both cases respectively. Then for fig (a),



(a)

$T - mg = ma \qquad \ldots(1)$

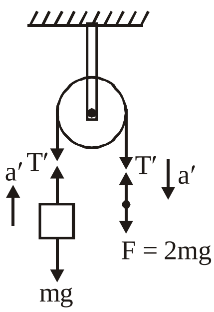
and $2mg - T = 2ma \qquad \ldots(2)$

Adding (1) and (2), we get

$mg = 3ma$

$\therefore\ a = \dfrac{g}{3}$

For fig (b),



(b)

$T' - mg = ma' \qquad \ldots(3)$

and $2mg - T' = 0 \qquad \ldots(4)$

Solving (3) and (4)

$a' = g$

$\therefore\ a = \dfrac{g}{3}$ and $a' = g$

85. (c) Linear momentum, $P = a + bt^2$

$\dfrac{dP}{dt} = 2bt$ (on differentiation)

$\therefore$ Rate of change of momentum, $\dfrac{dP}{dt} \propto t$

By 2nd law of motion, $\dfrac{dP}{dt} \propto F$

$\therefore\ F \propto t$

86. (d) For equilibrium of all 3 masses,

$T_3 = (m_1 + m_2 + m_3)a$ or

$a = \dfrac{T_3}{m_1 + m_2 + m_3}$

For equilibrium of m_1 & m_2

$T_2 = (m_1 + m_2).a$

or, $T_2 = \dfrac{(m_1 + m_2)T_3}{m_1 + m_2 + m_3}$

Given $m_1 = 10$ kg, $m_2 = 6$ kg, $m_3 = 4$ kg, $T_3 = 40$ N

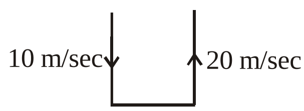
$\therefore\ T_2 = \dfrac{(10+6).40}{10+6+4} = 32N$

87. (a) If m_1, m_2 are masses and u_1, u_2 are velocity then by conservation of momentum $m_1u_1 + m_2u_2 = 0$ or $|m_1u_1| = |m_2u_2|$

88. (d) Apparent weight when mass is falling down is given by $W' = m(g - a)$

$\therefore\ W' = 1 \times (10 - 10) = 0$

89. (a) Velocity of ball after dropping it from a height of 5m



(using $v^2 = u^2 + 2gh$)

$v^2 = 0 + 2 \times 10 \times 5 \Rightarrow v = 10$ m/s

Velocity gained by ball by force exerted by bat

$0 = u^2 - 2gh$

$u^2 = 2 \times 10 \times 20$ or $u = 20$ m/s

Change in momentum = m(u + v)

$= 0.4\,(20 + 10) = 12$ kg m/s

$$F = \frac{\Delta P}{\Delta t} \text{ or } \Delta t = \frac{\Delta P}{F}$$

$$\Delta t = \frac{12}{100} = 0.12\,\text{sec}$$

90. (d) F_1 = Force of friction between B and A

$= \mu_1 m_1 g$

$= 0.25 \times 100 \times g = 25$ g newton

F_2 = Force of friction between (A + B) and surface

$= \mu_2 m_2 g = \mu_2$ (mass of A and B) g

$= \frac{1}{3}(100 + 200)g = \frac{300}{3}g = 100g$ newton

$\therefore\ F = F_1 + F_2$

$= 25\,g + 100\,g = 25g = 125 \times 10$ N

$\therefore$ F = 1250 N

91. (b) The rain drops falling vertically with velocity u do not affect the momentum along the horizontal track. A vector has no component in a perpendicular direction Rain drops add to the mass of the car

Mass added in t sec = (mt) kg

Momentum is conserved along horizontal track.

Initial mass of car = M

Initial velocity of car $= v_0$

Final velocity of (car + water) = v

Mass of (car + water) after time t = (M + mt)

$\therefore$ final momentum = initial momentum

$(M + mt)v = Mv_0$

$$\therefore\ v = \frac{Mv_0}{(M + mt)}$$

92. (d) Let v_1 = velocity when height of free fall is h_1

v_2 = velocity when height of free rise is h_2

$\therefore\ v_1^2 = u^2 + 2gh_1$ for free fall

or

For free rise after impact on ground

$0 = v_2^2 - 2gh_2$ or $v_2^2 = 2gh_2$

Initial momentum $= mv_1$

Final momentum $= mv_2$

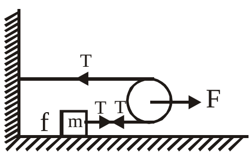
$\therefore$ Change in momentum $= m(v_1 - v_2)$

$= m(\sqrt{2gh_2} - \sqrt{gh_2})$

93. (b) T = tension is the string

$\therefore$ Applied force F = 2T

T = F/2 $\qquad\ldots$(i)



For block of mass m, force of friction due to surface f.

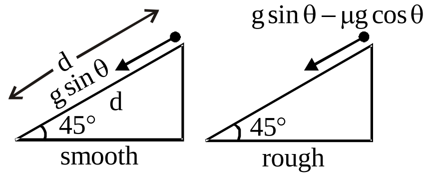
For sliding the block

T – f = force on the block = mass × acceleration

or acceleration of block $= \frac{T - f}{m}$. Put T from (i)

$$\therefore\quad \text{Acceleration} = \frac{\frac{F}{2} - f}{m}$$

94. (b)



When surface is smooth $\qquad$ When surface is rough

$$d = \frac{1}{2}(g\sin\theta)t_1^2, \quad d = \frac{1}{2}(g\sin\theta - \mu g\cos\theta)\,t_2^2$$

$$t_1 = \sqrt{\frac{2d}{g\sin\theta}}, \quad t_2 = \sqrt{\frac{2d}{g\sin\theta - \mu g\cos\theta}}$$

According to question, $t_2 = nt_1$

$$n\sqrt{\frac{2d}{g\sin\theta}} = \sqrt{\frac{2d}{g\sin\theta - \mu g\cos\theta}}$$

μ, applicable here, is coefficient of kinetic friction as the block moves over the inclined plane.

$$n = \frac{1}{\sqrt{1 - \mu_k}} \qquad \left(\because\ \cos 45° = \sin 45° = \frac{1}{\sqrt{2}}\right)$$

$$n^2 = \frac{1}{1 - \mu_k} \quad \text{or} \quad 1 - \mu_k = \frac{1}{n^2}$$

$$\text{or}\quad \mu_k = 1 - \frac{1}{n^2}$$

95. (d) Acceleration of block while sliding down upper half = $g\sin\phi$;

retardation of block while sliding down lower half = – $(g\sin\phi - \mu g\cos\phi)$

For the block to come to rest at the bottom, acceleration in I half = retardation in II half.

$g\sin\phi = -(g\sin\phi - \mu g\cos\phi)$

$\Rightarrow\ \mu = 2\tan\phi$

Alternative method : According to work-energy theorem, $W = \Delta K = 0$

(Since initial and final speeds are zero)

$\therefore$ Work done by friction + Work done by gravity = 0 i.e., $-(\mu\, mg\cos\phi)\frac{\ell}{2}+mg\ell\sin\phi=0$

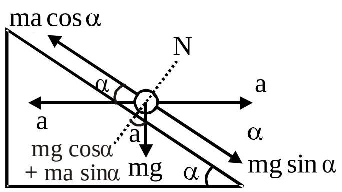
or $\frac{\mu}{2}\cos\phi=\sin\phi$ or $\mu=2\tan\phi$

96. (c) Mass (m) = 0.3 kg $\Rightarrow$ F = m.a = – 15 x

$a=-\frac{15}{0.3}x=\frac{-150}{3}x=-50x$

$a=-50\times0.2=10\,m/s^2$

97. (c) From free body diagram,



For block to remain stationary,

$mg\sin\alpha=ma\cos\alpha\Rightarrow a=g\tan\alpha$

98. (a) $v^2-u^2=2as$ or $0^2-u^2=2(-\mu_k g)s$

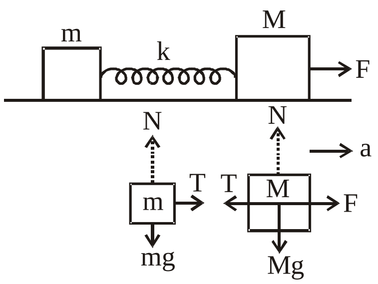
$-100^2=2\times-\frac{1}{2}\times10\times s$

s = 1000 m

99. (b) This is a standard formula and should be memorized.

$$a=\frac{g\sin\theta}{1+\frac{I}{MR^2}}$$

100. (d) Writing free body-diagrams for m & M,



we get,

T = ma and F – T = Ma

where T is force due to spring

$\Rightarrow$ F – ma = Ma

or, F = Ma + ma

$\therefore\quad a=\frac{F}{M+m}$.

Now, force acting on the block of mass m is

$ma=m\left(\frac{F}{M+m}\right)=\frac{mF}{m+M}$.

101. (a) Momentum, p = m × v

= (3.513) × (5.00) = 17.565 kg m/s

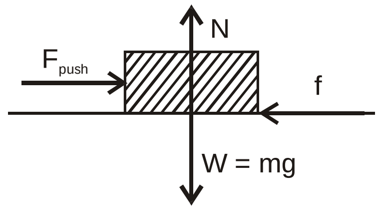
= 17.6 (Rounding off to get three significant figures)

PASSAGE 1

102. (b) Since f_s is always less than or equal to $\mu_s N$, its maximum possible value is

$f_{s\,max}=\mu_s N=\mu_s mg$.

(The normal force must equal the crate's weight, because the vertical forces cancel.)



The crate starts to move when the push force barely exceeds.fs max. This happens when

$F_{push}\approx 400$ N. So, 400N $\approx f_{s\,Max}=\mu_s mg$
$=\mu_s(100\text{ kg})(10\text{ m/s}^2)=\mu_s(1000\text{N})$.

Therefore, $\mu_s\approx 0.40$.

103. (d) If f_s were bigger than F_{push}, the crate would accelerate leftward, because it would feel a net leftward force. Therefore (c) is wrong.

Many students choose C because they calculate $f_s=\mu_s mg$ = 400 N. But that's the maximum possible force of static friction. Static friction "adjusts" itself, becoming bigger or smaller as needed in order to cancel the push force. When the push force is only 50 N, static friction reduces itself to 50 N. That's why we write is $f_s\le\mu_s N$ instead of $f_s=\mu_s N$

104. (b) First, use a kinematic equation to find the crate's acceleration during a particular trial. Then, apply Newton's 2nd law, F_{net} = ma. This reasoning works no matter which trial you consider. Here, we'll use trial 1.Since $x=v_0t+\frac{1}{2}at^2$, and since the crate begins with no velocity, we get $x=\frac{1}{2}at^2$ or

$1.0m=\frac{1}{2}a(1.0s)^2$

and hence, a = 2.0 m/s^2. That's the horizontal acceleration.

Since the crate only moves horizontally, the vertical forces cancel, and therefore N = mg (as above).

Therefore, the frictional force has magnitude

$f_k=\mu_k N=\mu_k mg=\mu_k(100kg)(10m/s^2)$

$=\mu_k(1000N)$

Newton's 2nd law, applied to the horizontal component of the forces, gives us

$$F_{net} = ma$$

$$f_{push} - f_k = ma$$

$$500N - (3.0)(1000N) = (100kg)(2.0m/s^2) = 200N$$

Solve for μ_k to get 0.30.

105. (d) Given μ_k, We can use Newton's 2nd law to figure out the create's acceleration during trial 3. Then we can use $v = v_0 + at$ to find the velocity at time t = 1.0 s, the moment the student stops pushing.

From Newton's 2nd law applied to trial 3,

$F_{net} = ma$

$F_{push} - f_k = ma$

$$700N - (0.3)(1000N) = (100kg)a,$$

and hence, a = 4.0 m/s^2

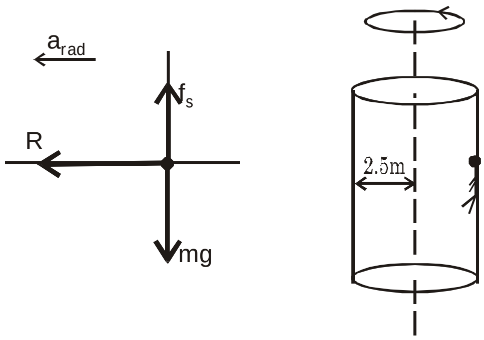
Since the crate speeds up by 4.0 m/s each second, its speed after 1 second is simply

$$v = v_0 + at = 0 + (4.0m/s^2)(1.0s) = 4.0m/s$$

106. (c) Graph B would correctly show the crate's velocity vs. time. The crate speeds up while the student pushes it, and then slows down while sliding freely across the floor. Crucially, after the student stops pushing, the crate does not move backwards, as represented in graph D. It continues moving forward, but at a slower and slower rate. Therefore, after t = 1 s, the position vs time graph continues upward, but with a smaller and smaller slope. when the crate stops, the graph levels off.

PASSAGE 2

107. (d) $a_{rad} = \dfrac{v^2}{R}$



Person is held up against gravity by static friction force exerted on him by the wall.

Acceleration of person is a_{rad} directed in towards the center.

108. (a) To find minimum μ_s we will take fs to have maximum value.

$f_s = \mu_s R$; $\Sigma f_y = ma_y$; $f_s - mg = 0$; $\mu_s R = mg$; $\Sigma f_x = ma_x$

$$\therefore R = \frac{mv^2}{R}$$

Combining the equations

$$\mu_s \frac{mv^2}{R} = mg \Rightarrow \mu_s = \frac{Rg}{v^2} = \frac{2.5 \times 9.8}{9.425} = 0.28.$$

109. (c,d) Mass of the person is cancelled as explained in above solution also smaller μ_s is larger should be the velocity to maintain in equilibrium

$$\mu_s = Rg / v^2.$$

110. (d) Work done in moving an object against gravitational force depends only on the initial and final position of the object, not upon the path taken. But gravitational force on the body along the inclined plane is not same as that along the vertical and it varies with angle of inclination.

111. (b) On a rainy day, the roads are wet. Wetting of roads lowers the coefficient of friction between the types and the road. Therefore, grip on a road of car reduces and thus chances of skidding increases.

112. (a) The force acting on the body of mass M are its weight *Mg* acting vertically downward and air resistance *F* acting vertically upward.

$\therefore$ Acceration of the body, $a = g - \dfrac{F}{M}$

Now M > m, therefore, the body with larger mass will have great acceleration and it will reach the ground first.