5

NEWTON'S LAWS OF MOTION AND FRICTION

NEWTON'S FIRST LAW OF MOTION (OR GALLEO'S LAW OF INERTIA)

Every body continues its state of rest or uniform motion in a straight line unless compelled by an external force to change its state. This fundamental property of body is called inertia at rest.

This law defines the force and states that the force is a factor which can change the state of object.

Definition of force from Newton's first law of motion "Force is the push or pull which changes or tends to change the state of rest or of uniform motion".

INERTIA

Inertia is the property of a body due to which it opposes the change in its state. Inertia of a body is measured by mass of the body. Inertia $\propto$ mass

Types of inertia :

1. **Inertia of rest :**
It is the inability of a body to change by itself, its state of rest. Examples :
* When we shake a branch of a mango tree, the mangoes fall down.
* When a bus or train starts suddenly the passengers sitting inside tends to fall backwards.
* The dust particles in a blanket fall off when it is beaten with a stick.
* When a stone hits a window pane, the glass is broken into a number of pieces whereas if the high speed bullet strikes the pane, it leaves a clean hole.

2. **Inertia of motion :** It is the inability of a body to change by itself its state of uniform motion. Examples :
* When a bus or train stops suddenly, a passenger sitting insider lean forward.
* A person jumping out of a speeding train may fall forward.
* A ball thrown upwards in a running train continues to move along with the train.

3. **Inertia of direction :** It is the inability of a body to change by itself its direction of motion. Examples :
* When a straight running car turns sharply, the person sitting inside feels a force radially outwards
* Rotating wheels of vehicle throw out mud, mudguard over the wheels stop this mud.
* A body released from a balloon rising up, continues to move in the direction of balloon.

MOMENTUM

The total quantity of motion possessed by a moving body is known as the momentum of the body. It is the product of the mass and velocity of a body.

Momentum $\vec{p} = m\vec{v}$

SI unit : kg m s^{-1}

Dimensions : $[MLT^{-1}]$

Note : The concept of momentum was introduced by Newton to measure the quantitative effect of force.

NEWTON'S SECOND LAW OF MOTION

Rate of change in momentum of a body is always equal to the unbalanced external force applied on it.

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

If m = constant then

$$\frac{dm}{dt} = 0$$

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

If $\vec{v}$ = constant then

$$\frac{d\vec{v}}{dt} = 0$$

i.e. $\vec{F} = v\frac{dm}{dt}$

(e.g. conveyor belt, rocket)

* The change in momentum always takes place in the direction of force.
* This law gives the magnitude of force.
* **Definition of One newton (N) :** If an object of mass one kilogram has an acceleration of 1 m/s^2 relative to an inertial reference frame, then the net force exerted on the object is one newton.

CONSEQUENCE OF NEWTON'S II LAW OF MOTION

Concept of inertial mass :

From Newton's II law of motion

$$M = \frac{F}{a}$$

i.e., the magnitude of acceleration produced by a given body is inversely proportional to mass i.e. greater the mass, smaller is the acceleration produced in the body. Thus, mass is the measure of inertia of the body. The mass given by above equation is therefore called the inertial mass.

An accelerated motion is the result of application of the force.

There may be two types of accelerated motion :

(i) When only the magnitude of velocity of the body changes: In this types of motion the force is applied along the direction of motion or opposite to the direction of motion.

(ii) When only the direction of motion of the body changes: In this case the force is applied at right angles to the direction of motion of the body, e.g. circular motion.

Acceleration produced in the body depends only on its mass and not on the final or initial velocity.

Example 1 :

A force $\vec{F} = (6\hat{i} - 8\hat{j} + 10\hat{k})$ N produces acceleration of 1 ms^{-2} in a body. Calculate the mass of the body.

Sol. $\because$ Acceleration $a = \dfrac{|\vec{F}|}{m}$

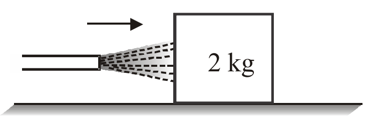
$$\therefore \quad m = \frac{|\vec{F}|}{a} = \frac{\sqrt{6^2 + 8^2 + 10^2}}{1} = 10\sqrt{2} \text{ kg}$$

Example 2 :

A block of 5 kg is resting on a frictionless plane. It is struck by a jet releasing water at a rate of 3 kg/s at a speed of 4 m/s. Calculate the initial acceleration of the block.

Sol. Force exerting on block

$$F = v\frac{dm}{dt} = 4 \times 3 = 12\text{N}$$



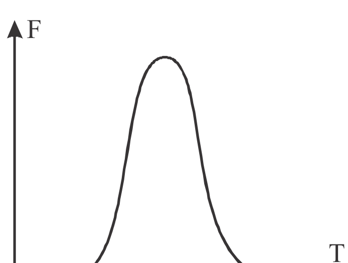
So acceleration of the block

$$a = \frac{F}{m} = \frac{12}{5} = 2.4 \text{ m/s}^2$$

IMPULSE

When a large force act for an extremely short duration, neither the magnitude of the force nor the time for which it acts is important. In such as case, the total effect of force is measured.

The total effect of force is called impulse (measure of the action of force).



Impulse = area under curve

This type of force is generally variable in magnitude and is sometimes called impulsive force.

If a large force act on a body or particle for a smaller time : then the impulse = product of force with time.

Suppose a force $\vec{F}$ acts for a short time dt then impulse $= \vec{F}\,dt$

For a finite internal of time t_1 to t_2 then the impulse $= \int_{t_1}^{t_2} \vec{F}\,dt$

If constant force acts for an interval Δt then

Impulse $= \vec{F}\,\Delta t$

Applications of concept of impulse :

* Bogies of a train are provided with buffers.
* A cricket player draws his hands back while catching a ball.
* A person jumping on hard cement floor receives more injuries than a person jumping on muddy or sandy road.
* Cars, buses, trucks, bogies of the train, etc. are provided with a spring system to avoid severe jerks.
* China wares are wrapped in straw or paper before packing.

Example 3 :

A hammer of mass 1 kg moving with a speed of 6 m/s strikes a wall and comes to rest in 0.1s. Calculate.

(a) Impulse of the force

(b) Average retarding force that stops the hammer.

(c) Average retardation of the hammer.

Sol. (a) Impulse $= F \times t = m(v - u) = 1(0 - 6) = -6$ Ns

(b) Average retarding force that stops the hammer

$$F = \frac{\text{Impulse}}{\text{time}} = \frac{6}{0.1} = 60\text{N}$$

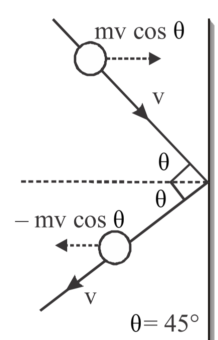
(c) Average retardation $= \dfrac{F}{m} = \dfrac{60}{1} = 60 \text{ m/s}^2$

Example 4 :

A ball of 0.20 kg hits a wall at an angle of 45° with a velocity of 25m/s. If the ball rebounds at 90° to the direction of incidence, calculate the change in momentum of the ball.

Sol. Change in momentum $= (-mv\cos 45°) - (mv\cos 45°)$

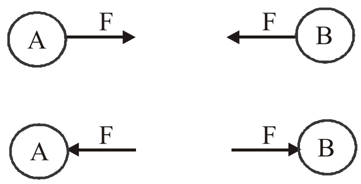
$= -2mv\cos 45°$



$$|\Delta\vec{p}| = 2mv\cos 45° = 2 \times 0.2 \times 25 \times \frac{1}{\sqrt{2}} = 5\sqrt{2} \text{ Ns}$$

NEWTON'S THIRD LAW OF MOTION

The first and second laws are statements about a single object, whereas the third law is a statement about two objects.



* According to this law, every action has equal and opposite reaction. Action and reaction act on different bodies and they are simultaneous. There can be no reaction without action.
* If an object A exerts a force F on an object B, then B exerts an equal and opposite force (–F) on A.
* Newton's III law contradicts theory of relativity, because it states that force signals can travel with infinite speed while theory of relatively states that nothing can travel with a velocity greater than velocity of light.
* Action and reaction never balance each other.
* Newton's III law can be derived from II law. (as given)

If two particles of masses m_1 and m_2 are moving under action of their mutually interacting forces with each other, such that no external force acts on the system.

Let force on 1^{st} due to 2^{nd} is

$$\vec{F}_{12} = \frac{d\vec{p}_1}{dt} \qquad \text{....... (i)}$$

and force on 2^{nd} due to 1^{st} is $\vec{F}_{21} = \frac{d\vec{p}_2}{dt}$ .... (ii)

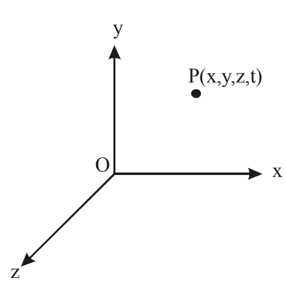
Adding the two equations, we have

$$\vec{F}_{12} + \vec{F}_{21} = \frac{d\vec{p}_1}{dt} + \frac{d\vec{p}_2}{dt} = \frac{d}{dt}(\vec{p}_1 + \vec{p}_2)$$

Since no external force $\vec{F}_{12} + \vec{F}_{21} = \vec{0}$ acts on the system, the total of momentum of the system must be constant.

FRAME OF REFERENCE

The position or location which defines a body or system w.r.t. a fixed point on a frame is called a frame of reference.



A Cartesian coordinate system is used as a simplest frame of reference in which three mutually perpendicular axes names as x-axis, y-axis and z-axis, intersect at a common point known as origin O.

Reference frames are of two types

(i) Inertial frames of reference :

A reference frame which is easier at rest or in uniform motion along the straight line. A non-accelerating frame of reference is called an inertial frame of reference.

(1) All the fundamental laws of physics have been formulated in respect of inertial frame of reference.

(2) All the fundamental laws of physics can be expressed as to have the same mathematical form in all the inertial frames of reference.

(3) The mechanical and optical experiments performed in an inertial frame in any direction will always yield the same results. It is called isotropic property of the inertial frame of reference.

Examples of inertial frames of reference :

(1) A frame of reference remaining fixed w.r.t. distance stars is an inertial frame of reference.

(2) A space-ship moving in outer space without spinning and with its engine cut-off is also inertial frame of reference.

(3) For practical purposes, a frame of reference fixed to the earth can be considered as an inertial frame. Strictly speaking, such a frame of reference is not an inertial frame of reference, because the motion of earth around the sun is accelerated motion due to its orbital and rotational motion. However, due to negligibly small effects of rotation and orbital motion, the motion of earth may be assumed to be uniform and hence a frame of reference fixed to it may be regarded as inertial frame of reference.

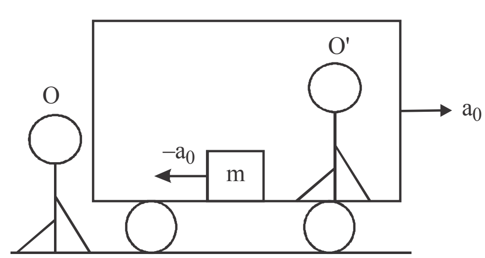
(ii) Non-inertial frame of reference :

A accelerating frame of reference is called a non-inertial frame of reference. Newton's law of motion are not directly applicable in such frames, before application we must use pseudo force.

Note : A rotating frame of references is a non-inertial frame of reference, because it is also an accelerated one due to its centripetal acceleration.

PSEUDO FORCE

The force on a body due to acceleration of non-inertial frame is called fictitious or apparent or pseudo force and is given by $\vec{F} = -m\vec{a}_0$ where $\vec{a}_0$ is acceleration of non-inertial frame with respect to an inertial frame and m is mass of the particle or body.



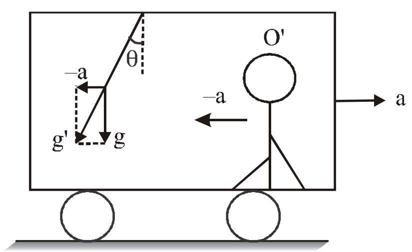
The direction of pseudo force must be opposite to the direction of acceleration of the non-inertial frame.

When we draw the free body diagram of a mass, with respect to an inertial frame of reference we apply only the real forces (forces which are actually acting on the mass).

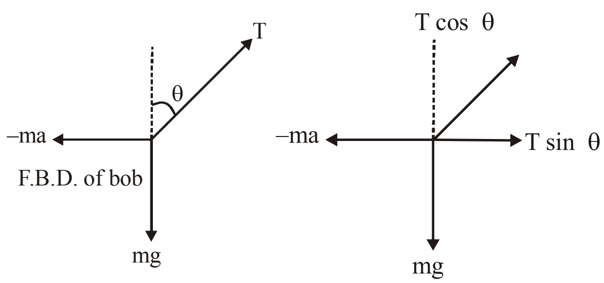
But when the free body diagram is drawn from a non-inertial frame of reference a pseudo force (in addition to all real forces) has to be applied to make the equation $\vec{F} = m\,\vec{a}$ to be valid in this frame also.

Example 5 :

A pendulum of mass m is suspended from the ceiling of a train moving with an acceleration 'a' as shown in figure. Find the angle θ in equilibrium position.



Sol.



Non-inertial frame of reference (Train)

F.B.D. of bob w.r.t. train (real forces + pseudo force) : with respect to train, bob is in equilibrium

$\therefore\ \Sigma F_y = 0 \Rightarrow T\cos\theta = mg$

and $\Sigma F_x = 0 \Rightarrow T\sin\theta = ma$

$$\Rightarrow \tan\theta = \frac{a}{g} \quad \Rightarrow \theta = \tan^{-1}\left(\frac{a}{g}\right)$$

FREE BODY DIAGRAM

A free body diagram is a diagram showing the chosen body by itself, "free" of its surroundings, with vectors drawn to show the magnitudes and directions of all the forces applied to the body by the various other bodies that interact with it.

Be careful to include all the forces acting on the body, but the equally careful not to include any forces that the body exerts on any other body. In particular, the two forces in an action-reaction pair must never appear in the same free-body diagram because they never act on the same body. [Forces that a body exerts on itself are never included, since these can't affect the body's motion.]

CONTACT FORCE

Contact forces arises when one body is in physical contact with another.

Example : Forces exerted by ropes or springs, the force involved in collisions, the force of friction between two surfaces, and the force exerted by a fluid on its container.

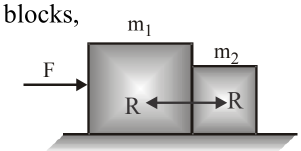
Two bodies in contact :

Two blocks of masses m_1 and m_2 placed in contact with each other on a frictionless horizontal surface.

Case I : Let a force F be applied on block of mass m_1.

Acceleration of both the blocks,

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

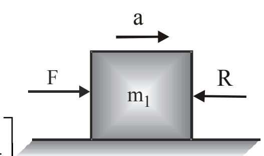


Let the force of contact = R

By FBD of m_1

$F - R = m_1 a$

$$R = F - m_1 a = F - m_1\left[\frac{F}{m_1 + m_2}\right]$$



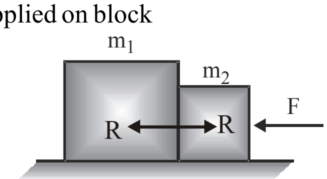
FBD of m_1

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

Case II : If force F is applied on block of mass m_2

Common acceleration,

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

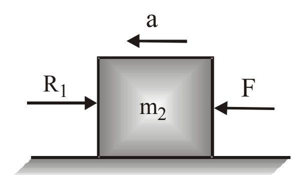


By FBD of m_2,

$F - R_1 = m_2 a$

or $R_1 = F - m_2 a$

or $R_1 = F - m_2\left[\frac{F}{m_1 + m_2}\right]$

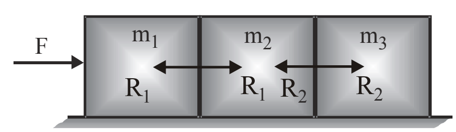


FBD of m_2

$$= \left[1 - \frac{m_2}{m_1 + m_2}\right]F = \frac{m_1 F}{m_1 + m_2}$$

Three bodies in contact :

Three blocks of masses m_1, m_2 and m_3 placed in contact on a smooth horizontal surface. Let a force F be applied on block of mass m_1. Let contact force between m_1 and m_2 is R_1 and the contact force between m_2 and m_3 is R_2.

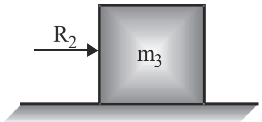


Acceleration of all the blocks,

$$a = \frac{F}{m_1 + m_2 + m_3} \qquad \text{.......... (i)}$$

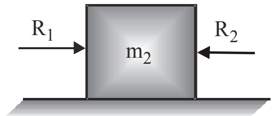
FBD of m_3 :

$R_2 = m_3 a$ .... (ii)



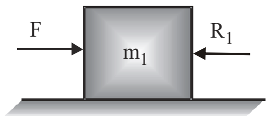
FBD of m_2 :

$R_1 - R_2 = m_2 a$ .... (iii)



FBD of m_1 :

$F - R_1 = m_1 a$ .... (iv)



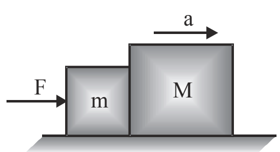
From (ii) and (i), $R_2 = \dfrac{m_3 F}{m_1 + m_2 + m_3}$

From eq. (iv), $R_1 = F - m_1 a$

or $R_1 = F - m_1\left[\dfrac{F}{m_1 + m_2 + m_3}\right] = \dfrac{(m_2 + m_3)F}{m_1 + m_2 + m_3}$

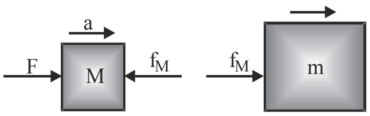
Example 6 :

Two blocks of mass m = 2 kg and M = 5 kg are in contact on a frictionless table. A horizontal force F (= 35N) is applied to m. Find the force of contact between the block, will the force of contact remain same if F is applied to M ?



Sol. As the blocks are rigid under action of a force F, both will move with same acceleration.

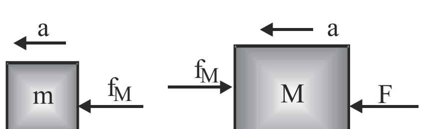
$$a = \frac{F}{m + M} = \frac{35}{2 + 5} = 5 \text{ m/s}^2$$



Force of contact $R_M = Ma = 5 \times 5 = 25$ N

If the force is applied to M then its action on m will be

$R_m = ma = 2 \times 5 = 10$ N



From this problem it is clear that acceleration does not depends on the fact that whether the force is applied to m or M, but force of contact does.

SYSTEM OF MASSES TIED BY STRINGS

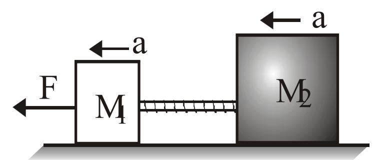
Tension in a string :

It is an intermolecular force between the atoms of a string, which acts or reacts when the string is stretched.

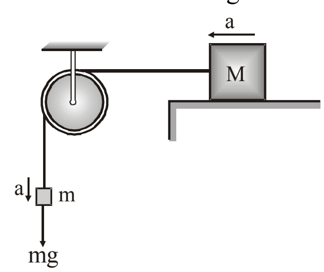
Important points about the tension in a string :

(a) Force of tension act on a body in the direction away from the point of contact or tied ends of the string.

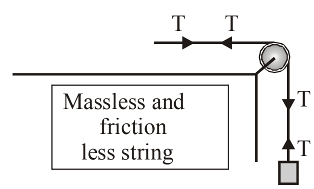
(b) (i) String is assumed to be inextensible so that the magnitude of acceleration of any number of masses connected through strings is always same.



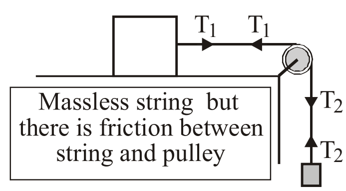
(ii) If the string is extensible the acceleration of different masses connected through it will be different until the string can stretch.



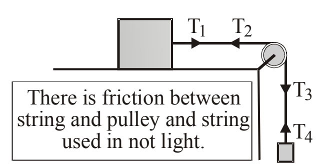
(c) (i) String is massless and frictionless so that tension throughout the string remains same.



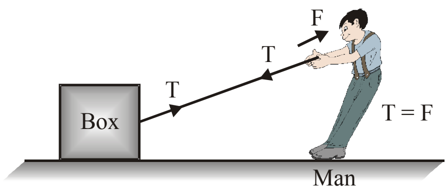
(ii) If the string is massless but not frictionless, at every contact tension changes.



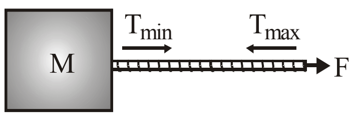
(iii) If the string is light tension at each point will be different depending on the acceleration of the string.



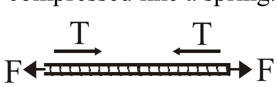
(d) If a force is directly applied on a string as say man is pulling a tied string from the other end with some force the tension will be equal to the applied force irrespective of the motion of the pulling agent, irrespective of whether the box will move or not, man will move or not.



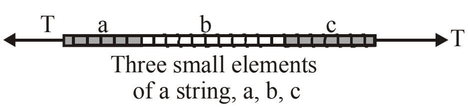
(e) String is assumed to be massless unless stated, hence tension in it every where remains the same and equal to applied force. However, if a string has a mass, tension at different points will be different being maximum (= applied force) at the end through which force is applied and minimum at the other end connected to a body.

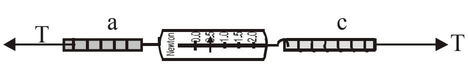


(f) In order to produce tension in a string two equal and opposite stretching forces must be applied. The tension thus produced is equal in magnitude to either applied force (i.e. T = F) and is directed inwards opposite to F. Here it must be noted that a string can never be compressed like a spring.



(g) If string is cut so that element b is replaced by a string scale (the rest of the string being undisturbed), the scale reads the tension T.





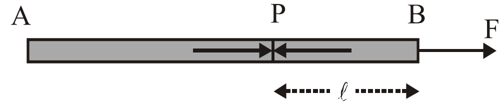
(h) Every string can bear a maximum tension, i.e. if the tension in a string is continuously increased it will break if the tension is increased beyond a certain limit. The maximum tension which a string can bear without breaking is called "breaking strength". It is finite for a string and depends on its material and dimension.

Example 7 :

A uniform rope of length L is pulled by a constant force F. What is the tension in the rope at a distance ℓ from the end where it is applied ?

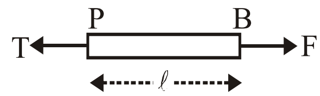
Sol. Let T be tension in the rope at point P, then

acceleration of rope, $a = \frac{F}{M}$



Equation of motion of part PB is

$F - T = (m\ell)\,a$

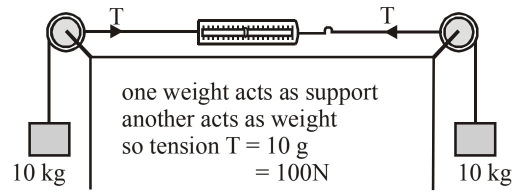


$\Rightarrow\ T = F - (m\ell)\,a = F - \left(\frac{M}{L}\right)(\ell)\left(\frac{F}{M}\right) = \left[1 - \frac{\ell}{L}\right]F$

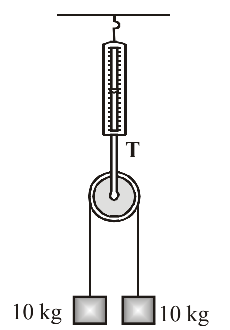
Example 8 :

The system shown in figure are in equilibrium. If the spring balance is calibrated in newtons, what does it record in each case ? ($g = 10\ m/s^2$)

Sol.

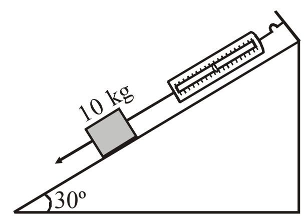


(A)



(B)

$T = 2\times10\times g = 2\times10\times10 = 200N$

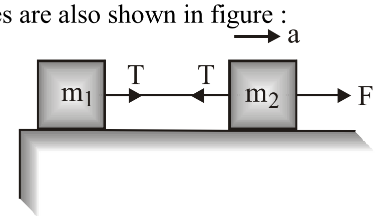


(C)

$T = 10\times10\ \sin30^\circ$
$= 10 \times 10 \times ½ = 50\ N$

MOTION OF BODIES CONNECTED BY STRINGS

Two bodies : Let us consider the case of two bodies of masses m_1 and m_2 connected by a thread and placed on a smooth horizontal surface as shown in figure. A force F is applied on the body of mass m_2 in forward direction as shown. Our aim is to consider the acceleration of the system and the tension T in the thread. The force acting separately on two bodies are also shown in figure :

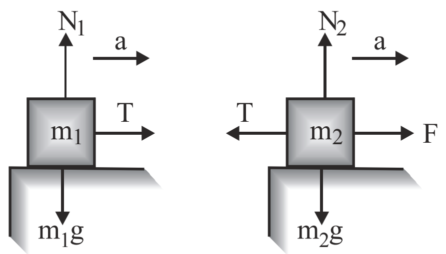


From figure,

$T = m_1 a$ ....(i)

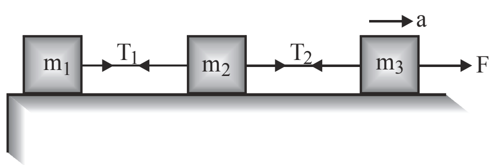
$F - T = m_2 a$ ....(ii)

$\Rightarrow\ F = (m_1 + m_2)a$



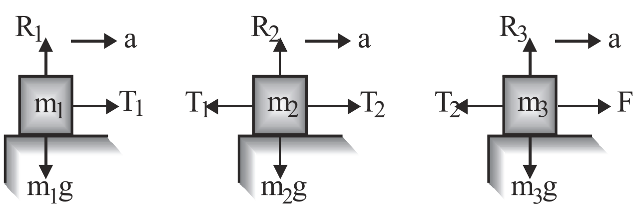
$$\Rightarrow \quad a = \frac{F}{m_1 + m_2} \quad \text{and} \quad T = \frac{m_1 F}{m_1 + m_2}$$

Three bodies : In case of three bodies, the situation is shown in figure



Acceleration, $a = \dfrac{F}{m_1 + m_2 + m_3}$

$$T_1 = m_1 a = \frac{m_1 F}{m_1 + m_2 + m_3}$$

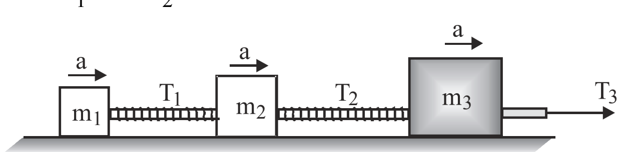


For block of mass m_3, $\quad F - T_2 = m_3 a$

$$\therefore \; T_2 = F - \frac{m_3 F}{m_1 + m_2 + m_3} = \frac{(m_1 + m_2)\, F}{m_1 + m_2 + m_3}$$

Example 9 :

Three blocks are connected by string as shown in figure, and are pulled by a force $T_3 = 120N$. If $m_1 = 5$ kg, $m_2 = 10$ kg and $m_3 = 15$ kg. Calculate the acceleration of the system and T_1 and T_2.



Sol. (i) Acceleration of the system

$$a = \frac{F}{m_1 + m_2 + m_3} = \frac{120}{5 + 10 + 15} = 4 \text{ m/s}^2$$

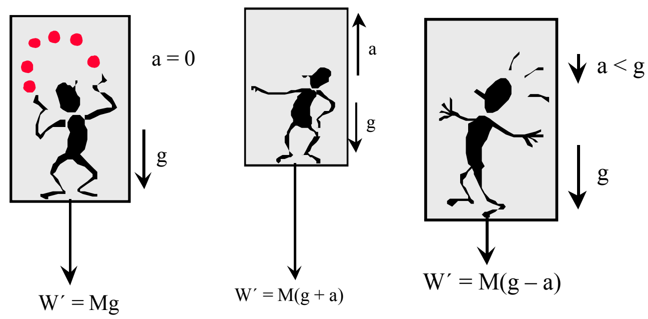
(ii) $T_1 = m_1 a = 5 \times 4 = 20$ N

$T_2 = (m_1 + m_2)\, a = (5 + 10)\, 4 = 60$ N

MOTION IN A LIFT

The weight of a body is simply the force exerted by earth on the body. If body is on an accelerated platform, the body experiences fictitious force, so the weight of the body appears changed and this new weight is called apparent weight. Let a man of weight W = Mg be standing in a lift.

Case (a) : If the lift moving with constant velocity v upwards or downwards.



Case (a) **Case (b)** **Case (c)**

In this case there is no accelerated motion hence no pseudo force experienced by observer O' in side the lift.

So apparent weight, W' = Actual weight W

Case (b): If the lift is accelerated (i.e., a = constant upward)

Then net forces acting on the man are

(i) Weight W = Mg downward

(ii) Fictitious force F_0 = Ma downward.

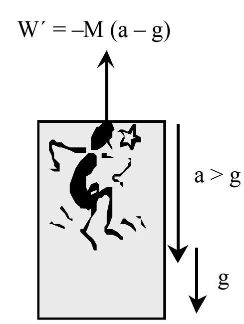
So apparent weight,

$W' = W - F_0 = Mg + Ma = M\,(g + a)$

Case (c) : If the lift is accelerated downward with acceleration a < g : The fictitious force F_0 = Ma acts upward while weight of a man W = Mg always acts downward, therefore, so apparent weight,

$W' = W + F_0 = Mg - Ma = M\,(g - a)$

Special case : If g = a then W ' = 0 condition of weightlessness. Thus, in a freely falling lift the man will experience weightlessness.



Case (d) : If lift accelerated downward with acc. a > g :

Then as in Case (c)

Apparent weight $W' = M\,(g - a)$ is negative.

i.e., the man will be accelerated upward and will stay at the ceiling of the lift.

Example 10 :

A spring weighing machine inside a stationary lift reads 50kg when a man stands on it. What would happen to the scale reading if the lift is moving upward with (i) constant velocity, and (ii) constant acceleration ?

Sol. (i) In the case of constant velocity of lift, there is no fictitious force, therefore the apparent weight = actual weight. Hence the reading of machine is 50 kg wt.

(ii) In this case the acceleration is upward, the fictitious force $R = ma$ acts downward, therefore apparent weight is more than actual weight i.e. $W' = W + R = m(g + a)$
Hence scale shows a reading $= m(g + a)$

$$= \frac{mg\left(1+\frac{a}{g}\right)}{g} = \left(50 + \frac{50a}{g}\right) \text{ kg. wt.}$$

Example 11 :
Two objects of equal mass rest on the opposite pans of an arm balance. Does the scale remain balanced when it is accelerated up or down in a lift ?

Sol. Yes, since both mass experience equal fictitious forces in magnitude as well as direction.

PULLEY

* Ideal pulley is considered weightless and frictionless.
* Ideal string is massless and inextensible.
* The pulley may change the direction of force in the string but not the tension.

Some cases of pulley

Case I : $m_1 = m_2 = m$

Tension in the string

$T = mg$

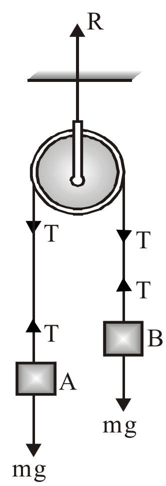
Acceleration 'a' = zero

Reaction at the suspension of the pulley.

$R = 2T = 2mg$

$$\text{Acceleration} = \frac{\text{net pulling force}}{\text{total mass to be pulled}}$$

$$\text{Tension} = \frac{2 \times \text{Product of masses}}{\text{Sum of two masses}}\, g$$



Case II : $m_1 > m_2$

Now for mass m_1,

$m_1 g - T = m_1 a$ .... (i)

for mass m_2

$T - m_2 g = m_2 a$ .... (ii)

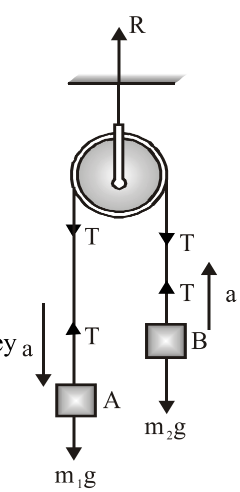
By (i) and (ii)

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

$$\text{and} \quad T = \frac{(2m_1 m_2)\, g}{(m_1 + m_2)}$$

Reaction at the suspension of pulley

$$R = 2T = \frac{4m_1 m_2\, g}{(m_1 + m_2)}$$



Case III :

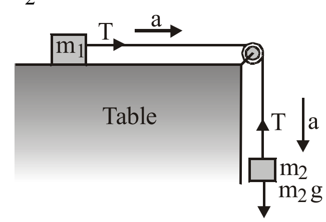
For mass m_1 : $T = m_1 a$

For mass m_2 : $mg_2 - T = m_2 a$

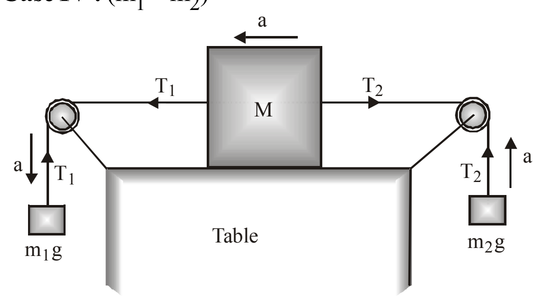
Acceleration,

$$a = \frac{m_2 g}{(m_1 + m_2)}$$

$$\text{and} \quad T = \frac{m_1 m_2 g}{(m_1 + m_2)}$$



Case IV : $(m_1 > m_2)$



$m_1 g - T_1 = m_1 a$ .....(i)

$T_2 - m_2 g = m_2 a$ .....(ii)

$T_1 - T_2 = Ma$ .....(iii)

By (i), (ii) and (iii), $a = \dfrac{(m_1 - m_2)\, g}{(m_1 + m_2 + M)}$

Case V : Mass suspended over a pulley from another on an inclined plane.

For mass m_1 :

$m_1 g - T = m_1 a$ .....(i)

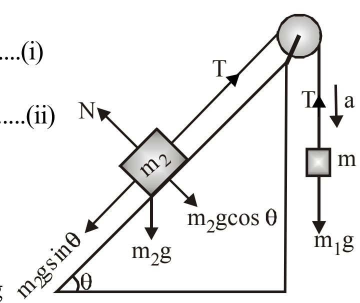
For mass m_2 :

$T_2 - m_2 g \sin\theta = m_2 a$ .....(ii)

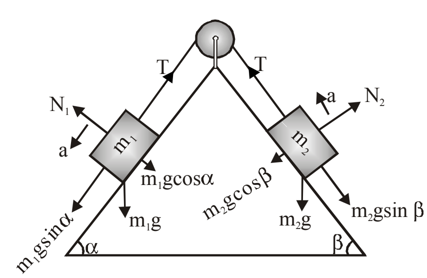
Acceleration,

$$a = \frac{(m_1 - m_2 \sin\theta)\, g}{(m_1 + m_2)}$$

$$T = \frac{m_1 m_2 (1 + \sin\theta)\, g}{(m_1 + m_2)}$$



Case VI : Masses m_1 and m_2 are connected by a string passing over a pulley $(m_1 > m_2)$



$$\text{Acceleration,} \quad a = \frac{(m_1 \sin\alpha - m_2 \sin\beta)}{(m_1 + m_2)}\, g$$

$$\text{Tension,} \quad T = \frac{m_1 m_2 (\sin\alpha + \sin\beta)}{(m_1 + m_2)}\, g$$

Case VII : For mass m_1 :

$T_1 - m_1 g = m_1 a$ .....(i)

For mass m_2 :

$m_2 g + T_2 - T_1 = m_2 a$ .....(ii)

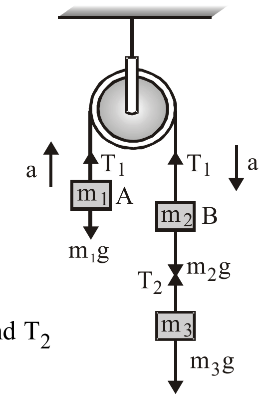
For mass m_3 :

$m_3 g - T_2 = m_3 a$ .....(iii)

Acceleration,

$$a = \frac{(m_2 + m_3 - m_1)}{(m_1 + m_2 + m_3)} g$$

We can calculate tensions T_1 and T_2 from above equations.



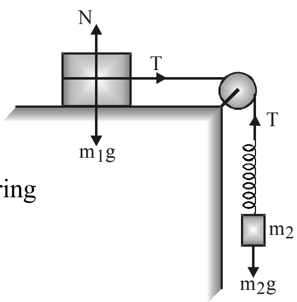
Case (VIII) :

From case (III)

Tension $T = \frac{m_1 m_2}{(m_1 + m_2)} g$

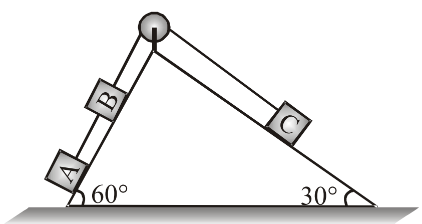
If x is the extension in the spring then $T = kx$

$$x = \frac{T}{k} = \frac{m_1 m_2 g}{k(m_1 + m_2)}$$



Example 12 :

In the adjacent figure, masses of A, B and C are 1 kg, 3 kg & 2kg respectively. Find (a) the acceleration of the system. (b) tensions in the string. Neglect friction ($g = 10 \text{ m/s}^2$)



Sol. (a) In this case net pulling force

$m_A g \sin 60° + m_B g \sin 60° - m_C g \sin 30°$

$= (m_A + m_B) g \sin 60° - m_C g \sin 30°$

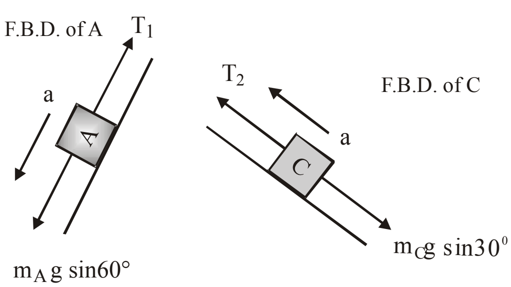
$$= (1+3) \times 10 \times \frac{\sqrt{3}}{2} - 2 \times 10 \times \frac{1}{2}$$

$= 20\sqrt{3} - 10 = 20 \times 1.732 - 10 = 24.64 \text{ N}$

Total mass being pulled $= 1 + 3 + 2 = 6$ kg

$\therefore$ Acceleration of the system, $a = \frac{24.64}{6} = 4.1 \text{ m/s}^2$

(b) For the tension in the string between A and B



$m_A g \sin 60° - T_1 = (m_A)(a)$

$\therefore$ $T_1 = m_A g \sin 60° - m_A a = m_A (g \sin 60° - a)$

$$\therefore \quad T_1 = (1)\left(10 \times \frac{\sqrt{3}}{2} - 4.1\right) = 4.56 \text{ N}$$

For the tension in the string between B and C

$T_2 - m_C g \sin 30° = m_C A$

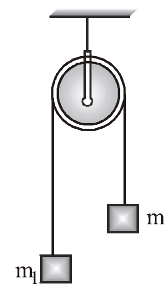
$$T_2 = m_C (a + g \sin 30°) = 2\left[4.1 + 10\left(\frac{1}{2}\right)\right] = 18.2 \text{ N}$$

CONSTRAINT EQUATIONS

The concept of constraint equations is used to understand the problems using multistring pulleys. Basically, these are the equations relating accelerations (or velocities) of different blocks connected by string(s). The few examples to understand the above method are :

Example 13 :

Find the relation between acceleration of blocks m_1 and m_2 using constraint method.



Sol. **Method 1 :** To get the constraint firstly we consider the centre of pulley as reference and assume the displacements of blocks m_1 and m_2 as x_1 and x_2 from reference as shown.

Then, $x_1 + x_2 = \text{constant} = c$

By differentiating with respect to time

$$\frac{d}{dx}(x_1 + x_2) = \frac{d}{dt}(c)$$

$v_1 + v_2 = 0$

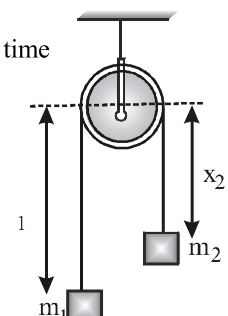
$\Rightarrow$ $v_1 = -v_2$

Again differentiating w.r.t. time

$a_1 + a_2 = 0$

$\Rightarrow$ $a_1 = -a_2 = 0$

i.e., acceleration of both the blocks are equal in magnitude but opposite in directions.



Method 2 : Consider the present situation as $\ell_1 + \ell_2 = c$ (constant) .... (i)

If m_1 displaces by x_1 down and m_2 displaces by x_2 up, then

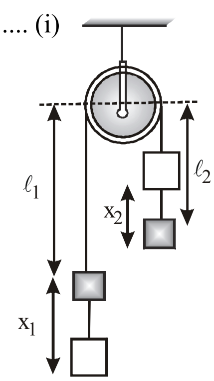
$(\ell_1 + x_1) + (\ell_2 - x_2) = c = \ell_1 + \ell_2$ (from eq. (i))

$\Rightarrow$ $x_1 - x_2 = 0$

$\Rightarrow$ $v_1 - v_2 = 0$

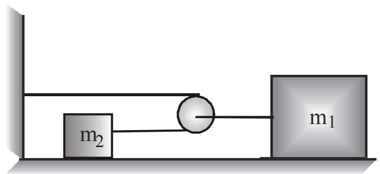
$\Rightarrow$ $a_1 - a_2 = 0$

$a_1 = a_2$



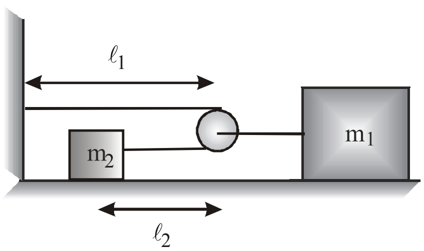
Example 14 :

In the given figure pulley and strings are massless and all surfaces are smooth. Find the relation between acceleration of the blocks.

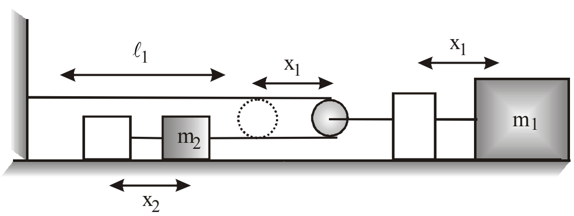


Sol. Consider the present situation as

$\ell_1 + \ell_2 = c$ (constant) ..... (i)



If m_1 displaces by x_1 and m_2 displaces by x_2, then



$(\ell_1 + x_1) + (\ell_2 + x_1 - x_2)$ = costant (c) = $\ell_1 + \ell_2$

$\Rightarrow 2x_1 - x_2 = 0$

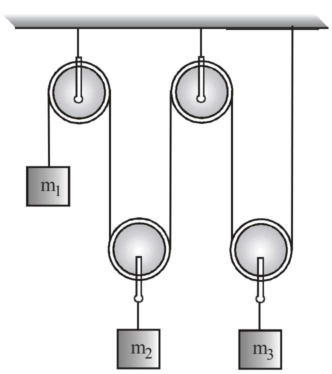
$\Rightarrow 2v_1 - v_2 = 0$ (by differentiating w.r.t. time)

$\Rightarrow 2a_1 - a_2 = 0$ (again differentiating w.r.t. time)

$a_1 = a_2/2$

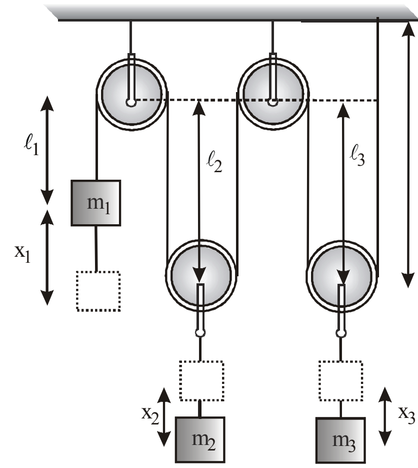
Example 15 :

Find the constraint relation between the acceleration of the blocks m_1, m_2 and m_3 as shown (Assume ideal system).



Sol. Consider the present situation as

$\ell_1 + \ell_2 + \ell_2 + \ell_3 + \ell_4$ = constant (c)



Now, if we assume that the displacements of m_1, m_2 and m_3 are m_1 (downward), x_2 and x_3 (upwards) respectively, then

$(\ell_1 + x_1) + (\ell_2 - x_2) + (\ell_2 - x_2) + (\ell_3 - x_3) + (\ell_4 - x_3)$ = const.

$= \ell_1 + 2\ell_2 + \ell_3 + \ell_4$ (from eq. (i))

$\Rightarrow x_1 - 2x_2 - 2x_3 = 0$

Two times differentiating w.r.t. time, we have

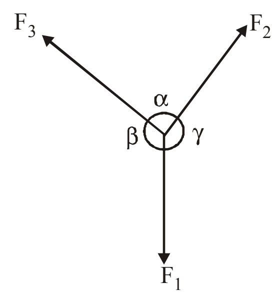
$a_1 - 2a_2 - 2a_3 = 0$

TRANSLATORY EQUILIBRIUM

When concurrent and coplanar forces act on body or on a system then to be in equilibrium

$$\Sigma \vec{F} = 0 \text{ or } \Sigma \vec{F}_x = 0 \;\&\; \Sigma \vec{F}_y = 0$$

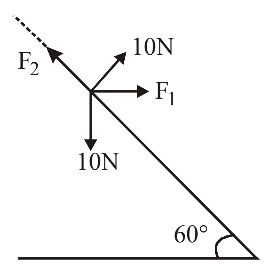
If only three concurrent forces are acting on the system then we can use Lami's theorem given as



$$\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$$

Example 16 :

In the given figure if all the forces are in equilibrium then calculate F_1 and F_2.



Sol. Resolving the forces as shown

In x-direction :

$\Sigma F_x = 0$ (for equilibrium)

$F_1 + 10 \sin 60° = F2 \cos 60°$

$$\Rightarrow F_1 + 10\left(\frac{\sqrt{3}}{2}\right) = F_2\left(\frac{1}{2}\right)$$

$$\Rightarrow 2F_1 - F_2 = 10\sqrt{3} \text{ .... (i)}$$

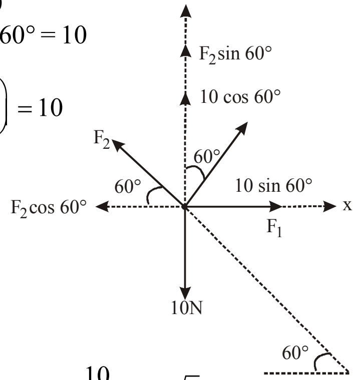
In y-direction : $\Sigma F_y = 0$

$F_2 \sin 60° + 10 \cos 60° = 10$

$$\Rightarrow F_1 + \left(\frac{\sqrt{3}}{2}\right) + 10\left(\frac{1}{2}\right) = 10$$

$$\Rightarrow F_2(\sqrt{3}) + 10 = 20$$

$$\Rightarrow F_2 = \left(\frac{10}{\sqrt{3}} N\right)$$



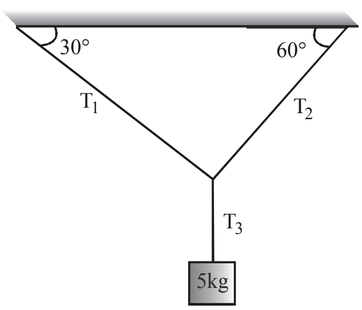
Now from eq. (i)

$$2F_1 - F_2 = 10\sqrt{3} \Rightarrow 2F_1 - \frac{10}{\sqrt{3}} = 10\sqrt{3}$$

$$\Rightarrow 2\sqrt{3}F_1 - 10 = 30 \Rightarrow F_1 = \frac{40}{2\sqrt{3}}$$

Example 17 :

Calculate the tension T_1, T_2 and T_3 in the massless strings shown in figure ($g = 10\ m/s^2$)

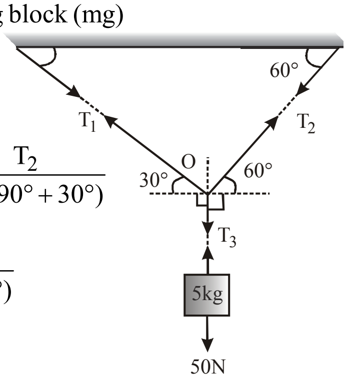


Sol. Consisting the adjoining figure

T_3 = wt. of the 5 kg block (mg)

$T_3 = 5 \times 10 = 50$ N

Now applying Lami's theorem at point O.



$$\frac{T_2}{\sin(90° + 60°)} = \frac{T_2}{\sin(90° + 30°)}$$

$$= \frac{T_3}{\sin(180° - 60° - 30°)}$$

$$T_1 = 50\frac{\cos 60°}{\sin 90°} = 25N$$

and $T_2 = 50\dfrac{\cos 60°}{\sin 90°} = 25\sqrt{3}$ N

TRY IT YOURSELF-1

Q.1 A mixed martial artist kicks his opponent in the nose with a force of 200 newtons. Identify the action-reaction force pairs in this interchange.

(A) foot applies 200 newton force to nose; nose applies a smaller force to foot because foot has a larger mass.

(B) foot applies 200 newton force to nose; nose applies a smaller force to foot because it compresses.

(C) foot applies 200 newton force to nose; nose applies a larger force to foot due to conservation of momentum.

(D) foot applies 200 newton force to nose; nose applies an equal force to the foot.

Q.2 Joanne exerts a force on a basketball as she throws the basketball to the east. Which of the following is always true?

(A) Joanne accelerates to the west.

(B) Joanne feels no net force because she and the basketball are initially the same object.

(C) The basketball pushes Joanne to the west.

(D) The magnitude of the force on the basketball is greater than the magnitude of the force on Joanne.

Q.3 A reference frame attached to the earth –

(A) is an inertial frame by definition.

(B) cannot be an inertial frame because the earth is revolving around the sun.

(C) is an inertial frame because Newton's laws are applicable in this frame.

(D) cannot be an inertial frame because the earth is rotating about its axis.

Q.4 A massive object is placed on a frictionless table. It takes 2 newtons of force to accelerate it at 0.5 m/s^2. The object is taken into space where it is weightless. The force required to accelerate the object at 0.5 m/s^2 will be

(A) less than,

(B) equal to

(C) more than 2 newtons.

Q.5 In the situation below, a person pulls a string attached to block A, which is in turn attached to another, heavier block B via a second string. Assume the strings are massless and inextensible; and ignore friction. Is the magnitude of the acceleration of block A.

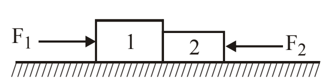
(A) greater than the magnitude of the acceleration of block B?

(B) equal to the magnitude of the acceleration of block B?

(C)less than the magnitude of the acceleration of block B?

(D) Do not have enough information to decide.

Q.6 Two blocks 1 and 2, on a frictionless table, are pushed from the left by a horizontal force $\vec{F}_1$, and on the right by a horizontal force of magnitude $\vec{F}_2$ as shown. Magnitudes of the pushing forces satisfy the inequality $|\vec{F}_1| > |\vec{F}_2|$.



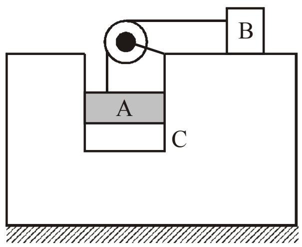
Which of the following statements is true about the magnitude N of the contact force between the two blocks?

(A) $N > |\vec{F}_1| > |\vec{F}_2|$ (B) $|\vec{F}_1| > N > |\vec{F}_2|$

(C) $|\vec{F}_1| > N = |\vec{F}_2|$ (D) $|\vec{F}_1| = N > |\vec{F}_2|$

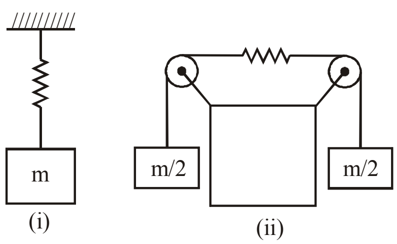
Q.7 Consider a person standing in an elevator that is accelerating upward. The upward normal force N exerted by the elevator floor on the person is –
(A) larger than the downward force of gravity on the person.
(B) identical to the downward force of gravity on the person.
(C) smaller than the downward force of gravity on the person.

Q.8 In the system shown in figure $m_A = 4m$, $m_B = 3m$ and $m_C = 8m$. Friction is absent everywhere. String is light and inextensible. If the system is released from rest find the acceleration of block B



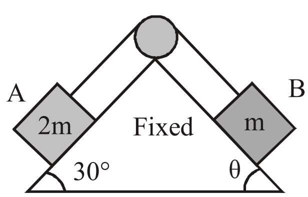
(A) g/8 (leftward) (B) g/2 (leftward)
(C) g/6 (rightward) (D) g/4 (rightward)

Q.9 A body of mass m is suspended from a spring with spring constant k in configuration (i) and the spring is stretched a distance x . If two identical bodies of mass m/2 are suspended from a spring with the same spring constant k in configuration (ii), how much will the spring stretch?



(A) x (B) 2x
(C) x/2 (D) x/4

Q.10 The value of angle θ such that the acceleration of A is g/6 downward along the incline plane. (All surfaces are smooth)



(A) θ = 30° (B) θ = 60°
(C) θ = 45° (D) θ = 53°

ANSWERS

(1) (D)	**(2)** (C)	**(3)** (BD)
(4) (B)	**(5)** (B)	**(6)** (B)
(7) (A)	**(8)** (B)	**(9)** (C)
(10) (A)		

FRICTION

INTRODUCTION

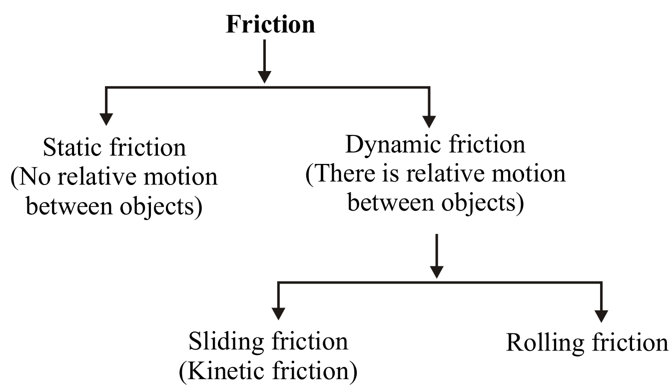
* Friction is the force acting between two surfaces in contact, or the force of a medium acting on a moving object (i.e. air on aircraft) to resist the relative motion.
* Frictional forces may also exist between surfaces when there is no relative motion. Frictional forces arise due to molecular interactions.

CAUSE OF FRICTION

Old View : When two bodies are in contact with each other, the irregularities in the surface of one body set interlocked in the irregularities of another surface. This locking opposes the tendency of motion.

Modern View: Friction arises on account of strong atomic or molecular forces of attraction between the two surfaces at the point of actual contact.

TYPES OF FRICTION



STATIC FRICTION

* It is the frictional force which is effective before motion starts between two planes in contact with each other.
* It's nature is self adjusting.
* Numerical value of static friction is equal to external force which creates the tendency of motion of body.
* Maximum value of static friction is called limiting friction.

LAWS OF LIMITING FRICTION

* The magnitude of the force of limiting friction (f_L) between any two bodies in contact is directly proportional to the normal reaction (N) between them $f_L \propto N$
* The direction of the force of limiting friction is always opposite to the direction in which one body is on the verge of moving over the other.
* The force of limiting friction is independent of the apparent contact area, so long as normal reaction between the two bodies in contact remains the same.
* Limiting friction between any two bodies in contact depends on the nature of material of the surfaces in contact and their roughness and smoothness.
* Its value is more than the other types of frictional force.

DYNAMIC FRICTION

If the body is in motion, the friction opposing its motion is called dynamic friction.
This is always slightly less than the limiting friction.

COEFFICIENT OF FRICTION

The frictional coefficient is a dimensionless scalar value which describes as the ratio of the force of friction between two bodies and the normal force pressing them together.

Coefficient of static friction $\mu_s = \frac{f_L}{N}$

Coefficient of sliding (kinetic) friction $\mu_k = \frac{f_k}{N}$

The values of μ_s and μ_k depend on the nature of both the surfaces in contact.

Note :

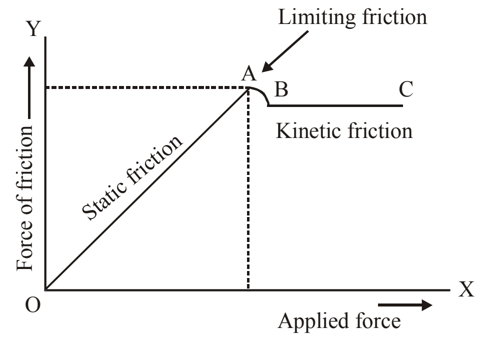
* Friction always opposes the tendency of relative motion.
* The force of static friction exactly balances the applied force during the stationary state of the body therefore it is known as self adjusting.
* μ_s and μ_k can exceed unity, although commonly they are less than one.
* Static friction is a self-adjusting force, the kinetic friction is not a self adjusting force.
* The frictional force is a contact force parallel to the surfaces in contact and directed so as to oppose the relative motion or attempted relative motion of the surfaces.
* When two highly polished surfaces are pressed hard, then a situation similar to welding occurs. It is called cold welding.
* When two copper plates are highly polished and placed in contact with each other, then instead of decreasing, the force of friction increases. This arises due to the fact that for two highly polished surfaces in contact, the number of molecules coming in contact increases and as a result the cohesive/adhesive forces increases. This in turn, increases the force of friction.
* Let f is the force and N is the normal reaction, then the net force applied by the surface on the object is

$$F_{surface} = \sqrt{N^2 + f^2}$$

Its minimum value (when f = 0) is Mg and maximum value (when f = μN) is $Mg\sqrt{1+\mu^2}$

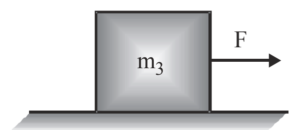
Graph between applied force and force of friction :

If we slowly increase the force with which we are pulling the box, graph shows that the friction force increases with our force upto a certain critical value, f_L, the box suddenly begins to move, and as soon as it starts moving, a smaller force is required to maintain its motion as in motion friction is reduced. The friction value from 0 to f_L is known as static friction, which balances the external force on the body and prevent it from sliding. The value f_L is the maximum limit up to which the static friction acts is known as limiting friction, after which body starts sliding and friction reduces to kinetic friction.



Example 18 :

A block of mass 1 kg is at rest on a rough horizontal surface having coefficient of static friction 0.2 and kinetic friction 0.15, find the frictional forces if a horizontal force,
(a) F = IN (b) F = 2.5 N , is applied on the block



Sol. Maximum force of friction or limiting friction

$f_L = 0.2 \times 1 \times 9.8\ N = 1.96\ N$

(a) For $F_{ext} = 1N,\ F_{ext} < f_L$
So, body is in rest means static friction is present and hence $f_s = F_{ext} = 1N$

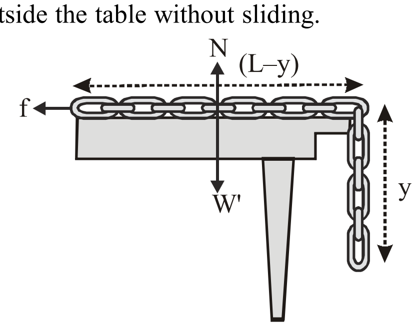
(b) For $F_{ext} = 2.5\ N$ so $F_{ext} > f_L$
Now body is in moving condition

$\therefore$ Frictional force
$f_L = F_k = \mu_k N = \mu_k mg = 0.15 \times 1 \times 9.8 = 1.47\ N$

Example 19 :

Length of a chain is L and coefficient of static friction is μ. Calculate the maximum length of the chain which can be hung from the table without sliding.

Sol. Let y be the maximum length of the chain can be hold outside the table without sliding.



Length of chain on the table = (L – y)
Weight of part of the chain on table

$$W' = \frac{M}{L}(L - y)\ g$$

Weight of hanging part of the chain $W = \frac{M}{L} yg$

For equilibrium : Limiting force of friction= weight of hanging part of the chain

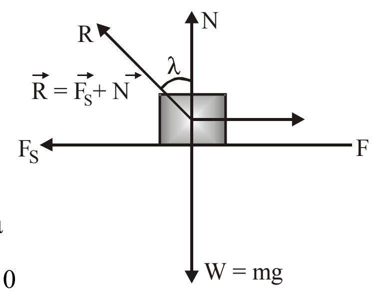
$\mu N = W \Rightarrow \mu W' = W$

$\Rightarrow \mu \frac{M}{L}(L - y)g = \frac{M}{L} yg$

$\Rightarrow \mu L - \mu y = y \Rightarrow y = \frac{\mu L}{1+\mu}$

ANGLE OF FRICTION

The angle of friction is the angle which the resultant of limiting friction f_L and normal reaction N makes with the normal reaction. It is represented by λ.



$\tan\lambda = \frac{F_L}{N} = \frac{\mu N}{N} = \mu$

For smooth surface $\lambda = 0$

ANGLE OF REPOSE (θ)

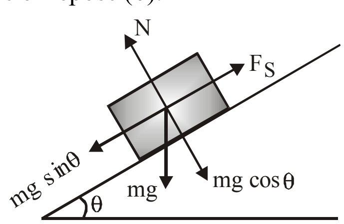
If a body is placed on an inclined plane and if its angle of inclination is gradually increased, then at some angle of inclination θ the body will just on the point to slide down. The angle is called angle of repose (θ).

$\therefore \quad F_L = mg\sin\theta$

and $N = mg\cos\theta$

So, $\frac{F_L}{N} = \tan\theta$

or $\mu = \tan\theta$



Relation between angle of friction (λ) and angle of repose (θ) : We know that $\tan\lambda = \mu$ and $\mu = \tan\theta$

hence $\tan\lambda = \tan\theta \Rightarrow \theta = \lambda$

Thus, angle of repose = angle of friction

ACCELERATION OF A BLOCK ON A ROUGH INCLINE

Case 1: When a plane is inclined to the horizontal at an angle θ, which is greater than the angle of repose, the mass m placed on the inclined plane slides down with an acceleration a.

$f = \mu N = \mu\, mg\cos\theta$

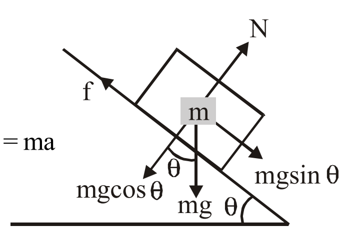
From FBD of block

$mg\sin\theta - f = ma$

$mg\sin\theta - \mu\, mg\cos\theta = ma$

$\Rightarrow a = g\sin\theta - \mu g\cos\theta$

here $a < g$



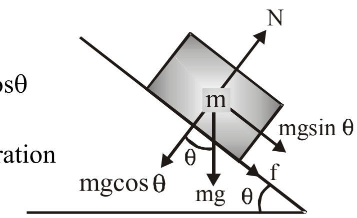
Case 2 : When a plane is inclined to the horizontal at an angle θ, which is less than the angle of repose, then the minimum force required to move the body up the inclined plane is

$F = mg\sin\theta + f$

$= mg\sin\theta + \mu mg\cos\theta$

where $f = \mu N = \mu\, mg\cos\theta$

and its upwards acceleration



$a = \frac{\text{Net force}}{n} = g(\sin\theta + \mu\cos\theta)$

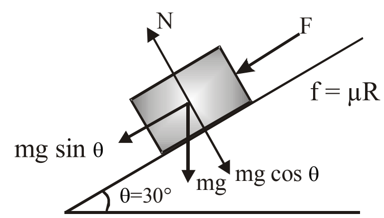
Example 20 :

A block of mass 2 kg slides down an inclined plane which makes an angle of 30° with the horizontal. The coefficient of friction between the block and the surface is $\sqrt{3}/2$.

(i) What force must be applied to the block so that the block moves down the plane without acceleration?

(ii) What force should be applied to the block so that it can move up without any acceleration?

Sol. Make a 'free-body' diagram of the block. Take the force of friction opposite to the direction of motion.

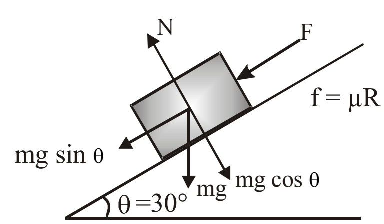


(i) From FBD

perpendicular to plane $N = mg\cos\theta$

along the plane $F + mg\sin\theta - f = 0$

($\because$ there is no acceleration along the plane)



$F + mg\sin\theta - \mu N = 0$

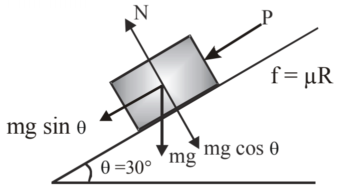
or $F + mg\sin\theta = \mu\, mg\cos\theta$

$F = mg(\mu\cos\theta - \sin\theta)$

$= 2 \times 9.8\left(\frac{\sqrt{3}}{2}\cos 30° - \sin 30°\right)$

$= 19.6\left(\frac{\sqrt{3}}{2} \times \frac{\sqrt{3}}{2} - \frac{1}{2}\right) = 19.6\left(\frac{3}{4} - \frac{1}{2}\right) = 4.9\text{N}$

(ii) This time the direction of F is reversed and that of the frictional force is also reversed.

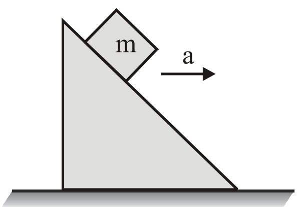


$N = mg\cos\theta$; $F = mg\sin\theta + f$

$$F = mg(\mu\cos\theta + \sin\theta) = 19.6\left(\frac{3}{4}+\frac{1}{2}\right) = 24.5N$$

Example 21 :

A block of mass 1 kg sits on an incline as shown in figure.



(a) What must be the frictional force between block and incline if the block is not to slide along the incline when the incline is accelerating to the right at 3 m/s^2 ?

(b) What is the least value μ_s can have for this to happen?

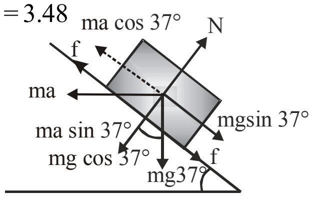
Sol. $N = m(g\cos 37° + a\sin 37°) = 1(9.8\times 0.8 + 3\times 0.6)$

& $mg\sin 37° = ma\sin 37° + f$

(a) $f = 1(9.8\times 0.8 - 3\times 0.8) = 3.48$

(b) $f = \mu N$

$$\therefore\ \mu = \frac{f}{N} = \frac{3.48}{9.64} = 0.36$$



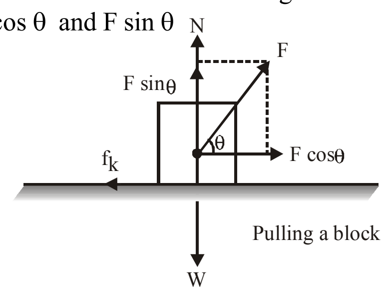
PULLING IS EASIER THAN PUSHING

Case of pulling :

Force F is applied to pull a block of weight W.

F can be resolved into two rectangular components:

$F\cos\theta$ and $F\sin\theta$



the normal reaction $N = W - F\sin\theta$

Force of kinetic friction

$f_k = \mu_k N$

$f_k = \mu_k (W - F\sin\theta)$ ....(i)

Case of pushing :

Force F is applied to push a block

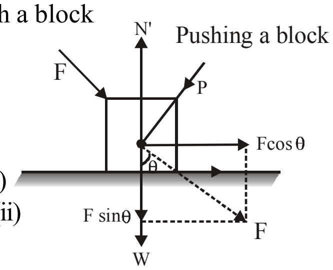
Normal reaction

$N' = W + F\sin\theta$

Force of kinetic reaction

$f'_k = \mu_k N'$

or $f'_k = \mu_k (W + F\sin\theta)$ .....(ii)



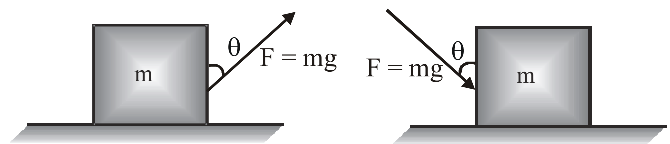
By (i) and (ii)

$f'_k > f_k$

The frictional force is more in the case of push. Hence it is easier to pull than to push a body.

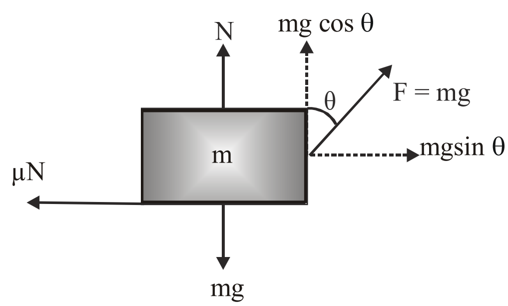
Example 22 :

A block of mass m rests on a rough horizontal surface as shown in figure (a) and (b). Coefficient of friction between block and surface is μ. A force F == mg acting at an angle θ with the vertical side of the block. Find the condition for which block will move along the surface.



(a) (b)

Sol. **For (a) :** Vertical component of force will decrease the weight as well as the normal reaction,



$N = mg - mg\cos\theta$

frictional force $= \mu N = \mu(mg - mg\cos\theta)$

Now block can be pulled when : Horizontal component of force ≥ frictional force

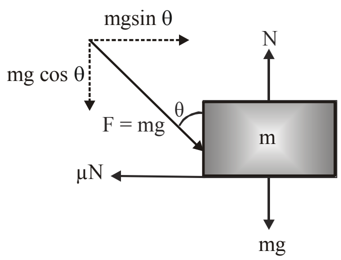
i.e. $mg\sin\theta \geq \mu(mg - mg\cos\theta)$

or $2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq \mu(1-\cos\theta)$ or $2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq 2\mu\sin^2\frac{\theta}{2}$

or $\cot\frac{\theta}{2} \geq \mu$

For (b) : Vertical component of the force increases the normal reaction i.e.

$N = mg + mg\cos\theta = mg(1+\cos\theta)$



Hence, block can be pushed along the horizontal surface when horizontal component of force ~ frictional force

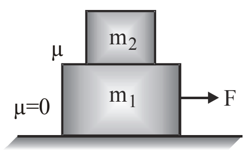
i.e. $mg \sin\theta \geq \mu\, mg\,(1 + \cos\theta)$

or $\quad 2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq \mu \times 2\cos^2\frac{\theta}{2} \Rightarrow \tan\frac{\theta}{2} \geq \mu$

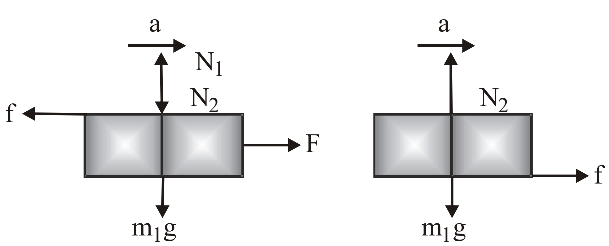
$\Rightarrow \cot\frac{\theta}{2} \geq \mu$

Example 23 :

When force F applied on m_1 and there is no friction between m_1 and surface and the coefficient of friction between m_1 and m_2 is μ. What should be the minimum value of F, so that there is no relative motion between m_1 and m_2.



Sol. For m_1, For m_2,



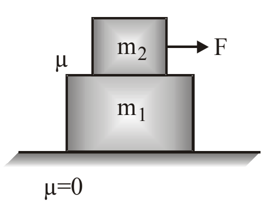
For system acceleration, $a = \dfrac{F}{m_1 + m_2}$

For m_2, $f = m_2 a \Rightarrow \mu m_2 g = m_2\left(\dfrac{F}{m_1 + m_2}\right)$

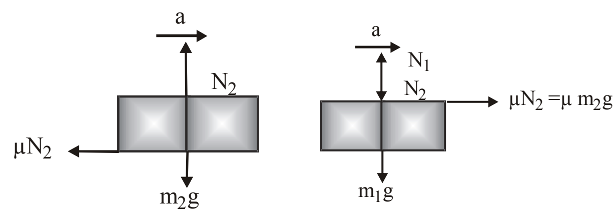
$\Rightarrow F_{min} = \mu\,(m_1 + m_2)\,g$

Example 24 :

When force F applied on m_2 and there is no friction between m_1 and surface and the coefficient of friction between m_2 and m_2 is μ. What should be the minimum value of F so that there is no relative motion between m_1 and m_2.



Sol. For m_2 For m_1



for system, acceleration, $a = \dfrac{F}{m_1 + m_2}$

For m_1, $\mu m_2 g = m_1 a = m_1\left(\dfrac{F}{m_1 + m_2}\right)$

$\Rightarrow F_{min} = (m_1 + m_2)\left(\dfrac{\mu m_2 g}{m_1}\right)$

PULLEY'S PROBLEMS WITH FRICTION

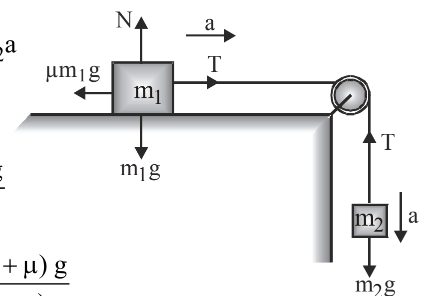
Case-I : For mass m_1

$T - \mu m_1 g = m_1 a$

For mass m_2

$m_2 g - T = m_2 a$

On solving,



$a = \dfrac{(m_2 - \mu m_1)g}{(m_1 + m_2)}$

$\Rightarrow T = \dfrac{m_1 m_2 (1 + \mu)\,g}{(m_1 + m_2)}$

Case-II :

For mass m_1

$m_1 g - T = m_1 a$ .... (i)

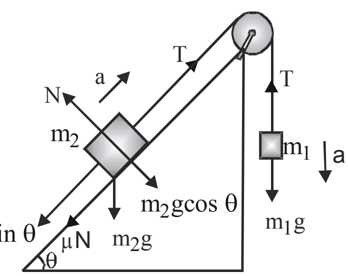
For mass m_2

$N = m_2 g \cos\theta$

$\mu N = \mu m_2\, g \cos\theta \quad m_2 g \sin\theta$

$T - m_2 g \sin\theta$

$-\mu m_2\, g\cos\theta = m_2 a$ .... (ii)



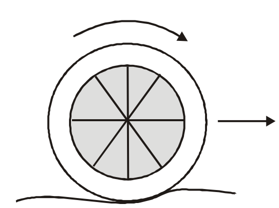
On solving (i) & (ii),

$$a = \left[\frac{m_1 - m_2(\sin\theta + \mu\cos\theta)}{(m_1 + m_2)}\right] g$$

ROLLING FRICTION

When a body rolls on a surface, the resistance offered by the surface is called rolling friction.

If a body rolls over the surface of another body,


Cause of rolling friction

then both the rolling body and the surface on which it rolls are compressed by a small amount. The rolling body has to continuously climb a hill. as shown in figure.

The rolling body has to continuously detach itself from the surface on which it rolls. This is opposed by the adhesive force between the two surfaces in contact and hence a force originates which retards the rolling motion. This retarding force is called the rolling friction. It is denoted by f_r.

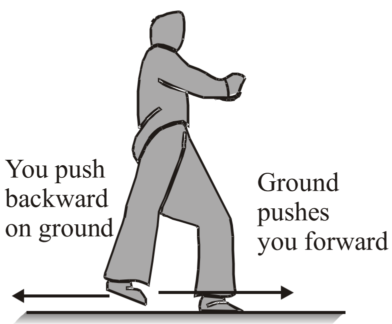
Comparison: For the same magnitude of normal reaction, the sliding friction is much greater than the rolling friction.

Ex. : The sliding friction of steel on steel is 100 times more than the rolling friction of steel on steel.

Note : Friction has advantages as well as disadvantages. In other words, friction is not desirable but without friction, we cannot think of survival, so we can say that "friction is a necessary evil".

* In some cases friction acts as a supporting force and in some cases it acts as opposing force.

(a) Supporting: Walking process can only take place because there is friction between the shoes and ground.

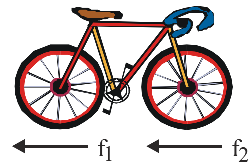


(b) Opposing: When a block slides over a surface the force' of friction acts as an opposing force in the opposite direction of the motion

(c) Both Supporting and Opposing :

(i) Pedaling: In the cycling, rear wheel move by the force communicated to it by pedaling, while front wheel moves by itself, therefore, like in walking force of friction on rear wheel is in forward direction and acts as a supporting force. As front wheel moves by itself, force of friction on front wheel is in the backward direction (nature opposing force).

(ii) Non-Pedaling : When pedaling is stopped, both the wheels moves by themselves so the force of friction on both the wheels is in backwards direction.



Disadvantages :

(i) A significant amount of energy of a moving object is wasted in the form of heat energy to overcome the force of friction.

(ii) The force of friction restricts the speed of moving vehicles like buses, trains, aeroplanes, rockets etc.

(iii) The efficiency of machines decreases due to the presence of force of friction.

(iv) The force of friction causes lot of wear and tear in the moving parts of a machine.

(v) Sometimes, a machine gets burnt due to the force friction between different moving parts.

Advantages :

(i) The force of friction helps us to move on the surface of earth. In the absence of friction, we cannot think of walking on the surface.

(ii) The force of friction between the tip of a pen and the surface of paper helps us to write on the paper.
It is not possible to write on the glazed paper as there is not force of friction.

(iii) The force of friction between the tyres of a vehicle and the road helps the vehicle to stop when brake is applied. In the absence of friction, the vehicle skid off the road. when brake is applied.

(iv) Moving belts remain on the rim of a wheel because of friction.

(v) The force of friction between a chalk and the black board helps us to write on the board.
Thus, we observe that inspect of various disadvantages of the friction, it is very difficult to part with it. So, friction is a necessary evil.

Methods of reducing friction :

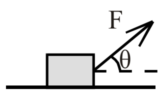
* By polishing the surface. (But extra polishing increase friction)
* By lubrication.
* By proper selection of material.
* By avoiding moisture.
* By use of alloys.
* By streamlining the shape.
* By using ball bearing or roller bearings.

TRY IT YOURSELF-2

Q.1 You are pushing a wooden crate across the floor at constant speed. You decide to turn the crate on end, reducing by half the surface area in contact with the floor. In the new orientation, to push the same crate across the same floor with the same speed, the force that you apply must be about

(A) four times as great as the force required before you changed the crate's orientation.
(B) twice as great as the force required before you changed the crate's orientation.
(C) equally great as the force required before you changed the crate's orientation.
(D) half as great as the force required before you changed the crate's orientation.

Q.2 A mass m has a force F applied to it as shown

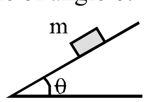


(A) The normal force on the block will be mg.
(B) The acceleration of the block will be a function of F only.
(C) If there was kinetic friction acting on the block, it would be directed toward the left.
(D) None of the above.

Q.3 An object is held in place by friction on an inclined surface. The angle of inclination is increased until the object starts moving. If the surface is kept at this angle, the object

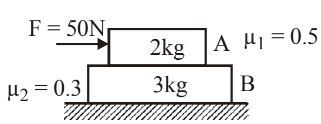
(A) slows down (B) moves at uniform speed.
(C) speeds up. (D) none of the above

Q.4 A mass m sits on a frictionless incline plane of angle θ.



(A) The acceleration of mass m will be g.
(B) The acceleration of mass m will be dependent upon the size of the mass.
(C) The acceleration of mass m will be dependent upon θ.
(D) All of the above.

Q.5 (i) From the figure shown, find out acceleration of 3 kg block.

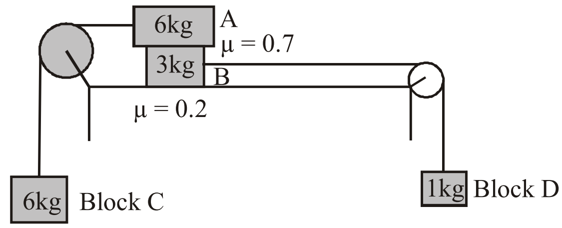


(A) 7 m/s^2
(B) 10 m/s^2
(C) 10/3 m/s^2
(D) zero

(ii) In the above question if the external force is applied on 3 kg block, then acceleration of the 3 kg block will be

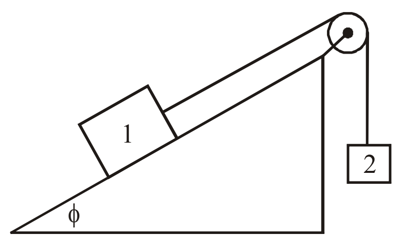
(A) 40/3 m/s^2 (B) 25/3 m/s^2
(C) 35/3 m/s^2 (D) none of these

Q.6 An arrangement of the masses and pulleys is shown in the figure. Strings connecting masses A and B with pulleys are horizontal and all pulleys and strings are light. Friction coefficient between the surface and the block B is 0.2 and between blocks A and B is 0.7. The system is released from rest. (use g = 10 m/s^2)



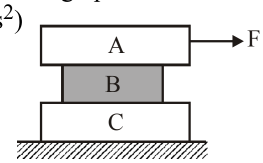
(A) The magnitude of acceleration of the system is 2 m/s^2 and there is no slipping between block A and block B.
(B) The magnitude of friction force between block A and block B is 42 N.
(C) Acceleration of block C is 1 m/s^2 downwards.
(D) Tension in the string connecting block B and block D is 12 N.

Q.7 A block of mass m_1, constrained to move along a plane inclined at angle ϕ to the horizontal, is connected via a massless inextensible rope that passes over a massless pulley to a bucket to which sand is slowly added. The coefficient of static friction is μ_s. Assume the gravitational constant is g . What happens to the tension in the string just after the block begins to slip upward?



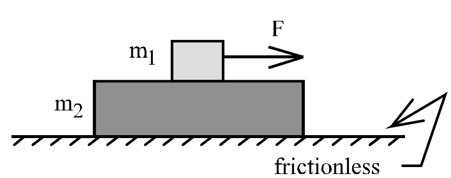
(A) Increases (B) Decreases
(C) Stays the same (D) Oscillates

Q.8 Given $m_A = 30$ kg, $m_B = 10$ kg, $m_C = 20$ kg. Between A and B friction coefficient $\mu_1 = 0.3$, between Band C friction coefficient $\mu_2 = 0.2$ and between C and ground $\mu_3 = 0.1$. The least horizontal force F to start the motion of any part of the system of three blocks resting upon one another as shown in figure is (g = 10 m/s^2)



(A) 60 N
(B) 90 N
(C) 80 N
(D) 150 N

Q.9 A mass m_1 sits on top of a second mass m_2 which sits on a frictionless surface. The coefficient of static friction between the two is 0.7. A force F is applied to the top mass (m_1).



(A) The maximum force F that m_1 can experience without slipping over m_2 is $\mu_s m_1 g$.
(B) The maximum force m_1 can experience without slipping over m_2 is $2\mu_s m_1 g$.
(C) The maximum force m_2 can experience without slipping relative to m_1 is $\mu_s m_1 g$.
(D) Both (B) and (C).

ANSWERS

(1) (C)	**(2)** (D)	**(3)** (C)
(4) (C)	**(5)** (i) (D), (ii) (B)	**(6)** (AD)
(7) (B)	**(8)** (A)	**(9)** (D)

ADDITIONAL EXAMPLES

Example 1 :

A 600 kg rocket is set for a vertical firing. If the exhaust speed is 1000 m/s. Then calculate the mass of gas ejected per second to supply the thrust needed to overcome the weight of rocket.

Sol. Force required to overcome the weight of rocket

$F = mg$ and thrust needed $= v\dfrac{dm}{dt}$, so $v\dfrac{dm}{dt} = mg$

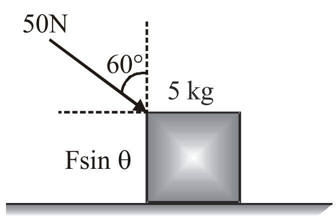
$\Rightarrow \dfrac{dm}{dt} = \dfrac{mg}{v} = \dfrac{600 \times 9.8}{1000} = 5.88$ kg/s

Example 2 :

A force of 50N acts in the direction as shown in figure. The block of mass 5 kg, resting on a smooth horizontal surface. Find out the acceleration of the block.

Sol. Horizontal component of the force

$= F \sin\theta$



$= 50 \sin 60° = \dfrac{50\sqrt{3}}{2}$

Acceleration of the block

$a = \dfrac{F\sin\theta}{m} = \dfrac{50\sqrt{3}}{2} \times \dfrac{1}{m}$

$= 5\sqrt{3}\ \text{m/s}^2$

Example 3 :

A cricket ball of mass 150g is moving with a velocity of 12m/s and is hit by a bat so that the ball is turned back with a velocity of 20m/s. If the duration of contact between the ball and bat is 0.01s, find their impulse and the average force exerted on the ball by the bat.

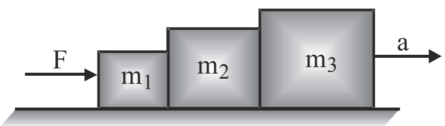
Sol. $\Delta p = p_f - p_i = m(v - u) = 150 \times 10^{-3}\,[20 - (-12)]$

So by time averaged definition of force in case of impulse

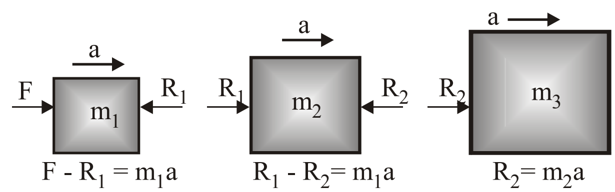
$F_{av} = \dfrac{I}{\Delta t} = \dfrac{\Delta p}{\Delta t} = \dfrac{4.80}{0.01} = 480\text{N}$

Example 4 :

Three blocks of masses $m_1 = 1$ kg, $m_2 = 1.5$ kg and $m_3 = 2$kg are in contact with each other on a frictionless surface as shown in figure. Find (a) horizontal force F needed to push the block as on unit with an acceleration of 4 m/s^2 (b) The resultant force on each block and (c) The magnitude of contact force between blocks.



Sol. (a) $F = (m_1 + m_2 + m_3)\, a$
$= (1 + 1.5 + 2) \times 4 = 4.5 \times 4 = 18$ N



(b) For m_1 $\quad F - R_1 = m1a = 1 \times 4$

$\Rightarrow F - R_1 = 4$ .... (i)

For m_2, $R_1 - R_2 = m_2 a = 1.5 \times 4 = 6$

$\Rightarrow R_1 - R_2 = 6\text{N}$ .... (ii)

For m_3, $R_2 = m_3 a = 2 \times 4$

$\Rightarrow R_2 = 8\text{N}$ .... (iii)

(c) Contact force between m_2 and $m_3 = R_2 = 8\text{N}$

Contact force between m_1 and m_2

$R_1 = R_2 + 6 = 8 + 6 = 14$ N

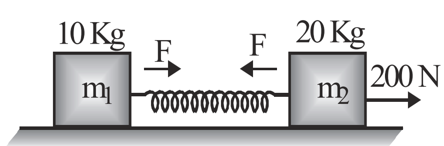
Example 5 :

Two masses 10 kg and 20 kg respectively are connected by a massless spring as shown in figure force of 200N acts on the 20 kg mass. At the instant shown in figure the 10 kg mass has acceleration of 12 m/s^2, what is the acceleration of 20 kg mass

Sol. Force equation for m_1 (= 10 kg) mass is

$F = m_1 a_1 = 10 \times 12 = 120$ N

Force on 10 kg mass is 120 N to the right.



As action and reaction are equal and opposite, the reaction force F on 20 kg mass F = 120 N to the left.

Equation of motion of mass $m_2 = 10$ kg is

$200 - F = 20a_2$

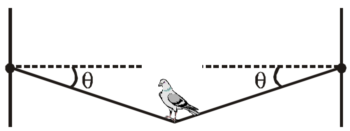
$\Rightarrow 200 - 120 = 20a_2 \Rightarrow 20a_2 = 80$

$\Rightarrow a_2 = \dfrac{80}{20} = 4\ \text{m/s}^2$

Example 6 :

A bird with mass m perches at the middle of a stretched string. Show that the tension in the string is given by

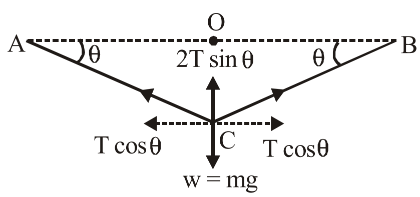
$T = \dfrac{mg}{2\sin\theta}$. Assume that each half of the string is straight.



Sol. Initial position of wire = AOB.

Final position of wire = ACB.

Let θ be the angle made by wire with horizontal, which is very small.



Resolving tension T of string in horizontal and vertical directions, we note that the horizontal components cancel while vertical components add and balance the weight.

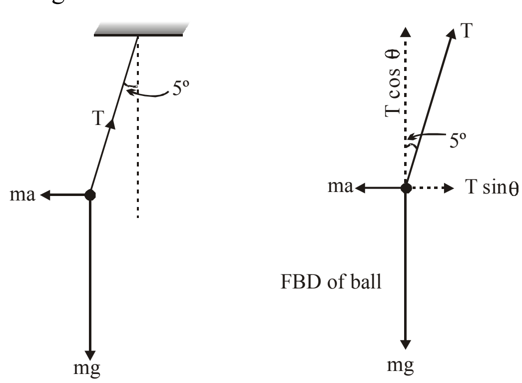
For equilibrium, $2T\sin\theta = W = mg$

$$\therefore \quad T = \frac{W}{2\sin\theta}$$

Example 7 :

A passenger on a large ship sailing in a quiet sea hangs a ball from the ceiling of her cabin by means of a long thread. Whenever the ship accelerates, he notes that the pendulum ball lags behind the point of suspension and so the pendulum no longer hangs vertically. How large is the ship's acceleration when the pendulum stands at an angle of 5° to the vertical ?

Sol. See figure.



The ball is accelerated by the force T sin 5°.

Therefore $T\sin 5° = ma$.

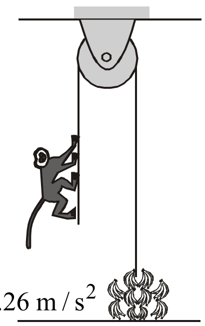
Vertically $\Sigma F = 0$, so $T\cos 5° = mg$.

Solving for $a = g\tan 5°$ gives,

$a = 0.0875g = 0.86\ m/s^2$

Example 8 :

A 12 kg monkey climbs a lift rope as shown in figure. The rope passes over a pulley and is attached to a 16 kg bunch of bananas. Mass and friction in the pulley are negligible so that the pulley's only effect is to reverse the direction of the rope. What is the maximum acceleration the monkey can have without lifting the bananas ?



Sol. Effective weight of monkey

$W_m = M_m(g + a)$

As per given condition

$W_m = M_b$

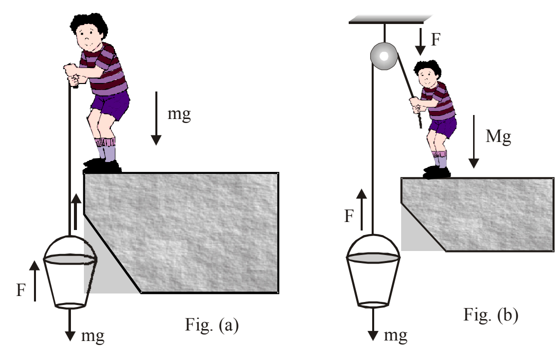
$\Rightarrow M_m(g + a) = M_b\, g$

$\Rightarrow a = \dfrac{(M_b - M_m)g}{M_m}$

$= \left(\dfrac{16-12}{12}\right) \times 9.8 \Rightarrow a = \dfrac{9.8}{3} = 3.26\ m/s^2$

Example 9 :

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



Sol. Mass of block, m = 25 kg, mass of the man, M = 50 kg

Force applied to lift the block, $F = mg = 25 \times 9.8 = 245$ N

Weight of the man, $mg = 50 \times 9.8 = 490$ N

(a) When the block is raised by the man by applying force F in upward direction, reaction equal and opposite to F will act on the floor in addition to the weight of the man.

$\therefore$ Action on the floor $Mg + F = 490 + 245 = 735$ N

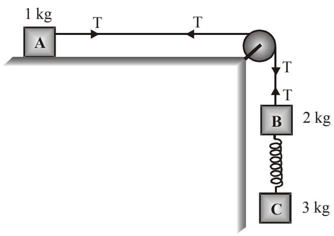
(b) When the blocks is raised by the man applying force F over the rope (passed over the pulley) in downward direction, reaction equal and opposite to F will act on the floor,

$\therefore$ Action on the floor, $Mg - F = 490 - 245 = 245$ N

Floor yields to a normal force of 700 N, the mode (b) should be adopted by the man to lift block.

Example 10 :

In the system shown in figure all surface are smooth, string is massless and inextensible. Find :

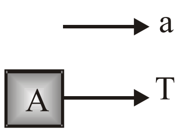


(a) acceleration of the system. (b) tension in the string and (c) extension in the string if force constant of spring is $k = 50$ N/m (Take $g = 10\ m/s^2$)

Sol. (a) In this case net pulling force is $m_c g + m_B g$ or 50N and total mass to be pulled is (1 + 2 + 3) kg of 6 kg.

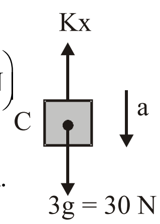
$\therefore$ Acceleration of the system is $a = \frac{50}{6}\ m/s^2$

(b) Free body diagram of 1 kg block gives



$$T = ma = (1)\left(\frac{50}{6}\right)N = \frac{50}{6}N$$

(c) Free body diagram of 3 kg block gives

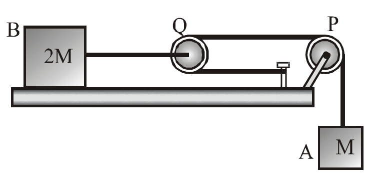


$$30 - kg = ma \qquad \left(ma = 3 \times \frac{50}{6} = 25N\right)$$

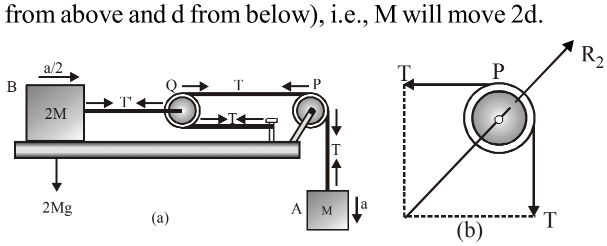
$$x = \frac{30-25}{k} = \frac{5}{50} = 0.1\ m\ ;\ x = 10\ cm.$$

Example 11:

Consider the situation shown in figure (A). Both the pulleys and the strings are light and all the surfaces are frictionless. Calculate (a) the acceleration of mass M, (b) tension in the string PQ and (c) force exerted by the clamp on the pulley P.



Sol. As pulley Q is not fixed so if it moves a distance d the length of string between P and Q will changes by 2d (d from above and d from below), i.e., M will move 2d.



This in turn implies that if a ($\rightarrow$ 2d) is the acceleration of M the acceleration of Q and of 2M will be $\frac{a}{2}(\rightarrow d)$.

Now if we consider the motion of mass M, it is accelerated downward, so $\quad T = M(g - a)$ .... (i)

And for the motion of Q,

$$2T - T' = 0 \times \frac{a}{2} = 0 \text{ i.e. } \quad T' = 2T \qquad \text{........ (ii)}$$

And for the motion of 2M,

$$2M - T' = 2M\frac{a}{2} = 0 \text{ i.e. } \quad T' = Ma \qquad \text{........ (iii)}$$

(a) From eq^n. (ii) and (iii) as $T = \frac{1}{2}Ma$,

so eq^n (i) reduces to $T = \frac{1}{2}Ma = M(g - a)$ or $a = \frac{2}{3}g$

(b) So the acceleration of mass M is $\frac{2}{3}g$ while tension in the string PQ from eq^n (1) will be,

$$T = M\left(g - \frac{2}{3}g\right) = \frac{1}{3}Mg$$

(c) Now from fig. (b), it is clear that force on pulley by the clamp will be equal and opposite to the resultant of T and T at 90° to each other, i.e.,

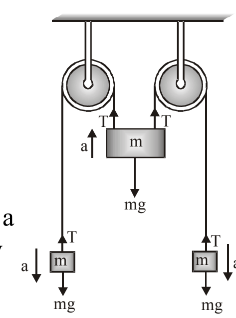
$$(R_2) = \sqrt{T^2 + T^2} = \sqrt{2}T = \frac{\sqrt{2}}{3}Mg$$

Example 12 :

Consider the double Atwood's machine as shown in the fig.

(a) What is acceleration of the masses ?

(b) What is the tension in each string ?



Sol. (a) Here the system behaves as a rigid system, therefore every part of the system will move with same acceleration.

Thus applying newton's law

$mg - T = ma$ .... (i)

$2T - mg = ma$ .... (ii)

Doubling the first equation and adding, $mg = 3ma$ or acceleration $a = (1/3)\ g$

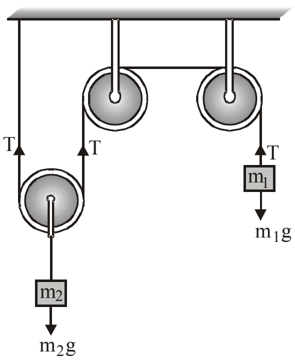
(b) Tension in the string

$$T = m(g - a) = m\left(g - \frac{g}{3}\right)$$

$$T = \frac{2}{3}mg$$

Example 13 :

Consider the system of masses and pulleys shown in figure with massless string and frictionless pulleys.



(a) Give the necessary relation between m_1 and m_2 such that system is in equilibrium and does not move.

(b) If $m_1 = 6$ kg and $m_2 = 8$ kg. calculate the magnitude and direction of the acceleration of m_1.

Sol. (a) Applying newton's law, $m_2g - 2T = 0$

(because there is no acceleration) and $T - m_1g = 0$

$(m_2 - 2m_1)g = 0 \Rightarrow m_2 = 2m_1$

(b) If the upwards acceleration of m_1 is a, then acceleration of m_2 is a/2 downwards for mass m_2.

$m_2g - 2T = m_2(a/2)$; $2m_2g - 4T = m_2a$

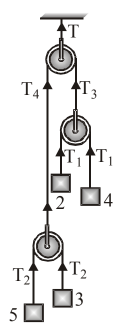
For mass m_1 : $T - m_1g = m_1a$

$$\Rightarrow \quad a = \left(\frac{2m_2 - 4m_1}{m_2 + 4m_1}\right) g = \frac{2\,(8-12)}{8+24} g = -\frac{g}{4}$$

–ve sign shows that acceleration is opposite to considered direction i.e. it is downwards for m_1 and upwards for m_2.

Example 14 :

In the given figure if $T_1 = 2T_2 = 50$N then find the value of T.



Sol. As given in figure,

$T_3 = 2T_1 = 2\,(2T_2) = 4T_2$

and $T4 = 2T2$

$\therefore \quad T = T_3 + T_4 = 4T_2 + 2T_2 = 6T_2$

$$= 6 \times \frac{50}{2} = 150 \text{ N}$$

Example 15 :

A body of mass M is kept on a rough horizontal surface (friction coefficient = μ). A person is trying to pull the body by applying a horizontal force F, but the body is not moving. What is the force by the surface on A.

Sol. Let f is the force of friction and N is the normal reaction, then the net force by the surface on the body is

$$F = \sqrt{N^2 + f^2}$$

Let the applied force is F ' (varying), applied horizontally then $f \le \mu_s N$ (adjustable with f = F ').

Now if F ' is zero, f = 0 and $F_{min} = N = Mg$

and when F ' is increased to maximum value permissible for no motion $f = \mu_s N$,

giving $F_{max} = \sqrt{N^2 + \mu_s^2 N^2} = Mg\sqrt{1+\mu_s^2}$

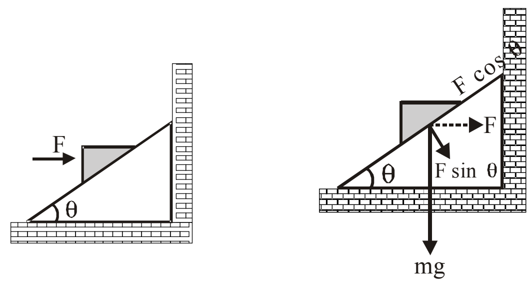
therefore we can $Mg \le F \le Mg\sqrt{1+\mu_s^2}$

Example 16 :

A block rest on a rough inclined plane as shown in fig. A horizontal force F is applied to it (a) Find out the force of reaction, (b) Can the force of friction be zero if yes when? and (c) Assuming that friction is not zero find its magnitude and direction of its limiting value.

Sol. (a) $N = mg\cos\theta + F\sin\theta$

(b) Yes, if mg mg $\sin\theta = F\cos\theta$

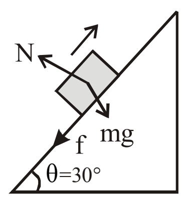


(c) $f = \mu R = \mu\,(mg\cos\theta + F\sin\theta)$; up the plane if the body has tendency to slide down and down the plane if the body has tendency to move up.

Example 17 :

A body of mass 5×10^{-3} kg is launched up on a rough inclined plane making an angle of 30° with the horizontal. Obtain the coefficient of friction between the body and the plane if the time of ascent is half of the time of descent.

Sol. For upward motion.



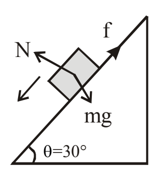
length of plane = s
time of ascent = t_1

$a_1 = g\,(\sin\theta + \mu\cos\theta)$

$a_1 = g\,(\sin 30° + \mu\cos 30°) \;= (1+\sqrt{3}\mu)\dfrac{g}{2}$

$\because \quad s = \frac{1}{2}a_1t_1^2$; $t_1 = \sqrt{\dfrac{2s}{a_1}} = \sqrt{\dfrac{4s}{(1+\sqrt{3}\mu)g}}$

For downward motion, downward acceleration



time of descent = t_2

$a_2 = g\,(\sin\theta - \mu\cos\theta)$

$$a_1 = g(\sin 30° - \mu \cos 30°) = (1-\sqrt{3}\mu)\frac{g}{2}$$

$$\Rightarrow \quad t_2 = \sqrt{\frac{2s}{a_2}} = \sqrt{\frac{4s}{(1-\sqrt{3}\mu)g}}$$

Now according to question, $2t_1 = t_2$

$$\Rightarrow \quad 2\sqrt{\frac{4s}{(1+\sqrt{3}\mu)g}} = \sqrt{\frac{4s}{(1-\sqrt{3}\mu)g}} \Rightarrow \frac{1-\sqrt{3}\mu}{1+\sqrt{3}\mu} = \frac{1}{4} \Rightarrow \mu = \frac{\sqrt{3}}{5}$$

Example 18 :

A block of mass 2 kg rests on a plane inclined at an angle of 37° with the horizontal. The coefficient of friction between the block and the surface is 0.7. (i) What will be the frictional force acting on the block? (ii) What is th, force applied by inclined plane of block?

Sol. Since the block is at rest, the frictional force will be static. Normal reaction of the surface R = mg cos 30°

$\therefore$ limiting force of friction

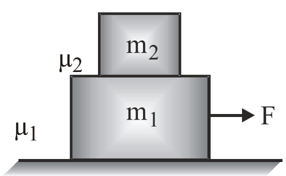
$$f_s = \mu_s N = \mu_s mg \cos 37° = 0.7 \times 2 \times 10 \times \frac{4}{5} = 11.2\text{N}$$

$\therefore$ mg sin 37° = 2 × 10 × (3/5) = 12 N

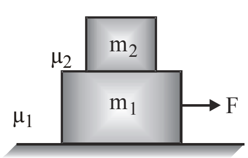
$\therefore$ force on friction = 11.2 N

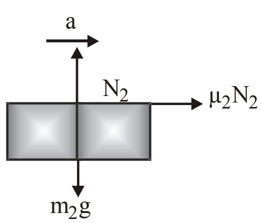
Example 19 :

When force F applied on m_1 and the coefficient of friction between m_1 and the coefficient of friction between m_1 and m_2 is μ_2. What should be the minimum value of F so that there is no relative motion between m_1 and m_2 .



Sol. For m_1 For m_2





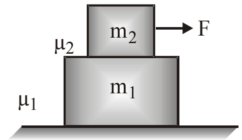
For system acceleration, $a = \dfrac{F - \mu_1(m_1+m_2)}{m_1+m_2}$

For $m_2 : \mu_2 = (m_2 g) \Rightarrow m_2 a = m_2\left(\dfrac{F-\mu_1(m_1+m_2)}{m_1+m_2}\right)$

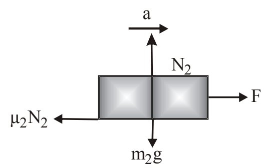
$$\Rightarrow \quad F_{min} = (m_1+m_2)(\mu_1+\mu_2)g$$

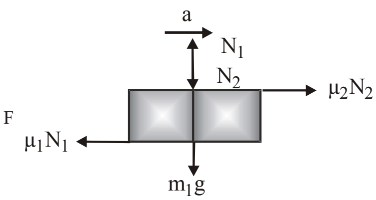
Example 20 :

When force F applied on m_2 and the coefficient of friction between mt and surface is μ_1 and the coefficient of friction between m_1 and m_2 is 2. What should be the minimum value of F so that there is no relative motion between m_1 and. m_2.



Sol. For m_2 For m_1





For system acceleration, $a = \dfrac{F - \mu_1(m_1+m_2)g}{m_1+m_2}$

For m_1, $\mu_2 m_2 g = \mu_1(m_1+m_2)g = m_1 a$

$$= m_2\left(\frac{F-\mu_1(m_1+m_2)}{m_1+m_2}\right)$$

$$\Rightarrow \quad F_{min} = \frac{m_2}{m_1}(\mu_2 m_2 - \mu_1 m_1 - \mu_1 m_2)g + \mu_2 m_2 g$$

Example 21 :

A book of 1 kg is held against a wall by applying a perpendicular force F. If $\mu_S = 0.2$ then what is the minimum value of F ?

Sol. The situation is shown in fig.

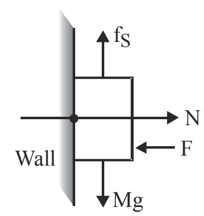
The forces acting on the book are

For book to be at rest it is essential

that $Mg = f_s$

But $f_{s\,max} = \mu_S N$ and N = F

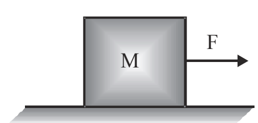
$\therefore$ $Mg = \mu_S F$



$$F = \frac{Mg}{\mu_s} = \frac{1 \times 9.8}{0.2} = 49\text{ N}$$

Example 22 :

For the block and surface shown in fig. $\mu_s = 0.5$, $\mu_k = 0.3$, mass M = 50 kg and F = 600 N Then what is its acceleration? (Take g = 10 m/s)



Sol. The forces acting on the block are shown in fig. Since

$F_s = \mu_s N = 0.5 \times 50 \times 10 = 250$ N

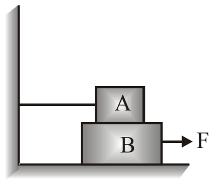
Since, $F > f_{s\,max}$ so the block is in motion.

Acceleration of block

$$= \frac{\text{Net force}}{\text{total mass}} = \frac{600 - 0.3(50 \times 10)}{50} = 9 \text{ m/s}^2$$

Example 23 :

A is a 100 kg block and B is a 200 kg block. As shown in fig., the block A is attached to a string tied to a wall. The coefficient of friction between A and B is 0.2 and the coefficient of friction between B and floor is 0.3. Then calculate the minimum force required to move the block B. (take g =10 m/s^2).

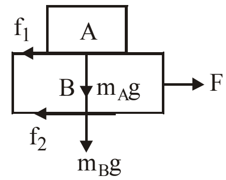


Sol. When B is tied to move, by applying a force F, then the frictional forces acting on the block Bare f_1 and f_2 with limiting values,

$f_1 = (\mu_S)_A m_A g$

and $f_2 = (\mu_S)_B (m_A + m_B)g$

Thep minimum value of F should be (for just tending to move),

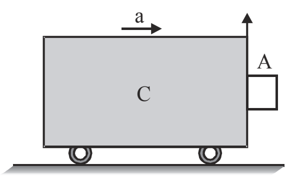


$F = f_1 + f_2$

$= 0.2 \times 100\,g + 0.3 \times 300\,g = 110\,g = 1100\,N$

Example 24 :

Consider the figure shown here of a moving cart C. If the coefficient of friction between the block A and the cart is μ, then calculate the minimum acceleration a of the cart C so that the block A does not fall.

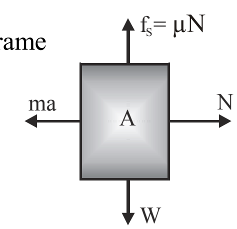


Sol. The forces acting on the block A (in block A's frame (i.e. non inertial frame)) are:

For A to be at rest in block A's frame i.e. no fall, we require

$W = f_L \Rightarrow m\,g = \mu\,(m\,a)$

Thus, $a = \dfrac{g}{\mu}$



Example 25 :

A block of mass 1kg lies on a horizontal surface in a truck, the coefficient of static friction between the block and the surface is 0.6, What is the force of friction on the block. If the acceleration of the truck is 5 m/s^2.

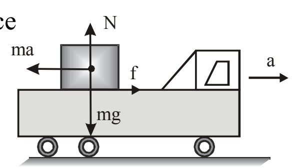
Sol. Fictitious force on the block opposite to the acceleration of the block $F = ma = 1 \times 5 = 5N$

While the limiting friction force

$F = \mu_s N = \mu_s mg$

$= 0.6 \times 1 \times 9.8$

$= 5.88$ newton



As applied force F lesser than limiting friction force.

The block will remain at rest in the truck and the force of friction will be equal to 5N and in the direction of acceleration of the truck.

Example 26 :

The force F_1 that is necessary to move a body up an inclined plane is double the force F_2 that is necessary to just prevent it from sliding down, then choose the correct options –

Where φ = angle of friction; θ = angle of inclined plane; w = weight of the body.

(1) $F_2 = w \sin(\theta - \phi) \sec\phi$

(2) $F_1 = w \sin(\theta - \phi) \sec\phi$

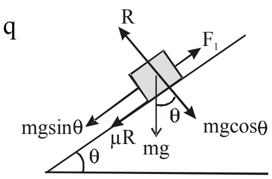
(3) $\tan\phi = 3\tan\theta$

(4) $\tan\theta = 3\tan\phi$

(A) 1, 4 (B) 1, 2

(C) 1, 3, 4 (D) all

Sol. **(A).** $F_1 = mg\sin\theta + \mu mg\cos\theta$

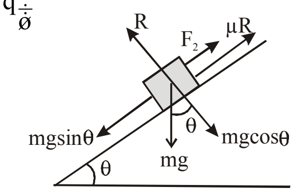


$F_2 = mg\sin\theta - \mu mg\cos\theta$

But, $mg = w$

$\mu = \tan\phi$

$\therefore\ F_1 = w\left(\sin\theta + \dfrac{\sin\phi}{\cos\phi}\cos\theta\right)$



$\Rightarrow\ F_1 = w\sin(\theta + \phi)\sec\phi$

$\therefore$ Now, $F_1 = 2F_2$

$mg\sin\theta + \mu mg\cos\theta$

$= 2\,(mg\sin\theta - \mu mg\cos\theta)$

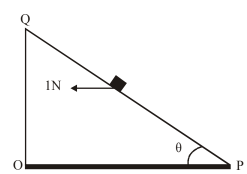
$\sin\theta + \mu\cos\theta = 2\sin\theta - 2\mu\cos\theta$

$\Rightarrow 3\mu\cos\theta = \sin\theta$

$\Rightarrow \tan\theta = 3\mu \Rightarrow\ \tan\theta = 3\tan\phi$

Example 27 :

A small block of mass of 0.1 kg lies on a fixed inclined plane PQ which makes an angle θ with the horizontal. A horizontal force of 1 N actson the block through its center of mass as shown in the fig. The block remains stationary if (take g=10 m/s^2)



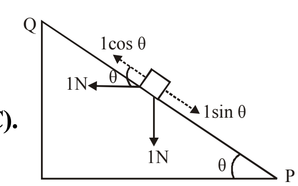
(A) θ = 45°

(B) θ > 45° & a frictional force acts on the block towards P

(C) θ > 45° & a frictional force acts on the block towards Q

(D) θ < 45° & a frictional force acts on the block towards Q

Sol. **(AC).**



(1) If sin θ = cos θ ⇒ θ = 45° ⇒ no friction will act and the block will remain at rest.

(2) If sin θ > cos θ ⇒ θ > 45° ⇒ friction will act towards Q

(3) If sin θ < cos θ ⇒ θ < 45° ⇒ friction will act towards P

QUESTION BANK

CHAPTER 5 : NEWTON'S LAWS OF MOTION AND FRICTION

EXERCISE - 1 [LEVEL-1]

Choose one correct response for each question.

PART - 1 : NEWTON'S FIRST LAW

Q.1 Choose the correct options –

(A) A reference frame in which Newton's first law is valid is called an inertial reference frame.

(B) Frame moving at constant velocity relative to a known inertial frame is also an inertial frame.

(C) Ideally, no inertial frame exists in the universe for practical purpose, a frame of reference may be considered as inertial if its acceleration is negligible with respect to the acceleration of the object to be observed.

(D) All of these

Q.2 Newton's first law of motion describes the following

(A) Energy (B) Work

(C) Inertia (D) Moment of inertia

Q.3 A particle is moving with a constant speed along a straight line path. A force is not required to

(A) Increase its speed

(B) Decrease the momentum

(C) Change the direction

(D) Keep it moving with uniform velocity

Q.4 A body is imparted motion from rest to move in a straight line. If it is then obstructed by an opposite force, then –

(A) The body may necessarily change direction.

(B) The body is sure to slow down

(C) The body will necessarily continue to move in the same direction at the same speed.

(D) None of these

Q.5 A car is moving with uniform velocity on a rough horizontal road. Therefore, according to Newton's first law of motion

(A) No force is being applied by its engine

(B) A force is surely being applied by its engine

(C) An acceleration is being produced in the car

(D) The kinetic energy of the car is increasing.

PART - 2 : NEWTON'S SECOND LAW

Q.6 The linear momentum p of a body moving in one dimension varies with time according to the equation $p = a + bt^2$ where a and b are positive constants. The net force acting on the body is –

(A) A constant

(B) Proportional to t^2

(C) Inversely proportional to t

(D) Proportional to t

Q.7 A force of 100 dynes acts on a mass of 5 gram for 10 sec. The velocity produced is –

(A) 2000 cm/sec (B) 200 cm/sec

(C) 20 cm/sec (D) 2 cm/sec

Q.8 A player kicks a football of mass 0.5 kg and the football begins to move with a velocity of 10 m/s. If the contact between the leg and the football lasts for 1/50 sec, then the force acted on the football should be

(A) 2500 N (B) 1250 N

(C) 250 N (D) 625 N

Q.9 A body whose mass 6 kg is acted upon by two forces $(8\hat{i}+10\hat{j})$ N and $(4\hat{i}+8\hat{j})$ N. The acceleration produced will be - (in m/s^2)

(A) $(3\hat{i}+2\hat{j})$ (B) $12\hat{i}+18\hat{j}$

(C) $\frac{1}{3}(\hat{i}+\hat{j})$ (D) $2\hat{i}+3\hat{j}$

Q.10 A force of 2 N is applied on a particle for 2 sec, the change in momentum will be –

(A) 2 Ns (B) 4 Ns

(C) 6 Ns (D) 3 Ns

Q.11 A massive object is placed on a frictionless table. It takes 2 newtons of force to accelerate it at 0.5 m/s^2. The object is taken into space where it is weightless. The force required to accelerate the object at 0.5 m/s^2 will be

(A) less than 2N (B) equal to 2N

(C) more than 2 N (D) None of these

PART - 3 : NEWTON'S THIRD LAW

Q.12 When we jump out of a boat standing in water it moves

(A) Forward (B) Backward

(C) Sideways (D) None of the above

Q.13 Joanne exerts a force on a basketball as she throws the basketball to the east. Which of the following is always true?

(A) Joanne accelerates to the west.

(B) Joanne feels no net force because she and the basketball are initially the same object.

(C) The basketball pushes Joanne to the west.

(D) The magnitude of the force on the basketball is greater than the magnitude of the force on Joanne.

PART - 4 : IMPULSE

Q.14 A rocket-driven sled speeds up from 40 meters per second to 55 meters per second in 5.0seconds, using an engine that produces 3500newtons of thrust. How much thrust would be needed to get the same increase in speed in 2.0 seconds –

(A) 8550 (B) 8750

(C) 8700 (D) 8500

Q.15 A body of mass m collides against a wall with a velocity v and rebounds with the same speed. Its change of momentum

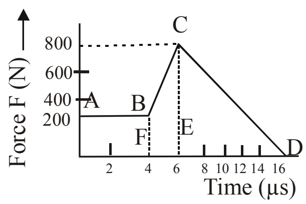
(A) 2 mv (B) mv

(C) – mv (D) Zero

Q.16 Raindrops of radius 1mm and mass 4 mg are falling with a speed of 30 m/s on the head of a bald person. The drops splash on the head and come to rest. Assuming equivalently that the drops cover a distance equal to their radii on the head, estimate the force exerted by each drop on the head.

(A) 1.8 N (B) 18 N
(C) 180 N (D) 3.6 N

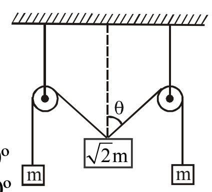
Q.17 The magnitude of the force (in Newtons) acting on a body varies with time t (in microseconds) as shown in fig. AB, BC, and CD are straight line segments. The magnitude of the total impulse of the force on the body from t = 4 μs to t = 16 μs is .... N-s.



(A) 5×10^{-4} N.s (B) 5×10^{-3} N.s
(C) 5×10^{-5} N.s (D) 5×10^{-2} N.s

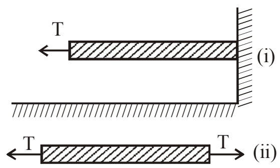
PART - 5 : EQUILIBRIUM

Q.18 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:



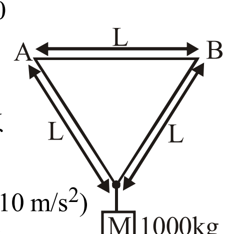
(A) 0º (B) 30º
(C) 45º (D) 60º

Q.19 In the figure (i) as extensible string is fixed at one end and the other end is pulled by a tension T. In figure (ii) another identical string is pulled by tension T at both the ends. The ratio of elongation in equilibrium of string in (i) to the elongation of string in (ii) is –



(A) 1 : 1 (B) 1 : 2
(C) 2 : 1 (D) 0

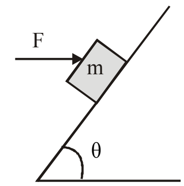
Q.20 In the following figure, the length of the rod AB is L. A weight of 1000 kg is suspended from its two ends with the help of two strings of length L. The tension in the rod AB will be ($g = 10\ m/s^2$)



(A) 5×10^3 N (B) $5 \times 10^3 \times \sqrt{3}$ N

(C) $\frac{5 \times 10^3}{\sqrt{3}}$ N (D) zero

Q.21 Find the magnitude of the horizontal force F required to keep the block of mass m stationary on the smooth inclined plane as shown in the figure.



(A) mg sin θ (B) mg cos θ
(C) mg tan θ (D) mg cot θ

PART - 6 : MOTION OF BODIES IN CONTACT OR CONNECTED BY STRINGS

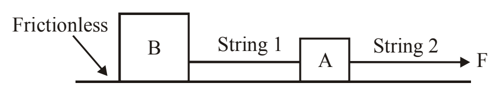
Q.22 The maximum tension a rope can withstand is 60 kg-wt. The ratio of maximum acceleration with which two boys of masses 20 kg and 30 kg can climb up the rope at the same time is

(A) 1 : 2 (B) 2 : 1
(C) 4: 3 (D) 3 : 2

Q.23 Two blocks of mass m = 1 kg and M = 2 kg are in contact on a frictionless table. A horizontal force F(= 3N) is applied to m. The force of contact between the blocks, will be-

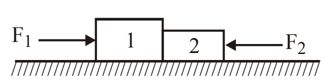
(A) 2 N (B) 1 N
(C) 4 N (D) 5 N

Q.24 In the situation below, a person pulls a string attached to block A, which is in turn attached to another, heavier block B via a second string. Assume the strings are massless and inextensible; and ignore friction. Is the magnitude of the acceleration of block A.



(A) greater than the magnitude of the acceleration of block B?
(B) equal to the magnitude of the acceleration of block B?
(C) less than the magnitude of the acceleration of block B?
(D) Do not have enough information to decide.

Q.25 Two blocks 1 and 2, on a frictionless table, are pushed from the left by a horizontal force $\vec{F}_1$, and on the right by a horizontal force of magnitude $\vec{F}_2$ as shown. The magnitudes of the pushing forces satisfy the inequality $|\vec{F}_1| > |\vec{F}_2|$.



Which of the following statements is true about the magnitude N of the contact force between the two blocks?

(A) $N > |\vec{F}_1| > |\vec{F}_2|$ (B) $|\vec{F}_1| > N > |\vec{F}_2|$
(C) $|\vec{F}_1| > N = |\vec{F}_2|$ (D) $|\vec{F}_1| = N > |\vec{F}_2|$

PART - 7 : MOTION IN A LIFT

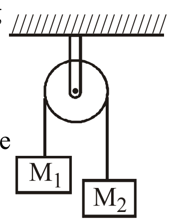
Q.26 A body of mass 2 kg is hung on a spring balance mounted vertically in a lift. If the lift descends with an acceleration equal to the acceleration due to gravity 'g', the reading on the spring balance will be
(A) 2 kg (B) $(4 \times g)$ kg
(C) $(2 \times g)$ kg (D) Zero

Q.27 The mass of a body measured by a physical balance in a lift at rest is found to be m. If the lift is going up with an acceleration a, its mass will be measured as –
(A) $m\left(1-\frac{a}{g}\right)$ (B) $m\left(1+\frac{a}{g}\right)$
(C) m (D) Zero

Q.28 Consider a person standing in an elevator that is accelerating upward. The upward normal force N exerted by the elevator floor on the person is
(A) larger than the downward force of gravity on the person.
(B) identical to the downward force of gravity on the person.
(C) smaller than the downward force of gravity on the person.
(D) None of these

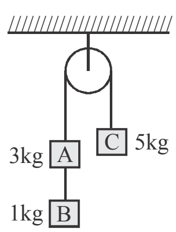
PART - 8 : PULLEY SYSTEM

Q.29 Two masses M_1 = 5 kg and M_2 = 10 kg are connected at the ends of an inextensible string passing over a frictionless pulley as shown.



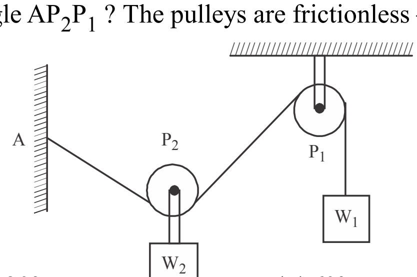
When the masses are released, then the acceleration of the masses will be
(A) g (B) g/2
(C) g/3 (D) g/4

Q.30 Three weight A, B and C are connected by string as shown in the figure. The system moves over a frictionless pulley. The tension in the string connecting A and B is (where g is acceleration due to gravity)



(A) g (B) g/9
(C) 8g/9 (D) 10g/9

Q.31 In the following figure, the pulley P_1 is fixed and the pulley P_2 is movable. If $W_1 = W_2$ = 100 N, what is the angle AP_2P_1 ? The pulleys are frictionless –

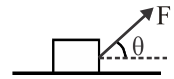


(A) 30° (B) 60°
(C) 90° (D) 120°

Q.32 Two bodies of mass 3 kg and 4 kg are suspended at the ends of massless string passing over a frictionless pulley. The acceleration of the system is (g = 9.8 m/s^2)
(A) 4.9 m/s^2 (B) 2.45 m/s^2
(C) 1.4 m/s^2 (D) 9.5 m/s^2

PART - 9 : FRICTION

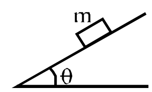
Q.33 A mass m has a force F applied to it as shown



(A) The normal force on the block will be mg.
(B) The acceleration of the block will be a function of F only.
(C) If there was kinetic friction acting on the block, it would be directed toward the left.
(D) None of the above.

Q.34 An object is held in place by friction on an inclined surface. The angle of inclination is increased until the object starts moving. If the surface is kept at this angle, the object
(A) slows down
(B) moves at uniform speed.
(C) speeds up.
(D) none of the above

Q.35 A mass m sits on a frictionless incline plane of angle θ.



(A) The acceleration of mass m will be g.
(B) The acceleration of mass m will be dependent upon the size of the mass.
(C) The acceleration of mass m will be dependent upon θ.
(D) All of the above.

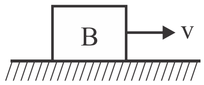
Q.36 Mark the INCORRECT statements about the friction between two bodies -
(A) static friction is always greater than the kinetic friction.
(B) coefficient of static friction is always greater than the coefficient of kinetic friction.
(C) limiting friction is always greater than the kinetic friction.
(D) limiting friction is never less than static friction.

Q.37 If the normal force is doubled, the coefficient of friction is
(A) Not changed (B) Halved
(C) Doubled (D) Tripled

Q.38 A stone weighing 1 kg and sliding on ice with a velocity of 2 m/s is stopped by friction in 10sec. The force of friction (assuming it to be constant) will be
(A) –20N (B) – 0.2 N
(C) 0.2 N (D) 20 N

Q.39 A block of mass 5 kg lies on a rough horizontal table. A force of 19.6 N is enough to keep the body sliding at uniform velocity. The coefficient of sliding friction is
(A) 0.5 (B) 0.2
(C) 0.4 (D) 0.8

Q.40 A block B is pushed momentarily along a horizontal surface with an initial velocity v. If μ is the coefficient of sliding friction between B and the surface, block B will come to rest after a time –

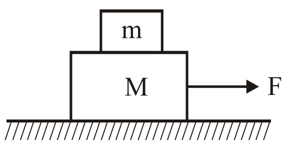


(A) v/g (B) v/(g μ)
(C) gμ/v (D) g/v

Q.41 A body of mass 400g slides on a rough horizontal surface if the frictional force is 3.0 N. Find the angle made by the contact force on the body with the vertical.
(A) 37º (B) 53º
(C) 63º (D) 27º

Q.42 The coefficient of static friction between a block of mass m and an incline is $\mu_s = 0.3$ What can be the maximum angle θ of the incline with the horizontal so that the block does not slip on the plane?
(A) $\tan^{-1}(0.1)$ (B) $\tan^{-1}(0.2)$
(C) $\tan^{-1}(0.3)$ (D) $\tan^{-1}(0.4)$

Q.43 The coefficient of static friction between the two blocks shown in figure is μ and the table is smooth. What maximum horizontal force F can be applied to the block of mass M so that the blocks move together?



(A) $\mu g(M+m)$ (B) $\mu g(M-m)$
(C) $2\mu g(M+m)$ (D) $\mu g(M+2m)$

Q.44 Block A weights 4 N and block B weight 8 N. The coefficient of kinetic friction is 0.25 for all surfaces. Find the force F to slide B at a constant speed when A rests on B and moves with it.
(A) 2N (B) 3N
(C) 1N (D) 5N

Q.45 Two cars of unequal masses use similar tyres. If they are moving at the same initial speed, the minimum stopping distance
(A) is smaller for the heavier car
(B) is smaller for the lighter car
(C) is same for both cars
(D) depends on the volume of the car

Q.46 A body of mass M is kept on a rough horizontal surface (friction coefficient = μ). A person is trying to pull the body by applying a horizontal force but the body is not moving. The force by the surface on A is F where –
(A) F = Mg (B) F = μ Mg
(C) $Mg \le F \le Mg\sqrt{1+\mu^2}$ (D) $Mg \ge F \ge Mg\sqrt{1-\mu^2}$

Q.47 A block is placed on a rough floor and a horizontal force F is applied on it. The force of friction f by the floor on the block is measured for different values of F and a graph is plotted between them –
(a) The graph is a straight line of slope 45°.
(b) The graph is straight line parallel to the F axis.
(c) The graph is a straight line of slope 45º for small F and a straight line parallel to the F-axis for large F.
(d) There is small kink on the graph.
Correct statements are –
(A) c, d (B) a, d
(C) a, b (D) a, c

Q.48 The contact force exerted by a body A on another body B is equal to the normal force between the bodies. We conclude that -
(a) the surfaces must be smooth.
(b) force of friction between two bodies may be equal to zero.
(c) magnitude of normal reaction is equal to that of friction.
(d) bodies may be rough.
(A) b, d (B) a, b
(C) c , d (D) a, d

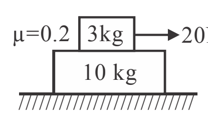
Q.49 It is easier to pull a body than to push, because
(A) the coefficient of friction is more in pushing than that in pulling.
(B) the friction force is more in pushing than that in pulling.
(C) the body does not move forward when pushed.
(D) None of these.

Q.50 A block of metal is lying on the floor of a bus. The maximum acceleration which can be given to the bus so that the block may remain at rest, will be -
(A) μg (B) μ/g
(C) $\mu^2 g$ (D) μg^2

Q.51 A car of mass m starts from rest and acquires a velocity along east $\vec{v} = v\hat{i}$ (v > 0) in two seconds. Assuming the car moves with uniform acceleration, the force exerted on the car is –
(A) (mv/2) eastward and is exerted by the car engine.
(B) (mv/2) eastward and is due to the friction on the tyres exerted by the road.
(C) more than (mv/2) eastward exerted due to the engine and overcomes the friction of the road.
(D) (mv/2) exerted by the engine.

Q.52 A block of mass m is placed on floor of a lift which is rough. The coefficient of friction between the block and the floor is μ. When the lift falls freely, the block is pulled horizontally on the lift floor. The force of friction
(A) zero (B) 2μ mg
(C) (1/2) μ mg (D) μ mg

Q.53 A 3 kg block is placed over a 10kg block and both are placed on a smooth horizontal surface. The coefficient of friction between the blocks is 0.2. If a horizontal force of 20N is applied to 3kg block, accelerations of the two blocks in m/s^2 are ($g = 10\ m/s^2$)



(A) 13/4, 0.6 (B) 14/4, 3
(C) 13/4, 3 (D) 14/3, 0.6

PART - 10 : MISCELLANEOUS

Q.54 If the tension in the cable of 1000 kg elevator is 1000 kg weight, the elevator
(A) Is accelerating upwards
(B) Is accelerating downwards
(C) May be at rest or accelerating
(D) May be at rest or in uniform motion

Q.55 A body of mass 2 kg is moving with a velocity 8m/s on a smooth surface. If it is to be brought to rest in 4 seconds, then the force to be applied is –
(A) 8 N (B) 4 N
(C) 2 N (D) 1 N

Q.56 A 30 gm bullet initially travelling at 120 m/s penetrates 12cm into a wooden block. The average resistance exerted by the wooden block is –
(A) 2850N (B) 2200 N
(C) 2000N (D) 1800 N

Q.57 If rope of lift breaks suddenly, the normal force exerted by the surface of lift (a = acceleration of lift)
(A) mg (B) m (g + a)
(C) m (g – a) (D) 0

Q.58 Two forces of magnitude F have a resultant of the same magnitude F. The angle between the two forces is –
(A) 45° (B) 120°
(C) 150° (D) 60°

Q.59 A man of weight mg is moving up in a rocket with acceleration 4 g. The apparent weight of the man in the rocket is
(A) Zero (B) 4 mg
(C) 5 mg (D) mg

Q.60 A boy standing on a weighing machine observes his weight as 200 N. When he suddenly jumps upwards, his friend notices that the reading increased to 400 N. The acceleration by which the boy jumped will be-
(A) 9.8 m/s^2 (B) 29.4 m/s^2
(C) 4.9 m/s^2 (D) 14.7 m/s^2

Q.61 A force of $(6\hat{i}+8\hat{j})$ N acted on a body of mass 10 kg. The displacement after 10 sec, if it starts from rest, will be -
(A) 50 m along $\tan^{-1} 4/3$ with x axis
(B) 70 m along $\tan^{-1} 3/4$ with x axis
(C) 10 m along $\tan^{-1} 4/3$ with x axis
(D) None

Q.62 A car of 1000 kg moving with a velocity of 18 km/hr is stopped by the brake force of 1000N. The distance covered by it before coming to rest is -
(A) 1 m (B) 162 m
(C) 12.5 m (D) 144 m

Q.63 A man fires the bullets of mass m each with the velocity v with the help of machine gun, if he fires n bullets every sec, the reaction force per second on the man will be -
(A) mn/vn (B) m n v
(C) mv/n (D) vn/m

Q.64 A body of mass 50 kg is pulled by a rope of length 8 m on a surface by a force of 108N applied at the other end. The force that is acting on 50 kg mass, if the linear density of rope is 0.5 kg/m will be -
(A) 108 N (B) 100 N
(C) 116 N (D) 92 N

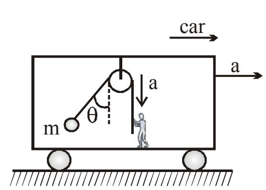
Q.65 A hockey player is moving northward and suddenly turns westward with the same speed to avoid an opponent. The force that acts on the player is –
(A) frictional force along westward.
(B) muscle force along southward.
(C) frictional force along south-west.
(D) muscle force along south-west.

Q.66 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 sustained without breaking the string is –
(A) 10 N (B) 20 N
(C) $20\sqrt{2}$ N (D) 40 N

Q.67 Maximum acceleration of the train in which a 50 kg box lying on its floor will remain stationary (Given : Coefficient of static friction between the box and the train's floor is 0.3 and g = 10 ms^{-2})
(A) 15 ms^{-2} (B) 1.5 ms^{-2}
(C) 3.0 ms^{-2} (D) 5.0 ms^{-2}

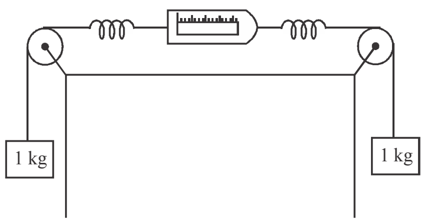
Q.68 A 2 kg mass starts from rest on an inclined smooth surface with inclination 30° and length 2m. How much will it travel before coming to rest on a frictional horizontal surface with frictional coefficient of 0.25 –
(A) 4m (B) 6m
(C) 8m (D) 2m

Q.69 A bob is hanging over a pulley inside a car through, a string . The second end of the string is in the hand of a person standing in the car. The car is moving with constant acceleration 'a' directed horizontally as shown in figure. Other end of the string is pulled with constant acceleration 'a' vertically. The tension in the string is equal to –



(A) $m\sqrt{g^2+a^2}$ (B) $m\sqrt{g^2+a^2}-ma$
(C) $m\sqrt{g^2+a^2}+ma$ (D) m (g + a)

Q.70 In the figure given, what is the reading of the balance – $(g = 10\ N\ kg^{-1})$



(A) 10N (B) 20 N
(C) 5N (D) 0

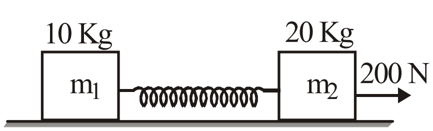
Q.71 A fire man has to carry an injured person of mass 40 kg from the top of a building with the help of the rope which can withstand a load of 100 kg. The acceleration of the fireman if his mass is 80kg, will be-
(A) 8.17 m/s^2 (B) 9.8 m/s^2
(C) 1.63 m/s^2 (D) 17.97 m/s^2

Q.72 A cricket ball of mass 250 gm moving with velocity of 24 m/s is hit by a bat so that it acquires a velocity of 28 m/s in the opposite direction. The force acting on the ball, if the contact time is 1/100 of a second, will be -
(A) 1300 N in the final direction of ball
(B) 13 N in the initial direction of ball
(C) 130 N in the final direction of ball
(D) 1.3 N in the initial direction of ball

Q.73 A block of mass 2 kg is placed on the floor. The coefficient of static friction is 0.4.A force F of 2.5 N is applied on the block. Calculate the force of friction between the block and the floor. $(g = 9.8\ ms^{-2})$
(A) 2.5 N (B) 25 N
(C) 7.84 N (D) zero

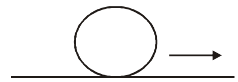
Q.74 A 600 kg rocket is set for a vertical firing. If the exhaust speed is 1000 m/s. Then calculate the mass of gas ejected per second to supply the thrust needed to overcome the weight of rocket.
(A) 5.88 kg/s (B) 4.88 kg/s
(C) 2.88 kg/s (D) 3.88 kg/s

Q.75 Two masses 10 kg and 20 kg respectively are connected by a massless spring as shown in figure force of 200N acts on the 20 kg mass. At the instant shown in figure the 10 kg mass has acceleration of 12 m/s^2, what is the acceleration of 20 kg mass.



(A) 2 m/s^2 (B) 6 m/s^2
(C) 3 m/s^2 (D) 4 m/s^2

Q.76 A ball rests upon a flat piece of paper on a table top. The paper is pulled horizontally but quickly towards right as shown. Relative to its initial position with respect to the table, the ball –



(a) remains stationary if there is no friction between the paper and the ball.
(b) moves to the left and starts rolling backwards, i.e. to the left if there is a friction between the paper and the ball.
(c) moves forward, i.e. in the direction in which the paper is pulled.

Here, the correct statement/s is/are –
(A) both (a) and (b) (B) only (c)
(C) only (a) (D) only (b)

Q.77 The resultant of two forces acting at an angle of 120° is 10kg wt and is perpendicular to one of the forces. That force is –
(A) $10/\sqrt{3}$ kg wt (B) 10 kg wt
(C) 20 $\sqrt{3}$ kg wt (D) 10 $\sqrt{3}$ kg wt

Q.78 A block slides down on an incline of angle 30° with an acceleration g/4. Find the coefficient of kinetic friction
(A) $1/2\sqrt{2}$ (B) 0.6
(C) $1/2\sqrt{3}$ (D) $1/\sqrt{2}$

Q.79 A block kept on a rough surface starts sliding when the inclination of the surface is 'θ' with respect to the horizontal. The coefficient of static friction between the block and the surface is –
(A) tan θ (B) cos θ
(C) sec θ (D) sin θ

Q.80 The X and Y components of a force F acting at 30° to x-axis are respectively –
(A) $\frac{F}{2}, \frac{\sqrt{3}}{2}F$ (B) $\frac{\sqrt{3}}{2}F, \frac{F}{2}$
(C) $F, \frac{F}{\sqrt{2}}$ (D) $\frac{F}{\sqrt{2}}, F$

Q.81 A stone of mass 0.05 kg is thrown vertically upwards. What is the direction and magnitude of net force on the stone during its upward motion?
(A) 0.98 N vertically downwards
(B) 0.49 N vertically upwards
(C) 9.8 N vertically downwards
(D) 0.49 N vertically downwards

EXERCISE - 2 [LEVEL-2]

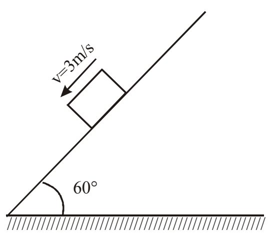
Q.1 A block A of mass 2 kg rests on another block B of mass 8 kg. Block B rests on a horizontal floor. The coefficient of friction between A and B is 0.2 while that between B and floor is 0.5. When a horizontal force of 25N is applied on the block B, then .... N is the force of friction between A and B and .... N is the force between B and ground.

(A) 0, 25 (B) 1, 18
(C) 2, 25 (D) 0, 12

Q.2 A light rope hangs over a smooth pulley. A monkey of mass 5 kg climbs down the portion of the rope on one side with an acceleration of 1 m/s^2. Find with what acceleration another monkey of mass 4 kg will climb up the portion of the rope on the other side so that the rope may remain at rest.

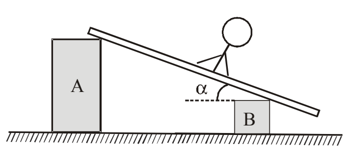
(A) 1.2 m/s^2 (B) 2.4 m/s^2
(C) 0.2 m/s^2 (D) 5.4 m/s^2

Q.3 A particle of mass 5 kg. is moving on rough fixed inclined plane with constant velocity of 3 m/s as shown in the figure. Find the friction force acting on a body by plane.



(A) $25\sqrt{3}$ N (B) 20N
(C) 30N (D) None of these

Q.4 A plank is held at an angle ex to the horizontal (Fig.) on two fixed supports A and B. The plank can slide against the supports (without friction) because of its weight Mg. Acceleration and direction in which a man of mass m should move so that the plank does not move.



(A) $g\sin\alpha\left(1+\frac{m}{M}\right)$ down the incline

(B) $g\sin\alpha\left(1+\frac{M}{m}\right)$ down the incline

(C) $g\sin\alpha\left(1+\frac{m}{M}\right)$ up the incline

(D) $g\sin\alpha\left(1+\frac{M}{m}\right)$ up the incline

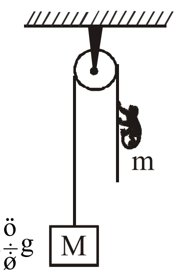
Q.5 A small mass slides down an fixed inclined plane of inclination θ with the horizontal. The coefficient of friction is $\mu = \mu_0 x$ where x is the distance through which the mass slides down and μ_0 is a constant. Then the speed is maximum after the mass covers a distance of –

(A) $\frac{\cos\theta}{\mu_0}$ (B) $\frac{\sin\theta}{\mu_0}$ (C) $\frac{\tan\theta}{\mu_0}$ (D) $\frac{2\tan\theta}{\mu_0}$

Q.6 A balloon of gross weight W newton descends with an acceleration f m/s^2. The weight that must be thrown out in order to give balloon an equal upward acceleration will be –

(A) Wf/g (B) 2 Wf / (g + f)
(C) 2 Wf/g (D) W (g + f) / f

Q.7 In the figure, the block of mass M is at rest on the floor. The acceleration with which a monkey of mass m should climb up along the rope of negligible mass so as to lift the block from the floor is –



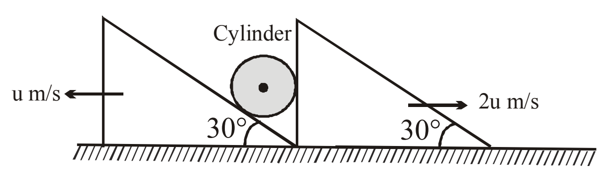
(A) equal to $\left(\frac{M}{m}-1\right)g$ (B) > $\left(\frac{M}{m}-1\right)g$

(C) equal to $\frac{M}{m}g$ (D) > $\frac{M}{m}g$

Q.8 A block of mass m_1 lies on top of fixed wedge as shown in figure 1 and another block of mass m_2 lies on top of wedge which is free to move as shown in figure 2. At time t = 0, both the blocks are released from rest from a vertical height h above the respective horizontal surface on which the wedge is placed as shown. There is no friction between block and wedge in both the figures. Let T_1 and T_2 be the time taken by block in figure 1 and block in figure 2 respectively to just reach the horizontal surface, then –

(A) $T_1 > T_2$
(B) $T_1 < T_2$
(C) Magnitude of normal reaction on block of mass m_2 is less than that on the block of mass m_1.
(D) After falling through same height (less than h) from top of wedge, the speed of block of mass m_2 is less than that of block of mass m_1.

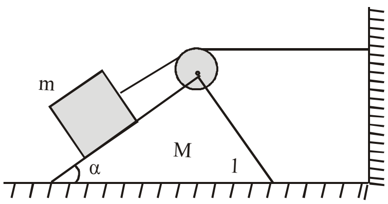
Q.9 System is shown in the figure. Assume that cylinder remains in contact with the two wedges. The velocity of cylinder is –



(A) $\sqrt{19-4\sqrt{3}}\,\frac{u}{2}$ m/s (B) $\frac{\sqrt{13}u}{2}$ m/s

(C) $\sqrt{3}u$ m/s (D) $\sqrt{7}u$ m/s

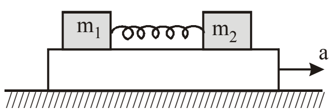
Q.10 In the arrangement shown in fig the masses m of the bar and M of the wedge, as well as the wedge angle α are known. The masses of the pulley and the thread are negligible. The friction is absent. Find the acceleration of the wedge M.



(A) $\frac{mg\cos\alpha}{2m(1-\cos\alpha)+M}$ (B) $\frac{mg\sin\alpha}{m(1+\cos\alpha)+M}$

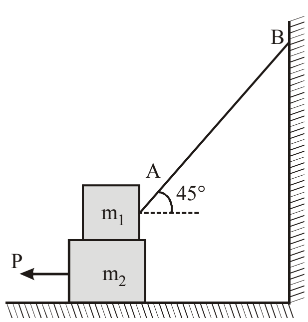
(C) $\frac{mg\sin\alpha}{2m(1-\cos\alpha)+M}$ (D) $\frac{2mg\sin\alpha}{m(1+\cos\alpha)+M}$

Q.11 Two blocks of masses m_1 = 1kg, and m_2 = 2kg are connected with a massless unstretched spring and placed over a plank moving with an acceleration 'a' as shown in figure. The coefficient of friction between the blocks and platform is μ.



(A) spring will be stretched if $a > \mu g$
(B) spring will be compressed if $a \le \mu g$.
(C) spring will neither be compressed nor be stretched for $a \le \mu g$.
(D) spring will be in its natural length under all conditions if the initial velocity of both blocks and platform is zero

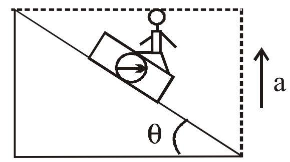
Q.12 The block of mass m_1 = 20kg lies on top of block of mass m_2 = 12 kg. A light inextensible string AB connects mass m_1 with vertical wall as shown. The coefficient of friction is μ = 0.25 for all surfaces in contact. A horizontal force P is applied to block of mass m_2 such that it just slides under block of mass m_1. Then the tension in the string AB is (Take g = 10 m/s^2)



(A) $40\sqrt{2}$ N (B) 24 N

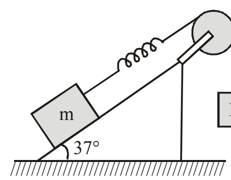
(C) 40 N (D) $24\sqrt{2}$ N

Q.13 A man of mass m = 60 kg. is standing on weighing machine fixed on a triangular wedge of angle θ = 60° as shown in the figure. The wedge is moving up with an upward acceleration a = 2 m/s^2. The weight registered by the machine is –



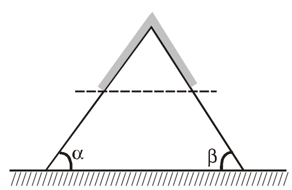
(A) 600 N (B) 1440 N
(C) 360 N (D) 240 N

Q.14 A block of mass m is attached with massless spring of force constant k. The block is placed over a fixed rough inclined surface for which the coefficient of friction is μ = 3/4. The block of mass m is initially at rest. The block of mass M is released from rest with spring in unstretched state. The minimum value of M required to move the block up the plane is (neglect mass of string and pulley and friction in pulley.)



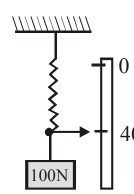
(A) (3/5) m (B) (4/5) m
(C) (6/5) m (D) (3/2) m

Q.15 A uniform rope of length L and mass M is placed on a smooth fixed wedge as shown. Both ends of rope are at same horizontal level. The rope is initially released from rest, then the magnitude of initial acceleration of rope is



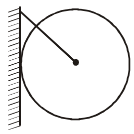
(A) M (cos α – cos β) g (B) zero
(C) M (tan α – tan β) g (D) None of these

Q.16 An ideal spring, wtih a pointer attached to its end, hangs next to a vertical scale. With a 100N weight attached and in equilibrium, the pointer indicates 40 on the scale as shown. Using a 20N weight instead results in 60 on the scale. Using an unknown weight X instead results in 30 on the scale. The value of X is –



(A) 50N (B) 80N
(C) 60N (D) 40N

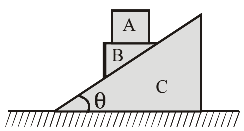
Q.17 A uniform disc of radius R and mass m is connected to a wall by string of length 2R. The normal reaction of wall is –



(A) mg (B) mg/2

(C) $mg/\sqrt{3}$ (D) 2mg

Q.18 In the figure shown all blocks are of equal mass 'm'. All surfaces are smooth. The acceleration of the block A with respect ground–



(A) $\frac{4g\sin q}{1+3\sin^2 q}$ (B) $\frac{4g\sin^2 q}{1+3\sin^2 q}$

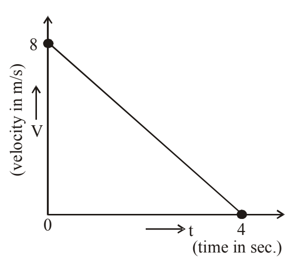
(C) $\frac{4g\sin^2 q}{\sqrt{1+3\sin^2 q}}$ (D) None of these

Q.19 Determine the maximum acceleration of the train in which a box lying on its floor will remain stationary, given that the co-efficient of static friction between the box and the train's floor is 0.15.

(A) 3.2 m/s^2 (B) 2.4 m/s^2

(C) 0.2 m/s^2 (D) 1.5 m/s^2

Q.20 A block of mass 2 kg is given a push horizontally and then the block starts sliding over a horizontal plane. The figure shows the velocity-time graph of the motion. Find the coefficient of sliding friction between the plane and the block. (Take g =10 m/s^2)



(A) 2.2m (B) 0.5 m

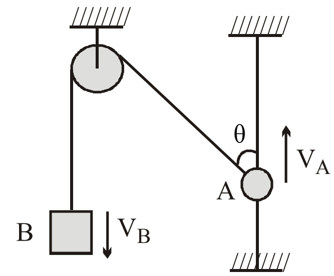
(C) 0.30m (D) 0.20m

Q.21 A bead of mass m is located on a parabolic wire with its axis vertical and vertex directed towards downward and whose equation is $x^2 = ay$. If the coefficient of friction is μ, find the highest distance above the x-axis at which the particle will be in equilibrium.

(A) $\frac{a\mu^2}{4}$ (B) $\frac{a\mu^2}{2}$

(C) $a\mu^2$ (D) $\frac{a\mu^2}{3}$

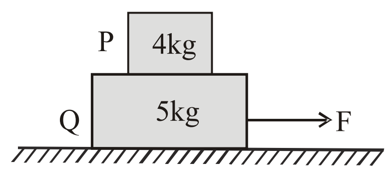
Q.22 Two masses A and B are connected with two an inextensible string to write constraint relation between $_A$ and v_B. Student A : $v_A \cos\theta = v_B$.
Student B : $v_B \cos\theta = v_A$.



(A) A is correct, B is wrong (B) B is correct, A is wrong

(C) Both are correct (D) Both are wrong

Q.23 The coefficient of friction between 4 kg and 5 kg blocks is 0.2 and between 5 kg block and ground is 0.1 respectively. Choose the correct statement –



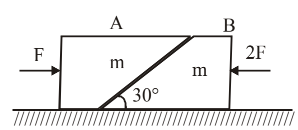
(A) Minimum force needed to cause system to move is 17N

(B) When force is 4N static friction at all surfaces is 4N to keep system at rest

(C) Maximum acceleration of 4 kg block is 2m/s^2

(D) Slipping between 4 kg and 5 kg blocks start when F is 17N

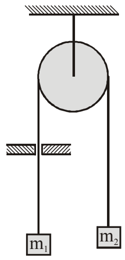
Q.24 Two blocks A and B each of mass are placed on a smooth horizontal surface. Two horizontal forces F and 2F are applied on the blocks A and B respectively as shown in figure. The block A does not slide on block B. Then the vertical component of normal reaction exerted by block B on block A is –



(A) $\frac{3\sqrt{3}}{2}F$ (B) F

(C) F/2 (D) 3F

Q.25 A weightless string thrown over a stationary pulley is passed through a slit (fig.). As the string moves it is acted upon by a constant friction force F on the side of the slit. The ends of the string carry two weights with masses m_1 and m_2, respectively. Find the acceleration a of the weights.



(A) $\frac{(m_1+m_2)g-F}{m_1-m_2}$ (B) $\frac{(m_1-m_2)g-F}{m_1+m_2}$

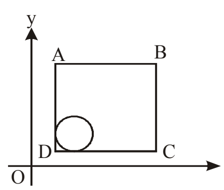
(C) $\frac{(m_1-m_2)g+F}{m_1+m_2}$ (D) None of these

Q.26 An iron nail is dropped from a height h from the level of a sand bed. If it penetrates through a distance x in the sand before coming to rest, the average force exerted by the sand on the nail is –

(A) $mg\left(\frac{h}{x}+1\right)$ (B) $mg\left(\frac{x}{h}+1\right)$

(C) $mg\left(\frac{h}{x}-1\right)$ (D) $mg\left(\frac{x}{h}-1\right)$

Q.27 A solid sphere of mass 2 kg is resting inside a cube as shown in the figure. The cube is moving with a velocity, $\vec{v}=(5t\hat{i}+2t\hat{j})$ m/s. Here t is the time in seconds. All surfaces are smooth. The sphere is at rest with respect to the cube. What is the total force exerted by the sphere . . . . ^{2})

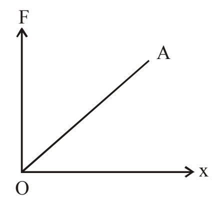


(A) 26N (B) 30N
(C) 15N (D) 10N

Q.28 A dog with mass M with its string attached to one end of a spring which runs without friction along a horizontal overhead rod. The other end of the spring is fixed to a wall. The spring constant is k. The string is massless and inextensible and it maintains a constant angle θ with the overhead rod, even when the dog moves. There is friction with coefficient μ between the dog and the ground. What is the maximum distance (in m) that the dog can stretch the spring beyond its natural length ?
[Use M = 30 kg, θ = 37°, k = 400 N/m and μ = 1/3]

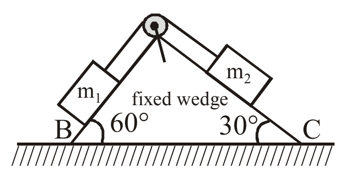
(A) 0.5m (B) 1.0m
(C) 0.7m (D) 0.2 m

Q.29 The force required to stretch a spring varies with the distance as shown in the figure. If the experiment is performed with the above spring of half length, the line OA will –



(A) Shift towards F-axis (B) Shift towards X-axis
(C) Remains as it is (D) Become double in length

Q.30 Two small masses m_1 and m_2 are at rest on a frictionless, fixed triangular wedge angles are 30° and 60° as shown. They are connected by a light inextensible string. The side BC of wedge is horizontal and both the masses are 1 metre vertically above the horizontal side BC of wedge. There is no friction between the wedge and both the masses. If the string is cut, which mass reaches the bottom of the wedge first ? (Take g = 10m/s^2)

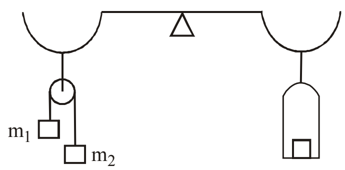


(A) Mass m_1 reaches the bottom of the wedge first.
(B) Mass m_2 reaches the bottom of the wedge first.
(C) Both reach the bottom of the wedge at the same time
(D) It's impossible to determine from the given informatioin

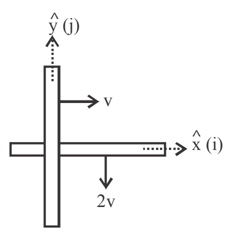
EXERCISE - 3 (NUMERICAL VALUE BASED QUESTIONS)

NOTE : The answer to each question is a NUMERICAL VALUE.

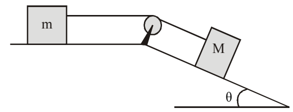
Q.1 A pulley is attached to one arm of a balance and a string passed around it carries two masses m_1 and m_2. The pulley is provided with a clamp due to which m_1 and m_2 do not move. On removing the clamp m_1 and m_2 start moving.
The counterweight reduced or increased to restore balance is $\frac{(m_1 - m_2)^x g}{m_1 + m_2}$. Find the value of x.



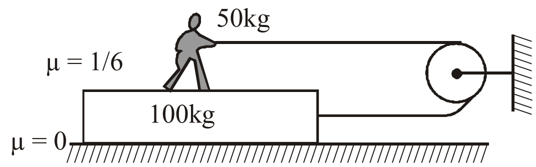
Q.2 Two rods moving perpendicular to each other along the axis one on the other with velocities v and 2v, as shown in the figure. The unit vector along which the friction force on the rod moving with velocity v by the rod moving with velocity 2v will act is $\frac{1}{\sqrt{A}}(-\hat{i} - 2\hat{j})$. Find the value of A.



Q.3 The maximum value of (M/m) in the situation shown in figure so that the system remains at rest is $\frac{x\mu}{y\sin\theta - \mu\cos\theta}$. Friction coefficient of both the contacts is μ, string is massless and pulley is frictionless. Find the value of x + y.



Q.4 In figure force applied by man is 100 N. If both man and plank move together, force of friction acting on man is $\frac{100}{X}$ N . Find the value of X.



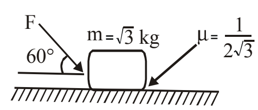
Q.5 A variable force F = 25t acts on a body of mass 10 kg kept on a rough horizontal surface ($\mu_s = 0.6$, $\mu_k = 0.4$). The velocity of the body at t = 4s is (A + 0.4) m/s. Find the value of A.

Q.6 Two particles of masses m_1 and m_2 ($m_1 > m_2$) are tied to the ends of a light inextensible string passing over a light smooth fixed pulley. The acceleration of m_1 is g/4 downwards. Then $m_1 : m_2$ is 5 : X. Find the value of X.

Q.7 A block is moving on an inclined planemaking an angle 45° with the horizontal and the coefficient of friction is μ. The force required to just push it up the inclined plane is 3 times the force required to just prevent it from sliding down. If we define N = 10 μ, then N is –

Q.8 A spring of force constant k is cut into two pieces such that one piece such that one piece is double the length of the other. Then the long piece will have a force constant of (X/2) k. Find the value of X.

Q.9 The maximum value of the force F such that the block shown in the arrangement, does not move is



EXERCISE - 4 [PREVIOUS YEARS AIEEE / JEE MAIN QUESTIONS]

Q.1 Three point masses A, B and C are 66 gram each are connected as shown. The acceleration of system is 5 m/s^2. Tension between B and C is approximately- **[AIEEE-2002]**

(A) 0.33 Newton (B) 4 Newton
(C) 5 Newton (D) 6 Newton

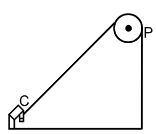
Q.2 A person in an aeroplane which is coming, down at acceleration a releases a coin. After release, the accleration of coin with respect to observer on ground and in aeroplane both will be respectively-**[AIEEE-2002]**

(A) g and (g –a) (B) (g – a), g
(C) (g + a), g (D) g, (g + a)

Q.3 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

Q.4 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 360N. With what value of minimum safe acceleration (in ms^{-2}) can a man of 60 kg slide down the rope ? **[AIEEE-2002]**



(A) 16 (B) 6
(C) 4 (D) 8

Q.5 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) 74 N (B) 15 N
(C) 49 N (D) 24 N

Q.6 Let $\vec{F}$ be the force acting on a particle having position vector $\vec{r}$, and $\vec{T}$ be the torque of this force about the origin. Then – **[AIEEE-2003]**

(A) $\vec{r}.\vec{T} \neq 0$ and $\vec{F}.\vec{T} = 0$ (B) $\vec{r}.\vec{T} \neq 0$ and $\vec{F}.\vec{T} \neq 0$

(C) $\vec{r}.\vec{T} = 0$ and $\vec{F}.\vec{T} = 0$ (D) $\vec{r}.\vec{T} = 0$ and $\vec{F}.\vec{T} \neq 0$

Q.7 A block of mass M is pulled along a horizontal frictionless surface by a rope of mass m. If a force P is applied at the free end of the rope, the force exerted by the rope on the block is – **[AIEEE-2003]**

(A) $\frac{Pm}{M-m}$ (B) P

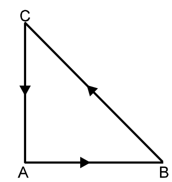
(C) $\frac{PM}{M+m}$ (D) $\frac{Pm}{M+m}$

Q.8 One end of a light spring balance hangs from the hook of the other light spring balance attached to roof and a block of mass M kg hangs from the other end. Then the true statement about the scale reading is – **[AIEEE-2003]**

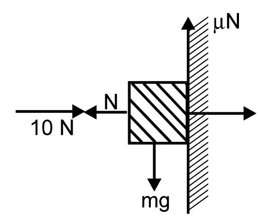
(A) The scale of the lower one reads M kg and of the upper one zero.
(B) The reading of the two scales can be anything but the sum of the reading will be M kg.
(C) Both the scales read M/2 kg each.
(D) both the scales read M kg each.

Q.9 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) Greater than $\vec{v}$
(B) |v| in the direction of the largest force BC
(C) $\vec{v}$, remaining unchanged
(D) Less than $\vec{v}$



Q.10 A horizontal force of 10 Newton 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 block is – **[AIEEE-2003]**



(A) 50 N (B) 100 N
(C) 2 N (D) 20 N

Q.11 A marble block of mass 2 kg lying on ice when given a velocity of 6 m/s is stopped by friction is 10 s. Then the coefficient of friction is – **[AIEEE-2003]**

(A) 0.03 (B) 0.04
(C) 0.06 (D) 0.02

Q.12 A machine gun fires a bullet of mass 40 g with a velocity 1200 ms^{-1}. The man holding it can exert a maximum force of 144 N on the gun. How many bullets can he fire per second at the most ? **[AIEEE-2004]**

(A) One (B) Four
(C) Two (D) Three

Q.13 A block rests on a rough indined 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 block (in kg) is (Take g = 10 m/s^2) **[AIEEE-2004]**

(A) 2.0 (B) 4.0
(C) 1.6 (D) 2.5

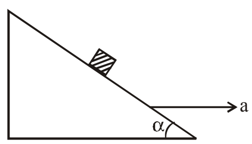
Q.14 Two masses $m_1 = 5$ kg and $m_2 = 4.8$ kg tied to a string are hanging over a light fricitionless pulley. What is the acceleration of the masses when left free to move ? $(g = 9.8 \text{ m/s}^2)$ **[AIEEE-2004]**

(A) 0.2 m/s^2 (B) 9.8 m/s^2
(C) 5 m/s^2 (D) 4.8 m/s^2

Q.15 A parachutist after bailing out falls 50 m without friction. When parachute opens, it decelerates at 2 m/s^2. He reaches the ground with a speed of 3 m/s. At what height, did he bail out ? **[AIEEE-2005]**

(A) 91 m (B) 182 m
(C) 293 m (D) 111 m

Q.16 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 **[AIEEE-2005]**



(A) $g / \tan\alpha$ (B) $g \operatorname{cosec}\alpha$
(C) g (D) $g \tan\alpha$

Q.17 A particle of mass 0.3 kg is subjected 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 ? **[AIEEE-2005]**

(A) 3 m/s^2 (B) 15 m/s^2
(C) 5 m/s^2 (D) 10 m/s^2

Q.18 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 **[AIEEE-2005]**

(A) $\mu_K = 1 - \dfrac{1}{n^2}$ (B) $\mu_k = \sqrt{1 - \dfrac{1}{n^2}}$

(C) $\mu_S = 1 - \dfrac{1}{n^2}$ (D) $\mu_S = \sqrt{1 - \dfrac{1}{n^2}}$

Q.19 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 **[AIEEE-2005]**

(A) $2 \sin\phi$ (B) $2 \cos\phi$
(C) $2 \tan\phi$ (D) $\tan\phi$

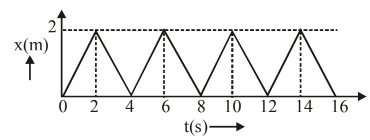
Q.20 A player caught a cricket ball of mass 150 g moving at a rate of 20 m/s. If the catching process is completed in 0.1 s, the force of the blow exerted by the ball on the hand of the player is equal to – **[AIEEE 2006]**

(A) 30 N (B) 300 N
(C) 150 N (D) 3 N

Q.21 A block of mass m is connected to another block of mass M by a spring (massless) of spring constant k. The blocks 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 on the block of mass m. **[AIEEE 2007]**

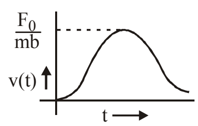
(A) $\dfrac{mF}{M}$ (B) $\left(\dfrac{M + mF}{M}\right)$ (C) $\dfrac{mF}{(m + M)}$ (D) $\dfrac{MF}{(m + M)}$

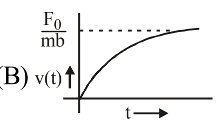
Q.22 The figure shows the position – time (x – t) graph of one-dimensional motion of a body of mass 0.4 kg. The magnitude of each impulse is – **[AIEEE 2010]**

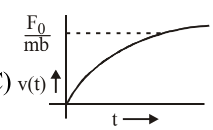


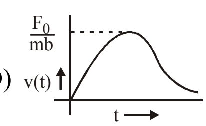
(A) 0.4 Ns (B) 0.8 Ns
(C) 1.6 Ns (D) 0.2 Ns

Q.23 A particle of mass m is at rest at the origin at time t = 0. It is subjected to a force $F(t) = F_0 e^{-bt}$ in the x-direction. Its speed v (t) is depicted by which of the following curves **[AIEEE 2012]**

(A)


(B)


(C)


(D)


Q.24 A uniform cylinder of length L and mass M having cross-sectional area A is suspended, with its length vertical, from a fixed point by a massless spring such that it is half submerged in a liquid of density σ at equilibrium position. The extension x_0 of the spring when it is in equilibrium is– **[JEE MAIN 2013]**

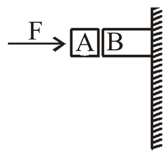
(A) $\dfrac{Mg}{k}$ (B) $\dfrac{Mg}{k}\left(1 - \dfrac{LA\sigma}{M}\right)$

(C) $\dfrac{Mg}{k}\left(1 - \dfrac{LA\sigma}{2M}\right)$ (D) $\dfrac{Mg}{k}\left(1 + \dfrac{LA\sigma}{M}\right)$

Q.25 A block of mass m is placed on a surface with a vertical cross section given by $y = x^3/6$. If the coefficient of friction is 0.5, the maximum height above the ground at which the block can be placed without slipping is – **[JEE MAIN 2014]**

(A) (1/3) m (B) (1/2) m
(C) (1/6) m (D) (2/3) m

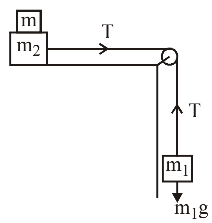
Q.26 Given in the figure are two blocks A and B of weight 20 N and 100N, respectively. These are being pressed against a wall by a force F as shown. If the coefficient of friction between the blocks is 0.1 and between block B and the wall is 0.15, the frictional force applied by the wall on block B is **[JEE MAIN 2015]**



(A) 80 N (B) 120 N
(C) 150 N (D) 100 N

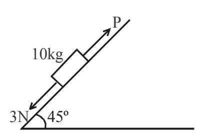
Q.27 A body of mass $m = 10^{-2}$ kg is moving in a medium and experiences a frictional force $F = -kv^2$. Its initial speed is $v_0 = 10\ ms^{-1}$. If, after 10 s, its energy is $\frac{1}{8}mv_0^2$, the value of k will be: **[JEE MAIN 2017]**
(A) 10^{-3} kg s^{-1} (B) 10^{-4} kg m^{-1}
(C) 10^{-1}kg m^{-1} $1s^{-1}$ (D) 10^{-3} kg m^{-1}

Q.28 Two masses $m_1 = 5$ kg and $m_2 = 10$ kg, connected by an inextensible string over a frictionless pulley, are moving as shown in the figure. The coefficient of friction of horizontal surface is 0.15. The minimum weight m that should be put on top of m_2 to stop the motion is : **[JEE MAIN 2018]**



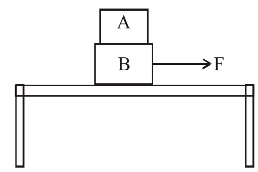
(A) 43.3 kg (B) 10.3 kg
(C) 18.3 kg (D) 27.3 kg

Q.29 A block of mass 10 kg is kept on a rough inclined plane as shown in the figure. A force of 3 N is applied on the block. The coefficient of static friction between the plane and the block is 0.6. What should be the minimum value of force P, such that the block does not move downward? (Take $g = 10\ ms^{-2}$) **[JEE MAIN 2019 (JAN)]**



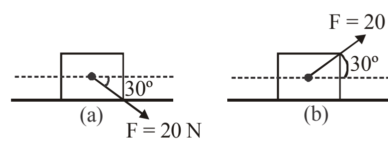
(A) 32 N (B) 25 N
(C) 23 N (D) 18 N

Q.30 Two blocks A and B of masses $m_A = 1$ kg and $m_B = 3$ kg are kept on the table as shown in figure. The coefficient of friction between A and B is 0.2 and between B and the surface of the table is also 0.2. The maximum force F that can be applied on B horizontally, so that the block A does not slide over the block B is
(Take $g = 10\ m/s^2$)



[JEE MAIN 2019 (APRIL)]
(A) 16 N (B) 40 N
(C) 12 N (D) 8 N

Q.31 A block of mass 5 kg is (i) pushed in case a and (ii) pulled in case b, by a force F = 20 N, making an angle of 30º with the horizontal, as shown in the figures. The coefficient of friction between the block and floor is m = 0.2. The difference between the accelerations of the block, in case b and case a will be : ($g = 10\ ms^{-2}$) **[JEE MAIN 2019 (APRIL)]**



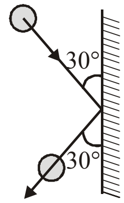
(A) 0 ms^{-2} (B) 0.8 ms^{-2}
(C) 0.4 ms^{-2} (D) 3.2 ms^{-2}

Q.32 A block of mass 10 kg is suspended from string of length 4m. When pulled by a force F along horizontal from midpoint. Upper half of string makes 45° with vertical, value of F is **[JEE MAIN 2020 (JAN)]**
(A) 100 N (B) 90 N
(C) 75 N (D) 70 N

EXERCISE - 5 (PREVIOUS YEARS AIPMT/NEET EXAM QUESTIONS)

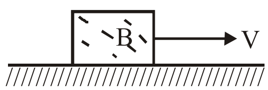
Choose one correct response for each question.

Q.1 A 0.5 kg ball moving with speed of 12m/s strikes a hard wall at an angle of 30° with the wall. It is reflected with the same speed and at the same angle. If the ball is in contact with the wall for 0.25 seconds, the average force acting on the wall is – **[AIPMT 2006]**



(A) 24N (B) 12N
(C) 96N (D) 48N

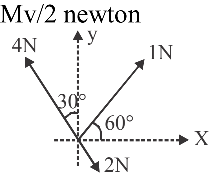
Q.2 A block B is pushed momentarily along a horizontal surface with an initial velocity V. If μ is the coefficient of sliding friction between B and the surface, block B will come to rest after a time – **[AIPMT 2007]**



(A) $g\mu/V$ (B) g/V
(C) V/g (D) $V/(g\mu)$

Q.3 Sand is being dropped on a conveyor belt at the rate of M kg/s. The force necessary to keep the belt moving with a constant velocity of v m /s will be **[AIPMT 2008]**
(A) Zero (B) Mv newton
(C) 2Mv newton (D) Mv/2 newton

Q.4 Three forces acting on a body are shown in the figure. To have the resultant force only along the y-direction, the magnitude of the minimum additional force needed is **[AIPMT 2008]**

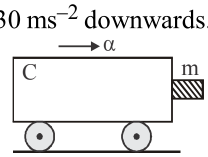


(A) $\sqrt{3}$N (B) 0.5 N
(C) 1.5 N (D) $\frac{\sqrt{3}}{4}$N

Q.5 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: **[AIPMT 2009]**
(A) 10 kg (B) 20 kg
(C) $10\sqrt{2}$ kg (D) $2\sqrt{10}$ kg

Q.6 The mass of a lift is 2000 kg. When the tension in the supporting cable is 28000 N, then its acceleration is: **[AIPMT 2009]**
(A) 4 ms^{-2} upwards (B) 4 ms^{-2} downwards.
(C) 14 ms^{-2} upwards (D) 30 ms^{-2} downwards.

Q.7 A block of mass m is in contact with the cart C as shown in the figure. The coefficient of static friction between the block and the cart is μ. The acceleration α of the cart that will prevent the block from falling satisfies **[AIPMT (PRE) 2010]**



(A) $\alpha > mg/\mu$ (B) $\alpha > g/\mu m$
(C) $\alpha \geq g/\mu$ (D) $\alpha < g/\mu$

Q.8 A gramophone record is revolving with an angular velocity ω. A coin is placed at a distance r from the centre of the record. The static coefficient of friction is μ. The coin will revolve with the record if – **[AIPMT (PRE) 2010]**

(A) $r = \mu g \omega^2$ (B) $r = \frac{\omega^2}{\mu g}$

(C) $r \leq \frac{\mu g}{\omega^2}$ (D) $r \geq \frac{\mu g}{\omega^2}$

Q.9 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 m/s^2, the tension in the supporting cable is – **[AIPMT (PRE) 2011]**
(A) 1200 N (B) 8600 N
(C) 9680 N (D) 11000 N

Q.10 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 **[AIPMT (MAINS) 2011]**
(A) 1.2 m (B) 0.6 m
(C) zero (D) 0.4 m

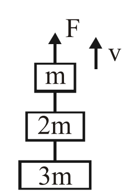
Q.11 A car of mass 1000 kg negotiates a banked curve of radius 90 m on a frictionless road. If the banking angle is 45°, the speed of the car is : **[AIPMT (PRE) 2012]**
(A) 20 ms^{-1} (B) 30 ms^{-1}
(C) 5 ms^{-1} (D) 10 ms^{-1}

Q.12 A car of mass m is moving on a level circular track of radius R. If μ_s represents the static friction between the road and tyres of the car, the maximum speed of the car in circular motion is given by **[AIPMT (MAINS) 2012]**

(A) $\sqrt{\mu_s mRg}$ (B) $\sqrt{Rg/\mu_s}$

(C) $\sqrt{mRg/\mu_s}$ (D) $\sqrt{\mu_s Rg}$

Q.13 Three blocks with masses m, 2m and 3m 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 **[NEET 2013]**



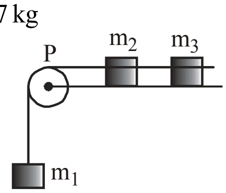
(A) 6 mg (B) zero
(C) 2 mg (D) 3 mg

Q.14 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. The coefficient of friction between the block and lower half of the plane is given by **[NEET 2013]**
(A) $\mu = \tan\theta$ (B) $\mu = 1/\tan\theta$
(C) $\mu = 2/\tan\theta$ (D) $\mu = 2\tan\theta$

Q.15 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 12m/s and the second part of mass 2 kg moves with 8 m/s speed. If the third part files off with 4 m/s speed, then its mass is – **[NEET 2013]**

(A) 17 kg (B) 3 kg
(C) 5 kg (D) 7 kg

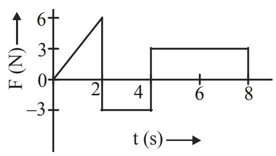
Q.16 A system consists of three masses m_1, m_2 and m_3 connected by a string passing over a pulley P. The mass m_1 hangs freely and m_2 and m_3 are on a rough horizontal table (the coefficient of friction = μ). The pulley is frictionless and of negligible mass. The downward acceleration of mass m_1 is (Assume $m_1=m_2=m_3=m$)



(A) $\frac{g(1-\mu)}{8}$ (B) $\frac{2g\mu}{3}$ **[AIPMT 2014]**

(C) $\frac{g(1-2\mu)}{3}$ (D) $\frac{g(1-2\mu)}{2}$

Q.17 The force F acting on a particle of mass m is indicated by the force-time graph shown. The change in momentum of the particle over the time interval from zero to 8s is **[AIPMT 2014]**



(A) 24 Ns (B) 20 Ns
(C) 12 Ns (D) 6 Ns

Q.18 A balloon with mass m is descending down with an acceleration a (where a<g). How much mass should be removed from it so that it starts moving up with an acceleration a? **[AIPMT 2014]**

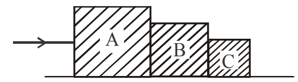
(A) $\frac{2ma}{g+a}$ (B) $\frac{2ma}{g-a}$ (C) $\frac{ma}{g+a}$ (D) $\frac{ma}{g-a}$

Q.19 A block A of mass m_1 rests on a horizontal table. A light string connected to it passes over a frictionless pulley at the edge of table and from its other end another block B of mass m_2 is suspended. The coefficient of kinetic friction between the block and the table is μ_k. When the block A is sliding on the table, the tension in the string is **[AIPMT 2015]**

(A) $\frac{(m_2-\mu_k m_1)g}{m_1+m_2}$ (B) $\frac{m_1 m_2(1+\mu_k)g}{m_1+m_2}$

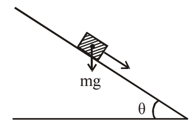
(C) $\frac{m_1 m_2(1-\mu_k)g}{m_1+m_2}$ (D) $\frac{(m_2+\mu_k m_1)g}{m_1+m_2}$

Q.20 Three blocks A, B and C of masses 4 kg, 2 kg and 1 kg respectively, are in contact on a frictionless surface, as shown. If a force of 14N is applied on the 4 kg block then the contact force between A and B is : **[AIPMT 2015]**



(A) 6 N (B) 8 N
(C) 18 N (D) 2 N

Q.21 A plank with a box on it at one end is gradually raised about the other end. As the angle of inclination with the horizontal reaches 30°, the box starts to slip and slides 4.0m down the plank in 4.0s. The coefficients of static and kinetic friction between the box and the plank will be, respectively : **[RE-AIPMT 2015]**



(A) 0.4 and 0.3 (B) 0.6 and 0.6
(C) 0.6 and 0.5 (D) 0.5 and 0.6

Q.22 Two stones of masses m and 2 m are whirled in horizontal circles, the heavier one in a radius r/2 and the lighter one in radius r. The tangential speed of lighter stone is n times that of the value of heavier stone when they experience same centripetal forces. The value of n is :

(A) 1 (B) 2 **[RE-AIPMT 2015]**
(C) 3 (D) 4

Q.23 A car is negotiating a curved road of radius R. The road is banked at an angle θ. The coefficient of friction between the tyres of the car and the road is μ_s. The maximum safe velocity on this road is –

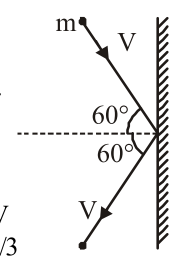
[NEET 2016 PHASE 1]

(A) $\sqrt{gR^2\frac{\mu_s+\tan\theta}{1-\mu_s\tan\theta}}$ (B) $\sqrt{gR\frac{\mu_s+\tan\theta}{1-\mu_s\tan\theta}}$

(C) $\sqrt{\frac{g}{R}\frac{\mu_s+\tan\theta}{1-\mu_s\tan\theta}}$ (D) $\sqrt{\frac{g}{R^2}\frac{\mu_s+\tan\theta}{1-\mu_s\tan\theta}}$

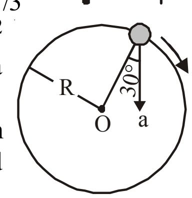
Q.24 A rigid ball of mass m strikes a rigid wall at 60° and gets reflected without loss of speed as shown in the figure. The value of impulse imparted by the wall on the ball will be

[NEET 2016 PHASE 2]



(A) mV (B) 2mV
(C) mV/2 (D) mV/3

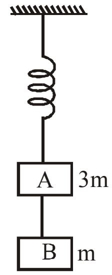
Q.25 In the given figure, a = 15 m/s^2 represents the total acceleration of a particle moving in the clockwise direction in a circle of radius R = 2.5 m at a given instant of time. The speed of the particle is



[NEET 2016 PHASE 2]

(A) 4.5 m/s (B) 5.0 m/s
(C) 5.7 m/s (D) 6.2 m/s

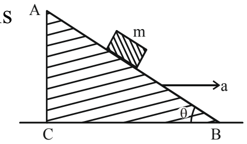
Q.26 Two blocks A and B of masses 3 m and m respectively are connected by a massless and inextensible string. The whole system is suspended by a massless spring as shown in figure. The magnitudes of acceleration of A and B immediately after the string is cut, are respectively **[NEET 2017]**



(A) g/3, g (B) g, g
(C) g/3, g/3 (D) g, g/3

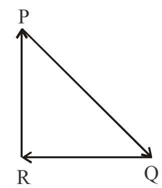
Q.27 Which one of the following statements is incorrect? **[NEET 2018]**
(A) Frictional force opposes the relative motion.
(B) Limiting value of static friction is directly proportional to normal reaction.
(C) Rolling friction is smaller than sliding friction.
(D) Coefficient of sliding friction has dimensions of length.

Q.28 A block of mass m is placed on a smooth inclined wedge ABC of inclination θ as shown in the figure. The wedge is given an acceleration 'a' towards the right. The relation between a and θ for the block to remain stationary on the wedge is **[NEET 2018]**



(A) $a = g\cos\theta$ (B) $a = g / \sin\theta$
(C) $a = g / \text{cosec}\,\theta$ (D) $a = g\tan\theta$

Q.29 A particle moving with velocity $\vec{V}$ is acted by three forces shown by the vector triangle PQR. The velocity of the particle will : **[NEET 2019]**



(A) Increase
(B) Decrease
(C) Remain constant
(D) Change according to the smallest force

ANSWER KEY

EXERCISE - 1

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	D	C	D	B	B	D	B	C	D	B	B	B	C	B	A	A	B	C	A	C	C	D	A	B	B
Q	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
A	D	C	A	C	D	D	C	D	C	C	A	A	B	C	B	A	C	A	B	C	C	A	A	B	A
Q	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
A	B	A	D	D	B	D	D	B	C	A	A	C	B	B	C	B	C	A	C	A	C	A	A	A	D
Q	76	77	78	79	80	81																			
A	A	A	C	A	B	D																			

EXERCISE - 2

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	A	A	A	B	C	B	B	A	D	C	D	A	C	A	B	A	C	B	D	D	A	A	C	A	B
Q	26	27	28	29	30																				
A	A	A	D	A	A																				

EXERCISE - 3

Q	1	2	3	4	5	6	7	8	9
A	2	5	2	3	6	3	5	3	20

EXERCISE - 4

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	A	A	B	C	D	C	C	D	C	C	C	D	A	A	C	D	D	A	C	A	C	B	C	C	C
Q	26	27	28	29	30	31	32																		
A	B	B	D	A	A	B	A																		

EXERCISE - 5

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
A	A	D	B	B	C	A	C	C	D	D	B	D	B	D	C	C	C	A	B	A	C	B	B	A	C	A	D	D	C

NEWTON'S LAWS OF MOTION AND FRICTION

TRY IT YOURSELF-1

(1) **(D).** Basic application of Newton's 3rd Law.

(2) **(C).** Newton's 3rd Law of Motion states that if Joanne applies a force on the basketball to the east, the basketball must apply a force back on Joanne in opposite direction, to the west.

(3) **(BD).**
A non-accelerated frame is defined as inertial frame.
Due to revolution of earth around sun it is accelerated towards the sun. Hence frame of option (B) is not an inertial frame.
Again due to rotation of earth about its axis a frame of option (D) is also an accelerated frame that is why it cannot be considered an inertial frame.

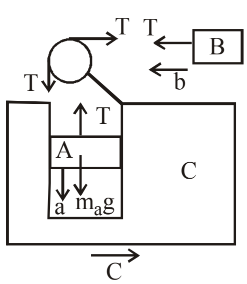
(4) **(B).** On a frictionless table, all your force is doing as it accelerates the object is overcoming the object's inertia. In gravitationless space, the same is the case. The two forces should, therefore, be the same.

(5) **(B).** Because the rope is does not stretch (inextensible) block A and block B move together, so they have the same acceleration.

(6) **(B).** Considered as a whole the blocks are pushed to the right by a force greater than that pushing to the left. Thus both blocks accelerate to the right. Block 1 is pushed to the right by $\vec{F}_1$ and to the left by $\vec{N}$. It accelerates to the right thus $|\vec{F}_1| > N$. Block 2 is pushed to the right by $\vec{N}$ and to the left by $\vec{F}_2$. It accelerates to the right, thus $N > |\vec{F}_2|$.

(7) **(A).** The normal force on the person is greater than the gravitational force on the person because the normal force must also accelerate the person, as well as oppose the gravitational force. Thus $N - mg = ma$ implies that $N = m(a+g)$. So the magnitude of upward normal force is larger than the magnitude of the downward gravitational force.

(8) **(B).** a = b + c [string constrained]



$T = m_B b$ [Newtons II law for B in horizontal direction]

$T = [m_A + m_C]\,c$ [Newton's II law for A and C in horizontal direction]

$m_A g - T = m_A a$ [Newton's II law for A in vertical direction].

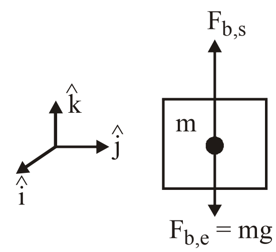
$$\frac{m_A g - T}{m_A} = \frac{T}{m_B} + \frac{T}{m_A + m_C}$$

$$\frac{4mg - T}{4m} = \frac{T}{3m} + \frac{T}{12m} \Rightarrow T = \frac{3mg}{2} \Rightarrow b = \frac{g}{2}$$

(9) **(C).** In part (a), assume that the spring is directly connected to the body. There are two forces acting on the body: the gravitational force between the body and the earth,

$\vec{F}_{b,e} = -mg\,\hat{k}$, and the force between the body and the spring, $\vec{F}_{b,s} = F_{b,s}\,\hat{k}$. (The spring is actually connected to the rope, but since the rope is massless, the tension in the rope is uniform and the spring force transmits through the rope so the tension in the rope is equal to the magnitude of the spring force). The interaction between the body and the spring stretches the spring a distance x from its equilibrium length. By Hooke's Law the magnitude of this force is $F = kx$ and so the force acting on the spring is $\vec{F}_{b,s} = k\,x\,\hat{k}$.

The force diagram on the body is shown below



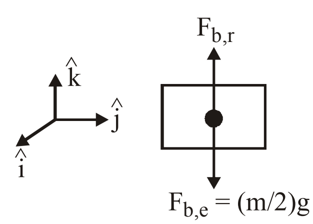
These two forces on the body balance since the body is in equilibrium, and so

$$\vec{F}_b^T = \vec{F}_{b.e} + \vec{F}_{b,s} = -mg\hat{k} + k\,x\,\hat{k} = \vec{0} \quad \text{......... (1)}$$

Therefore the spring stretches a distance

$$x = mg/k. \quad \text{......... (2)}$$

In configuration (b), the forces acting on the body are the gravitational force between the body and the earth, and the force between the rope and the body. The force diagram is shown in the figure below.



Since the body is in static equilibrium,

$$\vec{F}_b^T = \vec{F}_{b.e} + \vec{F}_{b,r} = -(mg/2)\,\hat{k} + F_{br}\hat{k} = \vec{0} \quad \text{..... (3)}$$

Therefore the magnitudes of the force of the rope (tension in the rope) and the gravitational force on the body are equal;

$$mg/2 = F_{b,r} \quad \text{......... (4)}$$

Suppose the spring stretches by an amount x_1. Just as in part (a), the tension in the rope is uniform, so the tension in the rope is equal to the magnitude of the spring force.

$F_{bx} = k\,x_1$ .... (5)

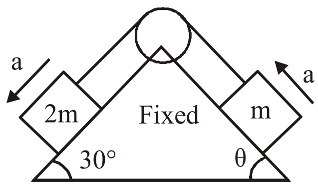
Combining Equations (4) and (5) yields

$kx_1 = (m/2)\,g$ .... (6)

Thus the spring stretches by half the amount as in part (a), as given by Equation (2),

$x_1 = (m/2)g / k = x/2$ .... (7)

(10) **(A).** Acceleration $= \dfrac{2mg\sin 30° - mg\sin\theta}{2m + m}$



Given $a = g/6$

So, $\dfrac{g\,(2\sin 30° - \sin\theta)}{3} = \dfrac{g}{6}$

$\Rightarrow \sin\theta = 1/2 \Rightarrow \theta = 30°$

TRY IT YOURSELF-2

(1) **(C).** The force is proportional to the coefficient of kinetic friction and the weight of the crate. Neither depends on the size of the surface in contact with the floor.

(2) **(D).**

(A) There is a component of F in the normal direction. N.S.L. yields $N - mg + F\sin\theta = ma_y = 0$.

This statement is false.

(B) The component of F that accelerates the block is a function of the angle θ. This statement is false.

(C) Because F is to the right, one might assume that the motion was to the right. If that were the case, this statement would be true. Unfortunately, nothing was said about the direction of motion (just because F is to the right doesn't mean the body is moving to the right--it could be slowing down while moving to the left). Because the statement could be false, it can-not be true.

(3) **(C).** Once the object starts moving it is accelerating because the force on the object is non-zero pointing in the direction down the inclined plane. Therefore the object speeds up.

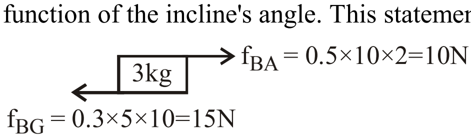
(4) **(C).**

(A) It isn't gravity that accelerates the body, it's the component of gravity along the line of the incline that accelerates the body. This statement is false.

(B) If you do the math, the mass terms cancel out. If you simply think about the interplay between inertial mass and gravitational mass, it should be obvious that the amount of mass will have no effect on the outcome. This statement is false.

(C) The component of gravity that accelerates the mass will be a function of the incline's angle. This statement is true.

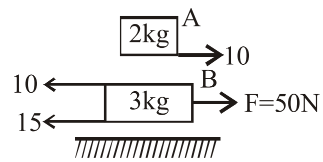
(5) (i) (D).



$\because\ f_{BA} < f_{BG}$

Hence, B will remain at rest, so $a_B = 0$

(ii) **(B).** $a = \dfrac{50-25}{3} = \dfrac{25}{3}$



(6) **(AD).** Suppose blocks A and B move together.

Applying NLM on C, A + B, and D

$60 - T = 6a \Rightarrow T - 18 - T' = 9a \Rightarrow T' - 10 = 1a$

Solving $a = 2\ m/s^2$

To check slipping between A and B, we have to find friction force in this case. If it is less than limiting static friction, then there will be no slipping between A & B.

Applying NLM on A.

$T - f = 6\,(2) \Rightarrow$ as $T = 48\ N \Rightarrow f = 36\ N$

and $f_s = 42$ N hence A and B move together.

and $T' = 12$ N

(7) **(B).** Before bucket starts to accelerate, the tension in the string satisfies $mg - T = 0$ so $T = mg$, where m is the combined mass of the bucket and sand. Once the bucket starts accelerating downward ,

$mg - T = ma$ or $T = m\,(g - a)$.

Thus the tension in the string decreases.

(8) **(A).** Limiting friction between A & B = 90 N

Limiting friction between B & C = 80 N

Limiting friction between C & ground = 60 N

Since limiting friction is least between C and ground, slipping will occur at first between C and ground. This will occur when F = 60 N.

(9) **(D).** The normal force acting on m_1 is m_1g, so the static frictional force will be $\mu_s m_1 g$.

This means that if m_2 had been fixed to the ground (i.e., held stationary), the largest non-slip value F could attain would be $\mu_s m_1 g$, Unfortunately, that's not the situation--m_2 isn't fixed to the ground, it resides on a frictionless surface. Therefore, this statement is false.

(B) Summing the forces on m_1 yields

$F - \mu_s m_1 g = m_1 a$, or $F = m_1 a + \mu_s m_1 g$.

To get a, noting that "no slippage" means that m_1's acceleration equals m_2's acceleration, we can use N.S.L. on m_2.

Doing so yields the following:

$\mu_s m_1 g = m_2 a$, or $a = (\mu_s m_1 g)/m_2$.

Substituting a into our first equations yields:

$F = m_1[\mu_s m_1 g)/m_2] + \mu_s m_1 g = 2\mu_s m_1 g$.

This statement is true . . . but are there other correct responses?

(C) The only force acting on m_2 is friction. The maximum static frictional force between m_1 and m_2 is, indeed,

$\mu_s m_1 g$. This response is true.

CHAPTER-5 :

NEWTON'S LAWS OF MOTION AND FRICTION

EXERCISE-1

(1) (D).
(1) A reference frame in which Newton's first law is valid is called an inertial reference frame.
(2) Frame moving at constant velocity relative to a known inertial frame is also an inertial frame.
(3) Ideally, no inertial frame exists in the universe for practical purpose, a frame of reference may be considered as Inertial if its acceleration is negligible with respect to the acceleration of the object to be observed.

(2) (C). Newton's first law of motion defines the inertia of body. It states that every body has a tendency to remain in its state (either rest or motion) due to its inertia.

(3) (D). Particle will move with uniform velocity due to inertia.

(4) (B). Opposite force causes retardation.

(5) (B). Since, force needed to overcome frictional force.

(6) (D). $F = \frac{dp}{dt} = 2bt \quad \therefore \; F \propto t$

(7) (B). $v = u + at = 0 + \left(\frac{F}{m}\right) t = \left(\frac{100}{5}\right) \times 10 = 200 \text{ cm/sec}$

(8) (C). Force on the football $F = m\frac{dv}{dt}$

$$F = \frac{m(v_2 - v_1)}{dt} = \frac{0.5 \times (10-0)}{1/50} = 250\text{N}.$$

(9) (D). Given that $\vec{F}_1 = 8\hat{i} + 10\hat{j}$ and $\vec{F}_2 = 4\hat{i} + 8\hat{j}$

Then the total force $\vec{F} = 12\hat{i} + 18\hat{j}$

So acceleration $\vec{a} = \frac{\vec{F}}{m} = \frac{12\hat{i} + 18\hat{j}}{6} = 2\hat{i} + 3\hat{j} \text{ m/sec}^2$

(10) (B). We know $\vec{F} = \frac{d\vec{p}}{dt} \Rightarrow \vec{F}dt = d\vec{p}$

$\Rightarrow 2 \times 2 = d\vec{p} \Rightarrow 4 = d\vec{p}$

Therefore change in momentum $= 4$ Ns

(11) (B). On a frictionless table, all your force is doing as it accelerates the object is overcoming the object's inertia. In gravitation less space, the same is the case. The two forces should be same.

(12) (B). Because for every action there is an equal and opposite reaction takes place.

(13) (C). Newton's 3rd Law of Motion states that if Joanne applies a force on the basketball to the east, the basketball must apply a force back on Joanne in opposite direction, to the west.

(14) (B). The same impulse is needed in both cases, so

$F_1 \Delta t_1 = F_2 \Delta t_2$ and

$$F_2 = F_1\left(\frac{\Delta t_1}{\Delta t_2}\right) = (3500\text{ N})\left(\frac{5.0\text{s}}{2.0\text{s}}\right) = 8750\text{ N}$$

(15) (A). $\Delta p = p_i - p_f = mv - (-mv) = 2mv$

(16) (A). $F = \frac{m\Delta v}{\Delta t}$; $s = \left(\frac{u+v}{2}\right)\Delta t$

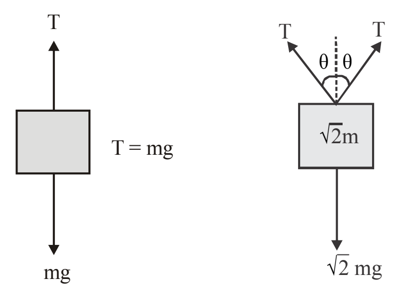
$10^{-3} = \left(\frac{30}{2}\right)\Delta t$; $F = \frac{4 \times 10^{-6} \times 30 \times 30}{2 \times 10^{-3}} = 1.8\text{ N}$

(17) (B). Impulse = F . t = Area under F-t curve from 4 μs to 16 μs = Area under BCDFB
= Area of trapezium BCEF + area of ΔCDE

$= \frac{1}{2}(200+800)(2\times 10^{-6}) + \frac{1}{2} \times 10 \times 10^{-6} \times 800$

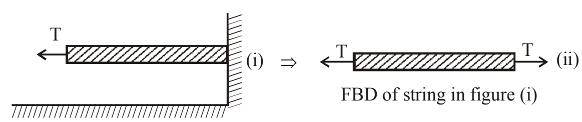
$= 10 \times 10^{-4} + 40 \times 10^{-4}$ N–s $= 5.0 \times 10^{-3}$ N-s

(18) (C). FBD of m is : FBD of mass $\sqrt{2}m$ is



$2T\cos\theta = \sqrt{2}mg$; $\cos\theta = \frac{1}{\sqrt{2}}$ or $\theta = 45°$

(19) (A). Tension in both string shall be same which can be observed by making FBD of string in figure (i)



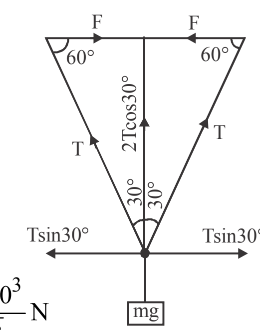
(20) (C). The given situation is shown as

$\therefore$ $F = T\sin 30°$

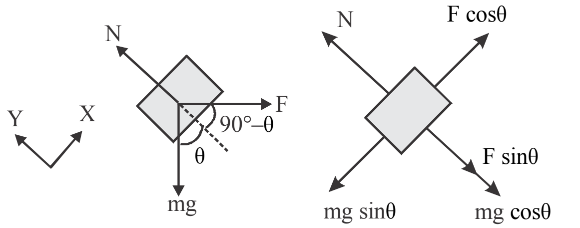
$2T\cos 30° = mg$

$\frac{2T\sqrt{3}}{2} = 10^4 \Rightarrow T = \frac{10^4}{\sqrt{3}}$

and $F = \frac{10^4}{\sqrt{3}} \times \frac{1}{2} = \frac{5 \times 10^3}{\sqrt{3}}$ N



(21) (C). The forces on the block are shown in the free body diagram.



F.B.D. of the block

$\Sigma F_x = 0$; $F \cos\theta - mg \sin\theta = 0$

or $F = \dfrac{mg \sin\theta}{\cos\theta} = mg \tan\theta$

(22) **(D).** $60 \text{ kg-wt} = 20\,(g + a_1) + 30\,(g + a_2)$

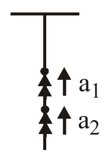
$= 20 \text{ kg-wt} + 30 \text{ kg-wt} + 20a_1 + 30a_2$

$20a_1 + 30a_2 = 10 \text{ kg-wt}$

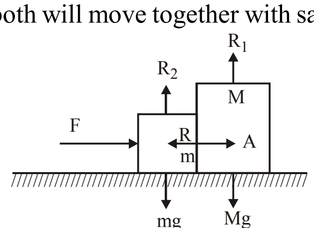
$2a_1 + 3a_2 = 1$

$a_1 = (1/4)\,g,\ a_2 = (1/6)\,g$

$a_1 : a_2 = 6 : 4 = 3 : 2$



(23) **(A).** All the forces acting on the two blocks are shown in fig. As the blocks are rigid under the action of a force F, both will move together with same acceleration.



$a = F/(m+M) = 3/(1+2) = 1 \text{ m/s}^2$

Force of contact, $R = Ma = \dfrac{MF}{M+m} = \dfrac{2\times 3}{2+1} = 2N$

(24) **(B).** Because the rope is does not stretch (inextensible) block A and block B move together, so they have the same acceleration.

(25) **(B).** Considered as a whole the blocks are pushed to the right by a force greater than that pushing to the left. Thus both blocks accelerate to the right. Block 1 is pushed to the right by $\vec{F}_1$ and to the left by $\vec{N}$. It accelerates to the right thus $|\vec{F}_1| > N$. Block 2 is pushed to the right by $\vec{N}$ and to the left by $\vec{F}_2$. It accelerates to the right, thus $N > |\vec{F}_2|$.

(26) **(D).** Reading on the spring balance $= m\,(g - a)$ and since $a = g$ $\therefore$ Force $= 0$

(27) **(C).** Mass measured by physical balance remains unaffected due to variation in acceleration due to gravity.

(28) **(A).** The normal force on the person is greater than the gravitational force on the person because the normal force must also accelerate the person, as well as oppose the gravitational force. Thus N – mg = ma implies that N = m (a + g) . So the magnitude of upward normal force is larger than the magnitude of the downward gravitational force.

(29) **(C).** $a = \dfrac{(M_2 - M_1)\,g}{M_2 + M_1} = \dfrac{(10-5)\,g}{(10+5)} = \dfrac{g}{3}$

(30) **(D).** $a = \left(\dfrac{5-4}{5+4}\right) g = \dfrac{g}{9}$; For block B, $T - mg = ma$

$T = 1\left(g + \dfrac{g}{9}\right) = \dfrac{10g}{9}$

(31) **(D).** Let the tension in the string AP_2 and P_2P_1 be T. Considering the force on pulley P_1, we get

$T = W$ .... (1)

Further, let $\angle AP_2P_1 = 2\theta$

Resolving tensions in horizontal and vertical directions and considering the forces on pulley P_2, we get $2T \cos\theta = W$ .... (2)

$\therefore$ $2W \cos\theta = W$ or $\cos\theta = 1/2$ or $\theta = 60°$

$\therefore$ $\angle AP_2P_1 = 2\theta = 120°$

(32) **(C).** Acceleration $= \dfrac{(m_2 - m_1)}{(m_2 + m_1)} g$

$= \dfrac{4-3}{4+3} \times 9.8 = \dfrac{9.8}{7} = 1.4 \text{ m/sec}^2$

(33) **(D).**

(A) There is a component of F in the normal direction. N.S.L. yields $N - mg + F\sin\theta = ma_y = 0$. This statement is false.

(B) The component of F that accelerates the block is a function of the angle θ. This statement is false.

(C) Because F is to the right, one might assume that the motion was to the right. If that were the case, this statement would be true. Unfortunately, nothing was said about the direction of motion (just because F is to the right doesn't mean the body is moving to the right--it could be slowing down while moving to the left). Because the statement could be false, it can-not be true.

(34) **(C).** Once the object starts moving it is accelerating because the force on the object is non-zero pointing in the direction down the inclined plane. Therefore the object speeds up.

(35) **(C).**

(A) It isn't gravity that accelerates the body, it's the component of gravity along the line of the incline that accelerates the body. This statement is false.

(B) If you do the math, the mass terms cancel out. If you simply think about the interplay between inertial mass and gravitational mass, it should be obvious that the amount of mass will have no effect on the outcome. This statement is false.

(C) The component of gravity that accelerates the mass will be a function of the incline's angle. This statement is true.

(36) **(A).**
(i) Coefficient of static friction is always greater than the coefficient of kinetic friction
(ii) Limiting friction is always greater than the kinetic friction.
(iii) Limiting friction is never less than static friction.

(37) **(A).** Coefficient of friction is constant for two given surface in contact. It does not depend upon the weight or normal reaction.

(38) **(B).** $u = 2\ m/s,\ v = 0,\ t = 10\ sec$

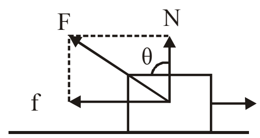
$\therefore\ a = \dfrac{v-u}{t} = \dfrac{0-2}{10} = -\dfrac{2}{10} = -\dfrac{1}{5} = -0.2\ m/s^2$

$\therefore$ Friction force $= ma = 1 \times (-0.2) = -0.2\ N$

(39) **(C).** $\mu_k = \dfrac{F}{R} = \dfrac{19.6}{5 \times 9.8} = \dfrac{2}{5} = 0.4$

(40) **(B).** By using, $v = u + at,\ 0 = v - \mu\, gt \Rightarrow\ t = \dfrac{v}{\mu g}$

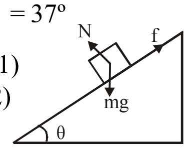
(41) **(A).** Let the contact force on the block by the surface be F which makes an angle θ with the vertical. The component of F perpendicular to the contact surface is the normal force N and the component F parallel to the surface is the friction f. As the surface is horizontal, N is vertically upward. For vertical equilibrium.



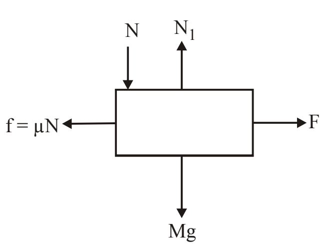
$N = Mg = (0.400)(10) = 4.0\ N$
The frictional force is $f = 3.0\ N$

$\tan\theta = \dfrac{f}{N} = \dfrac{3}{4} \Rightarrow \theta = \tan^{-1}(3/4) = 37^\circ$

(42) **(C).** $N = mg\cos\theta$ .... (1)
$f - mg\sin\theta = 0 \Rightarrow f = mg\sin\theta$ .... (2)
$\therefore\ \mu_S N = mg\sin\theta$
Dividing (2) by (1) $\mu_s = \tan\theta$
$\theta = \tan^{-1}\mu_S = \tan^{-1}(0.3)$

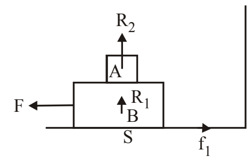


(43) **(A).**



$F = \mu N = Ma\ ;\ F - \mu mg = M\mu g\ ;\ F = \mu g(M+m)$

(44) **(B).** When A moves with B the force opposing the motion is the only force of friction between B and S the horizontal and velocity of the system is constant.



$F = f_1 = \mu R_1 = 0.25\,(4+8) = 3N$

(45) **(C).** Stopping distance is independent on mass.

(46) **(C).** Applied force $< \mu\, Mg\ ;\ f < \mu\, Mg$

Contact force $F = \sqrt{f^2 + N^2}$

$< \sqrt{(\mu Mg)^2 + (Mg)^2} < Mg\sqrt{1+\mu^2}$

(47) **(A).**
(i) In the force applied v/s friction graph :
The graph is a straight line of slope 45° for small F and a straight line parallel to the F-axis for large F.
(ii) There is small kink on the graph

(48) **(A).**
(i) Force of friction between two bodies may be equal to zero
(ii) Bodies may be rough

(49) **(B).** It is easier to pull a body than to push, because the friction force is more in pushing than that in pulling

(50) **(A).** $ma = \mu mg\ ;\ a = \mu g$

(51) **(B).** Here, mass of the car = m
Initial velocity, u = 0 (As the car starts from rest)
Final velocity $\vec{v} = v\,\hat{i}$ along east

$\xrightarrow{}$ x (East) ; $t = 2\ s$
+ve

Using, $v = u + at\ ;\ v\hat{i} = 0 + \vec{a} \times 2$ or $\vec{a} = \dfrac{v}{2}\hat{i}$

Force exerted on the car is $\vec{F} = m\vec{a} = \dfrac{mv}{2}\hat{i} = \dfrac{mv}{2}$ eastward

(52) **(A).** When the lift falls freely, $R = 0$
The force of friction, $F = \mu R = 0$

(53) **(D).** We know that, $F - f = ma$

Here for small body, $a_1 = \dfrac{20 - 0.2 \times 3 \times 10}{3} = \dfrac{14}{3}\ m/s^2$

Similarly $a_2 = \dfrac{6}{10} = 0.6\ m/s^2$

(54) **(D).** Since T = mg, it implies that elevator may be at rest or in uniform motion.

(55) **(B).** $F = ma = \dfrac{m(u-v)}{t} = \dfrac{2 \times (8-0)}{4} = 4N$

(56) **(D).** $F = \dfrac{m(u^2 - v^2)}{2S} = \dfrac{30 \times 10^{-3} \times (120)^2}{2 \times 12 \times 10^{-2}} = 1800\ N$

(57) **(D).** If rope of lift breaks suddenly, acceleration becomes equal to g so that tension, $T = m(g - g) = 0$

(58) **(B).** $F = \sqrt{(F)^2 + (F)^2 + 2F.F\cos\theta} \Rightarrow \theta = 120^\circ$

(59) **(C).** $R = m(g+a) = m(g+4g) = 5mg$

(60) **(A).** Force causing the acceleration = 400 – 200 = 200N

Mass of the boy = 200/9.8

$$\text{Acceleration} = F/m = \frac{200}{200} \times 9.8 = 9.8 \text{ m/s}^2$$

(61) **(A).** $\text{Acceleration} = \frac{\vec{F}}{m} = \frac{6\hat{i}+8\hat{j}}{10}$ in the direction of force and displacement

$$\vec{S} = \vec{u}t + \frac{1}{2}\vec{a}t^2 = 0 + \frac{1}{2}\left(\frac{6\hat{i}+8\hat{j}}{10}\right)\times 100 = 30\hat{i} + 40\hat{j}$$

So the displacement is 50 m along $\tan^{-1}(4/3)$ with x-axis.

(62) **(C).** $F = ma \Rightarrow a = \frac{F}{m} = \frac{1000}{1000} = 1 \text{ m/s}^2$

As the force is brake force, acceleration is – 1 m/s^2 using relation $v^2 = u^2 + 2as$,

$$2as = u^2 \Rightarrow s = \frac{u^2}{2a} = \frac{\left(18 \times \frac{5}{18}\right)^2}{2} = 12.5 \text{ m}$$

(63) **(B).** $F = \frac{dp}{dt} \Rightarrow F\,dt = dp = p_2 - p_1$

$\Rightarrow F \times 1 = mnv - 0 \Rightarrow F = mnv$

(Total mass of the bullets fired in 1 sec = mn)

(64) **(B).** Mass of the rope = 8 × (1/2) = 4 kg

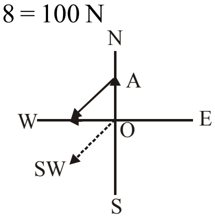
Total mass = 50 + 4 = 54 kg

$$\therefore a = \frac{F}{m} = \frac{108}{54} = 2 \text{ m/s}^2$$

Force utilised in pulling the rope = 4 × 2 = 8 N

Force applied on mass = 108 – 8 = 100 N

(65) **(C).** In figure, $\overrightarrow{OA} = \vec{p}_1$ = initial momentum of player northward.



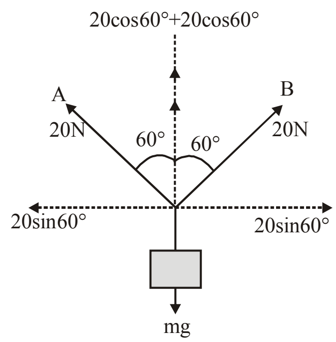
$\overrightarrow{OB} = \vec{p}_2$ = final momentum of player westward.

According to triangle law of vectors, $\overrightarrow{OA} + \overrightarrow{AB} = \overrightarrow{OB}$

$\overrightarrow{AB} = \overrightarrow{OB} - \overrightarrow{OA} = \vec{p}_2 - \vec{p}_1$ = change in momentum

The change in momentum of player is along south west. As motion is due to frictional force of reaction of the ground, therefore, force that acts on the player is frictional force along south west.

(66) **(B).** The situation before breaking the string is



From figure, 20cos 60° + 20 cos 60° = mg

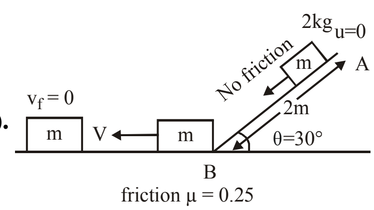
∴ mg = 20 N

(67) **(C).** Box is stationary, f = ma

$\mu N = ma$; $\mu mg = ma$

$0.3 \times 10 = a$; $a = 3 \text{ m/s}^2$

(68) **(A).**



$$F_{net} = mg\sin\theta = 2 \times 10 \times \frac{1}{2} = 10 \text{ N} \quad \text{...(i)}$$

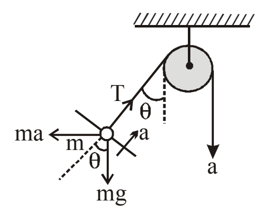
$$a = \frac{F_{net}}{m} = \frac{10}{2} = 5 \text{m/s}^2$$

$v^2 = u^2 + 2as = 0 + 2 \times 5 \times 2 = 20$

$v_f^2 = v^2 - 2(\mu g)S$

$0 = v^2 - 2\mu gS$; $S = 4$m

(69) **(C).** (Force diagram in the frame of the car)



Applying Newton's law perpendicular to string

$mg\sin\theta = ma\cos\theta$

$\tan\theta = a/g$

Applying Newton's law along string

$$T - m\sqrt{g^2 + a^2} = ma \;;\; T = m\sqrt{g^2 + a^2} + ma$$

(70) **(A).** One of the weights gives a reading and the other prevents the acceleration of the system. Therefore, the reading is not zero but 10N.

(71) **(C).** Total mass = 80 + 40 = 120 kg

The rope cannot with stand this load so the fire man should slide down the rope with some acceleration

∴ The maximum tension = 100 × 9.8 N

$m(g - a)$ = tension ,

$120(9.8 - a) = 100 \times 9.8 \Rightarrow a = 1.63 \text{m/s}^2$

(72) **(A).** The change in momentum in the final direction is equal to the impulse

$$= \frac{250}{1000} \times 28 - \left(-\frac{250}{1000} \times 24\right) = 13 \text{ Ns}$$

and $\text{force} = \frac{\text{impulse}}{\text{time}} = \frac{13}{1/100} = 1300\text{N}$

in the direction of the ball.

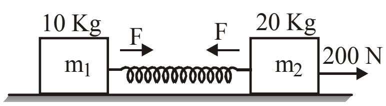
(73) **(A).** The limiting (maximum) force of static friction is
$f_s = \mu_s R = \mu_s mg = 0.4 \times 2\text{kg} \times 9.8\ \text{ms}^{-2} = 7.84\ \text{N}$
The applied force F is 2.5 N, that is less than the limiting frictional force. Hence under the force F, the block does not move. So long the block does not move, the (adjustable) frictional force is always equal to the applied force. Thus the frictional force is 2.5 N.

(74) **(A).** Force required to overcome the weight of rocket

$F = mg$ and thrust needed $= v\frac{dm}{dt}$

$v\frac{dm}{dt} = mg \Rightarrow \frac{dm}{dt} = \frac{mg}{v} = \frac{600 \times 9.8}{1000} = 5.88\ \text{kg/s}$

(75) **(D).** Force equation for m_1 (= 10 kg) mass is
$F = m_1 a_1 = 10 \times 12 = 120\ \text{N}$
Force on 10 kg mass is 120 N to the right.

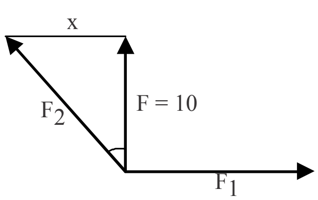


As action and reaction are equal and opposite, the reaction force F on 20 kg mass F = 120 N to the left.
Equation of motion of mass m_2 = 10 kg is
$200 - F = 20a_2$

$\Rightarrow 200 - 120 = 20a_2 \Rightarrow 20a_2 = 80 \Rightarrow a_2 = \frac{80}{20} = 4\ \text{m/s}^2$

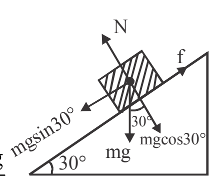
(76) **(A).** (a) From Newton first law.
(b) Friction will support rolling motion.

(77) **(A).**



$\tan 30° = \frac{1}{\sqrt{3}} = \frac{x}{10} \Rightarrow x = \frac{10}{\sqrt{3}}$

(78) **(C).** Let the mass of block be m.
The equation of forces



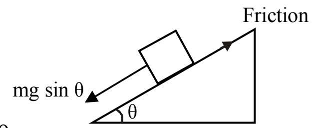
$mg \sin 30° - f = \frac{mg}{4}$; $f = \frac{mg}{4}$

Also, $N = mg \cos 30° = mg\frac{\sqrt{3}}{2}$

As the block is slipping on the incline, friction is

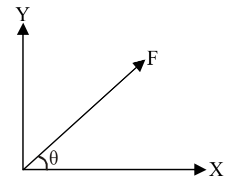
$\mu_n = \frac{F}{N} = \frac{mg}{4mg\frac{\sqrt{3}}{2}} = \frac{1}{2\sqrt{3}}$

(79) **(A).** When the body just start sliding.
$F = f_{lim}$
$mg \sin\theta = \mu\, mg \cos\theta$
$\mu = \tan\theta$



(80) **(B).** $F_x = F\cos\theta = \frac{\sqrt{3}}{2}F$

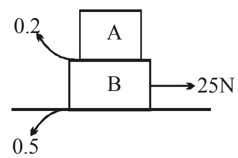
$F_y = F\sin\theta = \frac{F}{2}$



(81) **(D).** $F = m \times g = 0.05 \times 9.8 = 0.49\ \text{N}$, downwards.

EXERCISE-2

(1) **(A).** $f_{B\ lim} = 50$. Hence B will not move, thus A cannot move. So, friction between A and B = 0



$f = 0$.
Friction between B and ground = applied force = 25N

(2) **(A).** Let TN be the tension of the string and let a m/s^2 be the acceleration of the monkey which is rising up. The total force acting on this monkey $(T - 4g)$ N.
$\therefore$ $T - 4g = 4a$ .... (1)
Similarly, the equation of motion of the other monkey which is climbing down the rope with acceleration of $1\ \text{m/s}^2$ is $5g - T = 5 \times 1 = 5$ ...... (2)
Adding (1) and (2), we get

$g = 5 + 4a \Rightarrow \frac{9.8 - 5}{4} = a \Rightarrow \frac{4.8}{4} = a \Rightarrow a = 1.2$

Hence, the required acceleration of the other monkey is $1.2\ \text{m/s}^2$.

(3) **(A).** $f_k = \mu_k N = \mu_k mg\cos 30° = mg\sin 60° = 5(10)\left(\frac{\sqrt{3}}{2}\right)$

$\Rightarrow f_k = 25\sqrt{3}\ \text{N}$

(4) **(B).** F.B.D. of man plank are
For plank to be at rest, applying Newton's second law to plank along the incline
$Mg \sin\alpha = f$ ...... (1)
and applying Newton's second law to man along the incline $mg\sin\alpha + f = ma$ ...... (2)

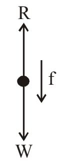
$a = g\sin\alpha\left(1 + \frac{M}{m}\right)$ down the incline.

(5) **(C).** Acceleration of mass at distance x

$a = g(\sin\theta - \mu_0 x \cos\theta)$

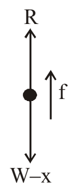
Speed is maximum, when $a = 0$

$g(\sin\theta - \mu_0 x \cos\theta) = 0$; $x = \dfrac{\tan\theta}{\mu_0}$



(6) **(B).** $W - R = \dfrac{W}{g} f$ .... (1)

(Here R is upthrust on the balloon)



$R - (W - x) = \dfrac{(W - x)}{g} f$ ..... (2)

Adding the equation

$$x = \frac{Wf}{g} + \frac{Wf}{g} - \frac{xf}{g}$$

$$\Rightarrow x\left(1 + \frac{f}{g}\right) = \frac{2Wf}{g} \Rightarrow x = \frac{2Wf}{g + f}$$

(7) **(B).** Equation of motion for M :

Since M is stationary, therefore

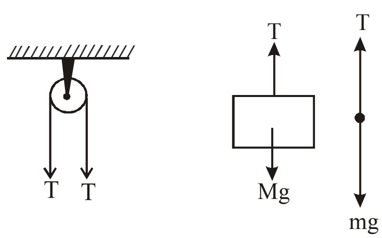
$T - Mg = 0 \quad \Rightarrow T = Mg$ .... (1)

Since the monkey moves up with an acceleration 'a', therefore

$T - mg = ma \quad \Rightarrow T = (g + a)$ .... (2)

Equating eq. (1) and eq. (2), we get

$Mg = m(g + a) \Rightarrow a = \left(\dfrac{M}{m} - 1\right)g$



i.e., if $a > \left(\dfrac{M}{m} - 1\right)g$,

the block M can be lifted from the floor.

(8) **(A).** We draw axes for each block along the incline and normal to incline.

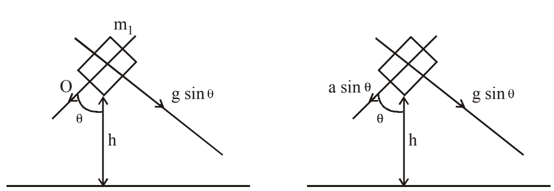


fig.-1 fig.-2

The component of acceleration for each block are as shown, where a is acceleration of wedge is figure 2. It is obvious that vertical component of acceleration is larger for block in figure 2.

$\therefore \; T_1 > T_2$

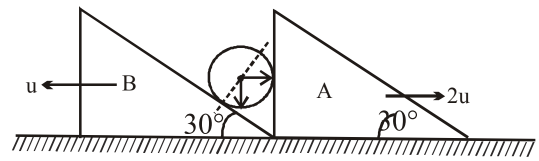
(9) **(D).** As cylinder will remain in contact with wedge A

$V_x = 2u$

As it also remain in contact with wedge B

$u \sin 30° = V_y \cos 30° - V_x \sin 30°$

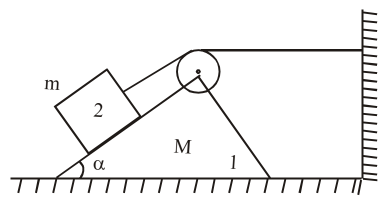
$$V_y = V_x \frac{\sin 30°}{\cos 30°} + \frac{u \sin 30°}{\cos 30°}$$

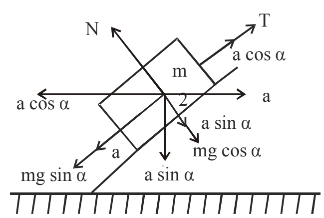


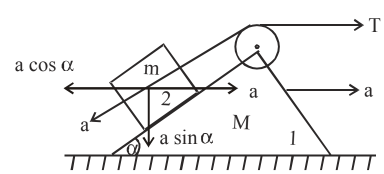
$V_y = V_x \tan 30° + u \tan 30°$

$V_y = 3u \tan 30° = \sqrt{3}u$; $V = \sqrt{V_x^2 + V_y^2} = \sqrt{7}u$

(10) **(C).** Here, the arrangement of the masses and string is such that when mass M goes back by small amount the mass m goes down the incline by the same amount . Since the mass m remains in contact with M, so m has two accelerations each of value a one-down the incline and other horizontal - left to right.







From fig .1 for the downward motion of body '2'

$mg \sin\alpha - T = m(a - a\cos\alpha)$ .... (1)

Here $(a - a\cos\alpha)$ is resultant acceleration of body 2 in down the incline direction.

Since, on the system of '2' and '1' only one horizontal force T is acting as in fig. 2 and body '1' is moving with a horizontal acceleration and body '2' is moving with $(a - a\cos\alpha)$ horizontal acceleration as shown in figure 1. So, for horizontal motion of

$T = m(a - a\cos\alpha) + Ma$ .... (2)

From equation (1) and (2)

$mg \sin\alpha = 2ma(1 - \cos\alpha) + Ma$

$$a = \frac{mg\sin\alpha}{2m(1-\cos\alpha)+M}$$

(11) **(D).** Let the value of 'a' be increased from zero. As long as a □≤ μg, there shall be no relative motion between m_1 or m_2 and platform, that is, m_1 and m_2 shall move with acceleration a. As a > μg the acceleration of m_1 and m_2 shall become μg each. Hence at all instants the velocity of m_1 and m_2 shall be same.

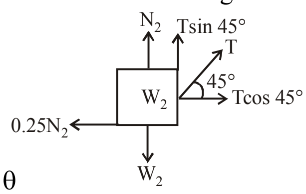
∴ The spring shall always remain in natural length.

(12) **(A).** For m_2 :

$N_2 + T\sin 45° = 200$

$T\cos 45° = 0.25\, N_2$

$\Rightarrow T = 40\sqrt{2}$ N



(13) **(C).** $N - mg\cos\theta = ma\cos\theta$

$N = m(g+a)\cos q = 60(10+2)\cos 60° = 360$ N

(14) **(A).** As long as the block of mass m remains stationary, the block of mass M released from rest comes down by $\frac{2Mg}{K}$ (before coming it rest momentarily again).

Thus the maximum extension in the spring is

$$x = \frac{2Mg}{K} \quad \text{....... (1)}$$

For block of mass m to just move up the incline

$kx = mg\sin\theta + \mu\, mg\cos\theta$ ...... (2)

$$2Mg = mg\times\frac{3}{5} + \frac{3}{4}mg\times\frac{4}{5} \quad \text{or} \quad M = \frac{3}{5}m$$

(15) **(B).** Let L_1 and L_2 be the portions (of length) of rope on left and right surface of wedge as shown.

∴ Magnitude of acceleration of rope

$$a = \frac{\frac{M}{L}(L_1\sin\alpha - L_2\sin\beta)g}{M} = 0$$

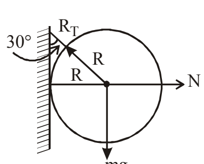
$(\because L_1\sin\alpha = L_2\sin\beta)$

(16) **(A).** $40 = L + \frac{100}{K} \Rightarrow 60 = L + \frac{200}{K}$ ∴ K = 5 and L = 20

Now, $30 = 20 + \frac{x}{5} \Rightarrow x = 50$

(17) **(C).** $mg = T\cos 30°$

$N = T\sin 30° \Rightarrow N = \frac{mg}{\sqrt{3}}$



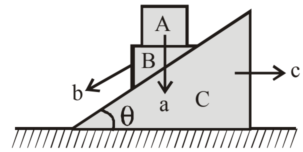
(18) **(B).**

a : acceleration of the block A downwards w.r.t. ground

b : acceleration of the block B w.r.t. inclined plane.

c : acceleration of the block C w.r.t. ground right side

$\vec{b} + \vec{c}$: acceleration of B w.r.t. ground



Applying Newton's law on system along horizontal direction $mc + m(c - b\cos q) = 0$

$2c = b\cos q$ .... (1)

Applying Newton's law on (A + B) along the inclined plane $2mg\sin q = m(b - c\cos q) + ma\sin q$

$2g\sin q = b - c\cos q + a\sin q$ .... (2)

From wedge constraints between A and B

$a = b\sin q$ .... (3)

From (1), (2) and (3)

$$b = \frac{4g\sin q}{1+3\sin^2 q} \; ; \; a = b\sin q = \frac{4g\sin^2 q}{1+3\sin^2 q}$$

(19) **(D).** Since the acceleration of the box is due to the static friction, $ma = f_s \le \mu_s N = \mu_s mg$ i.e. $a \le \mu_s g$

∴ $a_{max} = \mu_s g = 0.15 \times 10\text{ m s}^{-2} = 1.5\text{ m s}^{-2}$

(20) **(D).** At t = 0, v = 8 and at t = 4, v = 0

$v^2 = u^2 + 2as$

On putting the value

$0 = 64 - 2\times a\times s$ .... (1)

But s is area of v-t graph

$s = (1/2)\times 4\times 8 = 16$ .... (2)

By equation (1) and (2),

$0 = 64 - 2\times a\times 16 \Rightarrow a = 2$

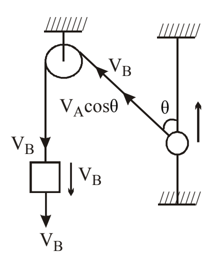
But $a = \mu g = 2$. So, $\mu = 2/10 = 0.20$

(21) **(A).** For the sliding not to occur when $\tan q £ m$

$$\tan q = \frac{dy}{dx} = \frac{2x}{a} = \frac{2\sqrt{2y}}{a} = 2\sqrt{\frac{y}{a}}$$

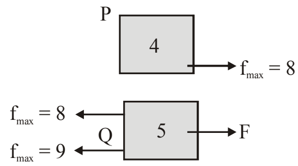
$$\therefore\; 2\sqrt{\frac{y}{a}} £ m \quad \text{or} \quad y £ \frac{am^2}{4} \; ; y_{max} = \frac{am^2}{4}$$

(22) **(A).** $V_B = V_A\cos\theta$.



(23) **(C).** So block Q is moving due to force while block P due to friction.

Friction direction on both +Q blocks as shown



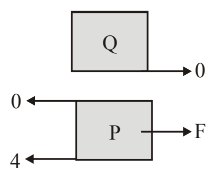
First block 'Q' will move and P will move with 'Q' so by FBD taking P and Q as system

$F - 9 = 0 \quad \Rightarrow \quad F = 9N$

When applied force is 4N then FBD

4 kg block is moving due to friction and maximum friction force is 8N.

So acceleration = 8/4 = 2 m/s² = a_{max}.



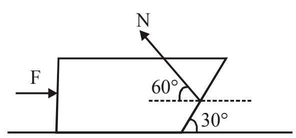
Slipping will start at when Q has +ve acceleration equal to maximum.

Acceleration of P i.e., 2 m/s^2

$F - 17 = 5 \times 2 \Rightarrow F = 27\,N$

(24) **(A).** Acceleration of two mass system is $a = \dfrac{F}{2m}$ leftward

FBD of block A



$N\cos 60° - F = ma = \dfrac{mF}{2m}$; Soving N = 3F

Vertical component of N is $N\sin 60° = \dfrac{N\sqrt{3}}{2} = \dfrac{3\sqrt{3}}{2}F$

(25) **(B).** Let us consider the string element in the slit .Assume that the string moves downward.

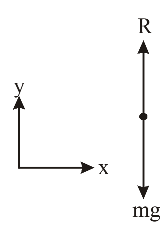
Then the string element will be acted upon by the force of string tension on both sides and the force of friction. Since the mass of this string element is neglected, $T_1 - F - T_2 = 0$.

$m_1 g - T_1 = m_1 a$

$m_2 g - T_2 = m_2 a$

Hence, $a = \dfrac{(m_1 - m_2)g - F}{m_1 + m_2}$

(26) **(A).** The nail hits the sand with a speed v_0 after falling a height h.



$\therefore\ v_0^2 = 2gh \ \Rightarrow\ v_0 = \sqrt{2gh}$ .... (1)

The nail stops after sometime (say t) penetrating through a distance, x into the sand. Since its velocity decreases gradually the sand exerts a retarding upward force, R (say).

Net force acting on the nail

$\Sigma F_y = R - mg = ma \ \Rightarrow\ R = m(g + a)$ .... (2)

[where a = deceleration of the nail]

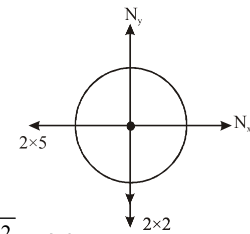
Since the nail penetrates a distance x, therefore

$0 - v_0^2 = -2ax$ .... (3)

Putting v_0 from eq. (1) and 'a' from eq. (2) in eq. (3), we get

$$2gh = 2\left(\frac{R - mg}{m}\right)x \Rightarrow R = \frac{mg\,(h+x)}{x} = mg\left(\frac{h}{x} + 1\right)$$

(27) **(A).** $\vec{v} = (5t\hat{i} + 2t\hat{j})$



$\therefore\ \vec{a} = 5\hat{i} + 2\hat{j}$

$\therefore\ N_x = 5 \times 2 = 10\,N$

$N_x = 2 \times 10 + 2 \times 2 = 24\,N$

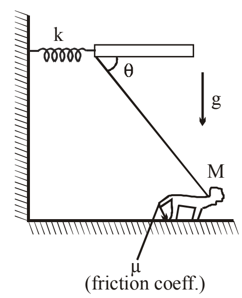
$\therefore$ Total force =

$\sqrt{N_x^2 + N_y^2} = \sqrt{(10)^2 + (24)^2} = 26\,N$

(28) **(D).** For the dog, $N + T\sin\theta - Mg = 0$ (vertical)

$F - T\cos\theta = 0$ (horizontal)

For maximum extension, $f = \mu N$



For spring, $T\cos\theta - kx = 0$ (horizontal)

We have four unknown (N, T, F, x) and four equations

Solve for T : $T\cos\theta = kx \Rightarrow T = \dfrac{kx}{\cos\theta}$

Substitute for F and solve for N :

$\mu N - T\cos\theta = 0 \Rightarrow N = \dfrac{T\cos\theta}{\mu} = \dfrac{kx}{\mu}$

$\dfrac{kx}{\mu} + \dfrac{kx\sin\theta}{\cos\theta} = Mg \ \Rightarrow\ kx\,(1 + \mu\tan\theta) = \mu Mg$

$\Rightarrow\ x = \dfrac{\mu Mg}{k\,(1 + \mu\tan\theta)}$ maximum stretch of spring

$\Rightarrow\ x = \dfrac{(1/3) \times 30 \times 10}{400\left(1 + \dfrac{1}{3} \times \dfrac{3}{4}\right)} = 0.2m$

(29) **(A).** $K' = 2K \Rightarrow F = 2Kx$

(30) **(A).** The vertical component of acceleration of mass 1 and mass 2 are $a_1 = g\sin^2 60°,\ a_2 = g\sin^2 30°$

Since vertical displacement for both masses is 1m, the block with larger acceleration will reach the base of wedge first. Hence block of mass m_1 shall reach base of wedge first.

EXERCISE-3

(1) **2.** When the clamp is removed, the pull on the left arm is $\frac{4m_1m_2g}{m_1+m_2}$. When m_1 and m_2 do not move, the pull is

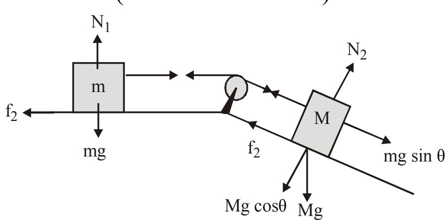
$(m_1+m_2)\,g$; $\Delta w = \frac{(m_1-m_2)^2 g}{m_1+m_2}$

(2) **5.** Velocity of vertical rod with respect to horizontal rod is

$\vec{v}_{rel} = v\hat{i}-(-2v\hat{j}) \quad \therefore \quad \hat{v}_{rel} = \frac{v\hat{i}+2v\hat{j}}{\sqrt{v^2+(2v)^2}} = \frac{\hat{i}+2\hat{j}}{\sqrt{5}}$

$\therefore$ Unit vector along friction force $= -\ \hat{v}_{rel}$

(3) **2.** The system is at rest ($F_{net} = 0$)
For maximum M/m ; Limiting friction will be acting on both blocks (at contact surfaces).



$F_{L_1} + F_{L_2}$ = Net pulling force on the whole system

μ mg + μ Mg cos θ = Mg sin θ

Mg (sin θ – μ cos θ) = μ mg

$$\frac{M}{m} = \frac{\mu}{(\sin\theta - \mu\cos\theta)}$$

(4) **3.** For man and plank [150] → 2T ;

$a = \frac{2T}{150} = \frac{4}{3}\ m/s^2$

Now for man T – f = ma ; $f = 100 - \frac{200}{3} = \frac{100}{3}$ N

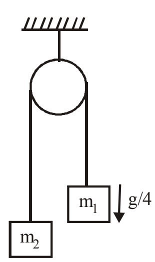
(5) **6.** The body starts moving when $25t = 0.6 \times 100 \Rightarrow t = 2.4$s

$\therefore \ 25t - 40 = 10 \times \frac{dv}{dt}$

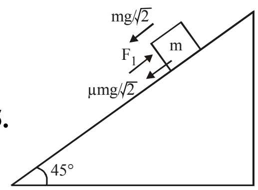
$\Rightarrow \int_0^v dv = \int_{2.4}^{4} \left(\frac{25t-40}{10}\right) dt = 6.4$ m/s

(6) **3.** Equation on (m_1+m_2) system :
$(m_1 - m_2)\,g = (m_1+m_2)\,g/4$

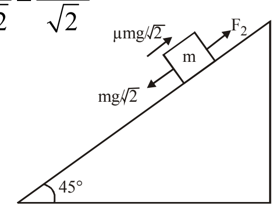
$\Rightarrow m_1 : m_2 = 5:3$



(7) **5.**



$F_1 = \frac{mg}{\sqrt{2}} + \frac{\mu mg}{\sqrt{2}}$; $F_2 = \frac{mg}{\sqrt{2}} - \frac{\mu mg}{\sqrt{2}}$



$F_1 = 3F_2$

$1+\mu = 3-3\mu$

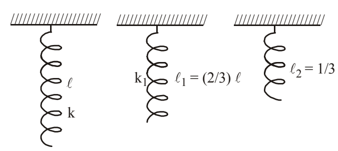
$4\mu = 2$

$\mu = 1/2$; N = 10μ ; N = 5

Alt. : For faster calculation,

mg (sin θ + μ cos θ) = 3mg (sin θ – μ cos θ)

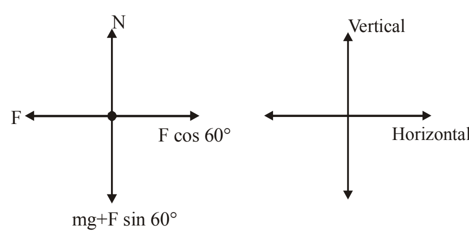
(8) **3.** $\ell_1 = 2\ell_2 \quad \therefore \quad \ell_1 = \frac{2}{3}\ell$



Force constant $\propto \frac{1}{\text{length of spring}} \quad \therefore$

$k_1 = \frac{3}{2}k$

(9) **20.** Free body diagram (FBD) of the block (shown by a dot) is shown in figure



For vertical equilibrium of the block

$N = mg + F\sin 60° = \sqrt{3}g + \sqrt{3}\frac{F}{2}$ .... (1)

For no motion, force of friction

$f \geq F\cos 60°$ or $\mu N \geq F\cos 60°$

or $\frac{1}{2\sqrt{3}}\left(\sqrt{3}g + \frac{\sqrt{3}F}{2}\right) \geq \frac{F}{2}$ or $g \geq \frac{F}{2}$

or $F \leq 2g$ or 20N. Maximum value of F is 20N.

EXERCISE-4

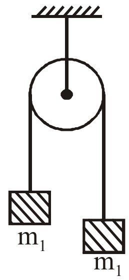
(1) **(A).** Telsion between B and C
$T = m_c a = (66 \times 10^{-3})\,(5) = 330 \times 10^{-3}\ N = 0.33$ N

(2) **(A).** With respect to ground = g
with respect to aeroplane, $a_{ca} = a_c - a_a = g - a$

(3) **(B).** $a = \dfrac{m_1g - m_2g}{m_1 + m_2} = \dfrac{g}{8}$

$8m_1 - 8m_2 = m_1 + m_2$
$7m_1 = 9m_2$

$\dfrac{m_1}{m_2} = \dfrac{9}{7}$



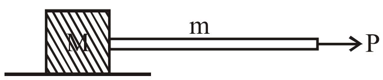
(4) **(C).** $T = m(g - a)$
$360 = 60\,(10 - a)$
$6 = 10 - a\,;\; a = 4 m/s^2$

(5) **(D).** $T = m\,(g - a)\,;\, T = 4.9\,(10 - 5)\,;\, T = 15 \times 4.9\,;\, T = 24N$

(6) **(C).** $\vec{\tau} = \vec{r} \times \vec{F}$; $\vec{\tau} \perp \vec{r}$ and $\vec{\tau} \perp \vec{F}$

So $\vec{\tau}.\vec{r} = 0$ and $\vec{\tau}.\vec{F} = 0$

(7) **(C).**



Acceleration $a = \dfrac{P}{M + m}$

Force exerted by rope on block

$F = Ma = M\left[\dfrac{P}{M + m}\right]$

(8) **(D).** Both will have same reading.

(9) **(C).** In same order $\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$.

(10) **(C).** Normal reaction N = 10 Newton
Maximum friction $= \mu N = 0.2 \times 10 = 2N$
For equilibrium f = weight
Weight = 2N.

(11) **(C).** $v = u + at$

$0 = 6 + (-\mu \times 10)\,10\,;\; \mu = \dfrac{6}{100} = 0.06$

(12) **(D).** Force applied on person
If person fires n bullets/sec

$F = \dfrac{nmu}{1}$; $144 = n(40 \times 10^{-3})\,(1200)\,;\, n = 3$

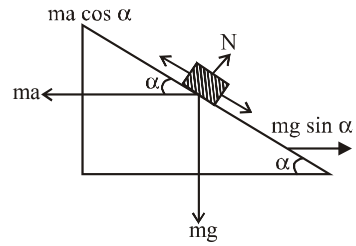
(13) **(A).** In equilibrium $F = mg \sin\theta$
$10 = m \times 10 \times \sin 30^o\,;\, m = 2kg$

(14) **(A).** $a = \dfrac{m_1g - m_2g}{m_1 + m_2}$

$a = \dfrac{(5 - 4.8)\,(9.8)}{5 + 4.8} = 0.2\ m/s^2$

(15) **(C).** $v^2 = u^2 + 2\,as$
$v^2 = 0 + 2(g)\,(50)$
$v^2 = u^2 + 2\,as$
$100g = (3)^2 + 2(-2)s$
So, s = 293 m

(16) **(D).** If particle is in equilibrium
$ma \cos\alpha = mg \sin\alpha$; $a = g \tan\alpha$



(17) **(D).** $F = -kx\,;\; a = \dfrac{F}{m} = \dfrac{-kx}{m}$

$a = \dfrac{-(15)\,(20 \times 10^{-2})}{0.3}$; $a = -10 m/s^2$

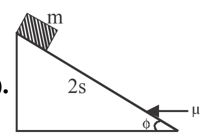
(18) **(A).** On rough surface $s = ut + \dfrac{1}{2}at^2$

$s = 0 + \dfrac{1}{2}\,[g \sin\theta - \mu g \cos\theta]\,(nt)^2$ ....(i)

On plane surface, $s = 0 + \dfrac{1}{2}\,(g \sin\theta)\,t^2$ ...... (ii)

From (i) and (ii), $\mu = 1 - \dfrac{1}{n^2}$

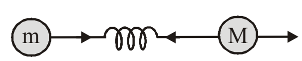
(19) **(C).**



By work energy theorem, $W_g + W_f = \Delta K = 0$
$-mg\,(2s \sin\phi) - (\mu\,mg \cos\phi)s = 0$
$2 \sin\phi - \mu \cos\phi = 0$; $\mu = 2 \tan\phi$

(20) **(A).** $F = \dfrac{m\,(v - u)}{t}$; $F = \dfrac{150 \times 10^{-3}\,(0 - 20)}{0.1} \Rightarrow F = -30N$

(21) **(C).** Acceleration of the system $= \dfrac{F}{M + m}$ and



Force on the block $m = Kx = ma = \dfrac{mF}{m + M}$

(22) **(B).** From the graph, it is a straight line so, uniform motion. Because of impulse direction of velocity changes as can be seen from the slope of the graph.

Initial velocity $= \dfrac{2}{2} = 1\ m/s$

Final velocity $= -\dfrac{2}{2} = -1\ m/s$

$\vec{P}_i = 0.4N\text{-}s\,;\; \vec{P}j_i = -0.4N\text{-}s$

$\vec{J} = \vec{P}_f - \vec{P}_i = -0.4 - 0.4 = -9.8\ N\text{-}s$ ($\vec{J}$ = impulse)

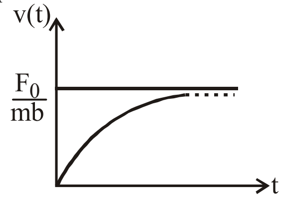
$|\vec{J}| = 0.8\ N\text{-}s$

(23) **(C).** $F = ma = F_0 e^{-bt}$

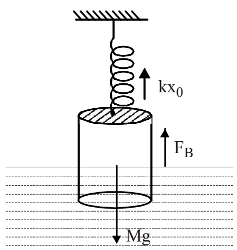
$$\frac{dv}{dt} = \frac{F_0}{m} e^{-bt} \; ; \; \int_0^v dv = \frac{F_0}{m} \int e^{-bt} dt$$

$$v = \frac{F_0}{m} \left[\frac{e^{-bt}}{-b} \right]_0^1$$

$$v = \frac{F_0}{mb}(1 - e^{-bt})$$



(24) **(C).**



$$kx_0 + F_B = mg$$

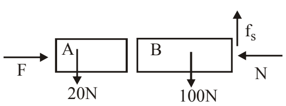
$$kx_0 + \sigma \frac{L}{2} Ag = Mg$$

$$x_0 = \frac{Mg - \frac{\sigma LAg}{2}}{k} = \frac{Mg}{k}\left(1 - \frac{\sigma LA}{2M}\right)$$

(25) **(C).** $mg \sin\theta = \mu mg \cos\theta$; $\tan\theta = \mu$

$$\frac{dy}{dx} = \tan\theta = \mu = \frac{1}{2} \; ; \; \frac{x^2}{2} = \frac{1}{2}, \; x = \pm 1 \; ; \; y = \frac{1}{6} m$$

(26) **(B).**



Clearly $f_s = 120$ N (for vertical equilibrium of the system)

(27) **(B).** $F = -kv^2$; $ma = -kv^2$

$$a = -\frac{k}{m} v^2 \Rightarrow \frac{dv}{dt} = -\frac{k}{m} v^2$$

$$\int_0^v \frac{dv}{v^2} = -\frac{k}{m} \int_0^t dt \Rightarrow \left(-\frac{1}{v}\right)_{10}^{v} = -\frac{k}{m} t$$

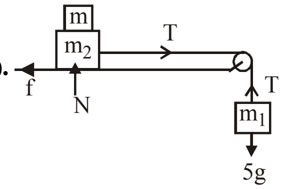
$$\Rightarrow \frac{1}{v} = 0.1 + \frac{kt}{m} \quad \Rightarrow v = \frac{1}{0.1 + \frac{kt}{m}} = \frac{1}{0.1 + 1000k}$$

$$\frac{1}{2} \times m \times v^2 = \frac{1}{8} v_0^2 \; ; \; v = \frac{v_0}{2} = 5$$

$$\Rightarrow \frac{1}{0.1 + 1000k} = 5 \Rightarrow 1 = 0.5 + 5000k$$

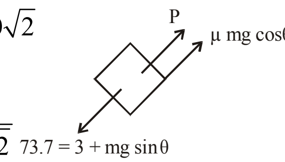
$$\Rightarrow k = \frac{0.5}{5000} \Rightarrow k = 10^{-4} \text{ kg/m}$$

(28) **(D).**



For m_1 to be at rest, $T = 5g$
For m & m_2 to be at rest, $f = T = 5g$
$f \le \mu (N) \Rightarrow f \le 0.15\,(m + m_2)\,g \Rightarrow m \ge 23.33$ kg
Amongst the options minimum mass that can be kept for no motion is 27.3 kg.

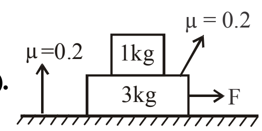
(29) **(A).** $mg \sin 45° = \frac{100}{\sqrt{2}} = 50\sqrt{2}$



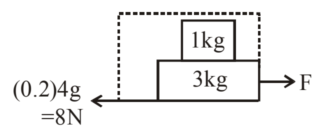
$$\mu mg \cos\theta = 0.6 \times mg \times \frac{1}{\sqrt{2}}$$
$$= 0.6 \times 50\sqrt{2}$$

$P = 31.28 = 32$ N

(30) **(A).**

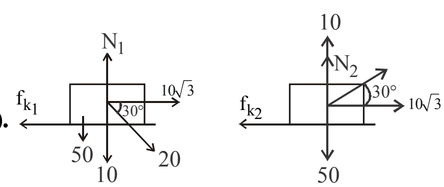


; $a_{Amax} = \mu g = 2 \text{ m/s}^2$



; $F - 8 = 4 \times 2$; $F = 16$ N

(31) **(B).**



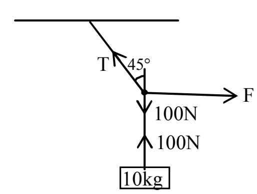
$N_1 = 60, \; N_2 = 40$

$$a_1 = \frac{10\sqrt{3} - 0.2 \times 60}{5} \; ; \; a_2 = \frac{10\sqrt{3} - 0.2 \times 40}{5}$$

$a_1 - a_2 = 0.8$

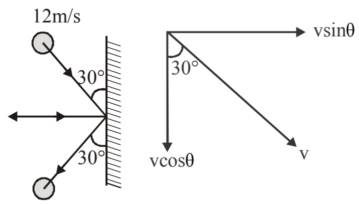
(32) **(A).** $\frac{T}{\sqrt{2}} = 100$; $\frac{T}{\sqrt{2}} = F$

F = 100N



EXERCISE-5

(1) **(A).** Resolving the velocities in vertical and horizontal directions, resolved parts of first velocity v sin θ perpendicular to the wall and v cos θ parallel to the wall.



In the second case, it is – v sin θ & v cos θ.
Here, –ve sign is because direction is opposite to the earlier ones. So we see a net change in velocity.
= v sin θ – (–v sin θ) = 2v sin θ
This change has occurred in 0.25 sec, so, rate of change of velocity

$$=\frac{2v\sin\theta}{0.25}=\frac{2\times12\times\sin30^\circ}{0.25}\Rightarrow\frac{24\times1}{2\times0.25}=48.$$

Acceleration $a = 48\ m/sec^2$
Force applied = m.a. = 0.5 × 48 = 24 N

(2) **(D).** Friction is the retarding force for the block
$F = ma = \mu R = \mu mg$
From the first equation of motion
$v = u - at\ ;\ 0 = V - \mu g \times t \Rightarrow \frac{V}{\mu g} = t$

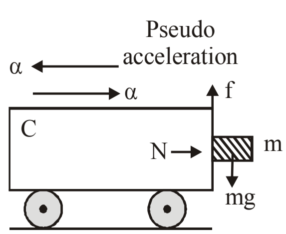
(3) **(B).** $F=\frac{d\,(mv)}{dt}=v\left(\frac{dm}{dt}\right)$ as V = constant ∴ F = Mv

(4) **(B).** $F_{required} = [-$ x component of res. force]
$\vec{F}_{res}=(4-2)\,(\cos30\hat{j}-\sin30\hat{i})+1\,(\cos60\hat{i}+\sin60\hat{j})$
$\therefore\quad \vec{F}_{reqd}=-\left[-\hat{i}+\frac{1}{2}\hat{i}\right]=\frac{1}{2}\hat{i}$

(5) **(C).** $\vec{F}=6\hat{i}-8\hat{j}+10\hat{k},$
$|F|=\sqrt{36+64+100}=10\sqrt{2}N$
$a=1\ ms^{-2}\ ;\ M=\frac{10\sqrt{2}}{1}=10\sqrt{2}\ kg$

(6) **(A).** 2000a = 28000 – 20000 = 8000
$a=\frac{8000}{2000}=4\ ms^{-2}\uparrow$

(7) **(C).**



Pseudo force or fictitious force, $F_{fic} = m\alpha$
Force of friction, $f = \mu N = \mu m\alpha$
The block of mass m will not fall as long as f ≥ mg
$\mu m\alpha \ge mg\ ;\ \alpha \ge g/\mu$

(8) **(C).** The coin will revolve with the record, if Force of friction ≥ Centrifugal force
$\mu mg \ge mr\omega^2$ or $r \le \frac{\mu g}{\omega^2}$

(9) **(D).** T = (M + m) (g + a) = (940 + 60) (10 + 1) = 11000 N

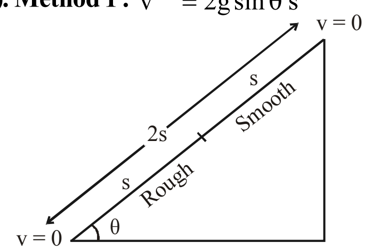
(10) **(D).** $a = \mu g = 5$
$v^2 = u^2 + 2as\ ;\ 0 = 2^2 + 2 \times (5)s$
s = –2/5 w.r.t. belt or distance = 0.4 m

(11) **(B).** For banking, $\tan\theta=\frac{V^2}{Rg}$; $\tan45^\circ=\frac{V^2}{90\times10}=1$;
V = 30 m/s

(12) **(D).** For smooth driving maximum speed of car v then
$\frac{mv^2}{R}=\mu_s mg\ ;\ v=\sqrt{\mu_s Rg}$

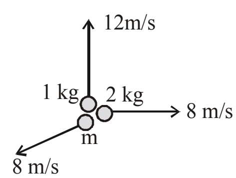
(13) **(B).** As block of mass 2m moves with constant velocity. So net force on it is zero.

(14) **(D).** **Method 1 :** $v'^2 = 2g\sin\theta\ s$



$0 = v'^2 - 2\,(\mu g\cos\theta - g\sin\theta)\ s$
$2g\sin\theta = 2\,(\mu g\cos\theta - g\sin\theta)$
$2\sin\theta = \mu\cos\theta\ ;\ \mu = 2\tan\theta$
Method 2 : From work energy theorem (W = Δ KE)
(mg sin θ) (2s) – (μmg cos θ) (s) = 0 – 0 ⇒ μ = 2 tan θ

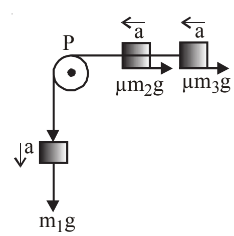
(15) **(C).** From conservation of momentum



$m\,(4)=\sqrt{(1\times12)^2+(2\times8)^2}\ ;\quad m=5\ kg$

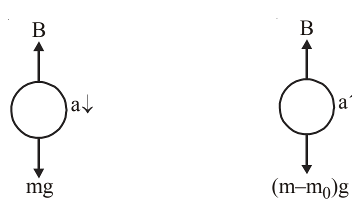
(16) **(C).**

$$a=\frac{m_1g-\mu\,(m_2+m_3)\,g}{m_1+m_2+m_3}$$
$$=\frac{m\,(g-2\mu g)}{3m}=\frac{g}{3}(1-2\mu)$$



(17) **(C).** Change in momentum
= Area between F and t graph
$=\left(\frac{1}{2}\times2\times6\right)-(2\times3)+(4\times3)=6-6+12=12\ Ns$

(18) **(A).**

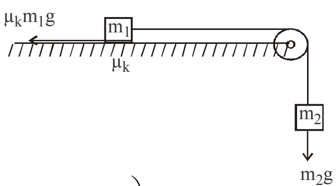


$mg - B = ma$ .... (1) $B - (m - m_0)g = (m - m_0)a$ .... (2)

Equation (1) + equation (2)

$\Rightarrow mg - mg + m_0 g = ma + ma - m_0 a \Rightarrow m_0 = \dfrac{2ma}{g+a}$

(19) **(B).** $a = \dfrac{m_2 g - \mu_k m_1 g}{m_1 + m_2}$



$m_2 g - T = (m_2)(a)$

$m_2 g - T = (m_2)\left(\dfrac{m_2 g - \mu_k m_1 g}{m_1 + m_2}\right)$

Solving get, $T = \dfrac{m_1 m_2 (1 + \mu_k) g}{m_1 + m_2}$

(20) **(A).** $a_c = 14/7 = 2 m/sec^2$

Contact force between A and B = 3 × 2 = 6 N

(21) **(C).** Coefficient of static friction,

$\mu_s = \tan 30° = \dfrac{1}{\sqrt{3}} = 0.6$

$a = g\sin 30° - \mu_k g \cos 30°$

$S = ut + \dfrac{1}{2}at^2$

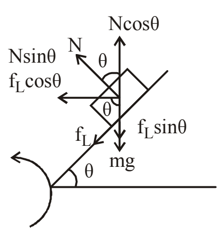
$\Rightarrow 4 = \dfrac{1}{2}\left[\dfrac{g}{2} - \dfrac{\mu_k g\sqrt{3}}{2}\right] \times 16 \Rightarrow \mu_k = 0.5$

(22) **(B).** $(F_C)_{heavier} = (F_C)_{lighter}$

$\dfrac{2mV^2}{(r/2)} = \dfrac{m(nV)^2}{r} \Rightarrow n^2 = 4 \Rightarrow n = 2$

(23) **(B).** Vertical equilibrium : $N\cos\theta = mg + f_L \sin\theta$

$\Rightarrow mg = N\cos\theta - f_L \sin\theta$ …(1)



Horizontal equilibrium

$N\sin\theta + f_L\cos\theta = mv^2/R$ …(2)

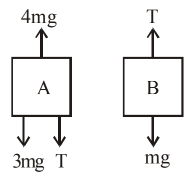
$\dfrac{\text{Eqn (2)}}{\text{Eqn (1)}} : \dfrac{v^2}{Rg} = \dfrac{\sin\theta + \mu_s\cos\theta}{\cos\theta - \mu_s\sin\theta}$

$v = \sqrt{Rg\dfrac{\sin\theta + \mu_s\cos\theta}{\cos\theta - \mu_s\sin\theta}} = \sqrt{Rg\dfrac{\tan\theta + \mu_s}{1 - \mu_s\tan\theta}}$

(24) **(A).** $\vec{J} = |\vec{P}_2 - \vec{P}_1| = 2mV\cos\theta = mV$

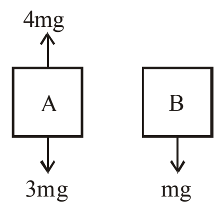
(25) **(C).** $a\cos 30° = \dfrac{v^2}{r} \Rightarrow 15\dfrac{\sqrt{3}}{2} = \dfrac{v^2}{2.5} \Rightarrow v = 5.7 m/s$

(26) **(A).** Before cutting the strip :



$\therefore T = mg$

After cutting the strip :



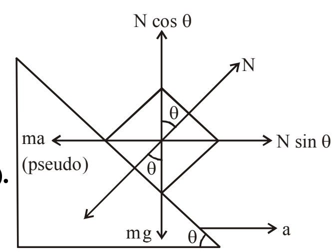
$a_A = \dfrac{4mg - 3mg}{3m} = \dfrac{g}{3}$

$a_B = \dfrac{mg}{m} = g$

(27) **(D).** Coefficient of sliding friction has no dimension.

$f = \mu_s N \Rightarrow \mu_s = \dfrac{f}{N}$

(28) **(D).**



In non-inertial frame,

$N\sin\theta = ma$ ...(i)

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

$\tan\theta = a/g$

$a = g\tan\theta$

(29) **(C).** As forces are forming closed loop in same order. So, $\vec{F}_{net} = 0$

$m\dfrac{d\vec{v}}{dt} = 0 \Rightarrow \vec{v} = \text{constant}$