Newtons Laws of Motion and Friction

NEWTONS LAWS OF MOTION

NEWTONS LAWS OF MOTION AND FRICTION

Force

- A pull or push which changes or tends to change the state of rest or uniform motion or direction of motion of any object is called a force.
- Force is the interaction between the object and the source (providing the pull or push). It is a vector quantity.

Unit of force: Newton and $\frac{kg \cdot m}{s^2}$ (MKS System)

$$dyne\ and\ \frac{g \cdot cm}{s^2}\ (CGS\ System)\quad 1\ Newton\ = 10^5\ dyne$$

Kilogram force (kgf) : The force with which the Earth attracts a 1 kg body towards its centre is called kilogram force, thus

$$kgf\ = \frac{Force\ in\ Newton}{g}\ \left(g\ =\ 9.8\ m/s^2\right)$$

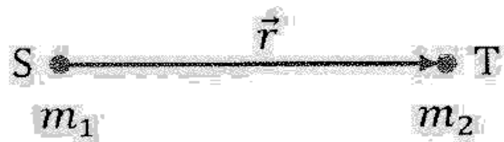
Dimensional Formula of force: $\left[MLT^{-2}\right]$

Fundamental Forces

All the forces observed in nature such as muscular force, tension, friction, elastic, weight, electric, magnetic, nuclear, etc., can be explained in terms of only following four basic interactions:

(A) Gravitational Force

The force of interaction which exists between two particles of masses m_1 and m_2, due to their masses is called gravitational force.

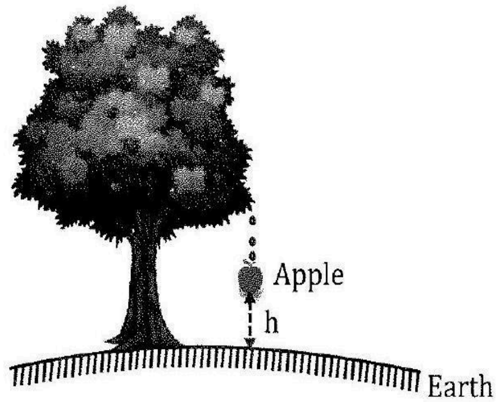


$$\vec{F}\ = -\ G\frac{m_1 m_2}{r^3}\vec{r}\quad \vec{r}\ =\ Position\ vector\ of\ test\ particle\ 'T'\ with\ respect\quad to\ source\ particle\ 'S'$$

$$G\ = \text{Universal gravitational constant}$$
$$=\ 6.67\times10^{-11} Nm^2/kg^2$$

(i) It is the weakest force and is always attractive.
(ii) It is a long-range force as it acts between any two particles situated at any distance in the universe.
(iii) It is independent of the nature of medium between the particles.
An apple is freely falling as shown in figure, when it is at a height h, force between the Earth and apple is given by

$$F\ = \frac{GM_e m}{\left(R_e + h\right)^2}$$



where M_e (mass of earth), R_e (radius of earth). It acts towards Earth's centre. Now rearranging above result,

$$F = m\frac{GM_e}{R_e^2} \cdot \left(\frac{R_e}{R_e+h}\right)^2 \quad F = mg\left(\frac{R_e}{R_e+h}\right)^2 \left\{g = \frac{GM_e}{R_e^2}\right\}$$

Here $h \ll R_e$, so $\frac{R_e}{R_e+h} = 1$

$\therefore F = mg$

This is the force exerted by the Earth on any particle of mass m near the Earth surface. The value of $g = 9.81\, m/s^2 \simeq 10\, m/s^2 \simeq \pi^2\, m/s^2 \simeq 32 ft/s^2$. It is also called acceleration due to gravity near the surface of the Earth.

(B) Electromagnetic Force

Force exerted by one particle on the other because of the electric charge on the particles is called electromagnetic force.

Following are the main characteristics of electromagnetic force

(a) These can be attractive or repulsive.

(b) These are long range forces

(c) These depend on the nature of medium between the charged particles.

(d) All macroscopic forces (except gravitational) which we experience as push or pull or by contact are electromagnetic, i.e., tension in a rope, the force of friction, normal reaction, muscular force, and force experienced by a deformed spring are electromagnetic forces. These are manifestations of the electromagnetic attractions and repulsions between atoms/molecules.

(C) Nuclear Force

It is the strongest force. It keeps nucleons (neutrons and protons) together inside the nucleus inspite of large electric repulsion between protons. Radioactivity, fission, and fusion, etc. result because of unbalancing of nuclear forces. It acts within the nucleus that too upto a very small distance.

(D) Weak Force

It acts between any two elementary particles. Under its action a neutron can change into a proton emitting an electron and a particle called antineutrino. The range of weak force is very small, in fact much smaller than the size of a proton or a neutron.

It has been found that for two protons at a distance of 1 Fermi :

$F_N : F_{EM} : F_W : F_G :: 1 : 10^{-2} : 10^{-7} : 10^{-38}$

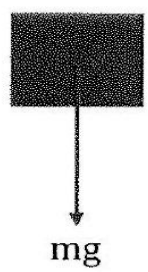
Classification of forces on the basis of contact :

(A) Field Force : Force which acts on an object at a distance by the interaction of the object with the field produced by other object is called field force.
Examples:
(a) Gravitational force
(b) Electromagnetic force
(B) Contact Force: Forces which are transmitted between bodies by short range atomic molecular interactions are called contact forces. When two objects come in contact they exert contact forces on each other.
Examples : Normal force, frictional force.
Some standard forces:

Weight: Force experienced by a body due to gravity is known as weight. It is applicable to all bodies having mass but specifically for a body near the Earth's surface, we compute it as:

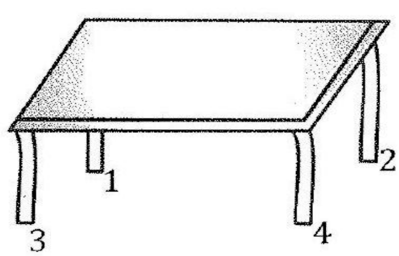
$$F = \frac{G\times \text{mass of the Earth} \times \text{mass of the body}}{(\text{radius of Earth})^2}$$

Where, $\frac{G\times \text{mass of the Earth}}{(\text{radius of the Earth})} = g$ (constant)
g = acceleration due to gravity of the Earth
The weight of an object of mass m near the surface of the Earth is mg directed towards the centre of the Earth.
m = mass of block
g = acceleration due to gravity of the Earth

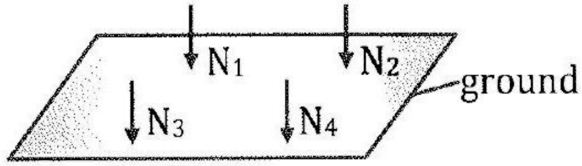


Normal Force (N) :

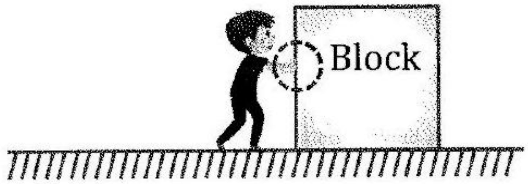
It is the component of contact force perpendicular to the surface. It measures how strongly the surfaces in contact are pressed against each other. It is the electromagnetic force. A table is placed on the Earth as shown in figure



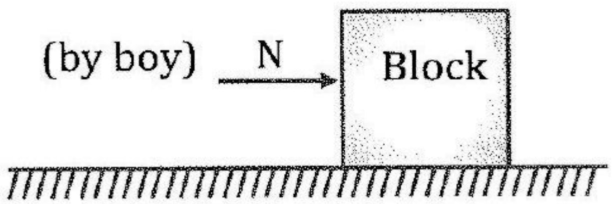
Here table presses the Earth so normal force exerted by four legs of table on the Earth are as shown in figure.



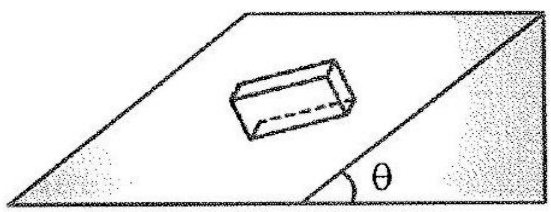
Now a boy pushes a block kept on a frictionless surface.



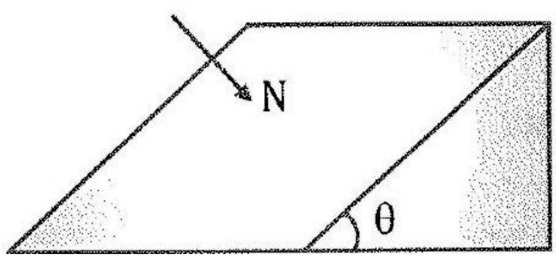
Here, force exerted by boy on block is electromagnetic interaction which arises due to similar charges appearing on finger and contact surface of block, it is normal force.



A block is kept on inclined surface. Component of its weight presses the surface perpendicularly due to which contact force acts between surface and block.



Normal force exerted by block on the surface of inclined plane is shown in figure.



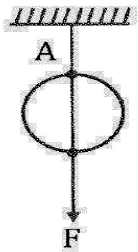
Force acts perpendicular to the surface.

Note :

Normal is a dependent force, it comes in role when one surface presses the other.

Tension :

Tension in a string is an electromagnetic force. It arises when a string is pulled. If a massless string is not pulled, tension in it is zero. A string suspended by rigid support is pulled by a force ' F ' as shown in figure, for calculating the tension at point ' A ' we draw F.B.D. of marked portion of the string; Here string is massless.

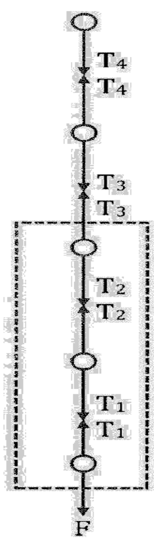


F.B.D of marked portion

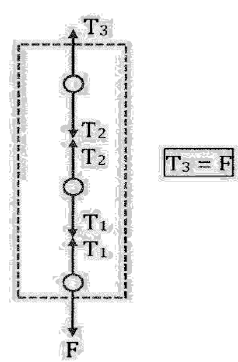
F.B.D of marked portion

$\Rightarrow T = F$

String is considered to be made of a number of small segments which attracts each other due to electromagnetic nature as shown in figure. The attraction force between two segments is equal and opposite due to Newton's third law.



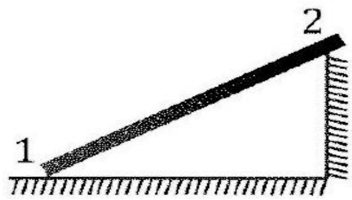
For calculating tension at any segment, we consider two or more than two parts as a system.



Here interaction between segments are considered as internal forces, so they are not shown in F.B.

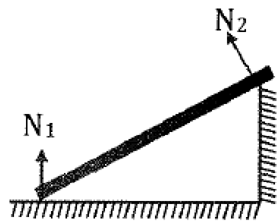
Illustration 1:

Draw normal forces on the massive rod at point 1 and 2 as shown in figure.



Solution:

Normal force acts perpendicular extended surface at point of contact.



(21 d)

Newton's Laws of Motion

Newton's First Law of Motion

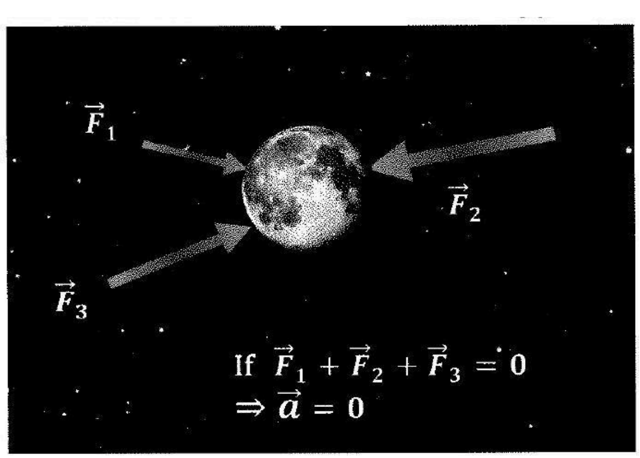
Every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force.

Or

To change state of motion of a body a external force is necessary. There are two states of motion of a body.
(1) State of rest ($v = 0, a = 0$)
(2) State of uniform motion ($v \neq 0, a = 0$)

Or

If the vector sum of all the forces acting on a particle is zero, then and only then the particle remains unaccelerated (i.e., remains at rest or moves with constant velocity).



- First law is also known as the law of inertia.
  Inertia: The resistance of a particle to change its state of rest or of uniform motion along a straight line.
  It could be of three types:

- Inertia of rest
- Inertia of motion
- Inertia of direction

Note:

1. Force is the cause of changes in motion
Force does not cause motion. We can have motion in the absence of force, as described in Newton's first law. Force is the cause of change in motion as measured by acceleration.
2. **ma is not a force**
Equation 2 does not say that the product ma is a force. All forces on object are added vectorially to generate the net force on the left side of the equation. This net force is then equated to the product of the mass of the object and the acceleration that results from the net force.

Newton's Second Law of Motion

The rate of change of linear momentum of a body is equal to net force acting on the body.

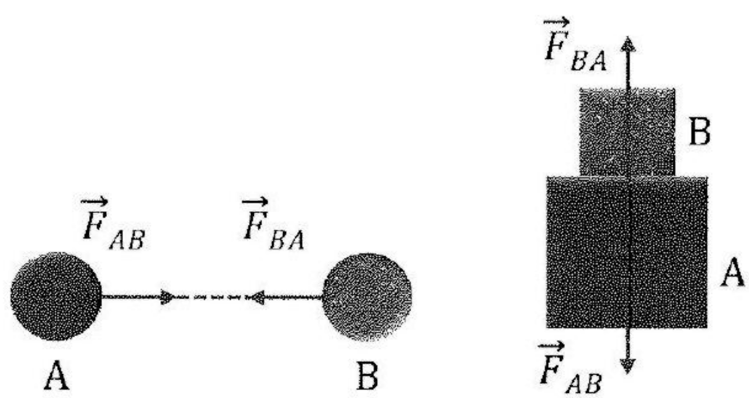
$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{d}{dt}(m\vec{v}) \quad (Mass\ is\ constant) \qquad (1)$$

$$\vec{F} = m\frac{d\vec{v}}{dt} = m\vec{a} \qquad (2)$$

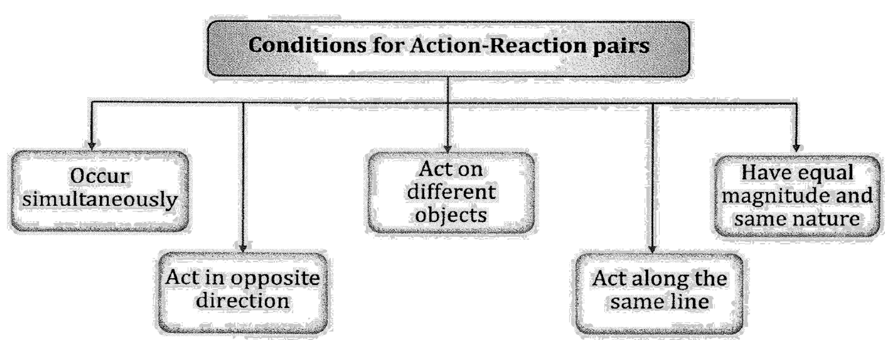
- Acceleration of a particle as measured from an inertial frame (ground) is given by the vector sum of all the forces acting on the particle divided by its mass.

Newton's Third Law of Motion

If a body A exerts a force $\vec{F}$ on another body B, then B exerts a force $-\vec{F}$ on A, the two forces acting along the line joining the bodies.



These two forces in Newton's third law are known as Action-Reaction pairs.
Properties of action - reaction pairs



Third law of motion :

To every action, there is always an equal and opposite reaction. Newton's law from an 1803 translation from Latin as Newton wrote

Important points about the Third Law

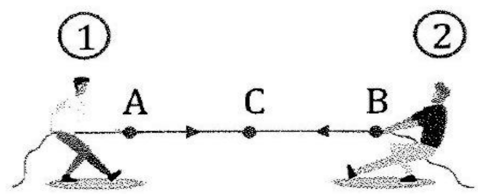
(a) The terms 'action' and 'reaction' in the Third Law mean nothing else but 'force'. A simple and clear way of stating the Third Law is as follows : Forces always occur in pairs. Force on a body A by B is equal and opposite to the force on the body B by A.

(b) The terms 'action' and 'reaction' in the Third Law may give a wrong impression that action comes before reaction i.e. action is the cause and reaction the effect. There is no such cause-effect relation implied in the Third Law. The force on A by B and the force on B by A act at the same instant. Any one of them may be called action and the other reaction.

(c) Action and reaction forces act on different bodies, not on the same body. Thus, if we are considering the motion of any one body (or B), only one of the two forces are relevant. It is an error to add up the two forces and claim that the net force is zero.

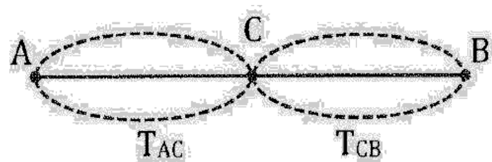
However, if you are considering the system of two bodies as a whole, F_{AB} (force on A due to) and F_{BA} (force on B due to A) are internal forces of the system $(A + B)$. They add up to give a null force. Internal forces in a body or a system of particles thus cancel away in pairs. This is an important fact that enables the Second Law to be applicable to a body or a system of particles.

Example:

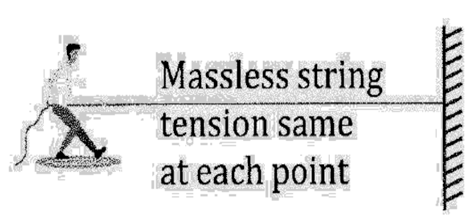


Tension at ' A ' is force applied by string on (1)

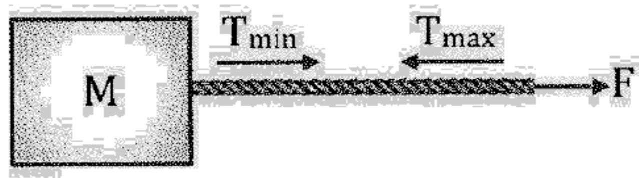
Tension at ' B ' is force applied by string on (2)



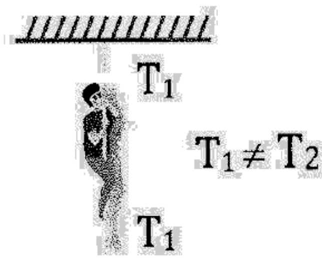
(d) String is assumed to be massless unless stated, hence tension in it everywhere remains the same and equal to applied force.



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. (eg.)



(e) 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 dimensions.



What is System?

Any group of objects which we decide to study together can be taken as system.

Internal and external forces

If the action-reaction pair exists in the considered system, then it is known as internal force, otherwise it is known as external force.

Free-Body Diagram (FBD)

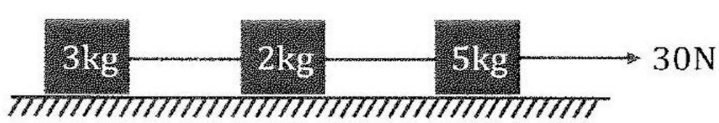
The diagrammatic representation of a body that is isolated from its surroundings, showing all the external forces acting on it, is known as the free-body diagram (FBD).

Steps for drawing the FBD

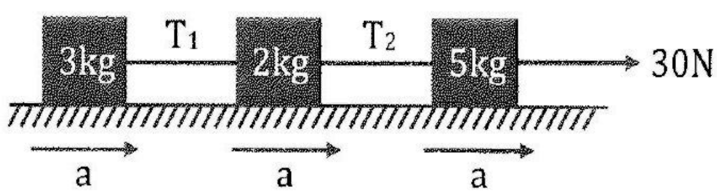
1. Isolate the free body.
2. Draw the external forces.
3. Choose the axes and resolve the forces.

Illustration 2:

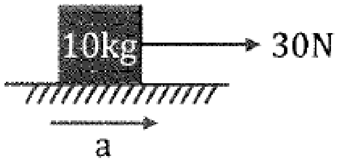
Draw the free body diagrams and find tension in each string and acceleration of the system.



Solution:



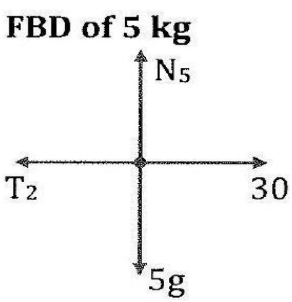
Acceleration $= \frac{Net\ pulling\ force}{Total\ mass\ to\ be\ pulled}$



$a = \frac{30}{10} = 3\, m/s^2$

FBD of $2kg$

$T_2 - T_1 = 2a$ $N_2 - 2g = 2\times0$ $N_2 = 20\, N$



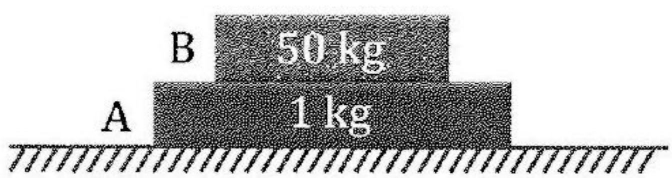
$30 - T_2 = 5a$ $N_5 - 5g = 5\times0$ $N_5 = 50N$

Note:

Here N_{AB} and N_{BA} are the action-reaction pair (Newton's third law).

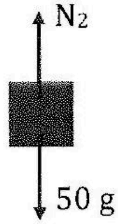
Illustration 3:

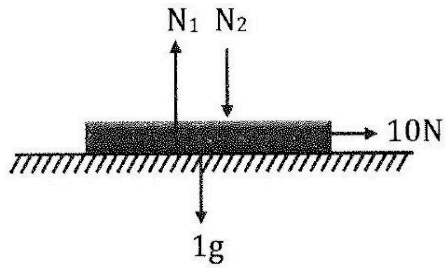
A block of mass 50 kg is kept on another block of mass 1 kg as shown in figure. A horizontal force of 10 N is applied on the 1 kg block. (All surface are smooth). Find ($g = 10\, m/s^2$)



(a) Acceleration of block A and B.
(b) Force exerted by B on A.

Solution:





(a) F.B.D. of 50 kg

$N_2 = 50\,g = 500\,N$

Along horizontal direction, there is no force $a_B = 0$

(b) F.B.D. of 1 kg block : along horizontal direction

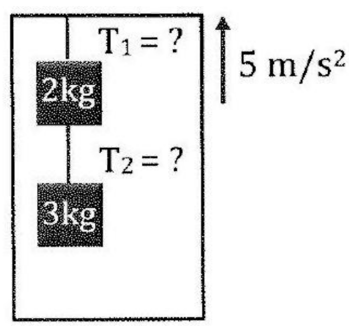
$10 = 1a_A \; a_A = 10\,m/s^2$

Along vertical direction

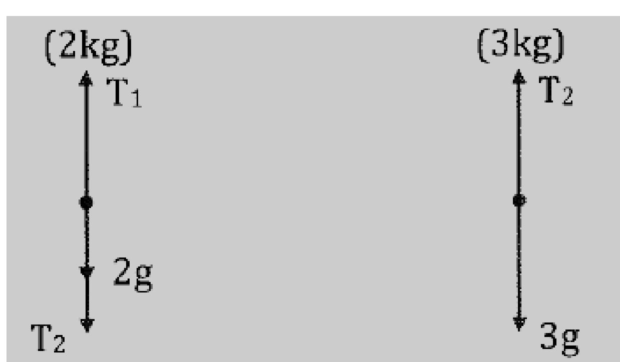
$\therefore N_1 = N_2 + 1g = 500 + 10 = 510N$

Illustration 4:

Find tension and acceleration.



Translational Equilibrium



$T_1 - T_2 - 2g = 2\times5$

$T_1 - T_2 = 30$

$T_2 - 3g = 3\times5$

$T_2 = 15 + 30$

$T_1 = 45 = 30$ $T_2 = 45$ N

$T_1 = 75$

Solution:

- A body in state of rest or moving with constant velocity is said to be in translational equilibrium. Thus, if a body is in translational equilibrium in a particular inertial frame of reference, it must have no linear acceleration.
- When it is at rest, it is in static equilibrium, whereas if it is moving at constant velocity it is in dynamic equilibrium.

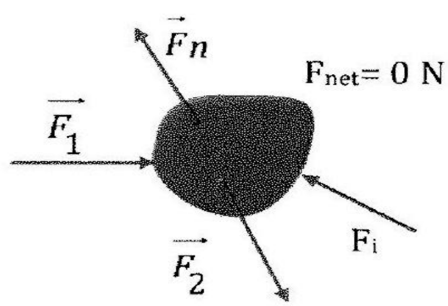
Conditions for translational equilibrium

- For a body to be in translational equilibrium, no net force must act on it i.e. vector sum of all the forces acting on it must be zero.

If several external forces $\vec{F}_1, \vec{F}_2 ..... \vec{F}_i .....$ and $\vec{F}_n$ act simultaneously on a body and the body is in translational equilibrium, the resultant of these forces must be zero.

$\sum \vec{F}_i = \vec{0}$

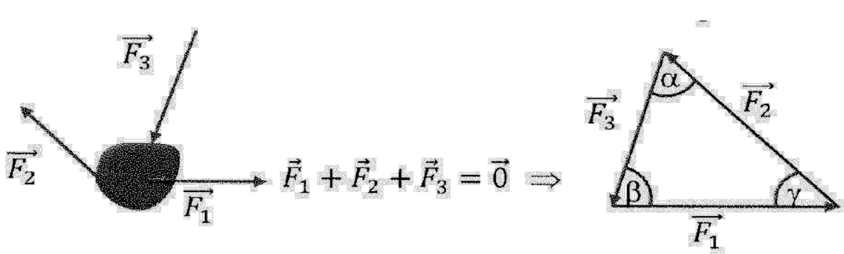
- If the forces



$\vec{F}_1, \vec{F}_2 ..... \vec{F}_i .....$ and $\vec{F}_n$ are expressed in Cartesian components, we have :

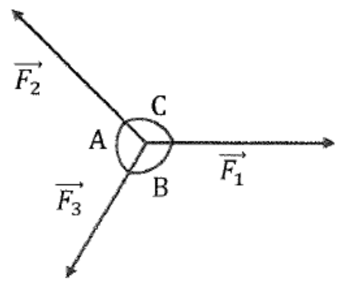
$\sum F_k = 0 \; \sum F_w = 0 \; \sum F_k = 0$

- If a body is acted upon by a single external force, it cannot be in equilibrium. If a body is in equilibrium under the action of only two external forces, the forces must be equal and opposite.
- If a body is in equilibrium under action of three forces, their resultant must be zero; therefore, according to the triangle law of vector addition they must be coplanar and make a closed triangle.



Lami's Theorem

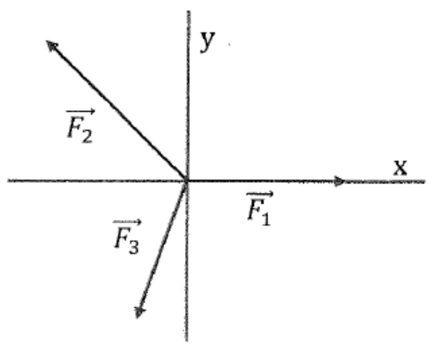
Graphical method makes use of sine rule or Lami's theorem.



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

Lami's theorem : $\frac{F_1}{sinA} = \frac{F_2}{sinB} = \frac{F_3}{sinC}$

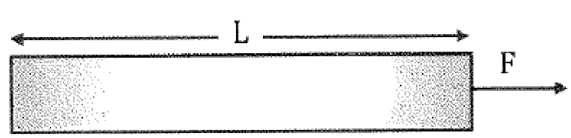
Analytical method makes use of Cartesian components. Since the forces involved make a closed triangle, they lie in a plane and a two-dimensional Cartesian frame can be used to resolve the forces. As far as possible orientation of the $x - y$ frame is selected in such a manner that angles made by forces with axes should have convenient values.



$$\sum F_x = 0 \Rightarrow F_{1x} + F_{2x} + F_{3x} = 0 \quad \sum F_y = 0 \Rightarrow F_{1y} + F_{2y} + F_{3y} = 0$$

Problems involving more than three forces should be analyzed by analytical method. However, in some situations, there may be some parallel or anti-parallel forces and they should be combined first to minimize the number of forces. This may sometimes lead a problem involving more than three forces to a three-force system.

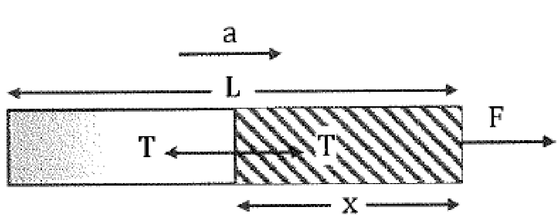
Tension in Rod or Massive String



$Mass\ of\ Rod = M$

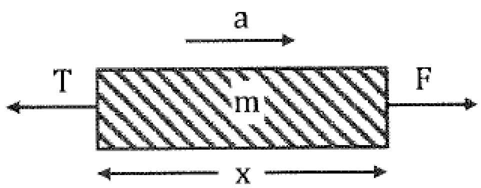
$Length\ of\ Rod = L$

$F - T = ma$



$T = F - ma$

$T = F - m\frac{F}{M}\left(\therefore a = \frac{F}{M}\right)$



$Mass\ of\ length\ 'L' = M \therefore Mass\ of\ unit\ length = \frac{M}{L}$

$Mass\ (m)\ of\ length\ 'x' = \frac{M}{L}x$

Put this value of ' m ' in equation (1)

$T = F - \left(\frac{M}{L}X\right) \times \frac{F}{M} T = F - \frac{Fx}{L};$

$$T = F\left(1 - \frac{x}{L}\right)$$

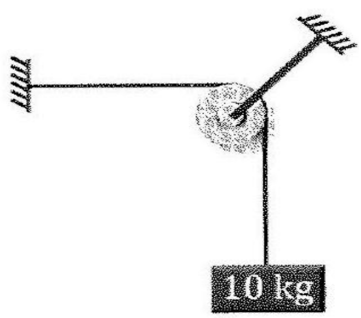
Pulley Systems

The only function of pulley (which has no friction on its axle to retard rotation) is to change the direction of the cord that joins the two blocks.

- 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.

Illustration 5:

Find magnitude of force exerted by string on pulley.



Solution:

F.B.D. of 10 kg block : $T = 10\ g = 100\ N$

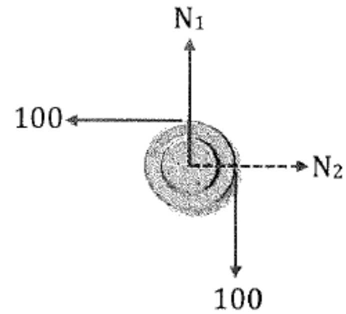
F.B.D. of pulley : Since string is massless, so tension in both sides of string is same.

Force exerted by string = $\sqrt{(100)^2 + (100)^2} = 100\sqrt{2}\ N$

Note:

Since pulley is in equilibrium position, so net forces on it is zero.

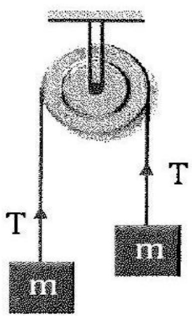
Hence force exerted by hinge on it is $100\sqrt{2}N$.



Some Cases of Pulley

Case I:

$m_1 = m_2 = m$

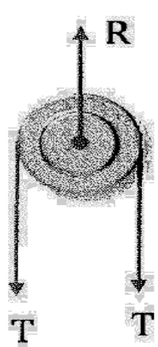


Tension in the string
$T = mg$
Acceleration ' a ' = zero

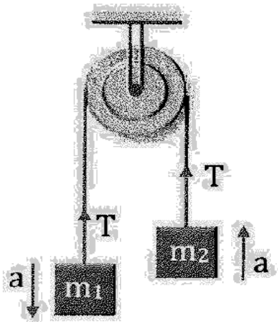
Reaction at the suspension of the pulley
$R = 2T = 2mg$

Acceleration $= \frac{Net\ pulling\ force}{Total\ mass\ to\ be\ pulled}$

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



Case II:



$m_1 > m_2$

Now for mass m_1,

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

For mass m_2,

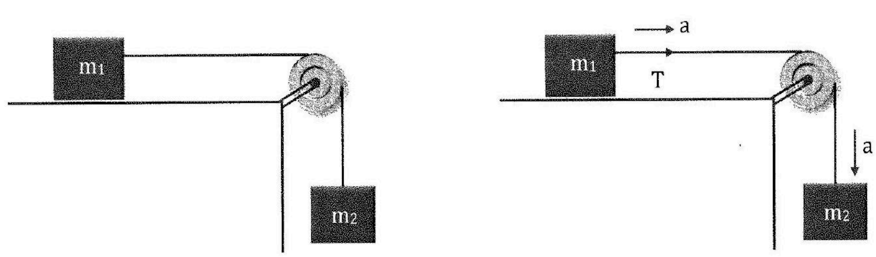
$T - m_2 g = m_2 a$ (ii)

By (i) and (ii)

$a = \frac{(m_1 - m_2)}{(m_1 + m_2)} g$ and $T = \frac{2m_1 m_2}{(m_1 + m_2)} g$

Reaction at the suspension of pulley $R = 2T = \left(\frac{4m_1 m_2}{m_1 + m_2}\right) g$

Case III:

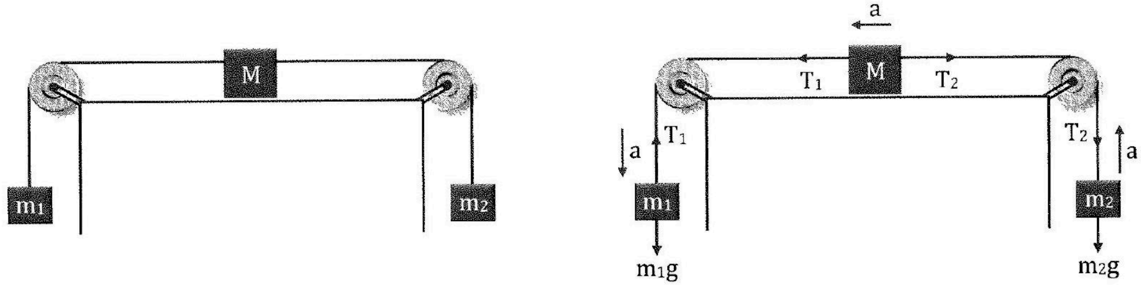


For mass m_1: $T = m_1 a$

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

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

Case IV : $(m_1 > m_2)$

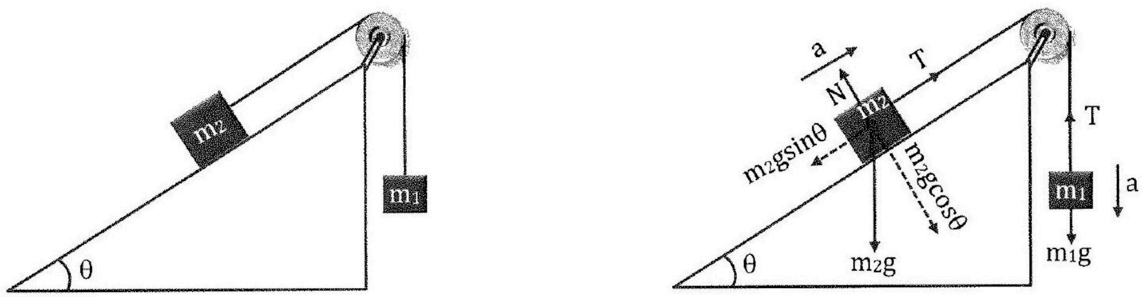


$m_1 g - T_1 = m_1 a (i)$ $T_2 - m_2 g = m_2 a\ (ii)$ $T_1 - T_2 = Ma\ (iii)$

By (i), (ii) and (iii)

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

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



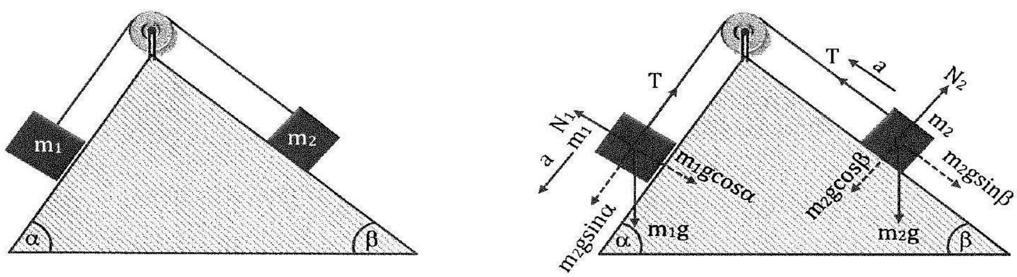
For mass m_1: $m_1 g - T = m_1 a$

For mass m_2: $T - m_2 g sin\theta = m_2 a$

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

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

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



Acceleration

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

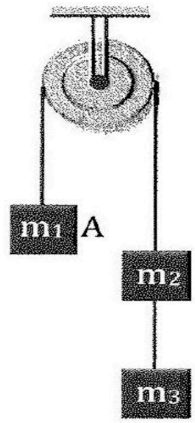
Tension, $T = \frac{m_1 m_2 (sin\alpha + sin\beta)}{(m_1 + m_2)} g$

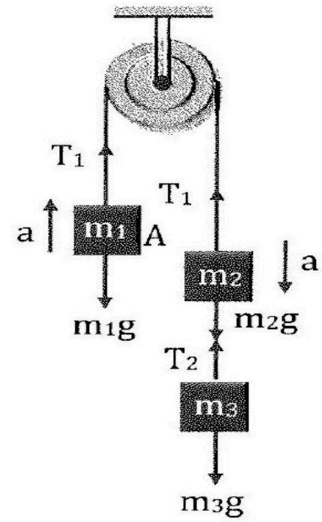
Case VII : For mass m_1: $T_1 - m_1 g = m_1 a$

For mass, m_2: $m_2 g + T_2 - T_1 = m_2 a$

For mass, m_3: $m_3 g - T_2 = m_3 a$

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

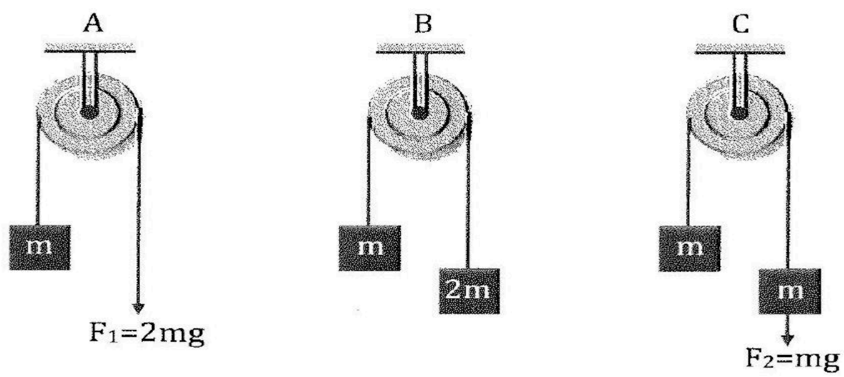




We can calculate tensions T_1 and T_2 from above equations.

Illustration 6:

In fig. A, B and C, each block has accelerations a_1, a_2 and a_3 respectively. F_1 and F_2 are external forces of magnitudes 2 mg and mg respectively. Find the value of a_1, a_2 and a_3.



Solution:

$$a_1 = \frac{2mg-mg}{m} = g \quad a_2 = \frac{2m-m}{2m+m} g = \frac{g}{3} \quad a_3 = \frac{mg+mg-mg}{2m} = \frac{g}{2}$$

Clearly $a_1 > a_3 > a_2$

Illustration 7:

A 12 kg monkey climbs a light rope as shown in fig. 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? (Take $g = 10\ m/s^2$)

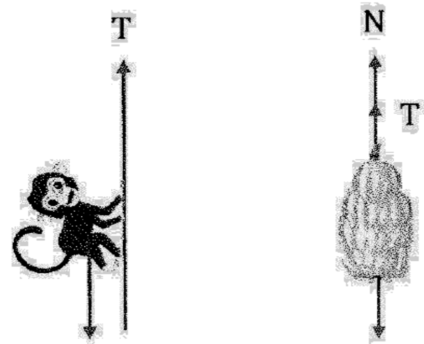
Solution:

For Monkey

$T - 120 = 12\times a$ (i)

For Bananas

$160 - T = N$



$m_1 g = 120\,N$ $m_2 g = 160\,N$

Condition for just a loosing contact $N = 0$

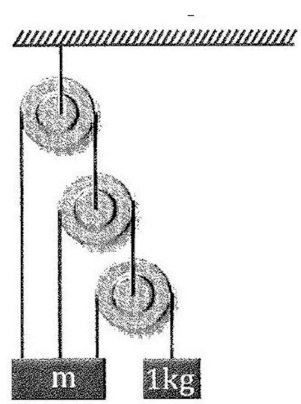
$$160 - T = 0 \Rightarrow T = 160\#(ii)$$

From equation (i) and (ii)

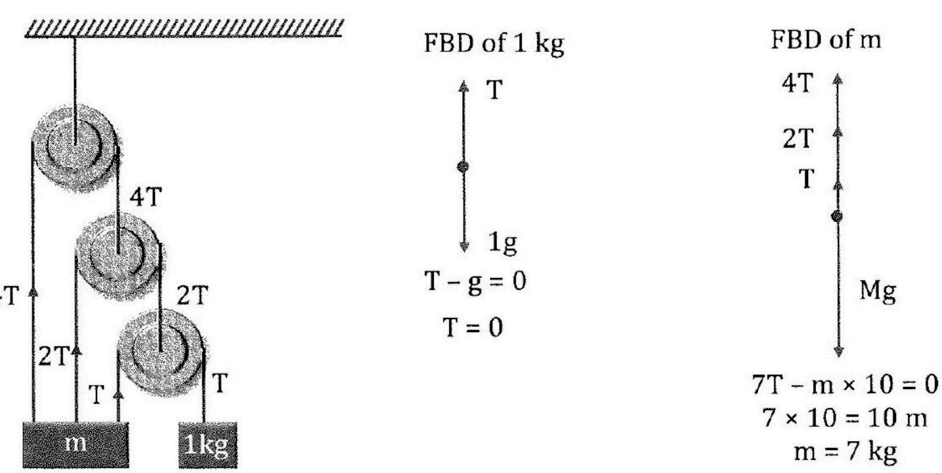
$$160 - 120 = 12\times a \Rightarrow a = 3.33\,m/s^2$$

Illustration 8:

Find M for system at rest also find tension in each string.



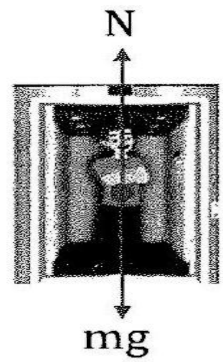
Solution:



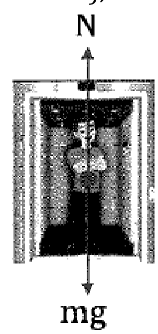
Weighing Machine

A weighing machine does not measure the weight but measures the force exerted by object on its upper surface.

Effective or Apparent weight of a man in lift



Let us analyse a situation where a man is travelling in a lift.
Case-I : If the lift is at rest or moving uniformly ($a = 0$), then

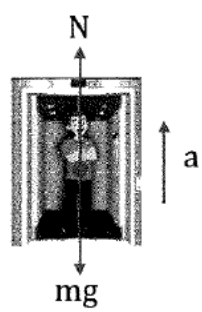


$$N = mg$$

$$So, W_{app} = W_{actual}$$

$W_{app} = N\, W_{actual} = mg$

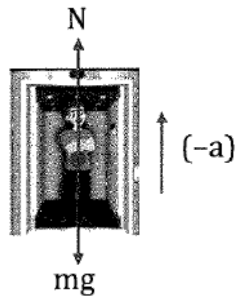
Case-II: If the lift is accelerated upwards, then - Net upward force on man = ma



$$N - mg = ma \;\; N = mg + ma \therefore \; N = m(g + a) \;\; W_{app} \; or \; N = m(g + a)$$

$$\text{So, } W_{app} > W_{actual}$$

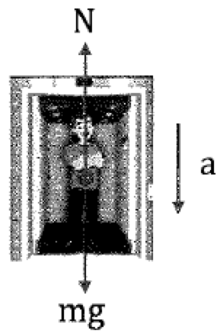
Case-III: If the lift is retarding upwards, then



$$N - mg = m(- a)\ N = mg - ma \therefore W_{app}\ or\ N = m(g - a)$$

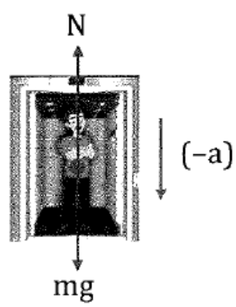
So, $W_{app} < W_{actual}$

Case-IV: If the lift is accelerated downwards, then –



$$mg - N = ma\ N = mg - ma\ W_{app}\ or\ N = m(g - a)$$

Case-V: If the lift is retarding downwards, then –



$$mg - N = m(- a)\ mg - N =- ma\ N = ma + mgs\ W_{app}\ or\ N = m(g + a)$$

So, $W_{app} > W_{actual}$

Two Special Cases of downward acceleration (IV Case)

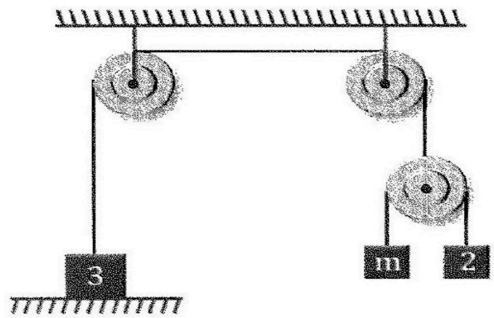
I Special Case :- If the lift is falling freely, means its acceleration in the vertically downward direction is equal to acceleration due to gravity. i.e. $a = g$, then -

$$W_{app.} = m(g - a) = m(g - g) = m\times0 = 0 \therefore W_{app.} = 0$$

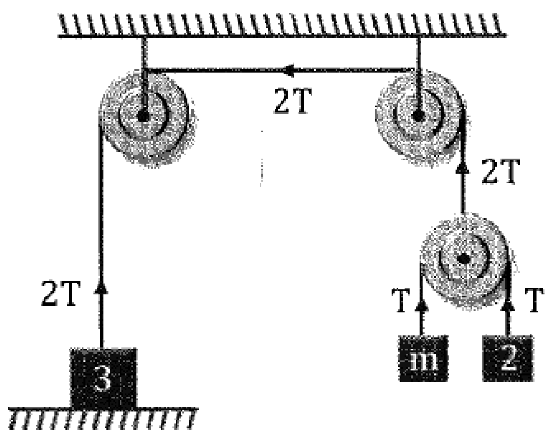
Means the man will feel weightless. This condition is known as Condition of Weightlessness.
The apparent weight of any freely falling body is always zero.
II Special Case :- If the lift is accelerating downwards with an acceleration which is greater than ' g ', then the man will move up with respect to lift and he will stick to the ceiling.

Illustration 9:

Find min. 'm' to lift 3 kg block.

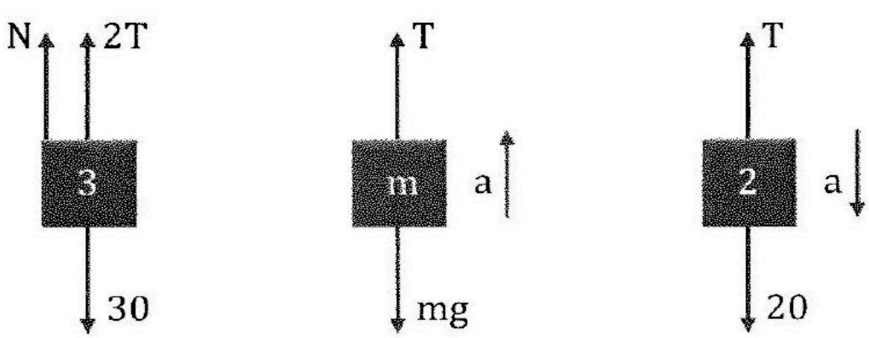


Solution:



$T = \frac{2\times2\times m}{2+m} \times g$

At the point of losing contact.



$N = 0 \; 2T = 30 \Rightarrow 2\times\frac{4m}{m+2} \times g = 3\times g \Rightarrow m = \frac{6}{5}\; kg$

Spring Force

It is the restoring force developed in a spring.

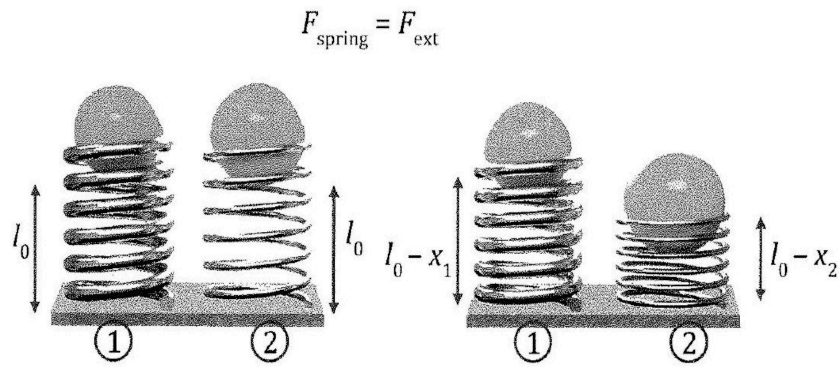
It is given by Hooke's law, $\vec{F} = -k\vec{x} = -kx\hat{x}$, where x is the change in length of the spring and k is the spring constant.

Spring force is always opposite to the direction of applied force or the direction of displacement. Hence, it is taken as negative.

For an ideal spring (massless) the restoring spring force, $F_{spring} = F_{ext}$

Spring constant (k): It denotes the stiffness of the spring which signifies how difficult it is to deform the spring. It is a measure of the inertia of spring to resist any kind of compression or extension.

In the figure, the same balls are kept on two springs of the same length, yet the change in length is different.



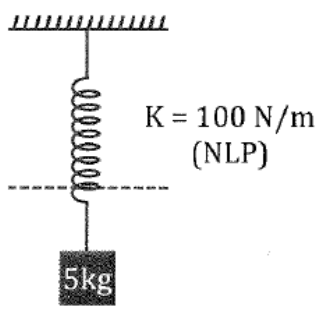
Thus, if the same force is applied on two springs of the same length, then the spring with higher spring constant will get elongated or compressed less than the spring with lower spring constant. Higher the spring constant k, more stiffer and robust the spring is, and more is the difficulty to compress or extend it.

Similarity between ideal spring and ideal string: Both are massless.

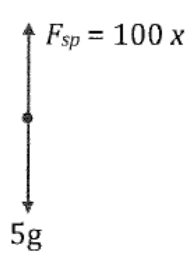
Difference between ideal spring and ideal string: Ideal string is inextensible, while due to helical nature of spring its length can be changed.

Illustration 10:

5 kg is in equilibrium and at rest find elongation in the spring.



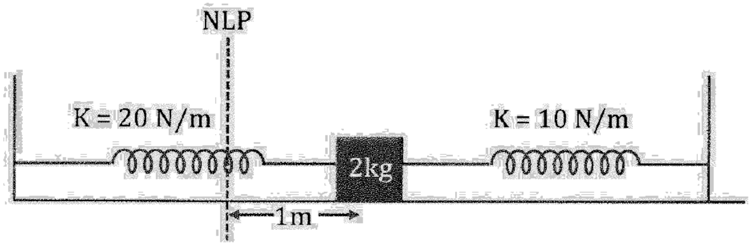
Solution:



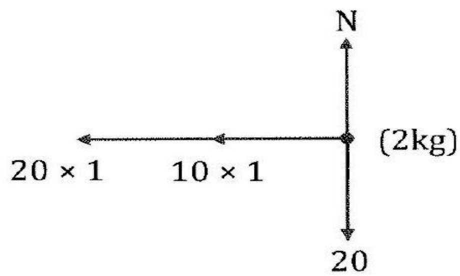
$F_{sp} = 100x \ 5g \ 100x = 50 \ x = 0.5\,m$

Illustration 11:

Find acceleration of block just after releasing?

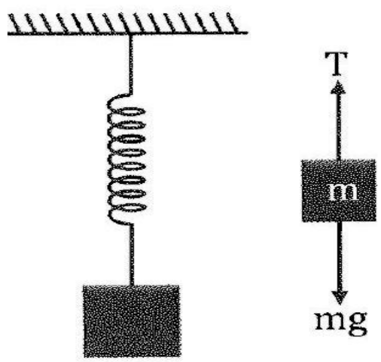


Solution:



$30 = 2aa = 15\,m/s$

Spring balance



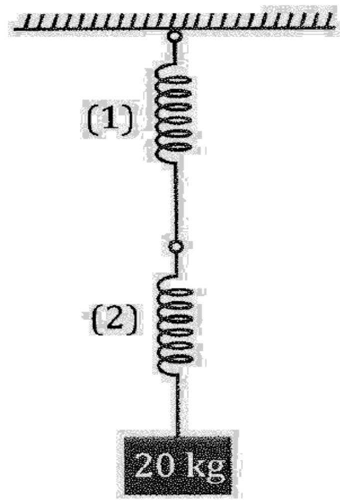
- It measures the restoring spring force which is equal to the tensile force on the spring. This tensile force is equal to the weight of the hanging body only under equilibrium condition.
- In the given figure, when the mass is hung to the vertical spring and the system comes in equilibrium, the tension in the string will be equal to the weight hung to it.
- It does not measure the weight. It measures the force exerted by the object at the hook.
- Symbolically, it is represented as shown in figure. A block of mass ' m ' is suspended at hook. When spring balance is in equilibrium, we draw the F.B.D. of mass m for calculating the reading of balance.
  F.B.D. of ' m '.

$mg - T = 0T = mg$

Magnitude of T gives the reading of spring balance.

Illustration 12:

A block of mass 20 kg is suspended through two light spring balances as shown in figure. Calculate the



(1) reading of spring balance (1).
(2) reading of spring balance (2).

Solution:

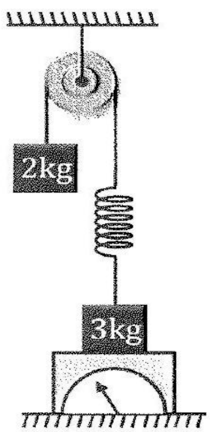
For calculating the reading, first we draw F.B.D. of 20 kg block.
F.B.D of 20 kg .

$$mg - T = 0T = 20\ g = 200\ N$$

Since both balances are light so, both the scales will read 20 kg

Illustration 13:

System is in equilibrium. Find reading of both weighing machine and balance.



Solution:

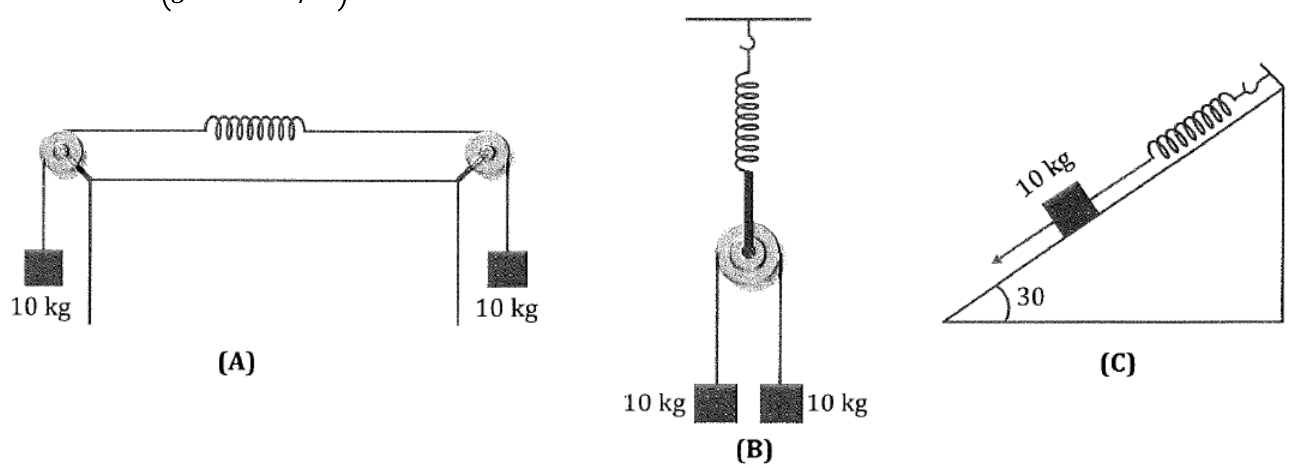
$\therefore SB = 2\,kgT + N = 30 \Rightarrow N = 10$

$\therefore WM$ (Weigning machine) $= \frac{10}{g} = 1\,kg$

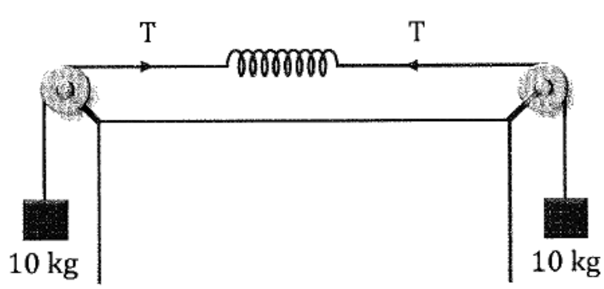
$T = 20\,N \quad N_{3g}$

Illustration 14:

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



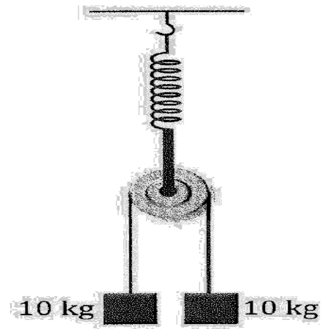
Solution:



(A)

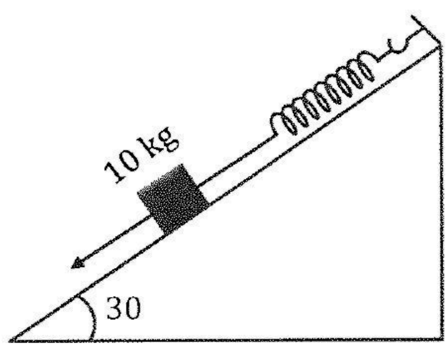
One weight act as support another acts as weight so tension $T = 10\,g$

$= 100\,N$



(B)

$$T^{'} = 2T = 2\left[\frac{2\times10\times10\times g}{20}\right] T^{'} = 200\ N$$

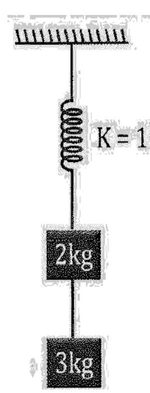


(C)

$$T = 10\times10\times sin30^{\circ} = 10\times10\times1/2 = 50\ N$$

Illustration 15:

Assume system is in equilibrium. If string is cut then find acceleration of 2 kg and 3 kg .

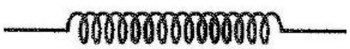


Solution

$kx = 50\ N$ | For 3 kg block
x = 5 m kx – 2g = 2a 30 = 2a | 3g = 3a
a = $15ms^{-2}$ | a = 10 m/s^2

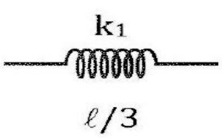
Variation of k with natural length

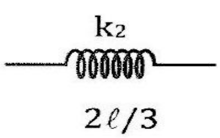
$kl =$ constant




natural length = l $l/2$ 2k

natural length = l





$kl = k_1\frac{l}{3}$; $kl = k_2\frac{2l}{3}$; $k_1 = 3k$ and $k_2 = \frac{3k}{2}$

Equivalent Spring Constant

- When Springs are connected in Parallel then we can replace them by single spring of spring constant k_e where

$$k_e = k_1 + k_2$$

  For more than two spring $k_e = k_1 + k_2 + k_3 + \ldots\ldots.$
- When Springs are connected in series then we can replace them by single spring of spring constant k_e where $1/k_e = 1/k_1 + 1/k_2$. As spring constants are not equal so extensions will not be equal, but total extension y can be written as sum of two extensions $y = y_1 + y_2$

  For more than two springs

$$\frac{1}{k_e} = \frac{1}{k_1} + \frac{1}{k_2} + \ldots\ldots\ldots\ldots$$

Newton's law on a system

Selection of system

Consider m_1, m_2, m_3, ... are the masses of the objects of the system and $\vec{a}_1, \vec{a}_2, \vec{a}_3$ ... are the acceleration of the objects respectively.

We can balance the forces on individual body as:

$$\left(\sum \vec{F}_{ext}\right)_1 = m_1\vec{a}_1 \quad \text{(i)}$$

$$\left(\sum \vec{F}_{ext}\right)_2 = m_2\vec{a}_2 \quad \text{(ii)}$$

$$\left(\sum \vec{F}_{ext}\right)_3 = m_3\vec{a}_3 \quad \text{(iii)}$$

Adding all equations,

$$\left(\sum \vec{F}_{ext}\right)_{sys} = m_1\vec{a}_1 + m_2\vec{a}_2 + m_3\vec{a}_3 + \ ...$$

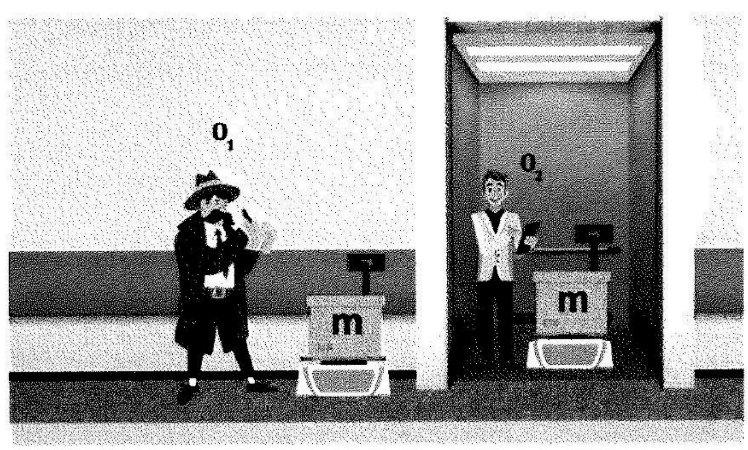
Thus, we can consider the group of masses as one system.

Pseudo Force

Consider a block of mass m kept on a weighing machine. Consider the system is kept in an elevator. Let observer O_1 observe this system from the ground frame. Let another observer O_2 be present inside the lift.

Case 1: Elevator is at rest

When the elevator is at rest, the reading on the weighing machine is same for both observers.

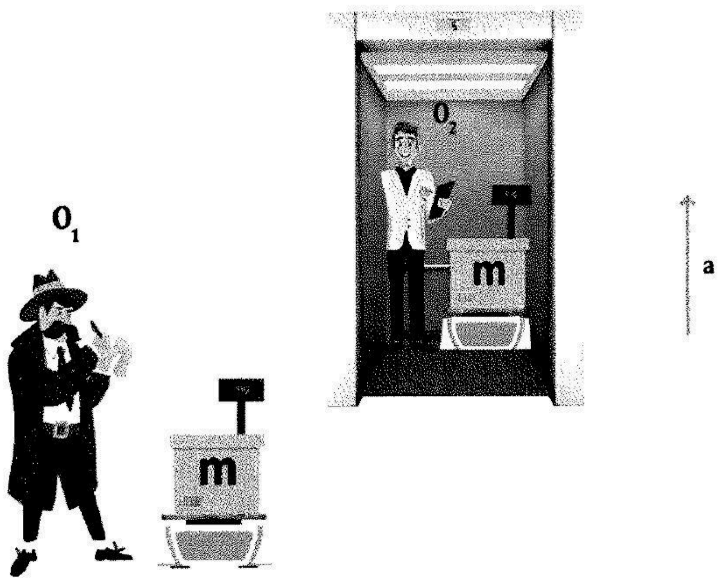


The forces acting on the block are weight (mg) and normal reaction (N).

Along vertical direction, $N = mg$

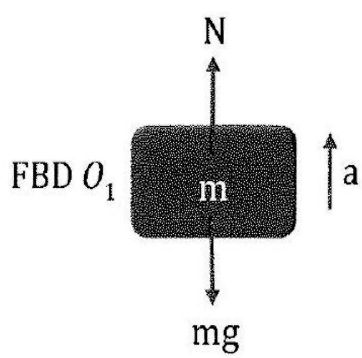
Case 2: Elevator is moving upwards with acceleration a

When the elevator starts moving upwards with an acceleration a, both observers observe different readings on the weighing machine than the reading when the elevator was at rest.



In order to understand why the reading is different in this case, they used concepts of physics as follows:
FBD of block for observer O_1 standing in ground frame:

This observer finds the system is moving upwards with acceleration a. Other forces acting on the block are its weight and normal reaction. Along vertical direction,

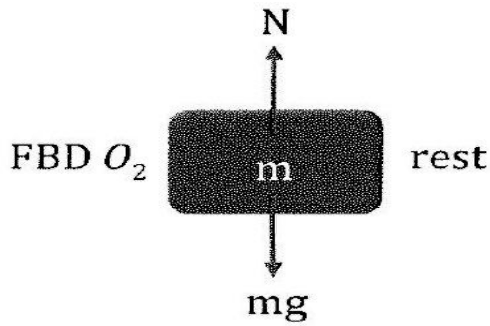


$$N - mg = ma \quad N = mg + ma \quad N = m(g + a)$$

As the weighing machine measures the normal reaction acting on it, the weighing machine will show a reading corresponding to $N = m(g + a)$.

FBD of block for observer O_2 standing in lift frame:

When the observer is in the elevator, the block is at rest with respect to him. So, for this case, the forces acting on the block are weight (mg) and normal reaction (N).



Along vertical direction,

$N = mg$

However, the observer O_2 sees the reading on the weighing machine is $m(g + a)$, and he couldn't explain his observation as his derivation was different. To find what is missing in this case, use the concept of relative motion.

Let $\vec{a}_{B,\, elevator}$ be the acceleration of the block with respect to elevator $\vec{a}_{B,G}$ be the acceleration of block with respect to ground and $\vec{a}_{elevator,\,,}$ be the acceleration of the elevator with respect to ground.

$$\vec{a}_{B,\, elevator} = \vec{a}_{B,G} - \vec{a}_{elevator\, ,G}$$

Multiplying both sides by m ,

$$m\vec{a}_{B,\, elevator} = m\vec{a}_{B,G} - m\vec{a}_{elevator\, ,G}$$

The normal reaction is the $\left(m\vec{a}_{B,\, elevator}\right)$ sum of $\left(m\vec{a}_{B,G}\right)$ and $\left(-\ m\vec{a}_{elevator,\, G}\right)$ when the elevator is accelerating. Here, $\left(m\vec{a}_{B,G}\right)$ is the weight of block and term $\left(-\ m\vec{a}_{elevator,\,,}\right)$ appears due to the accelerated frame. This can be written in terms of force as :

$$\left(\sum \vec{F}_{P_{eleater}}\right) = \left(\sum \vec{F}_{P_{Ground}}\right) + \left(-\ m\vec{a}_{elevator\, ,G}\right)$$

This new force term $(-\ m\vec{a}_{elevator,\, G})$ appears due to the mass of block and acceleration of the elevator which does not make any sense physically.

Non-Inertial Frames

The change in the net force in the ground and elevator frame is owing/attributed to the acceleration of the elevator. If the elevator was moving with uniform velocity, this term would be zero.

Thus, it is not about movement of the elevator but acceleration of the elevator. Such frames that are accelerating are known as non-inertial frames of reference.

In non-inertial frames of reference, Newton's law seems to be failing. Thus, Newton's law is not valid in non-inertial frames of reference.

The extra term is unreal and known as pseudo force.

What is a pseudo force?

A pseudo force (also known as fictitious force, inertial force, or d'Alembert force) is an apparent force that acts on all the masses whose motion is described using a non-inertial frame of reference. The magnitude of the pseudo force is the mass of an object multiplied by the acceleration of the frame of reference.

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

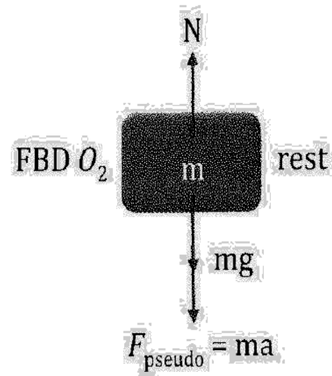
Thus, for non-inertial frames, Newton's law can be modified as,

$$\left(\sum \vec{F}_{ext\ elevator}\right) = \left(\sum \vec{F}_{ext}\right)_{Ground} + \vec{F}_{pseudo}$$

The pseudo forces are also known as inertial forces, although their need arises because of the use of non-inertial frames.

$$\vec{F}_{pseudo} = - m_{sys} \vec{a}_{non-inertial\ frame}$$

Properties of pseudo force:



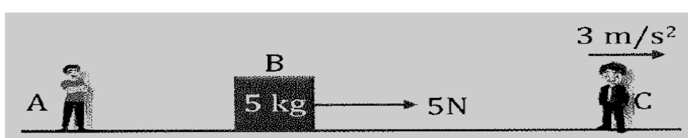
- It's a fictitious force i.e., it will not have a reaction pair.
- It always acts in the direction opposite to the acceleration of the frame of reference.

Thus, the FBD for mass moving with acceleration in the elevator frame is modified as:
Balancing the forces in vertical direction,

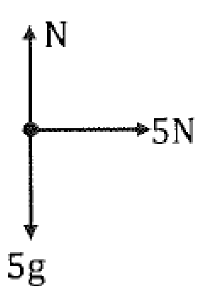
$N = mg + ma\ N = m(g + a)$

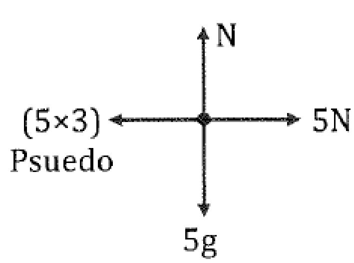
Illustration 16:

Find the acceleration of block with respect to A and C.



In Frame (A)
In Frame (C)
Solution:





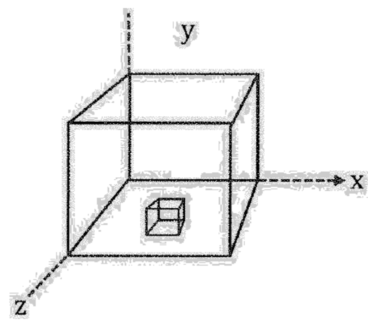
$5 = 5a_{B/A}$

$15 - 5 = 5a_{B/C}$

$a_{B/A} = 1\, m/s^2$ $\qquad$ $a_{B/C} = 2\, m/s^2$

Illustration 17:

A block of mass 2 kg is kept at rest on a big box moving with velocity $2\hat{i}\ m/s$ and having acceleration $-\ 3\hat{i} + 4\hat{j}\ m/s^2$. Find the value of 'Pseudo force' acting on block with respect to box.

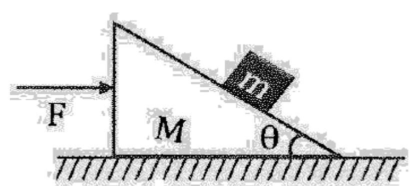


Solution:

$$\vec{F} = -\ m\vec{a}_{frame} = -\ 2(-\ 3\hat{i} + 4\hat{j})\ \ F = 6\hat{i} - 8\hat{j} N$$

Illustration 18:

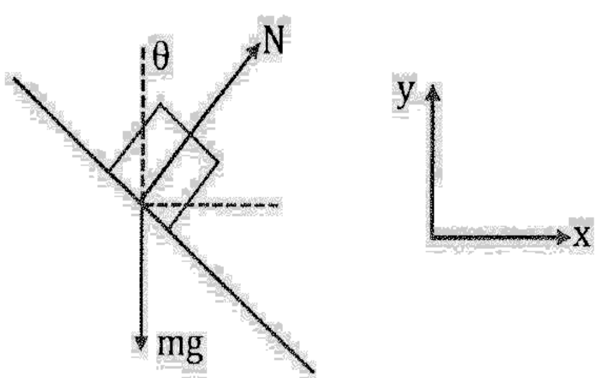
All surfaces are smooth in the adjoining figure. Find F such that block remains stationary with respect to wedge.



Solution:

Acceleration of (block + wedge) is $a = \frac{F}{(M+m)}$

Let us solve the problem by using both frames.



From inertial frame of reference (Ground)

F.B.D. of block w.r.t. ground (Apply real forces):

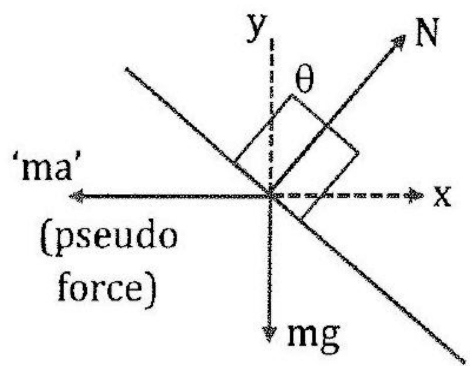
with respect to ground block is moving with an acceleration ' a '.

$\therefore \sum F_y = 0 \Rightarrow N\cos\theta = mg\ \ And\ \ \sum F_x = ma \Rightarrow N\sin\theta = ma$

From equations (i) and (ii)

$a = g tan\theta \therefore F = (M + m)a = (M + m)g tan\theta$

From non-inertial frame of reference (Wedge) :



F.B.D. of block w.r.t wedge (real forces + pseudo force) w.r.t. wedge, block is stationary

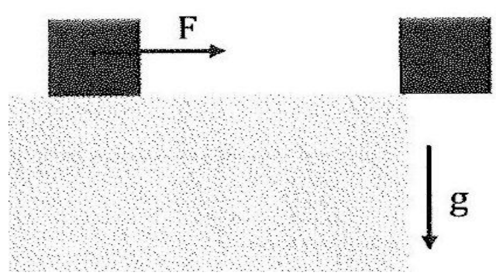
$\sum F_y = 0 \Rightarrow N cos\theta = mg$ (iii)

$\sum F_x = 0 \Rightarrow N sin\theta = ma$ (iv)

From equations (iii) and (iv), we will get the same result
i.e. $F = (M + m)g tan\theta$

Constrained Motion

Constrained motion results when an object is forced to move in a restricted way.
Here, the object is constrained to move along the surface of the block due to the force and then falls vertically downwards due to acceleration due to gravity.



Similarly, here the block is constrained to slide along an inclined plane. The force due to which the body is kept under a constraint is known as constraint force.
There are two primary constraints:

1. String/Rod constraints
2. Wedge constraints

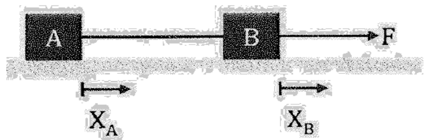
String Constraints

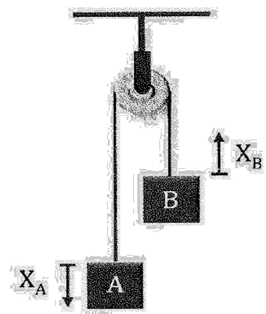
Consider objects connected through a string that has the following properties:

- The length of the string remains constant, i.e., string is inextensible.
  Which means that if one block moves x distance, the other block also moves the same distance.
  It can be mathematically written as,

$$x_A = x_B$$

Where x_A is displacement of block A and x_B is displacement of block B.





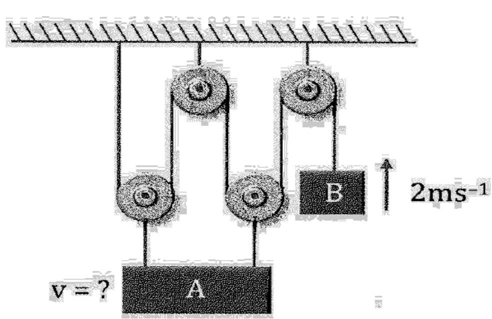
- It always remains tight and does not slack.
  Parameters of the motion of such objects along the length of the string and in the direction of extension have a definite relation between them.
  Here, the parameters of motion means the displacement, velocity, and acceleration.
  Objects mean the bodies that are directly connected to string.
  Definite relation means the constraint relation, such as $x_A = x_B$
  For a system involving ideal pulleys and ideal strings we can write,

$$\sum \vec{T} \cdot \vec{S} = 0 \text{ and } \sum \vec{T} \cdot \vec{V} = 0$$

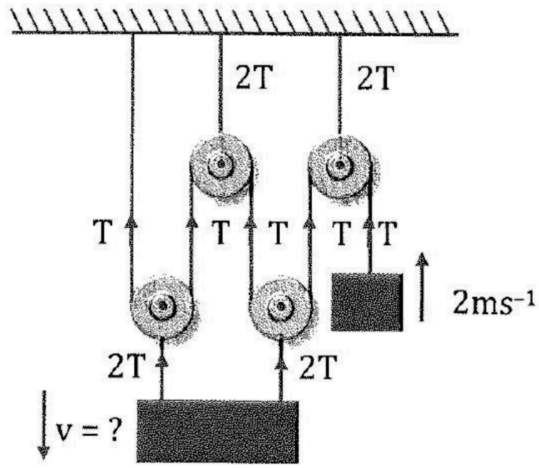
and if acceleration of blocks are collinear with their velocity then, $\sum \vec{T} \cdot \vec{a} = 0$

Illustration 19:

Find the velocity of block A.



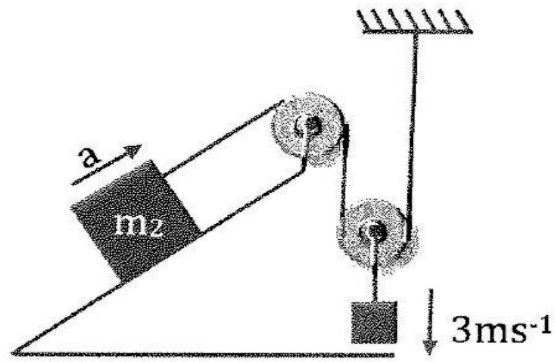
Solution:



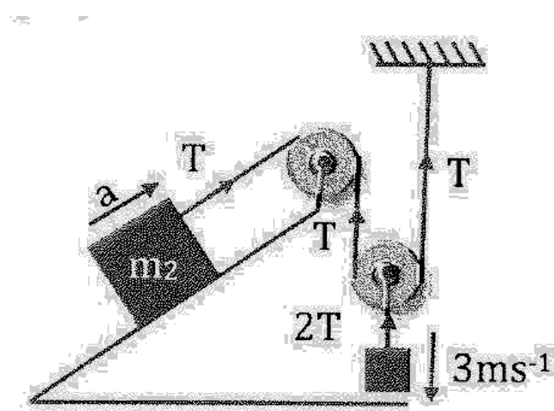
$$v(4T)(-1) + (T)(2) = 0 \quad 2 = 4v \therefore v = 1/2 ms^{-1} \downarrow$$

Illustration 20:

Find the velocity (a) of block.



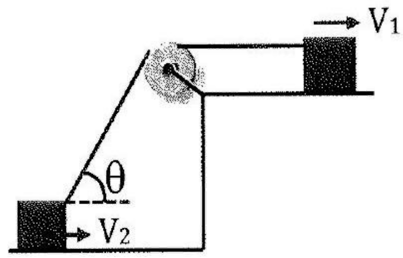
Solution:



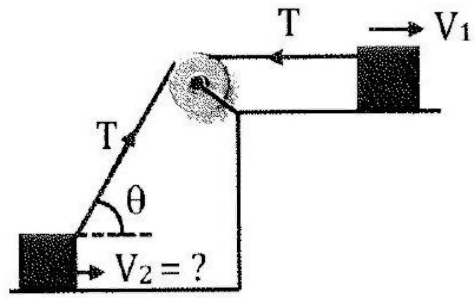
$$(2T)(3)(-1) + (a)(T) = 0 \quad a = 6ms^{-1} \uparrow$$

Illustration 21:

Find relation between V_1 and V_2 for the given figure.



Solution:



$-(T)(V_1) + T(V_2 cos\theta) = 0 \therefore V_2 = V_1 / cos\theta ms^{-1} \rightarrow$

Steps to follow to solve problem involving constraint motion

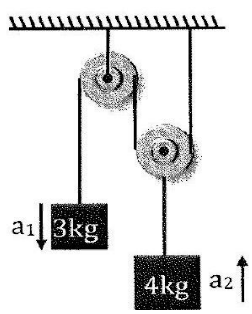
(i) Take acceleration of each block in some direction.

(ii) Make FBD of each block and write Newton's 2^{nd} law equation as per direction taken in Step-I

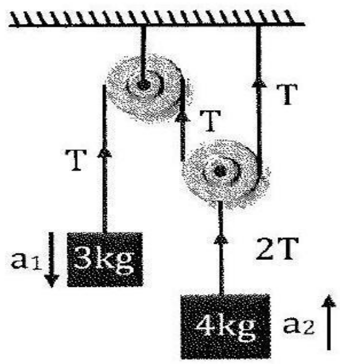
(iii) Write constraint equation and solve all equations to get acceleration of each block. If acceleration comes positive then the acceleration of the body is in the direction assumed in STEP-I and if acceleration comes negative then it is opposite to the direction assumed in STEP-I.

Illustration 22:

Find the acceleration (a_1 and a_2) of the blocks.



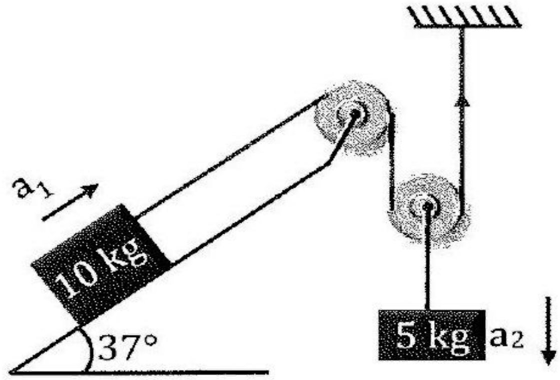
Solution:



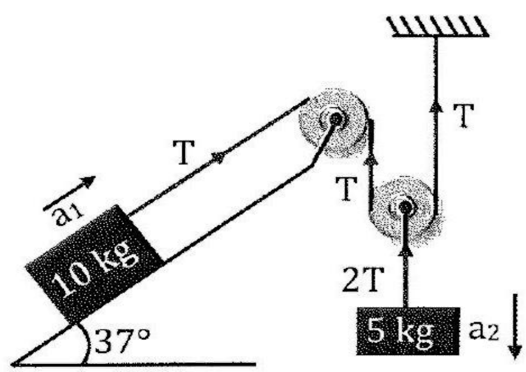
$3g - T = 3a_1$ $2T - 4g = 4a_3$ $T(a_1)(-1) + 2T(a_2)(1) = 0$ $2a_2 = a_1$ $3g - T = 3a_1$ $T - 2g = 2a_1$ $g = 4a_1 \therefore a_1 =$

Illustration 23:

Find acceleration of all the blocks.



Solution:



$T - 10g\sin 37^{\circ} = 10a_1$

$T - 60 = 10a_1$ ...(i)

$50 - 2T = 5a_2$ ...(ii)

From constraint relation,

$T(a_1) + 2(T)(-a_2) = 0$ $a_1 = 2a_2$ $2T - 120 = 40a_2$ $a_2 = \frac{-14}{9}\ m/s^2 \Rightarrow a_1 = \frac{-28}{9}\ m/s^2$

Key point:

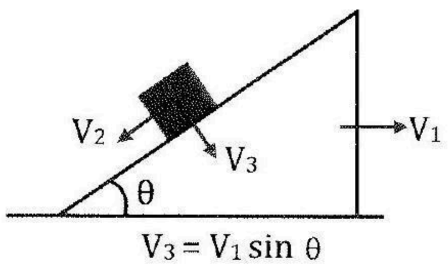
Constraint relation in string will also hold for string having mass provided it is inextensible.

Wedge Constraint

- Wedge constrained motion: When a body moves over a wedge, it follows certain sliding constraints known as wedge constraint.
- Wedge constraint says that component of velocity and acceleration perpendicular to the contact surface (interface) of two objects is always equal if there is no deformation and the objects remain in contact.

  Conditions:

  (i) There is a regular contact between two objects.
  (ii) Objects are rigid.
  The relative velocity perpendicular to the contact plane of the two rigid objects is always zero if there is a regular contact between the objects. Wedge constraint is applied for each contact.



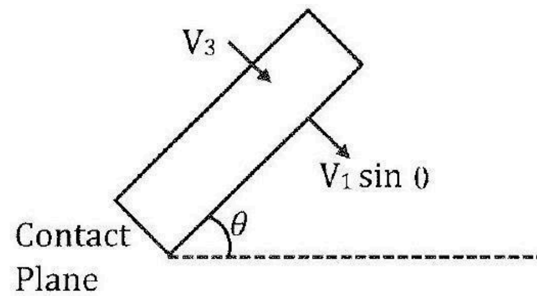
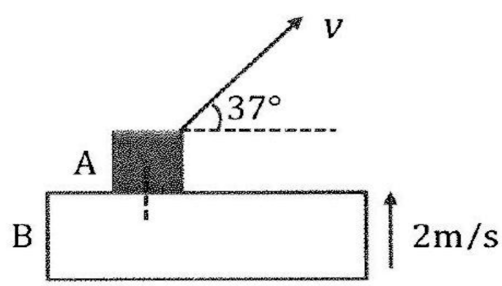


Illustration 24:

A and B are always is contact. Find ?



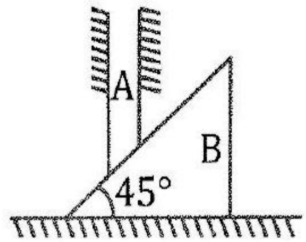
Solution:

$$v\sin 37^{\circ} = 2; \; v = \frac{10}{3} \; m/s$$

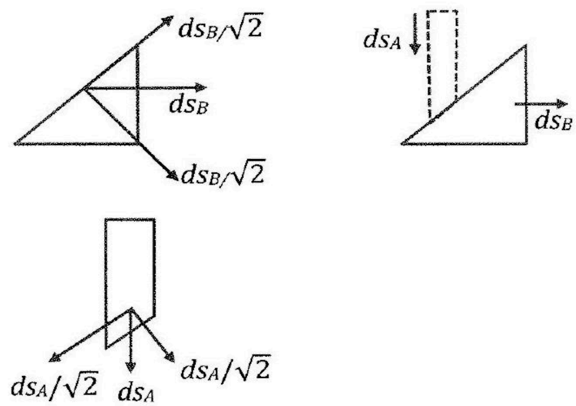
In other words, Components of velocity along perpendicular direction to the contact plane of the two objects is always equal if there is no deformations and they remain in contact.

Illustration 25:

Find the acceleration of $rod A$ and wedge B in the arrangement shown in fig. if the mass of rod equal that of the wedge and the friction between all contact surfaces is negligible. Take angle of wedge as 45°.



Solution:



Perpendicular to the plane of contact displacement must be same.

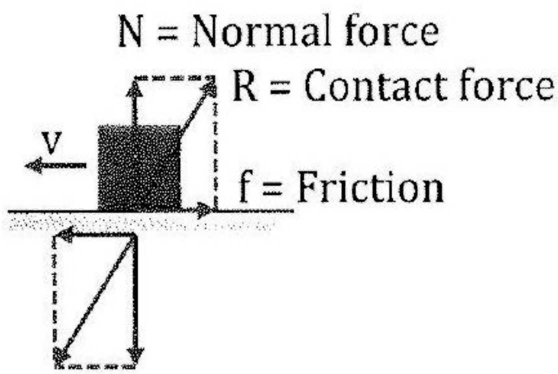
$$\frac{ds_B}{\sqrt{2}} = \frac{ds_A}{\sqrt{2}} \quad ds_B = ds_A$$

Differentiating, $a_B = a_A$

$$mg - N/\sqrt{2} = ma \quad N/\sqrt{2} = ma \quad mg = 2ma \Rightarrow a = g/2$$

FRICTION

When two bodies are kept in contact, electromagnetic forces act between the charged particles (molecules) at the surfaces of the bodies. Thus, each body exerts a contact force on the other. The magnitudes of the contact forces acting on the two bodies are equal but their directions are opposite and therefore the contact forces obey Newton's third law.



The direction of the contact force acting on a particular body is not necessarily perpendicular to the contact surface. We can resolve this contact force into two components, one perpendicular to the contact surface and the other parallel to it (see in figure). The perpendicular component is called the normal contact force or normal force (generally written as) and the parallel component is called friction (generally written as f).

Therefore, if R is contact force then $R = \sqrt{f^2 + N^2}$

Reasons for friction:

(i) Inter-locking of extended parts of one object into the extended parts of the other object. (Old view)

(ii) Bonding between the molecules of the two surfaces or objects in contact. (Modern view)

Static Friction Force

If there is a tendency of relative slipping (only tendency and not actual) between two surfaces in contact then the friction force acting between them is called static friction force.

It is a variable force whose value is equal to requirement to stop relative slipping till it reaches its limiting value. For example consider a bed inside a room ; when we gently push the bed with a finger, the bed does not move. This means that the bed has a tendency to move in the direction of applied force but does not move as there exists static friction force acting in the opposite direction of the applied force.

Laws of static friction:

1^{st} law : Static friction force acting between two surfaces in contact does not depend on area of contact.

2^{nd} law : Maximum value of static friction (Limiting friction) is directly proportional to normal force acting between the two surfaces.

$\left(f_s\right) \propto N \ \left(f_s\right)_{max.} = \mu_s N$

$$f_s = \ Limiting\ friction\ ;\ \mu_s = \ coefficient\ of\ static\ friction$$

Direction of static friction force :

The static friction force on an object is opposite to its impending motion relative to the surface. Following steps should be followed in determining the direction of static friction force on an object.

(i) Draw the free body diagram with respect to the other object on which it is kept.

(ii) Include pseudo force also if contact surface is accelerating.

(iii) Decide the resultant force and the component parallel to the surface of this resultant force.

(iv) The direction of static friction is opposite to the above component of resultant force.

Note:

Here once again the static friction is involved when there is no relative motion between two surfaces.

Kinetic Friction Force

→ Kinetic friction comes into picture when relative slipping occurs.
→ It acts in direction opposite to relative velocity.
→ Its value is constant.

Laws of kinetic friction:

1^{st} **law :** Kinetic friction acting between two surfaces in contact does not depend on area of contact.

2^{nd} **law :** Value of kinetic friction force is directly proportional to the normal force acting between the two surfaces in contact.

$f_k \propto N f_k = \mu_k N$

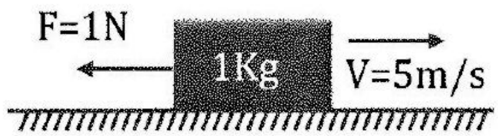
μ_k = coefficient of kinetic friction

Note:

$\mu_k = \mu_s = \mu$ (if not mentioned separately)

Illustration 26:

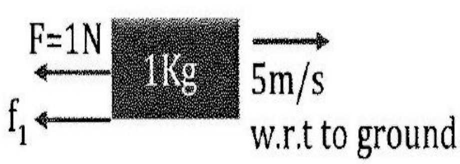
Find the direction of kinetic friction force



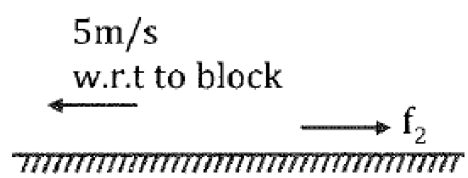
(a) on the block, exerted by the ground.
(b) on the ground, exerted by the block.

Solution:

(a)



(b) 5 m/s

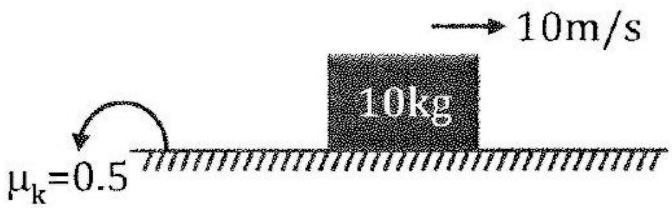


where f_1 and f_2 are the friction forces on the block and ground respectively.

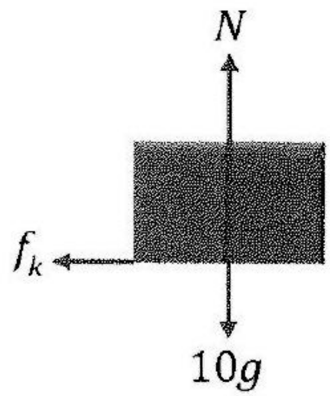
Also note that the direction of kinetic friction has nothing to do with applied force F.

Illustration 27:

Find out the distance travelled by the blocks shown in the figure before it stops.



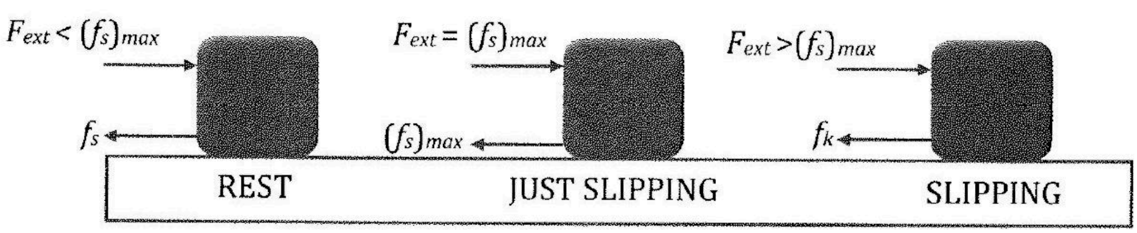
Solution:



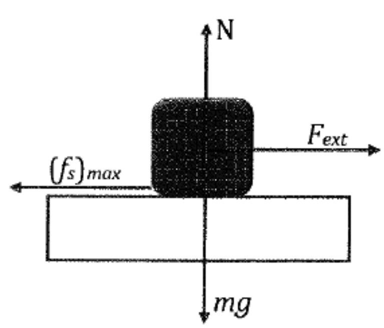
$N - 10g = 0$ $N = 100\,N$ $f_k = \mu_k N$ $(\mu = \mu_s = \mu_k$ *when not mentioned*$)$ $f_k = 0.5 \times 100 = 50\,N$ $F_x = ma$ $50 = 10a$

Limiting Friction

- The maximum possible friction force between the two surfaces before sliding begins is known as **limiting friction.**
- If the applied external force exceeds the value of the limiting friction $\{(f_s)\max\}$, then the slipping starts and the nature of friction changes to kinetic friction.



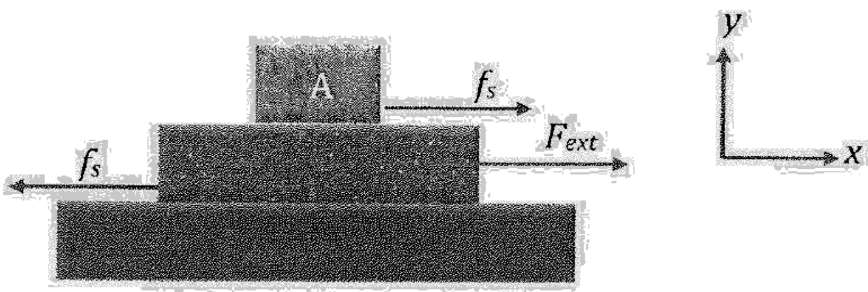
- The magnitude of limiting friction is proportional to normal reaction acting on the contact surface.
  Limiting Friction ∝ Normal Reaction



$$\left(f_s\right)_{max} \propto N \ \left(f_s\right)_{max} = \mu_s N$$

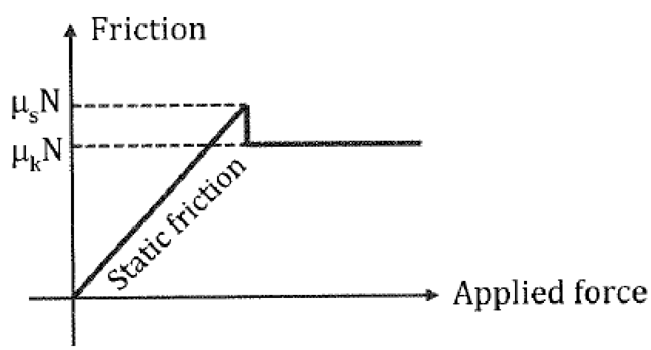
where μ_s is the coefficient of static friction.

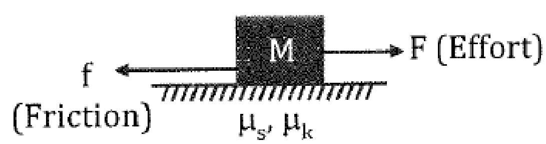
- Direction of static friction is always opposite to the tendency of relative motion.



In the given example, blocks A and B move together in positive x-direction when external force is applied, tendency of motion of A with respect to B is in negative x-direction. Hence, the direction of static friction on block A will be in positive x - direction.

Graph of Friction v/s Applied Force





Few Important Points

(1) Value of μ_k is always less than $\mu_s \left(\mu_k < \mu_s\right)$ from experimental observation.

(2) If only coefficient of friction (μ) is given in a problem then $\mu_s = \mu_k = \mu$

(3) Value of μ_s and μ_k is independent of surface area it depends only on surface properties of contact surface.

μ_k is independent of relative speed.

μ_s and μ_k are properties of a given pair of surfaces i.e. for wood to wood combination μ_1, then for wood to iron μ_2 and so on.

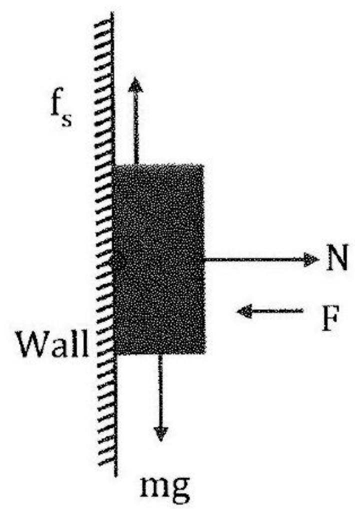
Frictional forces exist everywhere in nature and result in loss of energy that is primarily dissipated in form of heat. Wear and tear of moving bodies is another unwanted result of friction. Therefore, sometimes, we try to reduce their effects - such as in bearings of all types, between piston and the inner walls of the cylinder of an IC engine, flow of fluid in pipes, and aircraft and missile propulsion through air.

Though these examples create a negative picture of frictional forces, yet there are other situations where frictional forces become essential and we try to maximize the effects. It is the friction between our feet and the earth surface, which enables us to walk and run. Both the traction and braking of wheeled vehicles depend on friction.

Illustration 28:

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 ? (Take $g = 9.8\ m/s^2$)

Solution:



The situation is shown in fig. The forces acting on the book areFor book to be at rest it is essential that, $Mg = f_s$

But

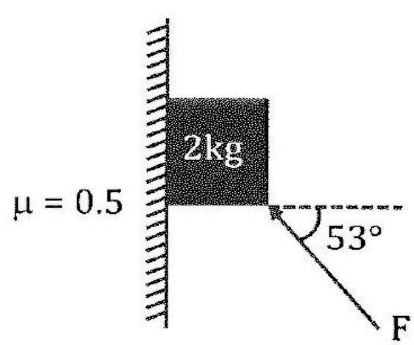
$f_{smax} = \mu_s N$

and $N = F$

$Mg = \mu_S F \Rightarrow F = \frac{Mg}{\mu_s} = \frac{1\times9.8}{0.2} = 49\ N$

Illustration 29:

Find acceleration and friction force in the situation shown.

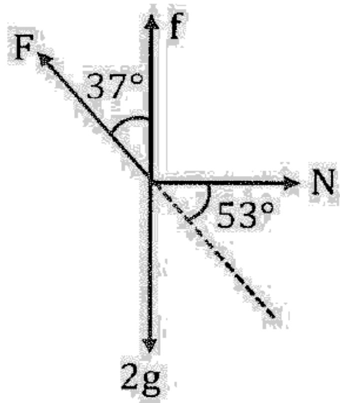


(i) $F = 20\ N$ (ii) $F = 100\ N$ (iii) $F = 10\ N$

Solution:

Assumption = No relative slipping

(i)



$N = Fsin37^{\circ}$

$$N = 20\times\frac{3}{5}$$

$N = 12N \therefore f + Fcos37^{\circ} = 2g$

$$f + 20\times\frac{4}{5} = 20$$

$f = 4N$

$\left(f_s\right)_{max} = 0.5\times12 = 6\ N \therefore f < \left(f_s\right)_{max}$

Assumption is correct

$\therefore a = 0\ \ f = 4N$

(ii) $N = Fsin37^{\circ}$

$N = 100\times\frac{3}{5}$

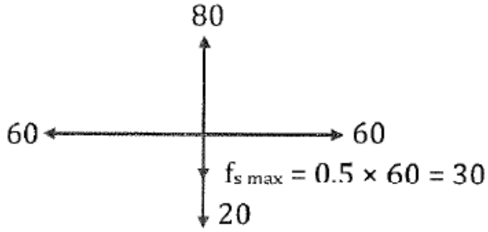
$N = 60N\ \ (f)_{max} = 0.5\times60 = 30N\ \ \therefore f + Fcos37^{\circ} = 20\ \ f + 100\times\frac{4}{5} = 20\ \ f = -60N$

$\therefore f$ acts downward $= 60\ N$

$f > \left(f_s\right)_{max}$

$\therefore$ Assumption is wrong

$\therefore f_k$



$f_k = \mu \times N = 0.5 \times 60 = 30N$

Since applied force is greater hence block will move in upward direction.

$\therefore 80 - 30 - 20 = 2a$

$80 - 50 = 2a$

$$a = 15\, m/s^2$$

(iii) $N = 10 \times sin37^\circ = 10 \times \frac{3}{5} = 6N$

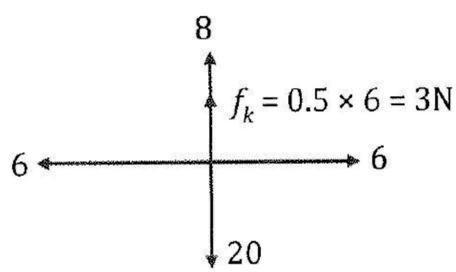
$\therefore (f_s)_{max} = 0.5 \times 6 = 3\, N$

$$f + Fcos37^\circ = 20$$

$$f + 10 \times \frac{4}{5} = 20 \;\; f = 12\, N \;\; f > (f_s)_{max}$$

$\therefore$ Assumption is wrong and hence block will move.

$\therefore$

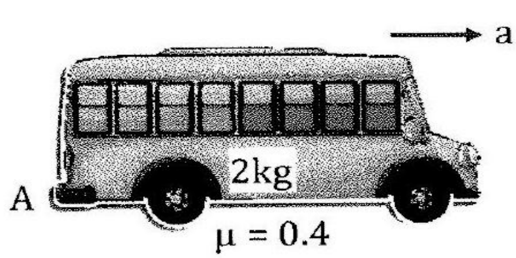


$\therefore 20 - 3 - 8 = 2a 9 = 2a$

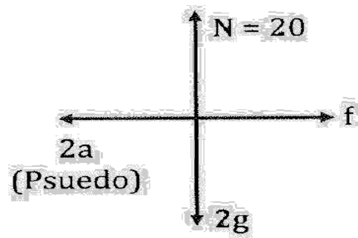
$a = 4.5\, m/s^2$.

Illustration 30:

Find a_{max} such that block do not slip w.r.t. bus.



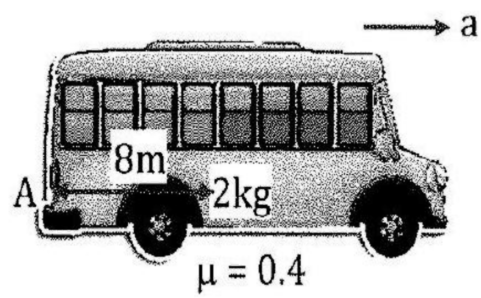
Solution:



$$f - 2a = 0 \quad f = 2a \quad \mu 2g = 2a \quad a = \mu g \quad a = 4\, m/s^2$$

Illustration 31:

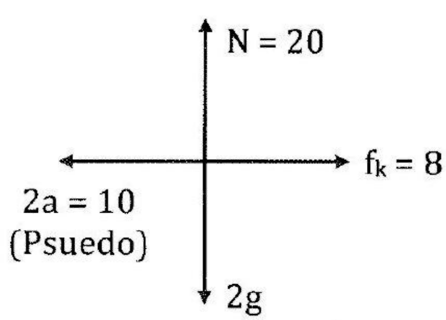
If $= 5\, m/s^2$; find time after which block will reach to surface A ?



Solution:

$$f_{req.} = 10\, N > (f_s)_{max} = 8\, N \quad 10 - 8 = 2a \quad a_{rel} = 1\, m/s^2 \quad s = \frac{1}{2} \times a \times t^2 \quad 8 = \frac{1}{2} \times 1 \times t^2 \quad t^2 = 16 \quad t = 4 sec.$$

Angle of Friction (a)

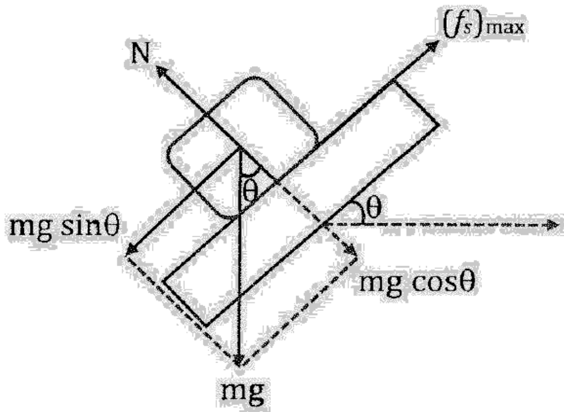


It is the angle made by the resultant of the normal reaction force and friction force, with the normal reaction.

$$tan\alpha = \frac{f}{N} \therefore tan\alpha_{max} = \frac{(f_s)_{max}}{N} = \frac{\mu_s N}{N} = \mu_s$$

Angle of Repose (θ)

It is the minimum angle (θ) made by an inclined plane with the horizontal such that an object placed on the inclined surface just begins to slide.



$$N = mgcos\theta \quad \left(f_s\right)_{max} = \mu_s N = \mu_s mgcos\theta$$

When the object just start to slide,

$$\left(f_s\right)_{max} = mgsin\theta \quad \mu_s mgcos\theta = mgsin\theta \quad tan\theta = \mu_s \therefore \ Angle\ of\ Repose,\ \theta = tan^{-1}\left(\mu_s\right)$$

Two Block Problems

Method of solving

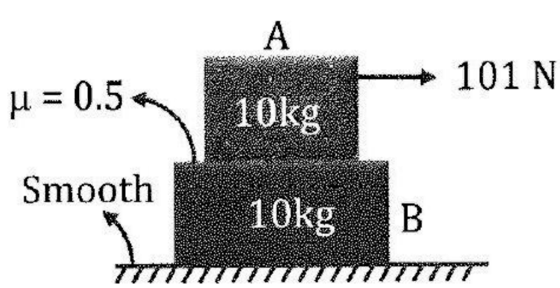
Step 1 : Make force diagram.
Step 2 : Show static friction force by f because value of friction is not known.
Step 3 : Calculate separately for two cases.
Case 1 : Move together

Step 4 : Calculate acceleration.
Step 5 : Check value of friction for above case.
Step 6 : If required friction is less than available it means they will move together else move separately.
Step 7(a) : Above acceleration will be common acceleration for both.
Case 2 : Move separately

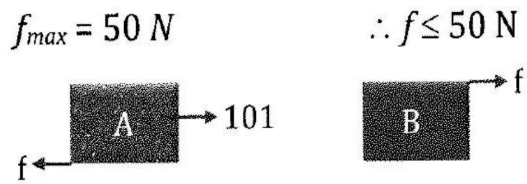
Step 7 (b) : If they move separately then kinetic friction is involved. Whose value is μN.
Step 8 : Calculate acceleration for above case.

Illustration 32:

Find the acceleration of the two blocks. The system is initially at rest and the friction coefficient are as shown in the figure?



Solution:



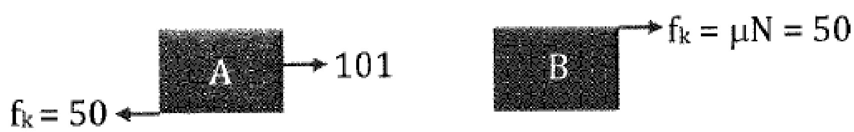
(i) If they move together $a = \frac{101}{20} = 5.05\ m/s^2$

(ii) Check friction on B

$f = 10 \times 5.05 = 50.5$ (required)

$50.5 > 50$ (therefore required friction > available friction). Hence they will not move together.

(iii) Hence, they move separately so kinetic friction is involved.

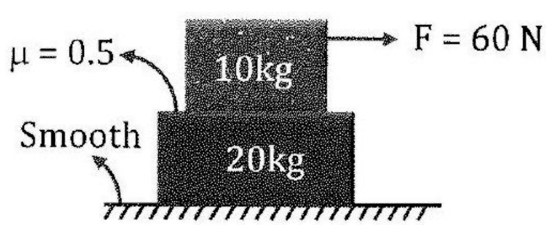


For $a_A = \frac{101-50}{10} = 5.1\ m/s^2$ For $a_B = \frac{50}{10} = 5\ m/s^2$

Also, $a_A > a_B$ as force is applied on A.

Illustration 33:

Find the acceleration of the two blocks. The system is initially at rest and the friction coefficient are as shown in the figure?



Solution:

Move Together

$a = \frac{60}{30} = 2\ m/s^2$

Check friction on 20 kg .

$f = 20 \times 2$

$f = 40$ (which is required)

$40 < 50$ (therefore required friction < available friction)

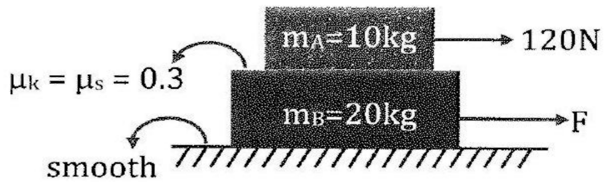
∴ Will move together.

Move Separately

No need to calculate.

Illustration 34:

In the figure given below force F applied horizontally on lower block, is gradually increased from zero. Discuss the direction and nature of friction force and the accelerations of the block for different values of F (Take $g = 10\ m/s^2$).



Solution:

In the above situation we see that the maximum possible value of friction between the blocks is $\mu_S m_A g = 0.3\times10\times10 = 30\ N$.

Case (i): When $F = 0$.

Considering that there is no slipping between the blocks the acceleration of system will be

$$a = \frac{120}{20+10} = 4\ m/s^2$$

But the maximum acceleration of B can be obtained by the following force diagram.

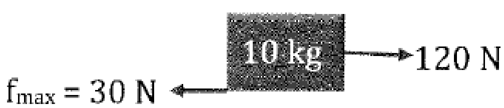
$$f_{max} = 30\ N$$

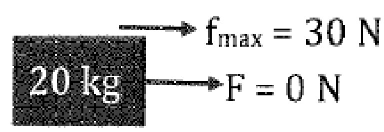
$$a_B = \frac{30}{20} = 1.5\ m/s^2$$

($\because$ only friction force by block A is responsible for producing acceleration in block B)

Because $4 > 1.5\ m/s^2$ we can conclude that the blocks do not move together.

Now drawing the F.B.D. of each block, for finding out individual accelerations.





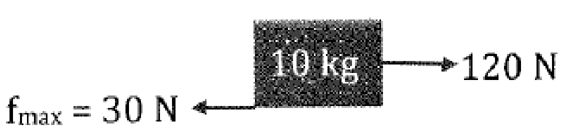
$f_{max} = 30\ N \leftrightarrows 100\ N$ $a_A = \frac{120-30}{10} = 9\ m/s^2$ *towards right* $a_B = \frac{30}{20} = 1.5\ m/s^2$ *towards right.*

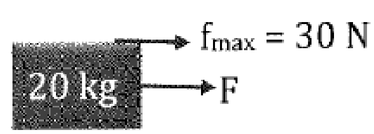
Case (ii) F is increased from zero till the two blocks just start moving together.

As the two blocks move together the friction is static in nature and its value is limiting. FBD in this case will be

$$a_A = \frac{120-30}{10} = 9\ m/s^2 \Rightarrow a_B = \frac{F+30}{20} = a_A \Rightarrow \frac{F+30}{20} = 9$$

$\therefore F = 150N$





Hence when $0 < F < 150N$ the blocks do not move together, and the friction is kinetic. As F increases acceleration of block B increases from $1.5\ m/s^2$.
At $F = 150\ N$ limiting static friction start acting and the two blocks start moving together.
Case (iii) When F is increased above 150 N .
In this scenario the static friction adjusts itself so as to keep the blocks moving together. The value of static friction starts reducing but the direction still remains same. This happens continuously till the value of friction becomes zero. In this case the FBD is as follows:

$$a_A = a_B = \frac{120-f}{10} = \frac{F+f}{20}$$

∴ When friction force f gets reduced to zero the above accelerations become

$$a_A = \frac{120}{10} = 12\ m/s^2 \Rightarrow a_B = \frac{F}{20} = a_A = 12\ m/s^2$$

$\therefore F = 240\ N$

Hence when $150 \le F \le 240N$ the static friction force continuously decreases from maximum to zero at $= 240\ N$. The accelerations of the blocks increase from $9\ m/s^2$ to $12\ m/s^2$ during the change of force F.

Case (iv) When F is increased again from 240 N the direction of friction force on the block reverses but it is still static. F can be increased till this reversed static friction reaches its limiting value. FBD at this junction will be

The blocks move together therefore.

$$a_A = \frac{120+30}{10} = 15\ m/s^2 \Rightarrow a_B = \frac{F-30}{20} = a_A = 15\ m/s^2 \therefore \frac{F-30}{20} = 15\ m/s^2$$

Hence $= 330\ N$.

Case (v) When F is increased beyond 330 N . In this case the limiting friction is achieved and slipping takes place between the blocks (kinetic friction is involved).

$\therefore a_A = 15\ m/s^2$ which is constant

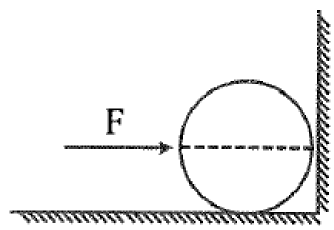
$$a_B = \frac{F-30}{20}\ m/s^2\ where\ F > 330\ N.s$$

EXERCISE - 0

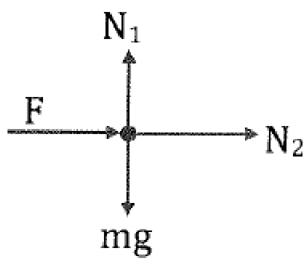
SINGLE CORRECT TYPE QUESTIONS

Newtons Laws of Motion

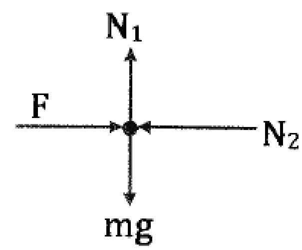
1. A ball of mass m kept at the corner as shown in the figure, is acted by a horizontal force F. The correct free body diagram of ball is



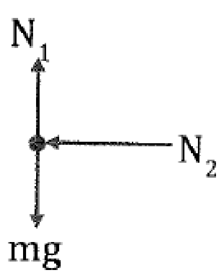
(A)



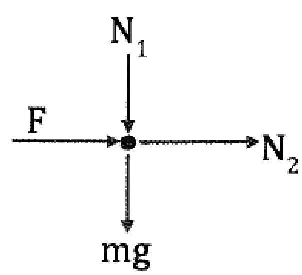
(B)



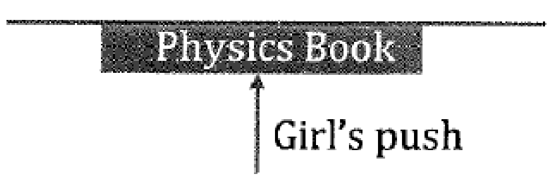
(C)



(D)



2. A girl pushes her physics book up against the horizontal ceiling of her room as shown in the figure. The book weighs 20 N and she pushes upwards with a force of 25 N . The choices below list the magnitudes of the contact force F_{CB} between the ceiling and the book, and F_{BH} between the book and her hand. Select the correct pair.



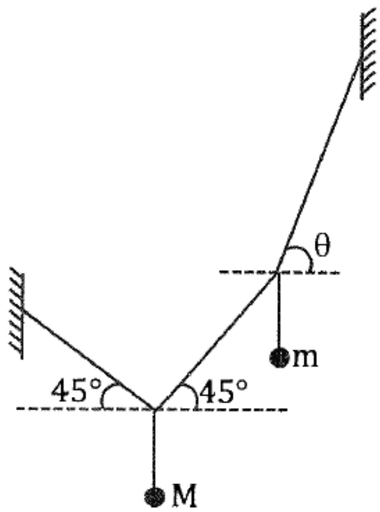
(A) $F_{CB} = 20N$ and $F_{BH} = 25N$

(B) $F_{CB} = 25\ N$ and $F_{BH} = 45\ N$

(C) $F_{CB} = 5\ N$ and $F_{BH} = 25\ N$

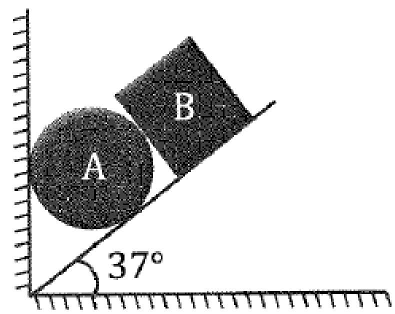
(D) $F_{CB} = 5\ N$ and $F_{BH} = 45\ N$

3. Two masses and M are attached to strings as shown in the figure. In equilibrium $tan\theta$ is :



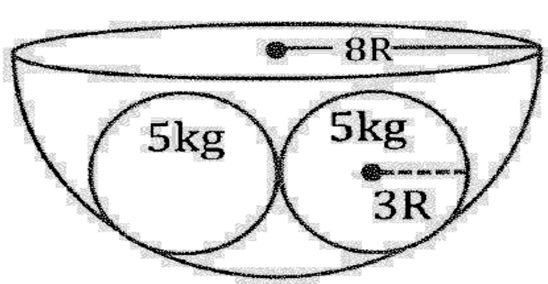
(A) $1 + (2M/m)$ (B) $1 + (2m/M)$ (C) $1 + (M/2m)$ (D) None of these

4. A perfect smooth sphere A of mass 2 kg is in contact with a rectangular block B of mass 4 kg and vertical wall as shown in the figure. All surfaces are smooth. Find normal reaction by vertical wall on sphere A



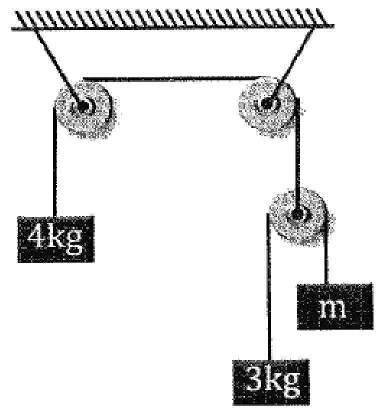
(A) 20 N (B) 25 N (C) 80 N (D) 45 N

5. In a hemispherical bowl of radius $8R$, two balls of mass 5 kg are placed in the equilibrium. Radius of the ball is $3R$. Normal contact force between the two balls is given by



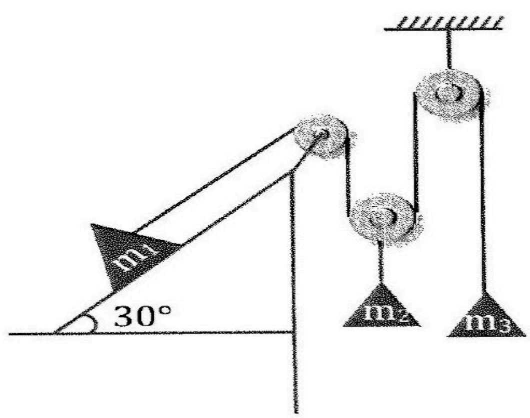
(A) $\frac{75}{2}$ (B) $\frac{75}{4}$ (C) $\frac{75}{6}$ (D) 15

6. What should be the value of " m " so that 4 kg block remains at rest :-



(A) 3 kg (B) 4 kg (C) 1.5 kg (D) 2.5 kg

7. All pulleys and strings are massless, for what ratio of $m_1 : m_2 : m_3$ system will be in equilibrium (inclined is frictionless)

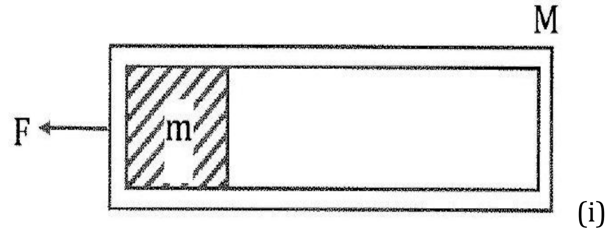


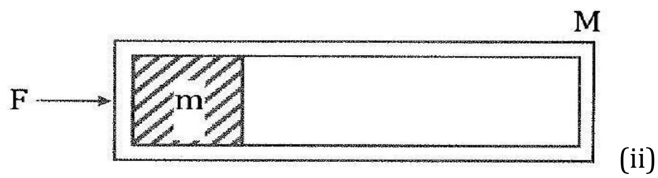
(A) 1: 2: 1 (B) 2: 2: 1 (C) 1: 2: 2 (D) 2: 1: 2

8. A flexible chain of weight W hangs between two fixed points A&B which are at the same horizontal level. The inclination of the chain with the horizontal at both the points of support is θ. What is the tension of the chain at the mid point?
(A) $\frac{W}{2} \cdot cosec\theta$ (B) $\frac{W}{2} \cdot tan\theta$ (C) $\frac{W}{2} cot\theta$ (D) none

9. Two astronauts A and B connected with a rope stay stationary in free space relative to their spaceship. Mass of A is more than that of B and the rope is straight. Astronaut A starts pulling the rope but astronaut B does not. If you were the third astronaut in the spaceship, what do you observe?
(A) Astronaut B accelerates towards A and A remains stationery.
(B) Both accelerate towards each other with equal accelerations of equal modulus.
(C) Both accelerate towards each other but acceleration of B is greater than that of A.
(D) Both accelerate towards each other but acceleration of B is smaller than that of A.

10. A block of mass m is placed in contact with one end of a smooth tube of mass M (see figure). A horizontal force F acts on the tube in each case (i) and (ii). Then mark incorrect option :





(A) $a_m = 0$ and $a_M = \frac{F}{M}$ in (i)

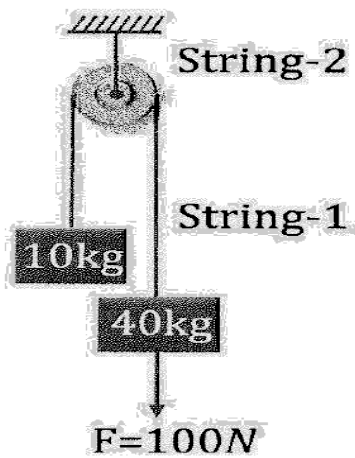
(B) $a_m = a_M = \frac{F}{M+m}$ in (i)

(C) $a_m = a_M = \frac{F}{M+m}$ in (ii)

(D) Force on m is $\frac{mF}{M+m}$ in (ii)

11. Mark the INCORRECT statement(s):

Magnitude of acceleration of both blocks is 8 m/s^2



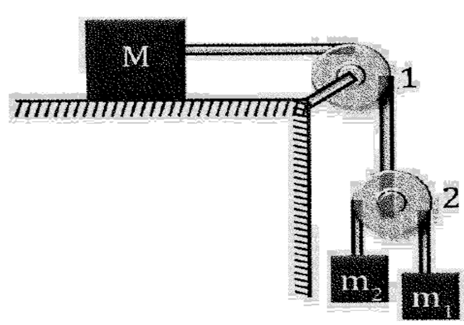
(A) tension in the string is 180 N

(B) acceleration of mass 10 kg is 8 m/s^2 upward

(C) acceleration of mass 10 kg is 8 m/s^2 downward

(D) acceleration of mass 40 kg is 8 m/s^2 downward

12. In the arrangement shown in figure $m_1 = 1\ kg, m_2 = 2\ kg$. Pulleys are massless and strings are light. For what value of M the mass m_1 moves with constant velocity (Neglect friction)



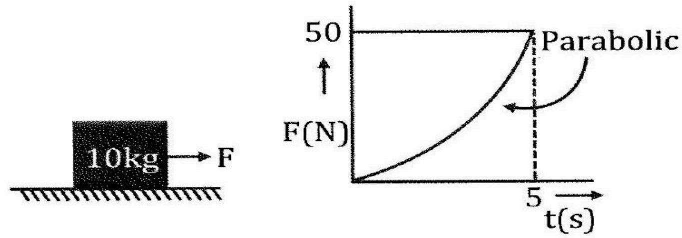
(A) 6 kg

(B) 4 kg

(C) 8 kg

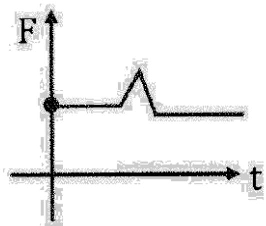
(D) 10 kg

13. A force F is applied to the initially stationary cart. The variation of force with time is shown in the figure. The speed of cart at $t = 5$ second is :-

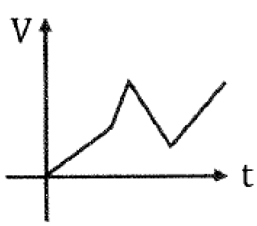


(A) 10 m/s (B) 8. 33 m/s (C) 2 m/s (D) zero

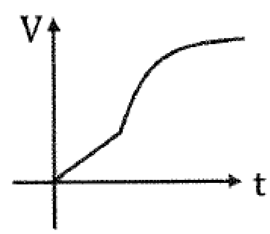
14. Curve between net force vs time is shown.-Initially particle is at rest. Which of the following best represents the resulting velocity - time graph of the particle?



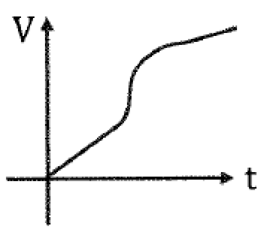
(A)



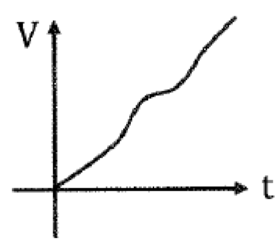
(B)



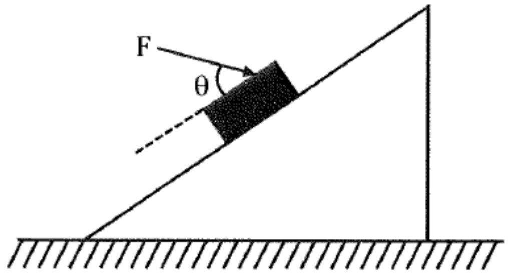
(C)



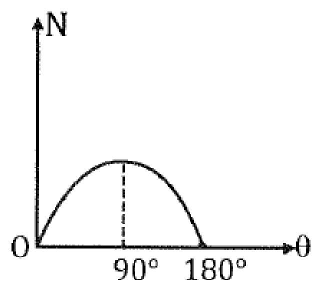
(D)



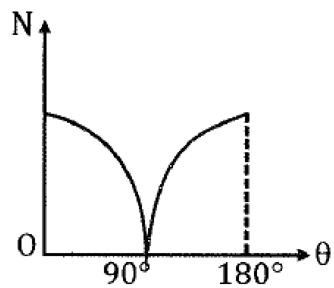
15. In a given figure a block is kept on the fixed wedge. A force of magnitude F is acting on the block such that it makes angle θ with the inclined plane. Now θ is changing from 0 to 180° then graph between normal reaction between block and wedge (N) and θ is :-



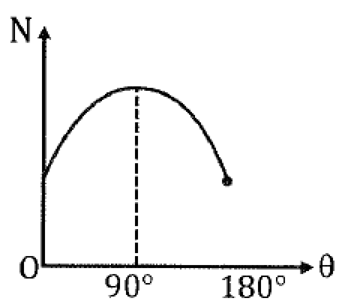
(A)



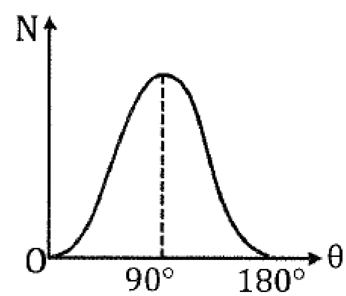
(B)



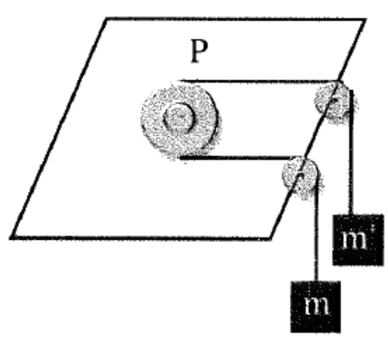
(C)



(D)

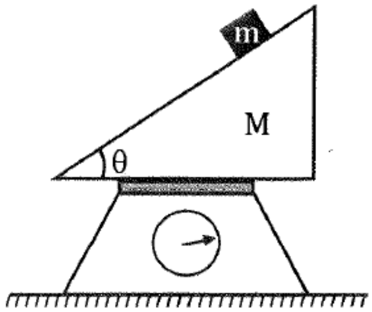


16. A smooth pulley P of mass $M = 2\ kg$ is lying on a smooth table. A light string passes round the pulley and has mass $m = 1\ kg$ and $m' = 2\ kg$ attached to its ends, the two portions of the string being perpendicular to the edge of the table so that the masses hang vertically. Acceleration of pulley is-



(A) $\frac{g}{2}$ (B) $\frac{2g}{3}$ (C) $\frac{4g}{9}$ (D) $\frac{4g}{7}$

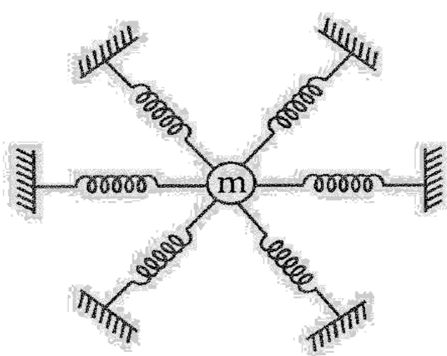
17. The wedge of mass M sits at rest on a scale as shown in figure. A small block of mass m slides down the frictionless incline of the wedge. The scale reading while the block slides, is :



(A) $(m + M)g$ (B) $Mg + mgcos^2\theta$

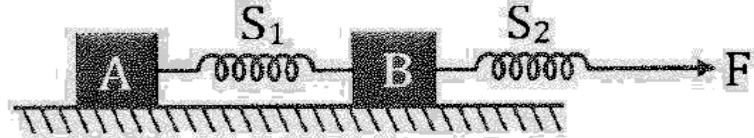
(C) $(m + M)g + mgsin^2\theta$ (D) $(M - m)g + mgsin^2\theta$

18. A sphere of mass ' m ' is kept in equilibrium with the help of several springs as shown in the figure. Measurements show that one of the springs applies a force $\vec{F}$ on the sphere. With what acceleration the sphere will move immediately after this particular spring is cut?



(A) Zero (B) $\frac{\vec{F}}{m}$ (C) $-\frac{\vec{F}}{m}$ (D) Insufficient information

19. Two blocks A and B of equal mass 2 kg are arranged as shown with springs S_1 and S_2. Spring S_2 is pulled with force $= 6\ N$. Acceleration of block B is $4\ m/s^2$ towards right at an instant. If F is suddenly removed at this instant, the instantaneous acceleration of A and B will be (Assume no friction)



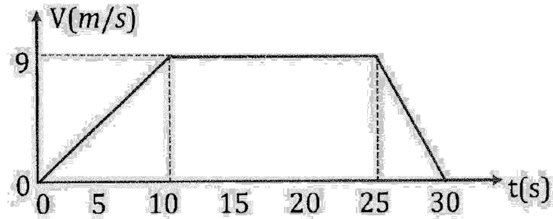
(A) $a_A = 1\ m/s^2$ towards right and $a_B = 4\ m/s^2$ left

(B) $a_A = 1\, m/s^2$ towards left and $a_B = 4\, m/s^2$ right

(C) $a_A = 1\, m/s^2$ towards left and $a_B = 1\, m/s^2$ right

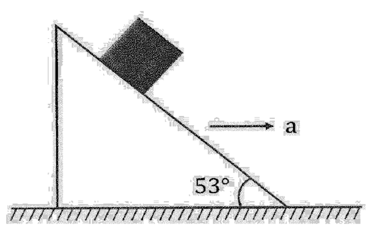
(D) $a_A = 0$ and $a_B = 4\, m/s^2$ right

20. A lift is going up. The total mass of the lift and the passengers is 500 kg . The speed of lift varies with time as shown in figure. What will be the tension (in kN) in the rope pulling the lift at $t = 27\, s$. $\left(g = 9.8\, m/s^2\right)$



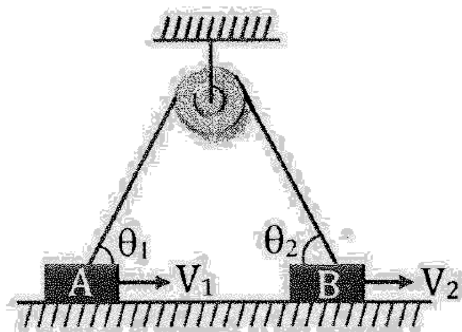
(A) 2 (B) 4 (C) 6 (D) 8

21. If acceleration (in $/s^2$) of wedge (rightwards) so that block does not move w.r.t. wedge is $\frac{8n}{3}$. Value of n.



(A) 7 (B) 8 (C) 5 (D) 9

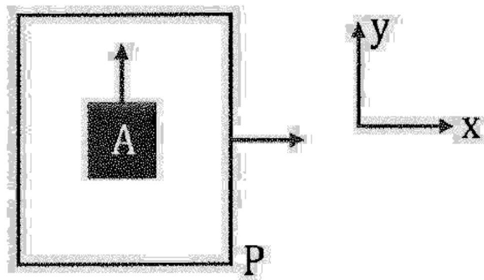
22. In the figure shown, blocks A and B move with velocities v_1 and v_2 along horizontal direction. Find the ratio of $\frac{v_1}{v_2}$.



(A) $\frac{cos\theta_1}{cos\theta_2}$ (B) $\frac{cos\theta_2}{cos\theta_1}$ (C) $\frac{sin\theta_2}{sin\theta_1}$ (D) $\frac{sin\theta_1}{sin\theta_2}$

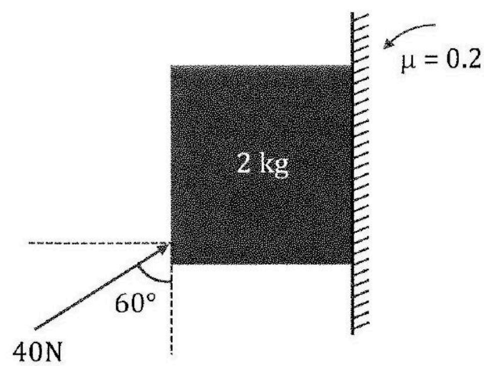
Friction

23. A block is moving along y-axis with velocity 4 m/s on a plank relative to ground and the plank is moving along x-axis with velocity 3 m/s at any instant of time. The unit vector in direction of friction force acting on block at this moment of time is



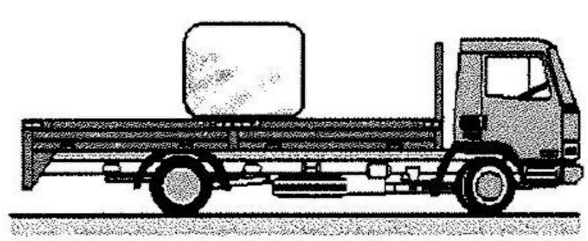
(A) $\frac{3\hat{i}+4\hat{j}}{5}$ (B) $\frac{3\hat{i}-4\hat{j}}{5}$ (C) $\frac{-3\hat{i}+4\hat{j}}{5}$ (D) $\frac{-3\hat{i}-4\hat{j}}{5}$

24. A block of mass 2 kg is pressed against the vertical wall of coefficient of friction $\mu = 0.2$. The value of friction force acting on the wall is :-



(A) $40\sqrt{3}N$ in upward direction
(B) $40\sqrt{3}N$ in downward direction
(C) 20 N in upward direction
(D) No friction force acts on the block

25. A truck carries a 2 Ton block on a level horizontal road. The coefficient of static and kinetic frictions between the stone-block and truck-bed are 0.4 and 0.2 respectively. When the truck accelerates at 2 m/s^2, how much friction acts between the stone-block and the truck-bed? $\left[g = 10\ m/s^2\right]$



(A) 2000 N (B) 4000 N (C) 8000 N (D) 10000 N

26. The coefficient of friction between the block and the horizontal surface is μ as shown in figure. The block moves towards right under action of horizontal force F (figure-a). Sometime later another force P is applied to

the block making an angle θ (such that $n\theta = \mu$) with vertical as shown in (figure - b). After application of force P, the acceleration of block shall

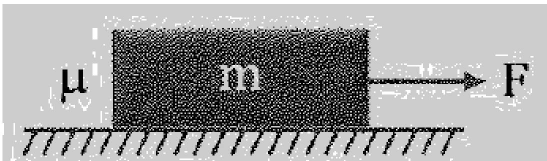


Fig. (a)

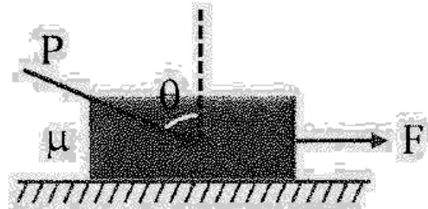
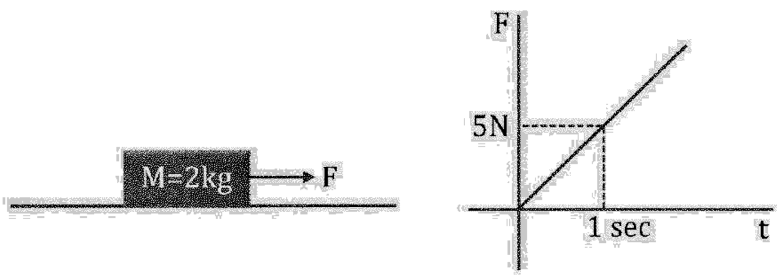


Fig. (b)

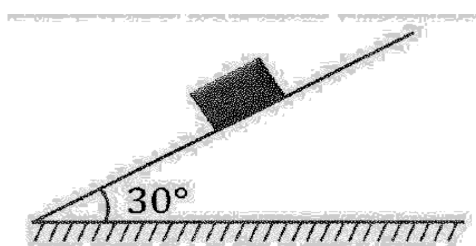
(A) increase
(B) decrease
(C) remains same
(D) information insufficient for drawing inference.

27. A block of mass 2 kg is at rest on a rough surface, of coefficient of friction 0.5 . A force F is applied on the block, variation of force is represented in the figure. Speed of the block at $t = 4sec$ is:



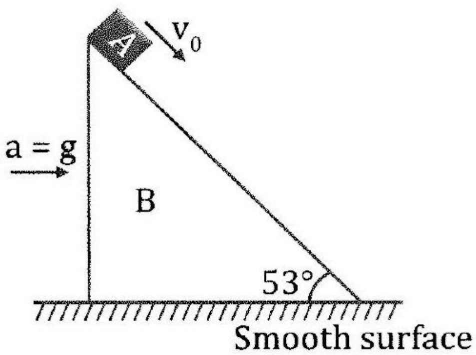
(A) 20 m/s
(B) 10 m/s
(C) 5 m/s
(D) 15 m/s

28. Figure shows a block kept on a rough inclined plane. The maximum external force down the incline for which the block remains at rest is $2N$ while the maximum external force up the incline for which the block is at rest is 10 N . The coefficient of static friction μ is



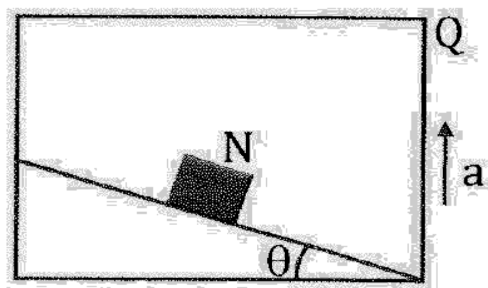
(A) $\frac{\sqrt{3}}{2}$
(B) $\frac{1}{\sqrt{6}}$
(C) $\sqrt{3}$
(D) $\frac{1}{\sqrt{3}}$

29. Block A is placed on a rough wedge B which is placed on a smooth surface. The wedge has angle of inclination of 53° and is imparted a horizontal acceleration g towards right. Block A is given an initial velocity v_0 with respect to wedge. Find the coefficient of friction for which block A moves with constant velocity v_0 with respect to wedge. $\left(g = 10\, m/s^2\right)$



(A) 2/3 (B) 3/7 (C) 1/7 (D) 1/3

30. A block of mass m is at rest with respect to a rough incline kept in elevator moving up with acceleration a. Which of following statements is /are correct.



(A) The contact force between block and incline is vertical.
(B) The contact force between block and incline is of magnitude $m(g - a)$.
(C) The contact force between block and incline is perpendicular to the incline.
(D) The contact force is of magnitude $mg\cos\theta$.

31. Base angles of triangular wedge ABC are 37° and 90°. A uniform rope is kept over the wedge as shown in two figures. The maximum length of string which can be hanged vertically is x_1 (fig. I) and minimum length is x_2 (fig. II) in equilibrium. If $\frac{x_1}{x_2} = 3$, find the value of coefficient of friction between rope and wedge.

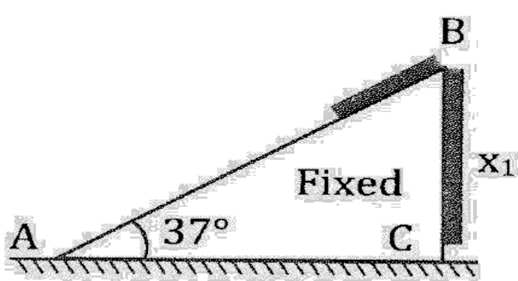


Fig. (i)

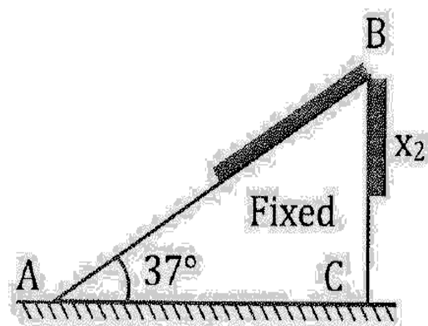
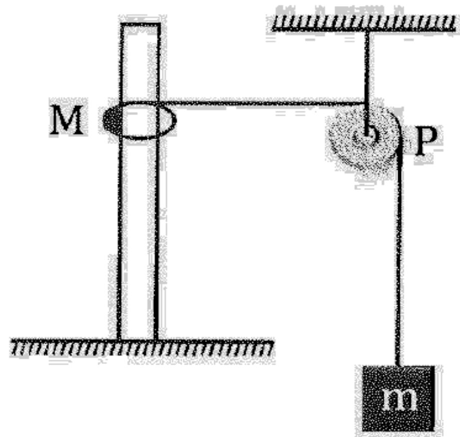


Fig. (ii)

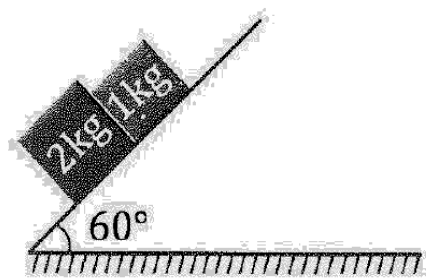
(A) 0.5 (B) 0.4 (C) 0.6 (D) 0.8

32. In the figure shown a ring of mass M and a block of mass m are in equilibrium. The string is light and pulley P does not offer any friction and coefficient of friction between pole and M is μ. The frictional force offered by the pole on M is



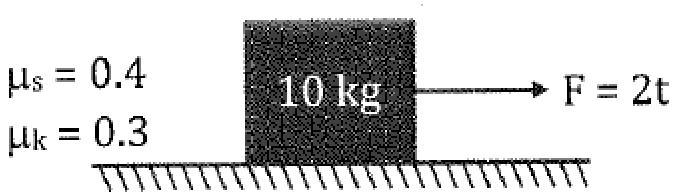
(A) Mg directed up
(B) μmg directed up
(C) $(M - m)g$ directed down
(D) μmg directed down

33. In the figure shown if friction coefficient of block 1 kg and 2 kg with inclined plane is $\mu_1 = 0.5$ and $\mu_2 = 0.4$ respectively, then

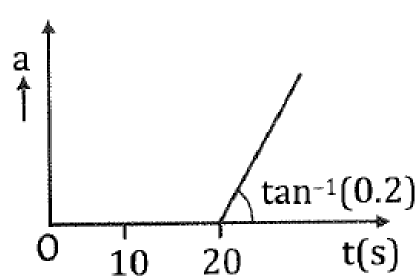


(A) both blocks will move together.
(B) both blocks will move separately.
(C) there is a non-zero contact force between two blocks.
(D) none of these

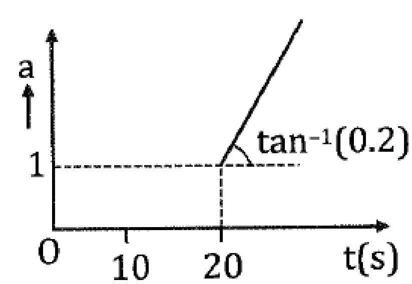
34. For shown situation the acceleration of block is represented by : (Here t is time in second) ($g = 10\ ms^{-2}$)
So, acceleration of block remains same.



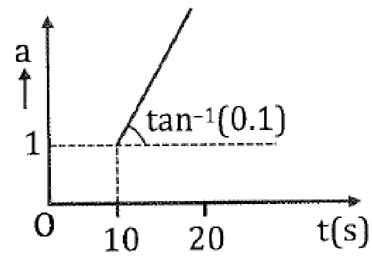
(A)



(B)

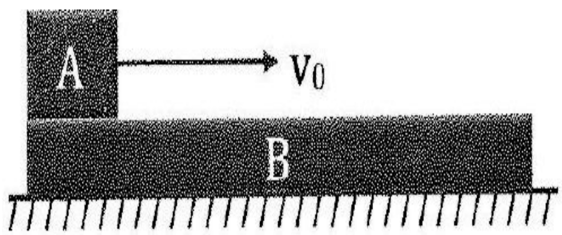


(C)

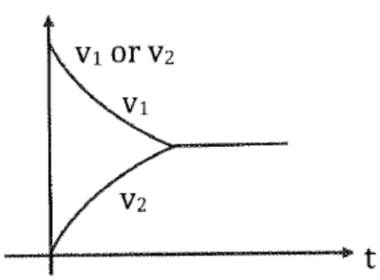


(D) None of these

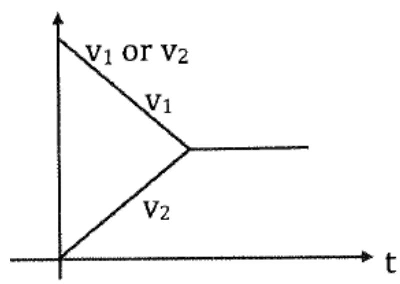
35. A block A is placed over a long rough plank B of same mass as shown in figure. The plank is placed over a smooth horizontal surface. At time $t = 0$, block A is given a velocity v_0 in horizontal direction. Let v_1 and v_2 be the velocities of A and B at time t. Then choose the correct graph between v_1 or v_2 and t.



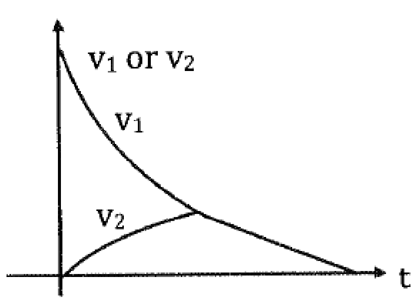
(A)



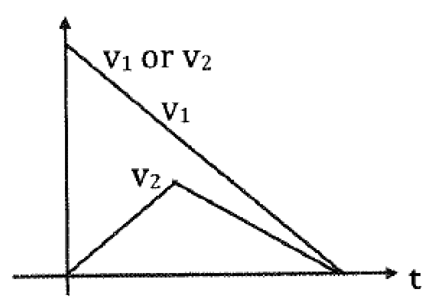
(B)



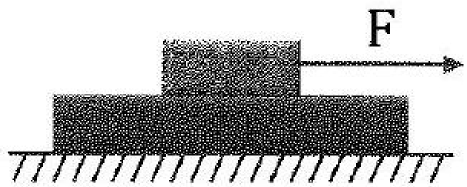
(C)



(D)

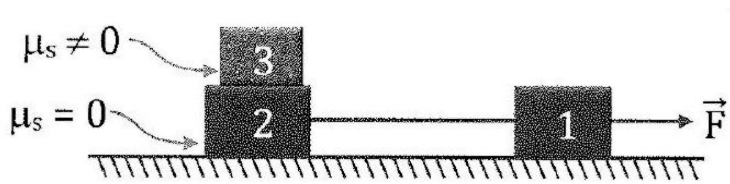


36. In the figure shown, the friction coefficient between the block of mass 1 kg and the plank of mass 2 kg is 0.4 while that between the plank and floor is 0.1 . A constant force ' F ' starts acting horizontally on the upper 1 kg block. The acceleration of plank if $F = 10\ N$ is



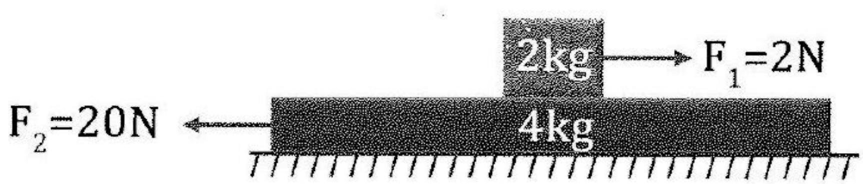
(A) $2.5\ m/s^2$ (B) $3.833\ m/s^2$ (C) $0.5\ m/s^2$ (D) $1.0\ m/s^2$

37. Three blocks of equal mass M are initially at rest on smooth floor. A force is applied to the system so that the three blocks are to move together. Mark the correct option.



(A) The minimum coefficient of friction required is $\frac{F}{3Mg}$.
(B) The minimum coefficient of friction required is $\frac{F}{Mg}$.
(C) The minimum coefficient of friction required is $\frac{F}{2g}$.
(D) The minimum coefficient of friction required is $\frac{3F}{2Mg}$.

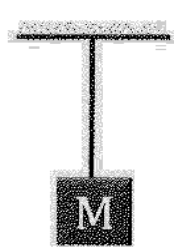
38. In the arrangement shown in figure, coefficient of friction between the two blocks is $\mu = 1/2$. The force of friction acting between the two blocks is :-



(A) 8 N (B) 10 N (C) 6 N (D) $4N$

MULTIPLE CORRECT TYPE QUESTIONS

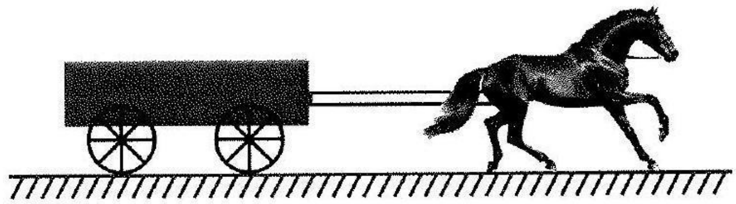
39. Consider a block suspended from a light string as shown in the figure. Which of the following pairs of forces constitute Newton's third law pair?



(A) Force with which string pulls on the ceiling and the force with which string pulls on block

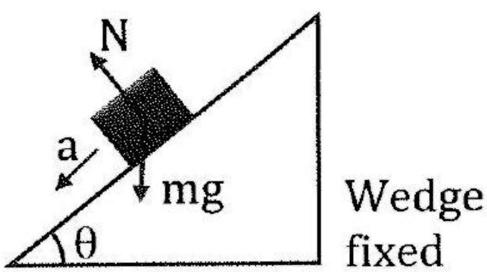
(B) Force with which string pulls on the block and weight of the block
(C) Force acting on block due to the earth and force the block exerts on the earth
(D) Force with which block pulls on string and force with which the string pulls on the block

40. A horse is pulling a cart on a rough surface. If we take (horse + cart) as a system, then which of the following statement(s) is/are correct?



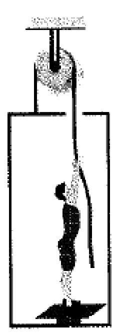
(A) Force by horse on cart is an internal force.
(B) Force by ground on horse is an external force.
(C) Force by cart on horse is an internal force.
(D) Force by ground on cart is an external force.

41. For the system shown which of the option(s) are CORRECT :



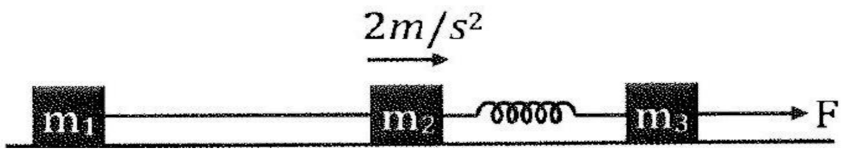
(A) $N\cos\theta = mg$
(B) $N = mg\cos\theta$
(C) $N - mg\cos\theta = ma$
(D) $mg - N\cos\theta = ma\sin\theta$

42. A carpenter of mass 50 kg is standing on a weighing machine placed in a lift of mass 20 kg . A light string is attached to the lift. The string passes over a smooth pulley and the other end is held by the carpenter as shown. When carpenter keeps the lift moving upward with constant velocity :- $\left(g = 10\ m/s^2\right)$



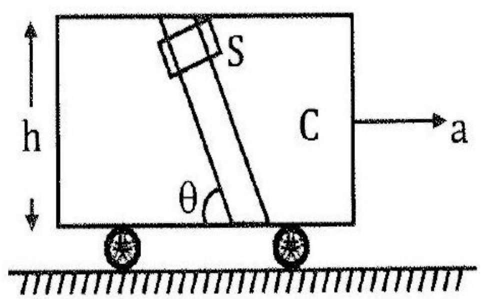
(A) the reading of weighing machine is 15 kg
(B) the man applies a force of 350 N on the string
(C) net force on the man is 150 N
(D) Net force on the weighing machine is 150 N

43. In the given figure $m_1 = 1\ kg, m_2 = 2\ kg, m_3 = 3\ kg, F = 18\ N$ and spring constant is $100\ N/m$ then choose the correct options. (Assume string and spring are ideal)



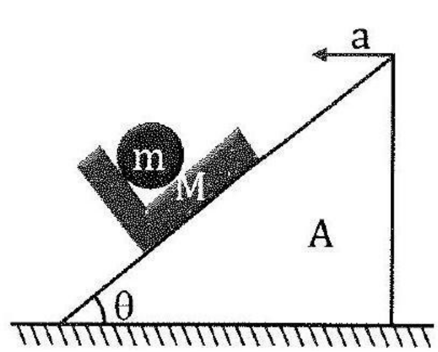
(A) Acceleration of m_1 is $2\ m/s^2$
(B) Tension in string is 2 N
(C) Force applied by spring on block of mass m_2 is 6 N
(D) Acceleration of block of mass m_3 is $4\ m/s^2$

44. A sleeve S of mass m starts sliding down along a smooth inclined rod through a vertical distance h from rest. Cart(C) carrying the rod is moving with constant horizontal acceleration a. If N is the normal force between sleeve and rod, $V_{S/C}$ is the speed of sleeve relative to cart on reaching the lowest point and T is the time taken to reach lowest point then:



(A) $N = m(g\cos\theta + a\sin\theta)$
(B) $V_{S/C} = \sqrt{2h(g - a\cot\theta)}$
(C) $V_{S/C} = \sqrt{2h(g - a\tan\theta)}$
(D) $T = \sqrt{\frac{2h}{\sin\theta(g\cos\theta - a\sin\theta)}}$

45. A ball of mass m is placed on a sledge of mass M. The sledge moves on an inclined plane A of angle of inclination θ. Inclined plane A is moving with constant horizontal acceleration ' a ' towards left (Neglect friction everywhere)



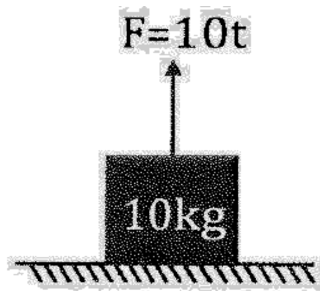
(A) Normal reaction force between m and M is $m(g\cos\theta + a\sin\theta)$

(B) Normal reaction force between A and M is $(M + m)(g\cos\theta + a\sin\theta)$

(C) $a_{M/A} = a_{m/A} = (g\sin\theta - a\cos\theta)$

(D) $a_M = a_m = \sin\theta\sqrt{g^2 + a^2}$

46. A block of $m = 10\ kg$ is kept on ground. A vertically upward force $F = (10t)N$, where t is the time in seconds starts acting on it at $t = 0$ as shown in figure.



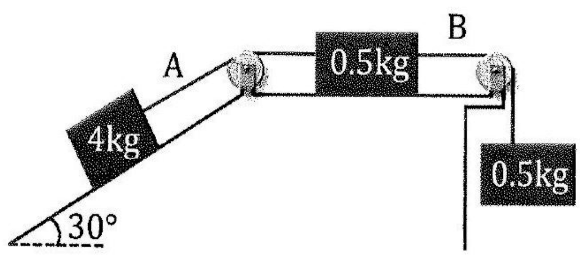
(A) Time at which block loose contact from the surface is 10 sec .

(B) Velocity of block at $t = 20sec$ is 50 m/s.

(C) Velocity of block at $t = 20sec$ is 200 m/s.

(D) Displacement of block in 20 sec is $\frac{500}{3}$ m.

47. System shown in the figure is released from rest.



Which of the following statements is/are true? $\left[g = 10\ m/s^2\right]$

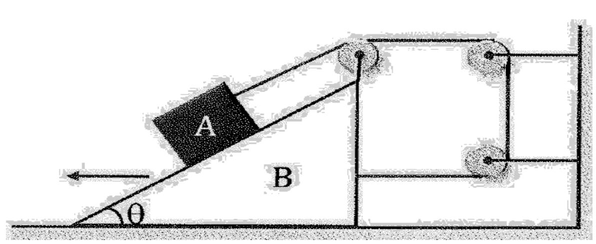
(A) Magnitude of acceleration of each block is 3 m/s^2.

(B) Tension in the cord A is 6.5 N .

(C) Tension in the cord B is 8 N .

(D) Difference of magnitudes of tensions in both the cord is 1.5 N .

48. A block A and wedge B connected through a string as shown. The wedge B is moving away from the wall with acceleration 2 m/s^2 horizontally and acceleration of block A is vertically upwards. Then



(A) Acceleration of A with respect to B is 4 m/s^2.

(B) Acceleration of A with respect to B is $2\sqrt{3}\ m/s^2$.

(C) Angle θ is 60°.

(D) Acceleration of A is $2\sqrt{3}\ m/s^2$.

49. A block is kept on a rough surface and applied with a horizontal force as shown which is gradually increasing from zero. The coefficient of static and kinetic friction are $\frac{1}{\sqrt{3}}$ then

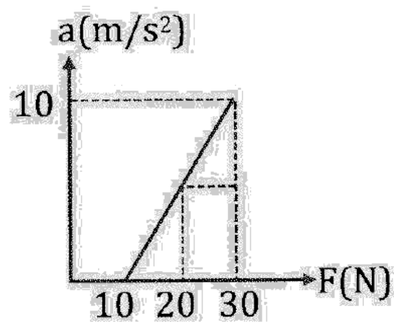
(A) When F is less than the limiting friction, angle made by net force on the block by the surface is less than 30° with vertical.

(B) When the block is just about to move, the angle made by net force by the surface on the block becomes equal to 30° with vertical.

(C) When the block starts to accelerate, the angle made by net force by the surface on the block becomes constant and equal to 30° vertical.

(D) The angle made by net force with vertical on the block by the surface, depends on the mass of the block.

50. A block placed on a rough horizontal surface is pushed with a force F acting horizontally on the block. The magnitude of F is increased and acceleration produced is plotted in the graph shown.



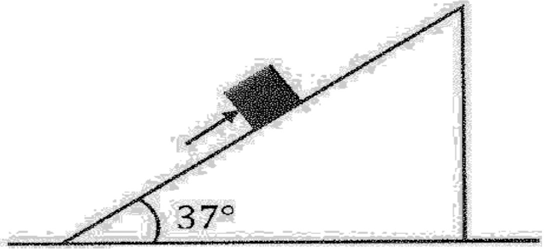
(A) Mass of the block is 2 kg .

(B) Coefficient of friction between block and surface is 0.5 .

(C) Limiting friction between block and surface is 10 N .

(D) When $= 8\ N$, friction between block and surface is 10 N .

51. A block placed on rough inclined plane is pushed with a force F. The coefficient of friction is $\mu = 0.5$ and mass of block is 10 kg .



(A) If $= 30\ N$, acceleration of block is zero and friction acting on block is 30 N .

(B) If $= 60\ N$, acceleration of block is zero and friction acting on block is 60 N .

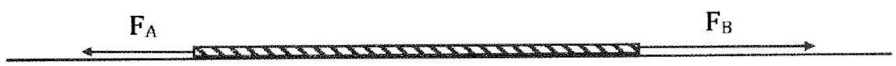
(C) If = 90 N, acceleration of block is zero and friction acting on block is 30 N .

(D) If = 120 N, acceleration of block is 2 m/s^2 and friction acting on block is 40 N .

COMPREHENSION TYPE QUESTIONS

PARAGRAPH FOR QUESTION NO. 52 TO 55

A uniform rope of mass (m) and length (L) placed on frictionless horizontal ground is being pulled by two forces F_A and F_B at its ends as shown in the figure. As a result, the rope accelerates toward the right.



52. Acceleration (a) of the rope is

(A) zero (B) $a = \frac{F_A+F_B}{m}$ (C) $a = \frac{F_A-F_B}{m}$ (D) $a = \frac{F_B-F_A}{m}$

53. Tension (T) at the mid point of the rope is

(A) $T = F_B - F_A$ (B) $T = F_A + F_B$ (C) $T = \frac{1}{2}(F_B - F_A)$ (D) $T = \frac{1}{2}(F_A + F_B)$

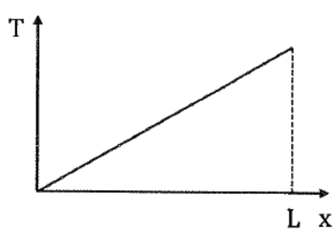
54. Expression (T_x) of tension at a point at distance x from the end A is

(A) $T_x = \left(\frac{F_B-F_A}{L}\right)x + F_A$ (B) $T_x = \left(\frac{F_B-F_A}{L}\right)x - F_A$

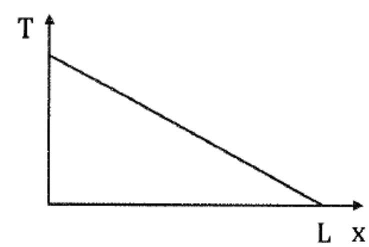
(C) $T_x = \left(\frac{F_B-F_A}{L}\right)x + F_B$ (D) $T_x = \left(\frac{F_B-F_A}{L}\right)x - F_B$

55. Which of the following graph best represents variation in tension at a point on the rope with distance x of the point from the end ?

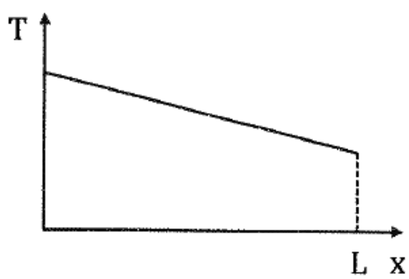
(A)



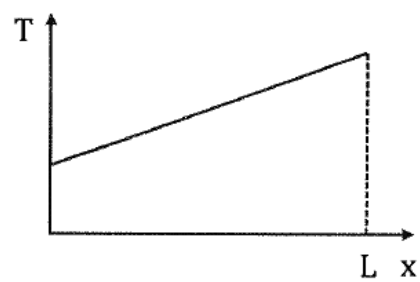
(B)



(C)

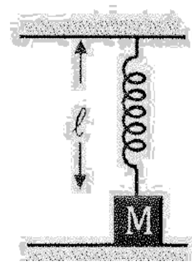


(D)



PARAGRAPH FOR QUESTION NO. 56 TO 58

A block of mass m is placed on a smooth horizontal floor is attached to one end of spring. The other end of the spring is attached to fixed support. When spring is vertical it is relaxed. Now the block is pulled towards right by a force F, which is being increased gradually. When the spring makes angle 53° with the vertical, block leaves the floor.



56. When blocks leaves the table, the normal force on it from table is

(A) mg (B) zero (C) $\frac{4mg}{3}$ (D) $\frac{3mg}{4}$

57. Force constant of the spring is :-

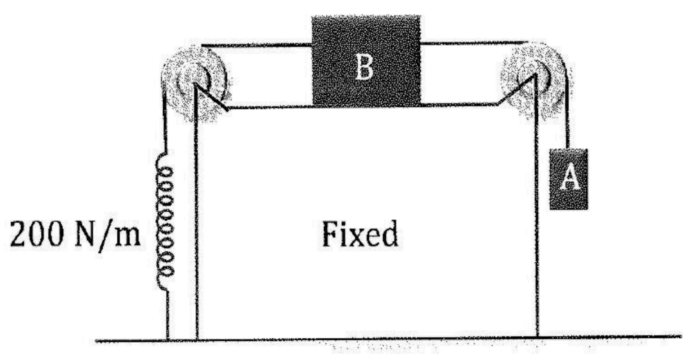
(A) $\frac{5mg}{2l}$ (B) $\frac{15mg}{8l}$ (C) $\frac{5mg}{3l}$ (D) $\frac{5mg}{4l}$

58. When the block leaves the table, the force F is :-

(A) $\frac{3mg}{4}$ (B) $\frac{4mg}{3}$ (C) $\frac{3mg}{5}$ (D) $\frac{4mg}{5}$

PARAGRAPH FOR QUESTION NO. 59 TO 61

In the figure shown blocks A and B are of mass 2 kg and 8 kg and they are connected through strings to a spring connected to ground. The blocks are in equilibrium. ($g = 10\ m/s^2$)



59. The elongation of the spring is

(A) 1 cm (B) 10 cm (C) 0.1 cm (D) 1 m

60. Now the block A is pulled downwards by a force gradually increasing to 20 N . The new elongation of spring is :-

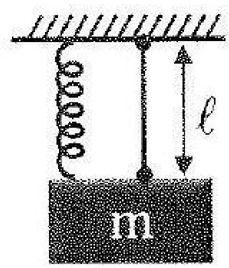
(A) 2 cm (B) 4 cm (C) 20 cm (D) 40 cm

61. Now the force on A is suddenly removed. The acceleration of block B becomes :-

(A) $1.0\ m/s$ (B) $2.0\ m/s^2$ (C) $3.0\ m/s^2$ (D) $4.0\ m/s^2$

PARAGRAPH FOR QUESTION NO. 62 TO 64

An object of mass m is suspended in equilibrium using a string of length l and a spring having spring constant ($< 2mg/l$) and unstreched length $l/2$.



62. Find the tension in the string in newton ?

(A) $mg - \frac{kl}{2}$ (B) $mg - kl$ (C) $2mg - \frac{kl}{2}$ (D) $2mg - kl$

63. Find the acceleration of block just after cut the string ?

(A) $2g - \frac{kl}{2m}$ (B) $g - \frac{kl}{2m}$ (C) $2g - \frac{kl}{m}$ (D) $g - \frac{kl}{m}$

64. What happens if $> 2mg/l$?

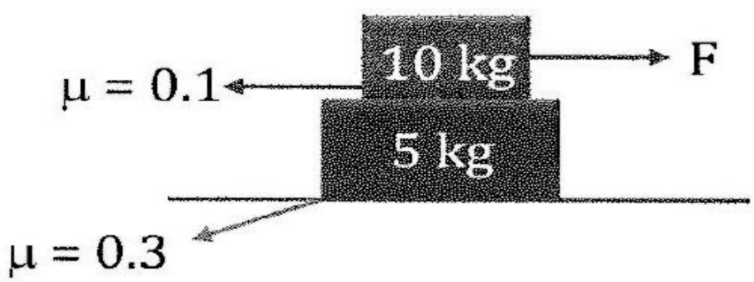
(A) at equilibrium tension in string is negative

(B) at equilibrium position change in length of spring is greater then $\frac{l}{2}$

(C) at equilibrium tension in string is zero.

(D) if we cut the sting, block will accelerate in upward direction.

PARAGRAPH FOR QUESTION NO. 65 TO 69



65. When $F = 2N$, the frictional force between 5 kg block and ground is

(A) 2 N (B) 0 (C) 8 N (D) 10 N

66. When $F = 2\ N$, the frictional force between 10 kg block and 5 kg block is

(A) 2 N (B) 15 N (C) 10 N (D) None

67. The maximum F which will not cause motion of any of the blocks is

(A) 10 N (B) 15 N (C) data insufficient (D) None

68. The maximum acceleration of 5 kg block is :-

(A) $1\ m/s^2$ (B) $3\ m/s^2$ (C) 0 (D) None

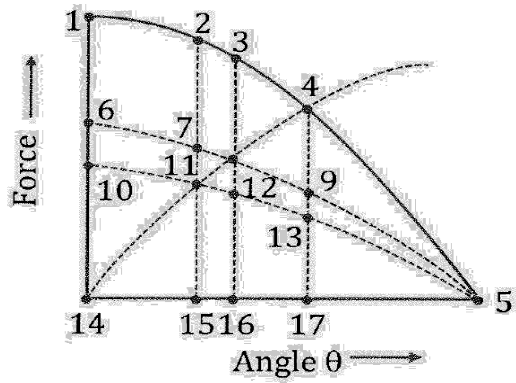
69. The acceleration of 10 kg block when $F = 30\ N$ is

(A) $2\ m/s^2$ (B) $3\ m/s^2$ (C) $1\ m/s^2$ (D) None

PARAGRAPH FOR QUESTION NO. 70 AND 71

Given graph is a plot of magnitude of normal, limiting friction, kinetic friction and static friction versus angle of inclination θ for the coin lying on book. 17 points are labeled with numbers. The coin slips at a certain angle θ_c.

The coefficient of static friction is 0.6 , and the coefficient of kinetic friction is 0.4 .



70. The magnitude of the normal force on the coin from the book,

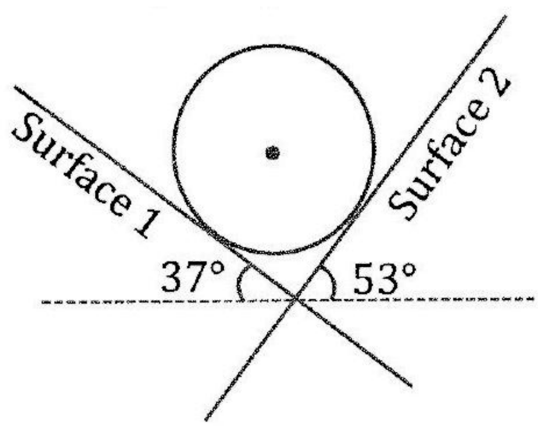
(A) 6 (B) 2 (C) 7 (D) 11

71. θ_C is given by point

(A) 14 (B) 15 (C) 16 (D) 17

MATRIX MATCH TYPE QUESTION

72. A sphere of mass 10 kg is placed in equilibrium in a V shaped groove plane made of two smooth surfaces 1 and 2 as shown in figure. ($g = 10\ ms^{-2}$)



Column-I	Column-II
(A) Normal reaction by Surface 1	(P) Zero
(B) Normal reaction by surface 2	(Q) 60 N
(C) Force on sphere by Earth	(R) 80 N
(D) Net force on sphere	(S) 100 N
	(T) 120 N

73. Velocity of three particles A, B and C varies with time t as, $\vec{v}_A = (2t\hat{i} + 6\hat{j})m/s$; $\vec{v}_B = (3\hat{i} + 4\hat{j})m/s$ and $\vec{v}_C = (6\hat{i} - 4t\hat{j})m/s$. Regarding the pseudo force match the following table

Column-I **Column-II**

(A) On A as observed by B

(B) On B as observed by C

(C) OnA as observed by C

(D) On C as observed by A

(P) Along positive x-direction

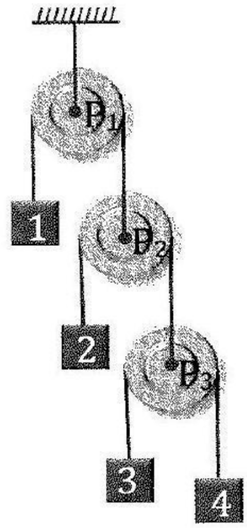
(Q) Along negative x-direction

(R) Along positive y-direction

(S) Along negative y-direction

(T) Zero

74. In the figure shown, acceleration of 1 is x (upwards). Acceleration of pulley P_3, w.r.t. pulley P_2 is y (downwards) and acceleration of 4 w.r.t. to pulley P_3 is z (upwards). Then



Column-I

(A) Absolute acceleration of 2

(B) Absolute acceleration of 3

(C) Absolute acceleration of 4

Column-II

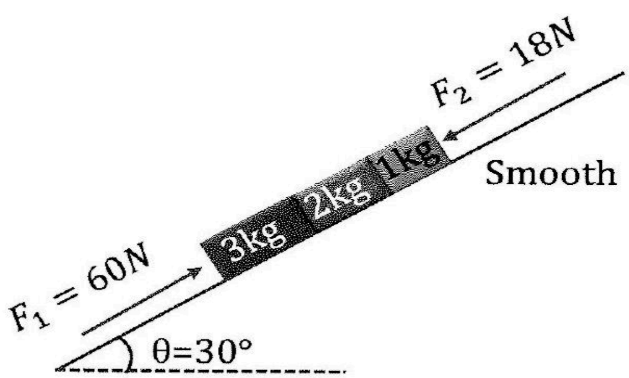
(P) $(y - x)$ downwards

(Q) $(z - x - y)$ upwards

(R) $(x + y + z)$ downwards

(S) None

75. In the diagram shown in figure $\left(g = 10\ m/s^2\right)$



Column-I

(A) Acceleration of 2 kg block in m/s^2

(B) Net force on 3 kg block in newton

Column-II

(P) 8

(Q) 25

(C) Normal reaction between 2 kg and 1 kg in newton (R) 2

(D) Normal reaction between 3 kg and 2 kg in newton (S) 45

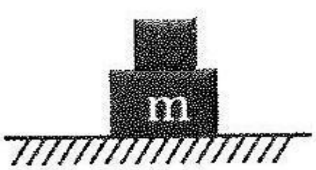
(T) None

EXERCISE - S

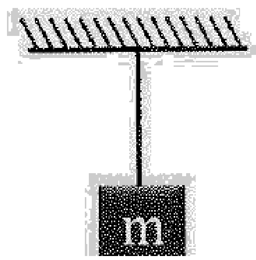
Newtons Laws of Motion

1. Draw free body diagram of block of mass m.

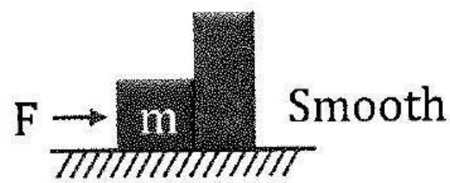
(a)



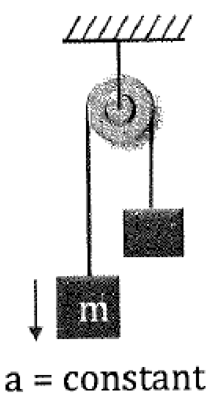
(b)



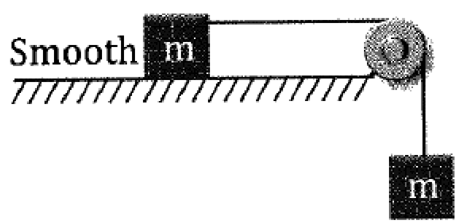
(c)



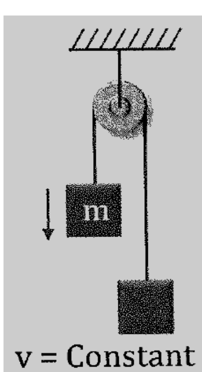
(d)



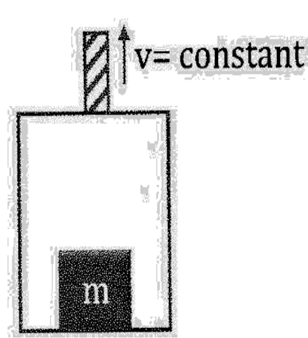
(e)



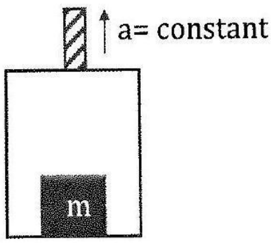
(f)



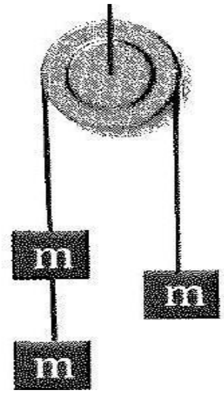
(g)



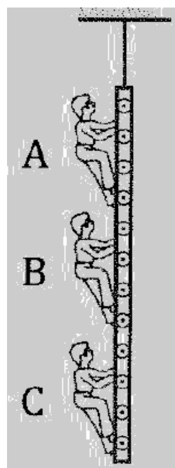
(h)



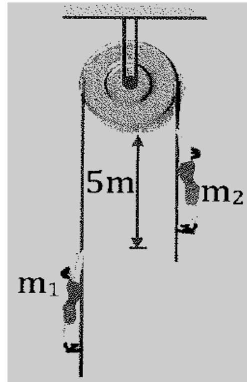
(i)



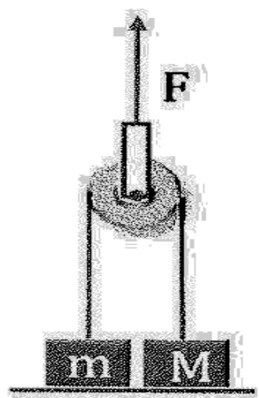
2. A ladder is hanging from ceiling as shown in figure. Three men A, B and C of masses 40 kg, 60 kg, and 50 kg are climbing the ladder. Man A is going up with retardation 2 m/s^2, C is going up with an acceleration of 1 m/s^2 and man B is going up with a constant speed of 0. 5 m/s. Find the tension in the string supporting the ladder. $\left[g = 9.8\, m/s^2\right]$



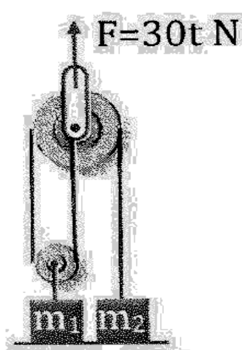
3. A 40 kg monkey climbs a rope that passes over an ideal pulley. The other end of the rope is attached to a 60 kg weight placed on the ground. What is the maximum upward acceleration the monkey can have without lifting the weight? If he climbs the rope with upward acceleration $2g$, with what acceleration the weight will rise up?
4. Two men of masses m_1 and m_2 hold on the opposite ends of a rope passing over a frictionless pulley. The man m_1 climbs up the rope with an acceleration of 1. 2 m/s^2 relative to the rope. The man m_2 climbs up the rope with an acceleration of 2 m/s^2 relative to the rope. Find the tension in the rope if $m_1 = 40\ kg$ and $m_2 = 60\ kg$. Also find the time after which they will be at same horizontal level if they start from rest and are initially separated by 5 m .



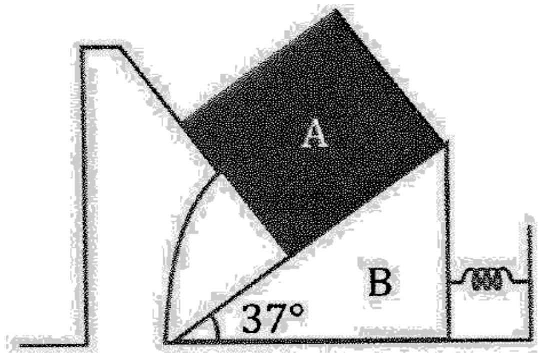
5. In the system shown, pulley and strings are ideal. The vertically upward pull F is being increased gradually, find magnitude of F and acceleration of the 5 kg block at the moment the 10 kg block leaves the floor.



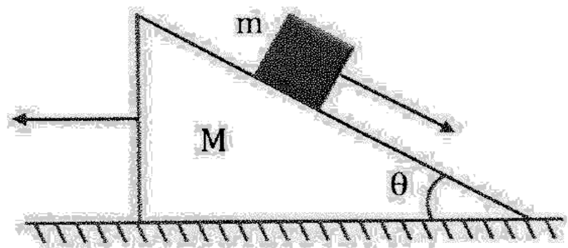
6. Force F is applied on upper pulley. If $F = 30tN$ where t is time in second. Find the time when m_1 loses contact with floor.



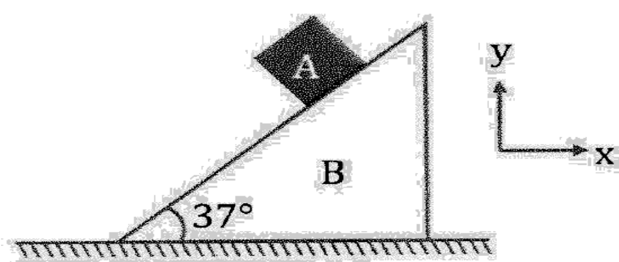
7. In the figure shown, all surfaces are smooth and block A and wedge B have mass 10 kg and 20 kg respectively. Find normal reaction between block A and B, spring force and normal reaction of ground on block B. $\left(g = 10\, m/s^2\right)$.



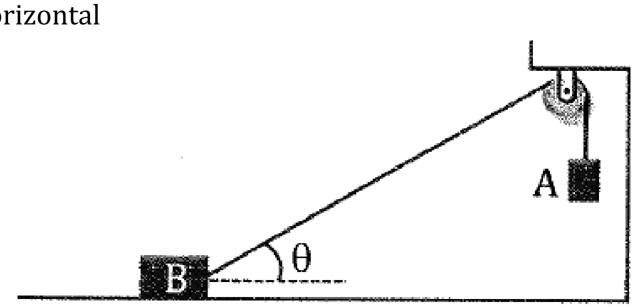
8. All the surfaces shown in figure are assumed to be frictionless. The block of mass m slides on the prism which in turn slides backward on the horizontal surface. Find the acceleration of the smaller block with respect to the prism.



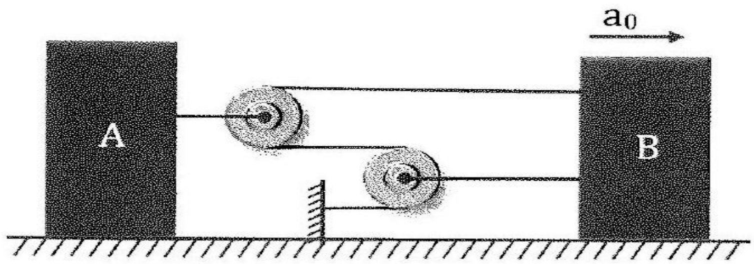
9. In the figure shown the acceleration of A is, $\vec{a}_A = (15\hat{i} + 15\hat{j}) m/s^2$. If A is sliding on B then the acceleration of B is.



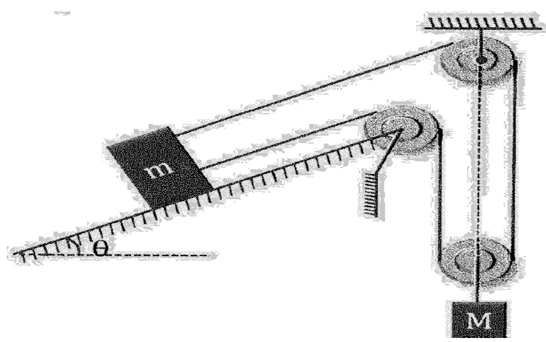
10. The block A is moving downward with constant velocity v_0. Find the velocity of the block B, when the string makes an angle θ with the horizontal



11. Calculate the relative acceleration of A w.r.t. B if B is moving with acceleration a_0 towards right.

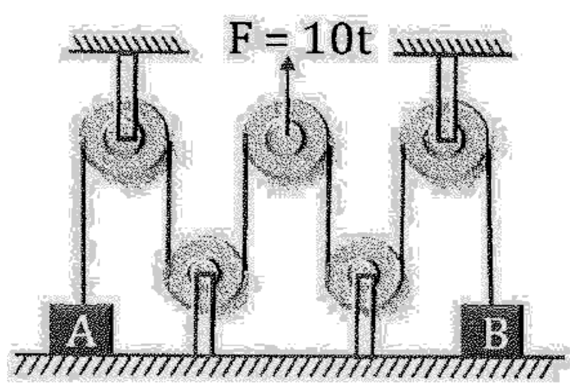


12. In the figure shown all strings and pulleys are massless. If all surfaces are smooth and mass of the blocks are $M = 15\ kg$ and $m = 10\ kg$ then find the acceleration of mass m (in m/s^2)
(Given angle of incline $\theta = 30^\circ$)

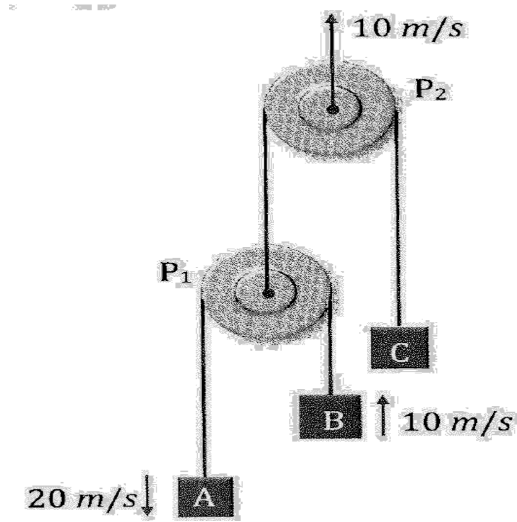


13. A box of mass m is placed on a smooth horizontal platform as shown in the figure. The platform is made to move in direction 30° above the horizontal with acceleration a so that the contact force between the box and the platform becomes $3mg/2$. Find the magnitude of the acceleration (m/s^2).

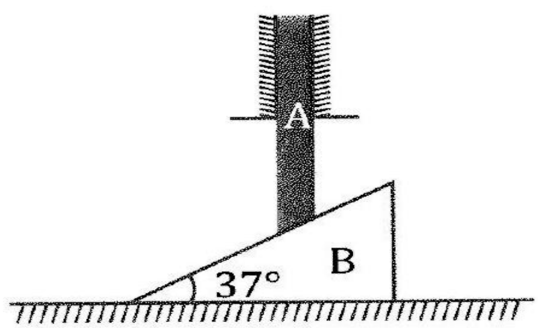
14. In the arrangement shown $m_A = 1\ kg$ and $m_B = 2\ kg$ while all the pulleys and strings are massless and frictionless. At $t = 0$, a force $F = 10t$ starts acting over central pulley in vertical direction. Where B losses contact with floor the velocity of A is ($5n$) m/s. Find out the value of ' n '.



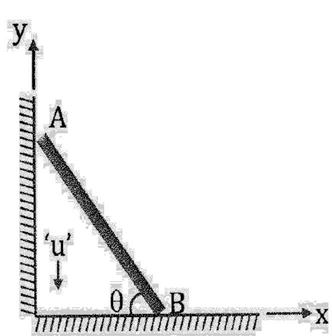
15. Velocities of blocks A, B and pulley p_2 are shown in figure. Find velocity of pulley p_1 and block C.



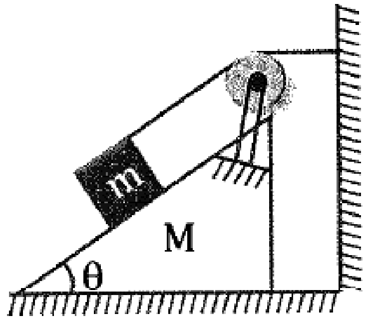
16. Find the acceleration of $rod A$ and wedge B in the arrangement shown in figure if the mass of rod is equal to that of the wedge and the friction between all contact surfaces is negligible and rod A is free to move downwards only. Take angle of wedge as 37°.



17. The velocity of end ' A ' of rigid rod placed between two smooth vertical walls is ' u ' along vertical direction. Find out the velocity of end ' B ' of that rod, rod always remains in contact with the vertical wall.



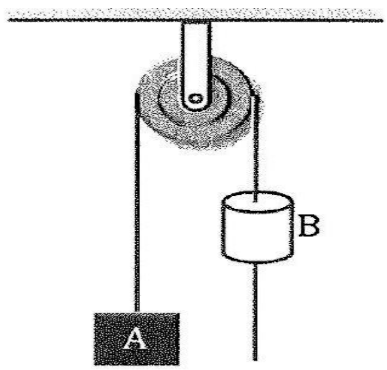
18. For the arrangement shown in figure when the system is released, find the acceleration of wedge. Pulley and string are ideal and friction is absent.



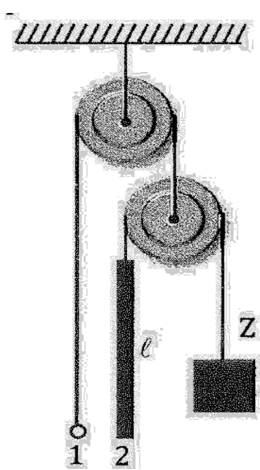
A 2 kg block A is attached to one end of a light string that passes over an ideal pulley and a 1 kg sleeve B slides down the other part of the string with an acceleration of 5 m/s^2 with respect to the string. Find the acceleration of the block, acceleration of sleeve and tension in the string.

$\left[g = 10\ m/s^2\right]$

19.

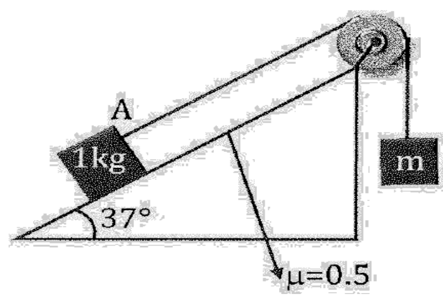


20. In the arrangement shown in figure the mass of ball is $\eta = 1.8$ times as great as that of rod 2 . The length of the latter is $= 100\ cm$. The masses of the pulleys and the threads, as well as the friction, are negligible. The ball is set on the same level as the lower end of the rod and then released. How soon will the ball be opposite the upper end of the rod?

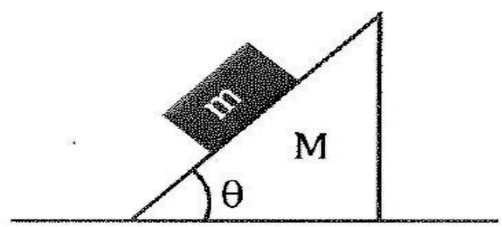


Friction

21. In the figure, what should be mass m so that block A slides *up* with a constant velocity?

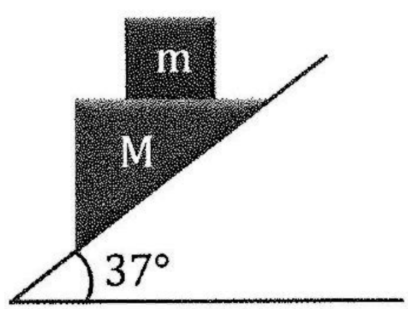


22. A block of mass m lies on wedge of mass M as shown in figure. Find the minimum friction coefficient required between wedge M and ground so that it does not move while block m slips down on it.



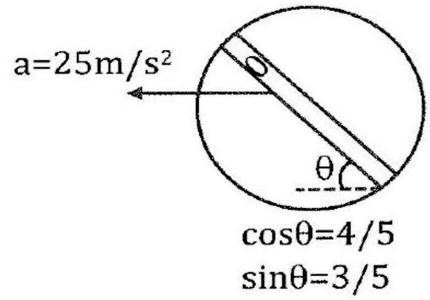
23. You pour a quantity of flour of volume $V = 72\ cm^3$ onto a board, where it forms a conical pile. The coefficient of static friction between flour grains is $\mu_s = \sqrt{\pi}$. Find the maximum height (in cm) of the pile.

24. Block M slides down on frictionless incline as shown. The minimum friction coefficient so that m does not slide with respect to M is $\frac{n}{4}$, find the value of n.

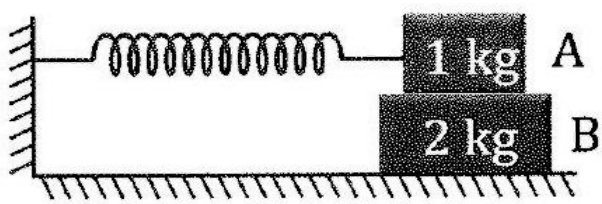


25. A block is moving on an inclined plane making an angle 45° with the horizontal and the coefficient of friction is μ. The force required to just push it up the inclined plane is 3 times the force required to just prevent it from sliding down. If we define $N = 10\mu$, then N is

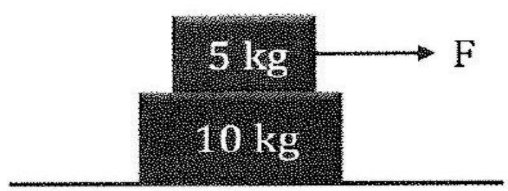
26. A circular disc with a groove along its diameter is placed horizontally. A block of m ass 1 kg is placed as shown. The co-efficient of friction between the block and all surface of groove in contact is $\mu = 2/5$. The disc has an acceleration of 25 m/s^2. Find the acceleration of the block with respect to disc.



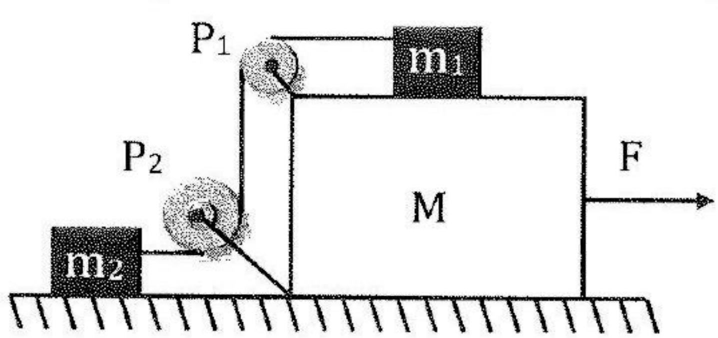
27. In the arrangement shown coefficient of friction between the two blocks A and B is 0.6 and ground is frictionless. Force constant of spring is 900 N/m. Find the maximum elongation of spring (in cm) such that the blocks do not slip over each other when released.



28. Coefficient of friction between 5 kg and 10 kg block is 0.5 . If friction between them is 20 N . What is the value of force being applied on 5 kg . The floor is frictionless.



29. In the figure masses m_1, m_2 and M are 20 kg, 5 kg and 50 kg respectively. The co-efficient of friction between M and ground is zero. The co-efficient of friction between m_1 and M and that between m_2 and ground is 0.3 . The pulleys and the string are massless. The string is perfectly horizontal between P_1 and m_1 and also between P_2 and m_2. The string is perfectly vertical between P_1 and P_2. An external horizontal force F is applied to the mass M. Take $= \ 10\ m/s^2$.



(i) Draw a free-body diagram for mass M, clearly showing all the forces.

(ii) Let the magnitude of the force of friction between m_1 and M be f_1 and that between m_2 and ground be f_2.

For a particular F it is found that $f_1 = 2f_2$. Find f_1 and f_2. Write down equations of motion of all the masses.

Find F, tension in the string and accelerations of the masses.

A thin rod of length 1 m is fixed in a vertical position inside a train, which is moving horizontally with constant acceleration $4\ m/s^2$. A bead can slide on the rod, and friction coefficient between them is 1/2. If the bead is released from rest at the top of the rod, find the time when it will reach at the bottom.

$\left[g = 10\ m/s^2\right]$

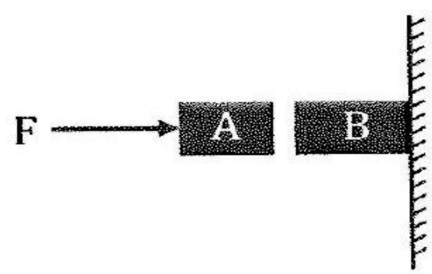
30.

EXERCISE - JEE (Main) PYQ

1. A block of mass m is placed on a surface with a vertical cross section given by $y = \frac{x^3}{6}$. 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]

   (1) $\frac{1}{3}m$ (2) $\frac{1}{2}m$ (3) $\frac{1}{6}m$ (4) $\frac{2}{3}m$

2. Given in the figure are two blocks A and B of weight 20 N and 100 N , 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]

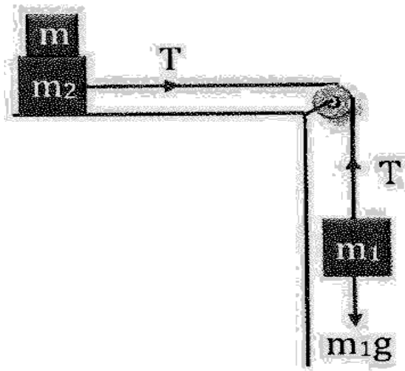


   (1) 120 N (2) 150 N (3) 100 N (4) 80 N

3. A rocket is fired vertically from the earth with an acceleration of $2g$, where g is the gravitational acceleration. On an inclined plane inside the rocket, making an angle θ with the horizontal, a point object of mass m is kept. The minimum coefficient of friction μ_{min} between the mass and the inclined surface such that the mass does not move is: [JEE (Main) 2016]

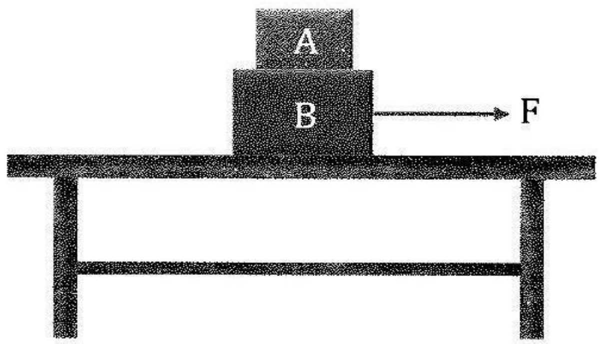
   (1) $2tan\theta$ (2) $3tan\theta$ (3) $tan\theta$ (4) $tan2\theta$

4. 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]



(1) 27.3 kg (2) 43.3 kg (3) 10.3 kg (4) 18.3 kg

5. 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]



(1) 16 N (2) 40 N (3) 12 N (4) 8 N

6. A ball is thrown upward with an initial velocity V_0 from the surface of the earth. The motion of the ball is affected by a drag force equal to $m\gamma v^2$ (where m is mass of the ball, v is its instantaneous velocity and γ is a constant). Time taken by the ball to rise to its zenith is [JEE (Main) 2019]

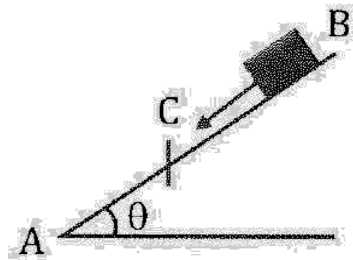
(1) $\frac{1}{\sqrt{\gamma g}} sin^{-1}\left(\sqrt{\frac{\gamma}{g}} V_0\right)$ (2) $\frac{1}{\sqrt{\gamma g}} tan^{-1}\left(\sqrt{\frac{\gamma}{g}} V_0\right)$

(3) $\frac{1}{\sqrt{2\gamma g}} tan^{-1}\left(\sqrt{\frac{2\gamma}{g}} V_0\right)$ (4) $\frac{1}{\sqrt{\gamma g}} ln\left(1 + \sqrt{\frac{\gamma}{g}} V_0\right)$

7. A spring whose unstretched length is l has a force constant k. The spring is cut into two pieces of unstretched lengths l_1 and l_2 where, $l_1 = nl_2$ and n is an integer. The ratio k_1/k_2 of the corresponding force constants, k_1 and k_2 will be : [JEE (Main) 2019]

(1) $\frac{1}{n^2}$ (2) n^2 (3) $\frac{1}{n}$ (4) n

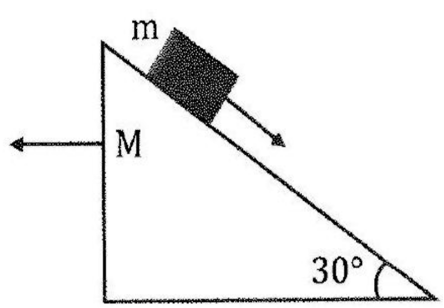
8. A small block starts slipping down from a point B on an inclined plane AB, which is making an angle θ with the horizontal section BC is smooth and the remaining section CA is rough with a coefficient of friction μ. It is found that the block comes to rest as it reaches the bottom (point) of the inclined plane. If $BC = 2AC$, the coefficient of friction is given by $\mu = k tan\theta$). The value of k is . [JEE (Main) 2020]



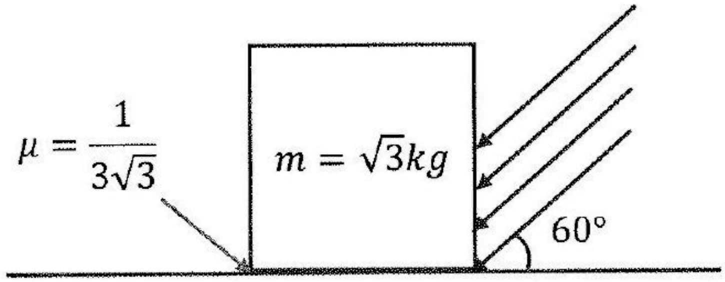
9. An insect is at the bottom of a hemispherical ditch of radius 1 m . It crawls up the ditch but starts slipping after it is at height h from the bottom. If the coefficient of friction between the ground and the insect is 0.75 , then h is: $\left(g = 10\ ms^{-2}\right)$ [JEE (Main) 2020]
(1) 0.80 m (2) 0.60 m (3) 0.45 m (4) 0.20 m
10. A mass of 10 kg is suspended by a rope of length 4 m , from the ceiling. A force F is applied horizontally at the mid-point of the rope such that the top half of the rope makes an angle of 45° with the vertical. Then F equals: (Take $g = 10\ ms^{-2}$ and the rope to be massless) [JEE (Main) 2020]
(1) 100 N (2) 90 N (3) 75 N (4) 70 N
11. A particle of mass M originally at rest is subjected to a force whose direction is constant but magnitude varies with time according to the relation

$$F = F_0\left[1 - \left(\frac{t-T}{T}\right)^2\right]$$

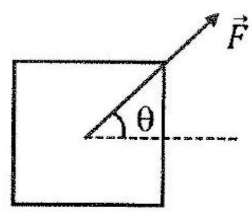
Where F_0 and T are constants. The force acts only for the time interval $2T$. The velocity v of the particle after time $2T$ is : [JEE (Main) 2021]
(1) $2F_0T/M$ (2) $F_0T/2M$ (3) $4F_0T/3M$ (4) $F_0T/3M$
12. A block of mass m slides on the wooden wedge, which in turn slides backward on the horizontal surface. The acceleration of the block with respect to the wedge is: Given $m = 8\ kg, M = 16\ kg$ Assume all the surfaces shown in the figure to be frictionless. [JEE (Main) 2021]



(1) $\frac{4}{3}g$ (2) $\frac{6}{5}g$ (3) $\frac{3}{5}g$ (4) $\frac{2}{3}g$
13. The coefficient of static friction between a wooden block of mass 0.5 kg and a vertical rough wall is 0.2 . The magnitude of horizontal force that should be applied on the block to keep it adhere to the wall will be $N.\left[g = 10\ ms^{-2}\right]$ [JEE (Main) 2021]
14. As shown in the figure, a block of mass $\sqrt{3}\ kg$ is kept on a horizontal rough surface of coefficient of friction $\frac{1}{3\sqrt{3}}$. The critical force to be applied on the vertical surface as shown at an angle 60° with horizontal such that it does not move, will be $3x$. The value of x will be $\left[g = 10\ m/s^2; sin60^{\circ} = \frac{\sqrt{3}}{2}; cos60^{\circ} = \frac{1}{2}\right]$ [JEE (Main) 2021]



15. A block of mass m slides along a floor while a force of magnitude F is applied to it at an angle θ as shown in figure. The coefficient of kinetic friction is μ_k. Then, the block's acceleration ' a ' is given by: (g is acceleration due to gravity) [JEE (Main) 2021]



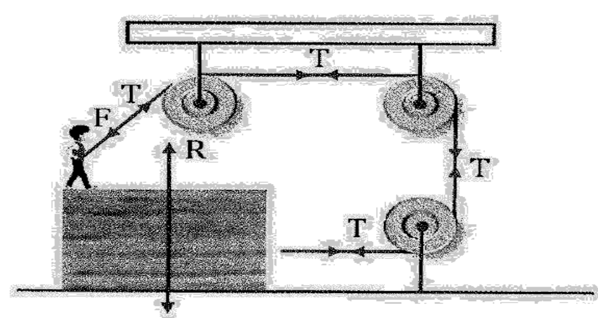
(1) $-\frac{F}{m}cos\theta - \mu_K\left(g - \frac{F}{m}sin\theta\right)$

(2) $\frac{F}{m}cos\theta - \mu_K\left(g - \frac{F}{m}sin\theta\right)$

(3) $\frac{F}{m}cos\theta - \mu_K\left(g + \frac{F}{m}sin\theta\right)$

(4) $\frac{F}{m}cos\theta + \mu_K\left(g - \frac{F}{m}sin\theta\right)$

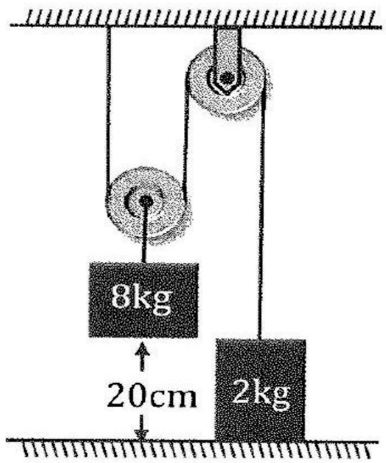
16. A boy of mass 4 kg is standing on a piece of wood having mass 5 kg . If the coefficient of friction between the wood and the floor is 0.5 , the maximum force that the boy can exert on the rope so that the piece of wood does not move from its place is N. (Round off to the Nearest Integer) [Take $g = 10\ ms^{-2}$] [JEE (Main) 2021]



17. When a body slides down from rest along a smooth inclined plane making an angle of 30° with the horizontal, it takes time T. When the same body slides down from the rest along a rough inclined plane making the same angle and through the same distance, it takes time αT, where is α constant greater than 1 . The co-efficient of friction between the body and the rough plane is $\frac{1}{\sqrt{x}}\left(\frac{\alpha^2-1}{\alpha^2}\right)$ where $x =$

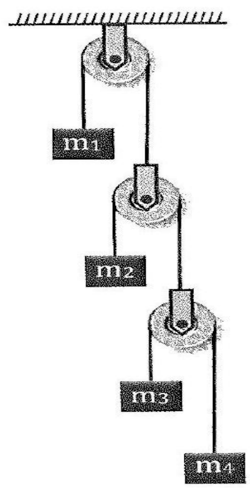
18. The boxes of masses 2 kg and 8 kg are connected by a massless string passing over smooth pulleys. Calculate the time taken by box of mass 8 kg to strike the ground starting from rest. (Use $g = 10\ m/s^2$)

[JEE (Main) 2021]



(1) 0.34 s (2) 0.2 s (3) 0.25 s (4) 0.4 s

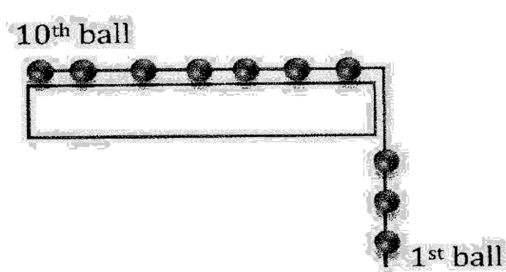
19. In the arrangement shown in figure a_1, a_2, a_3 and a_4 are the accelerations of masses m_1, m_2, m_3 and m_4 respectively. Which of the following relation is true for this arrangement? [JEE (Main) 2022]



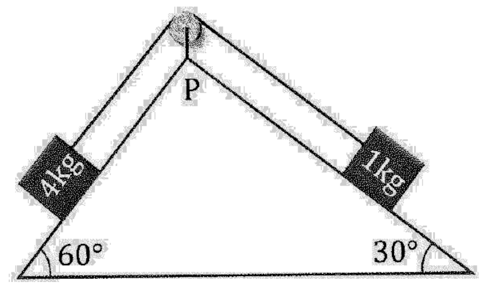
(1) $4a_1 + 2a_2 + a_3 + a_4 = 0$ (2) $a_1 + 4a_2 + 3a_3 + a_4 = 0$

(3) $a_1 + 4a_2 + 3a_3 + 2a_4 = 0$ (4) $2a_1 + 2a_2 + 3a_3 + a_4 = 0$

20. A system to 10 balls each of mass 2 kg are connected via massless and unstretchable string. The system is allowed to slip over the edge of a smooth table as shown in figure. Tension on the string between the 7^{th} and 8^{th} ball is N when 6^{th} ball just leaves the table. [JEE (Main) 2022]

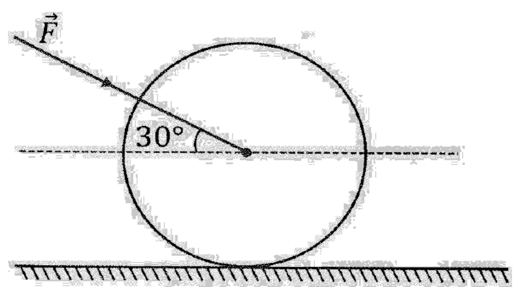


21. As per given figure, a weightless pulley P is attached on a double inclined frictionless surface. The tension in the string (massless) will be (if $g = 10\ m/s^2$) [JEE (Main) 2023]



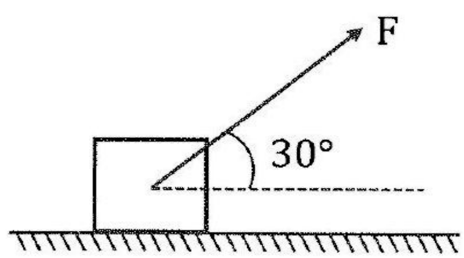
(1) $(4\sqrt{3} + 1)N$ (2) $4(\sqrt{3} + 1)N$ (3) $4(\sqrt{3} - 1)N$ (4) $(4\sqrt{3} - 1)N$

22. As shown in figure, a 70 kg garden roller is pushed with a force of $\vec{F} = 200N at$ an angle of 30° with horizontal. The normal reaction on the roller is (Given $g = 10\ ms^{-2}$) [JEE (Main) 2023]



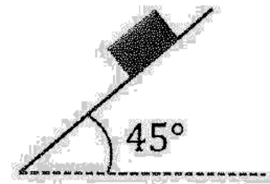
(1) $800\sqrt{2}\ N$ (2) 600 N (3) 800 N (4) $200\sqrt{3}\ N$

23. As shown in the figure a block of mass 10 kg lying on a horizontal surface is pulled by a force F acting at an angle 30°, with horizontal. For $\mu_s = 0.25$, the block will just start to move for the value of F : [Given $g = 10\ ms^{-2}$] [JEE (Main) 2023]



(1) 33.3 N (2) 25.2 N (3) 20 N (4) 35.7 N

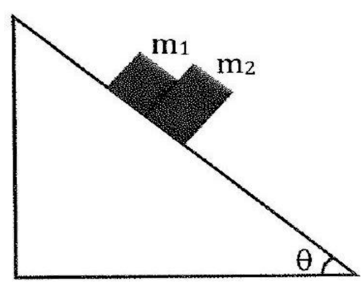
24. Consider a block kept on an inclined plane (inclined at 45°) as shown in the figure. If the force required to just push it up the incline is 2 times the force required to just prevent it from sliding down, the coefficient of friction between the block and inclined plane (μ) is equal to : [JEE (Main) 2023]



(1) 0.33 (2) 0.60 (3) 0.25 (4) 0.50

EXERCISE - JEE (Advanced) PYQ

1. A block of mass $m_1 = 1\ kg$ another mass $m_2 = 2\ kg$, are placed together (see figure) on an inclined plane with angle of inclination θ. Various values of θ are given in List-I. The coefficient of friction between the block m_1 and the plane is always zero. The coefficient of static and dynamic friction between the block m_2 and the plane are equal to $\mu = 0.3$. In List-II expressions for the friction on block m_2 are given. Match the correct expression of the friction in List-II with the angles given in List-I and choose the correct option. The acceleration due to gravity is denoted by g.
[Useful information : $tan(5.5^\circ) \approx 0.1$; $tan(11.5^\circ) \approx 0.2$; $tan(16.5^\circ) \approx 0.3$] [JEE (Advanced) 2014]



List-I	**List-II**
(P) $\theta = 5^\circ$	(1) $m_2 g sin\theta$
(Q) $\theta = 10^\circ$	(2) $(m_1 + m_2) g sin\theta$
(R) $\theta = 15^\circ$	(3) $\mu m_2 g cos\theta$
(S) $\theta = 20^\circ$	(4) $\mu (m_1 + m_2) g cos\theta$

Code:

(A) P-1, Q-1, R-1, S-3
(B) P-2. Q-2, R-2, S-3
(C) P-2, Q-2, R-2, S-4
(D) P-2, Q-2, R-3, S-3

2. A particle of mass m is moving in the xy-plane such that its velocity at a point (x, y) is given as $\vec{v} = \alpha(y\hat{x} + 2x\hat{y})$, where α is a non-zero constant. What is the force $\vec{F}$ acting on the particle? [JEE

(Advanced) 2023]

(A) $\vec{F} = 2m\alpha^2(x\hat{x} + y\hat{y})$

(B) $\vec{F} = m\alpha^2(y\hat{x} + 2x\hat{y})$

(C) $\vec{F} = 2m\alpha^2(y\hat{x} + x\hat{y})$

(D) $\vec{F} = m\alpha^2(x\hat{x} + 2y\hat{y})$

JEE (Main) Practice Paper

(This paper is for yourself practice and assessment the discussion of this paper is optional though you can) see PDF solutions or video solutions or solutions in hardcopy whichever is provided.

SECTION-A

- This section contains TWENTY questions.
- Each question has FOUR options (1), (2), (3) and (4). ONLY ONE of these four options is correct.
- For each question, darken the bubble corresponding to the correct option in the ORS.
- For each question, marks will be awarded in one of the following categories:
  Full Marks : + 4, if only the bubble corresponding to the correct option is darkened.
  Zero Marks : 0, if none of the bubbles is darkened.
  Negative Marks : -1 in all other cases.

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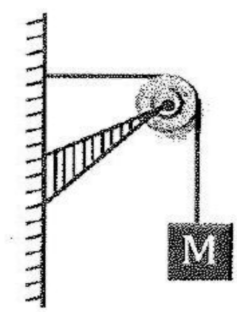
1. A string of negligible mass going over a clamped pulley of mass m supports a block of mass M as shown in the figure. The force on the pulley by the clamp is given



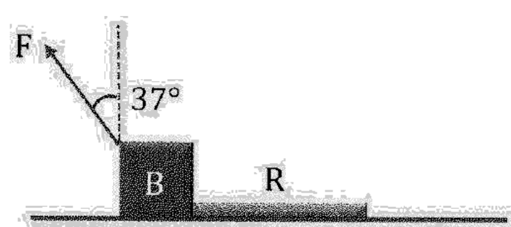
(1) $\sqrt{2}Mg$

(2) $\sqrt{2}mg$

(3) $\sqrt{(M + m)^2 + m^2}g$

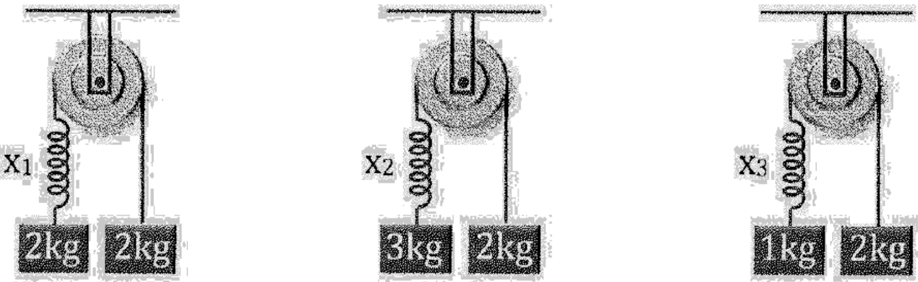
(4) $\sqrt{(M + m)^2 + M^2}g$

2. A block B is tied to one end of a uniform rope R as shown. The mass of block is 2 kg and that of rope is 1 kg . A force $F = 15\ N$ is applied at angle 37° with vertical. The tension at the mid-point of rope is



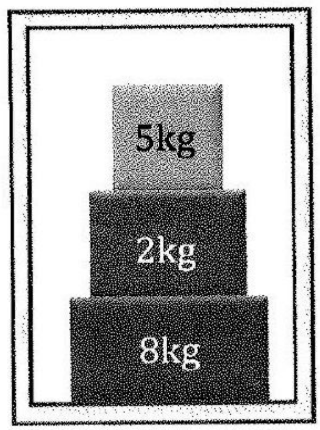
(1) 1.5 N (2) 2 N (3) 3 N (4) 4.5 N

3. Same spring is attached with 2 kg, 3 kg and 1 kg blocks in three different cases as shown. If x_1, x_2 and x_3 be the extensions in the spring in these three cases, when acceleration of both the blocks have same magnitude, then



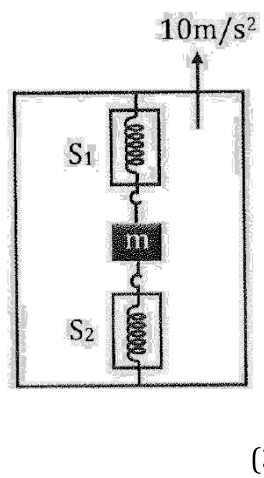
(1) $x_2 > x_3 > x_1$ (2) $x_2 > x_1 > x_3$ (3) $x_3 > x_1 > x_2$ (4) $x_1 > x_2 > x_3$

4. Three boxes are placed in a lift. When acceleration of the lift is 4 m/s^2, the net force on the 8 kg box is closest to



(1) 80 N (2) 48 N (3) 40 N (4) 32 N

5. Reading shown in two spring balances S_1 and S_2 is 90 kg and 30 kg respectively when lift is accelerating upwards with acceleration 10 m/s^2. The mass is stationary with respect to lift. Then the mass of the block will be :

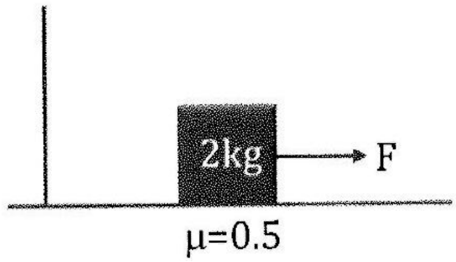


(1) 60 kg (2) 30 kg (3) 120 kg (4) None of these

6. On one rainy day, a sports car starts moving with a constant acceleration of 7. 5 m/s^2. If a toy monkey is suspended from the ceiling of the car by a string, then at what angle the string is inclined with the vertical?

(1) 37° (2) 53° (3) 45° (4) Can't be determined

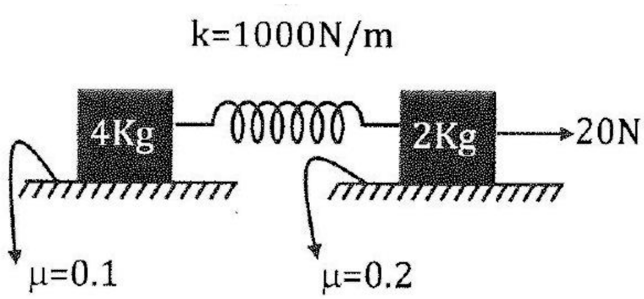
7. A block is placed on a rough horizontal surface. The coefficient of friction between block and surface is 0.5 . A time dependent force $F = - t^2 + 6t$ is acting on the block for time $t = 0$ to $t = 6sec$ as shown in figure. Then which statement is incorrect?



(1) At time $t = 3sec$ the friction force is maximum.
(2) Block will not move in time 0 to 6 sec .
(3) Maximum friction acting on block is 10 N .
(4) Maximum friction acting on block is 9 N .

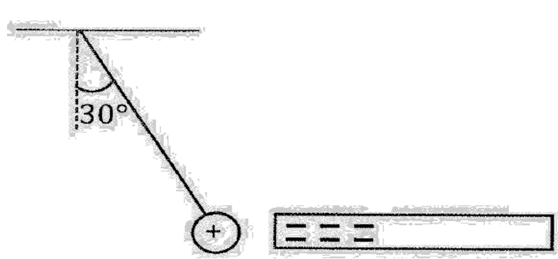
8. A lift is going upward when suddenly cable supporting the lift breaks. From a reference frame attached to the lift, pseudo force acting on an object will have direction (After the cable broke) :-
(1) Vertically downward when lift goes upward and vertically upward when lift goes downward.
(2) Always vertically upward
(3) Always vertically downward
(4) Vertically upward when lift goes upward and vertically downward when lift goes downward.

9. In the figure as shown if 2 kg block is moving at an acceleration of 2 m/s^2 towards right, find the elongation in spring and acceleration of 4 kg block at this instant. Take $= 10\ m/s^2$.

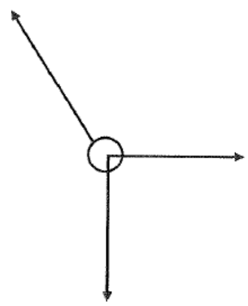


(1) $0.012\ m, 2\ m/s^2$
(2) $0.42\ m, 1\ m/s^2$
(3) $0.012\ m, 1\ m/s^2$
(4) $0.02\ m, 2\ m/s^2$

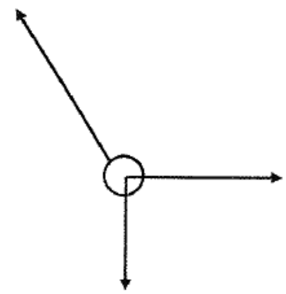
10. A small electrically charged sphere is suspended vertically from a thread. An oppositely charged rod is brought close to the sphere such that the sphere is in equilibrium displaced from the vertical by an angle of 30°. Which one of the following best represents the free body diagram for the sphere?



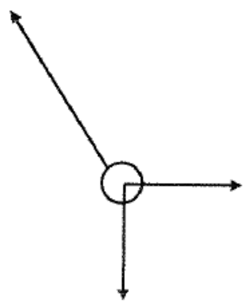
(1)



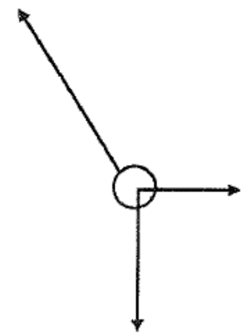
(2)



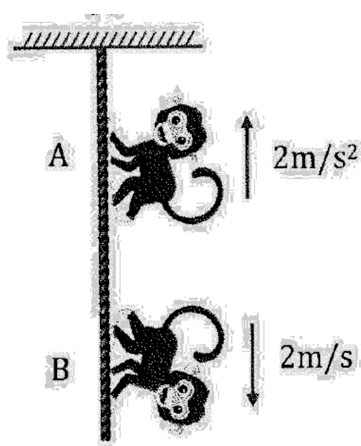
(3)



(4)

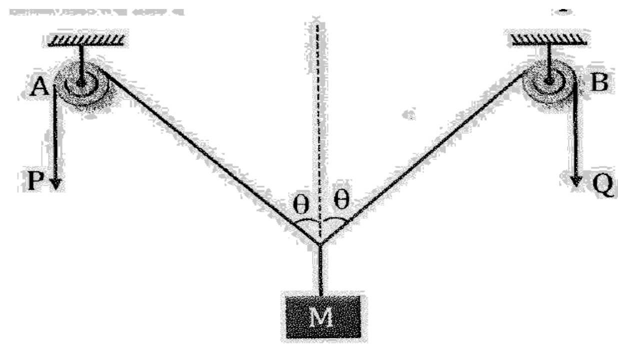


11. Two monkeys of masses 10 kg and 8 kg are moving along a vertical light rope, the former climbing up with an acceleration of 2 m/s^2, while the latter coming down with a uniform velocity of 2 m/s. Find tension in the rope at the fixed support.



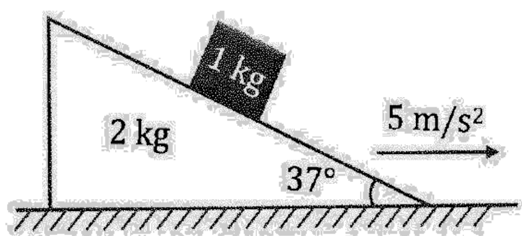
(1) 180 N (2) 200 N (3) 80 N (4) 216 N

12. In the arrangement shown in fig. the ends P and Q of an unstretchable string move downwards with uniform speed U. Pulleys A and B are fixed. Mass M moves upwards with a speed.



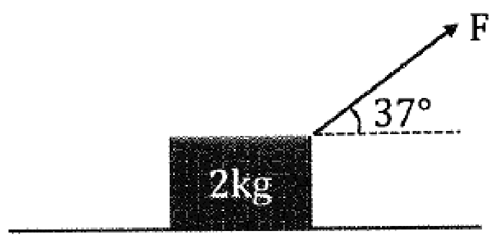
(1) $2U\cos\theta$ (2) $U\cos\theta$ (3) $2U/\cos\theta$ (4) $U/\cos\theta$

13. As shown in figure a wedge of mass 2 kg is resting on frictionless floor. A block of mass 1 kg is kept on the wedge and the wedge is given an acceleration of 5 m/sec^2 towards right. Then :



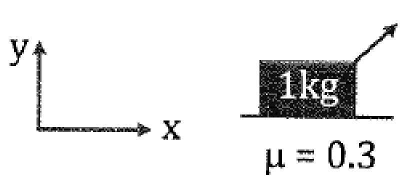
(1) Block will remain stationary w.r.t wedge.
(2) The block will have an acceleration of 2 m/sec^2 w.r.t the wedge.
(3) Normal reaction on the block is 8 N .
(4) Net force acting on the wedge is $4N$.

14. A block of mass 2 kg is kept on a rough horizontal floor and pulled with a force F. If the coefficient of friction is 0.5 . then the minimum force required to move the block is :-



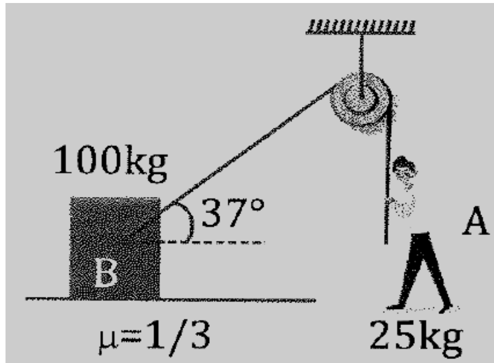
(1) 10 N (2) $\frac{100}{11}N$ (3) $\frac{100}{8}N$ (4) 20 N

15. A force $\vec{F} = \hat{\ } + 4\hat{j}$ acts on block as shown. The force of friction acting on the block is :



(1) $-1\hat{\ }$ (2) $-1.8\hat{\ }$ (3) $-2\hat{\ }$ (4) $-2.5\hat{\ }$

16. Block B of mass 100 kg rests on a rough surface of friction coefficient $\mu = 1/3$. A rope is tied to block B as shown in figure. The maximum acceleration with which boy A of mass 25 kg can climbs on rope without making block move is :



(1) $\frac{4g}{3}$ (2) $\frac{g}{3}$ (3) $\frac{g}{2}$ (4) $\frac{3g}{4}$

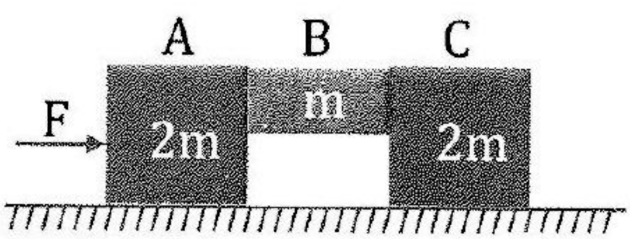
17. The rear side of a truck is open and a box of mass 20 kg is placed on the truck 4 m away from the open end, $m = 0.15\ kg$ and $g = 10\ m/s^2$. The truck starts from rest with an acceleration of 2 m/s^2 on a straight road. The distance moved by the truck when box falls down from the truck is :-

(1) 4 m (2) 8 m (3) 16 m (4) 32 m

18. A block is pushed with some velocity up a rough inclined plane. It stops after ascending few meters and then reverses its direction and returns back to point from where it started. If angle of inclination is 37° and the time to climb up is half of the time to return back then coefficient of friction is

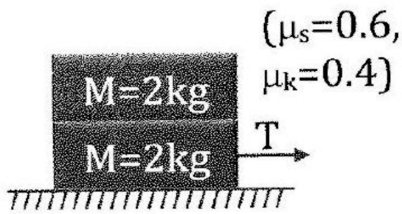
(1) $\frac{9}{20}$ (2) $\frac{7}{5}$ (3) $\frac{7}{12}$ (4) $\frac{5}{7}$

19. The system is pushed by a force F as shown in figure. All surfaces are smooth except between B and C. Friction coefficient between B and C is μ. Minimum value of F to prevent block B from downward slipping is :-



(1) $\left(\frac{3}{2\mu}\right)mg$ (2) $\left(\frac{5}{2\mu}\right)mg$ (3) $\left(\frac{5}{2}\right)\mu mg$ (4) $\left(\frac{3}{2}\right)\mu mg$

20. The coefficient of static and kinetic friction between the two blocks and also between the lower block and the ground are $\mu_S = 0.6$ and $\mu_K = 0.4$. Find the value of tension T applied on the lower block at which the upper block begins to slip relative to lower block.

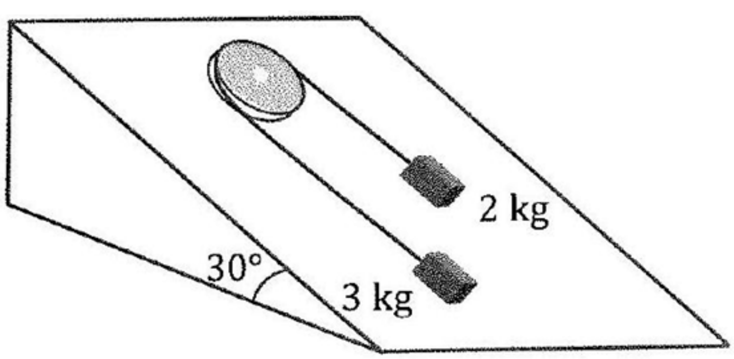


(1) 25 N (2) 30 N (3) 40 N (4) 45 N

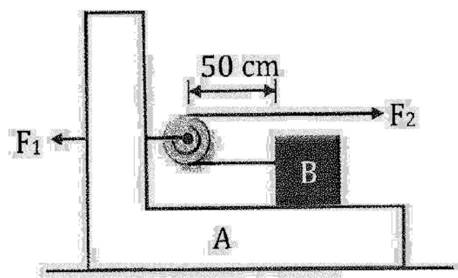
SECTION-B

- This section will have TEN questions. Candidate can choose to attempt any 5 questions out of these 10 questions. In case if candidate attempts more than 5 questions, first 5 attempted questions will be considered for marking.
- The answer to each question is a NUMERICAL VALUE.
- For each question, enter the correct numerical value (Answer should be rounded off to the nearest integer).
- Answer to each question will be evaluated according to the following marking scheme:
  Full Marks : +4, if only correct answer is given.
  Zero Marks : 0 , if no answer is given.
  Negative Marks : -1 for incorrect answer.

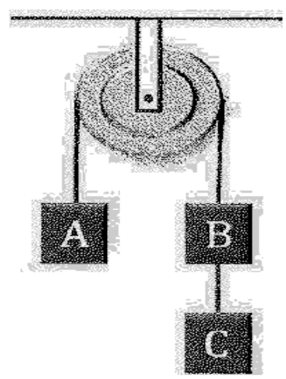
1. Two blocks of masses 2.0 kg and 3.0 kg are connected by light inextensible string. The string passes over an ideal pulley pivoted to a fixed axle on a smooth incline plane as shown in the figure. When the blocks are released, find magnitude of their accelerations $\left(m/s^2\right)$.



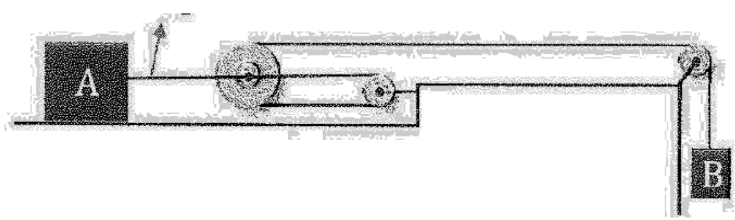
2. A 1 kg block B rests as shown on a bracket A of same mass. Constant forces $F_1 = 20\ N$ and $F_2 = 8\ N$ start to act at time $t = 0$ when the distance of block B from pulley is 50 cm . Time (s) when block B reaches the pulley is $\frac{1}{n}$, find the value of n.



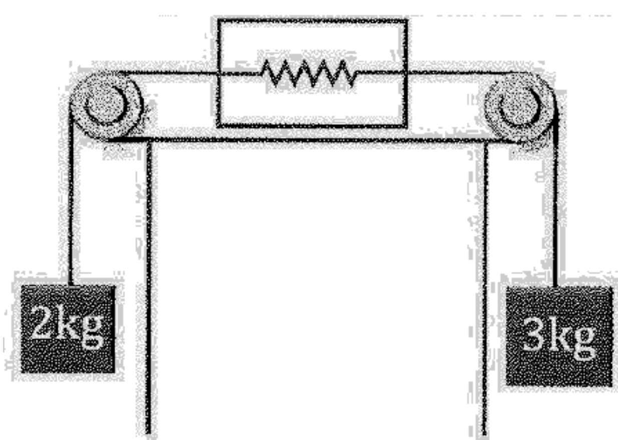
3. In the system shown, the blocks A, B and C are of weight $4W$, W and W respectively. The system set free. The tension in the string connecting the blocks B and C is ($W = 30N$)



4. A train has 10 wagons each of mass 1000 kg attached to it. They are being pulled by force 10^4 N. The force exerted on last four wagons is $\times\ 10^3$ N. Value of N is –
5. If block A has a velocity of $0.6\ m/s$ to the right, the velocity (m/s) of block B is $\frac{n}{5}$, find the value of n. Light Rod



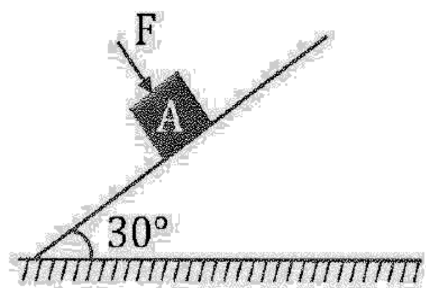
6. Find the reading (N) of the massless spring balance in the given condition



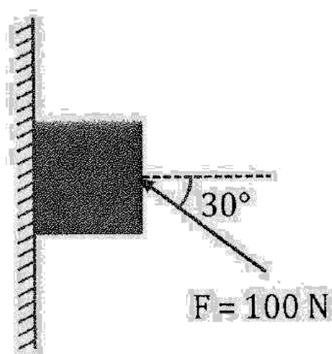
7. A thin rod of length 1 m is fixed in a vertical position inside a train, which is moving horizontally with constant acceleration $4\ m/s^2$. A bead can slide on the rod, and friction coefficient between them is 1/2. If the bead is

released from rest at the top of the rod, then the time (in second) when it will reach at the bottom is $\frac{n}{2}$, find the value of $n \cdot \left[g = 10\ m/s^2\right]$

8. A block of mass $m = 2\ kg$ is resting on a rough inclined plane of inclination 30° as shown in figure. The coefficient of friction between the block and the plane is $\mu = 0.5$. The minimum force F which should be applied perpendicular to the inclined plane on the block, so that block does not slip on the plane is $\frac{n}{25}$, find the value of $n \cdot \left(g = 10\ m/s^2\right)$



9. A force of 100 N is applied on a block of mass 3 kg as shown in figure. The coefficient of friction between the wall and the surface of the block is 1/4. Calculate frictional force (in) acting on the block.



10. A block of mass 1 kg is horizontally thrown with a velocity of 10 m/s on a stationary long plank of mass 2 kg whose surface has $\mu = 0.5$. Plank rests on frictionless surface. The time (in second) when block comes to rest w.r.t. plank is $\frac{n}{3}$, find the value of n.

JEE (Advanced) Practice Paper

This paper is for yourself practice and assessment the discussion of this paper is optional though you can }{ see PDF solutions or video solutions or solutions in hardcopy whichever is provided. }

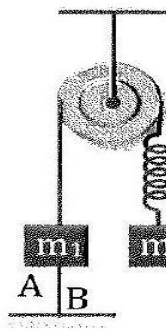
SECTION-I

- This section contains FIVE questions.
- Each question has FOUR options (A), (B), (C) and (D). ONLY ONE of these four options is correct.
- For each question, darken the bubble corresponding to the correct option in the ORS.
- For each question, marks will be awarded in one of the following categories:
  Full Marks : + 3 if only the bubble corresponding to the correct option is darkened.
  Zero Marks : 0 if none of the bubbles is darkened.
  Negative Marks : -1 in all other cases.

1. The upper half of an inclined plane with inclination ϕ is perfectly smooth, while the lower half is rough. A body starting from rest at the top will again come to rest at the bottom, if the coefficient of friction for the lower half is given by -

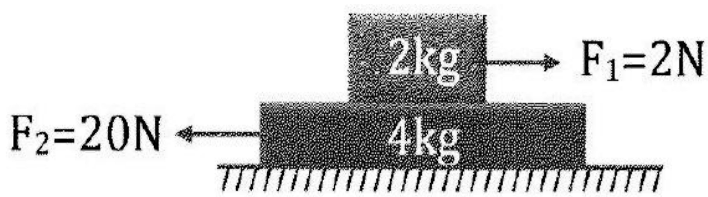
(A) $2sin\phi$ (B) $2cos\phi$ (C) $2tan\phi$ (D) $tan\phi$

2. In a given figure two masses m_1 and $m_2 (m_2 > m_1)$ are at rest in equilibrium position. Find the tension in string AB



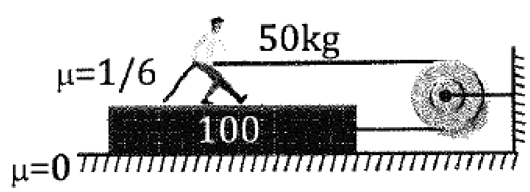
(A) $m_1 g$ (B) $m_2 g$ (C) $(m_1 + m_2)g$ (D) $(m_2 - m_1)g$

3. In the arrangement shown in figure, coefficient of friction between the two blocks is $\mu = 1/2$. The force of friction acting between the two blocks is :-



(A) 8 N (B) 10 N (C) 6 N (D) $4N$

4. A man of mass 50 kg is pulling on a plank of mass 100 kg kept on a smooth floor as shown with force of 100 N . If both man and plank move together, find force of friction acting on man.

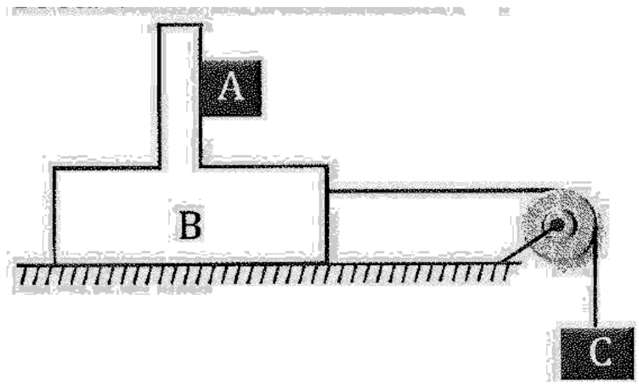


(A) $\frac{100}{3} N$ towards left (B) $\frac{100}{3} N$ towards right

(C) $\frac{250}{3} N$ towards left (D) $\frac{250}{3} N$ towards right

5. In the arrangement shown in the figure, mass of the block B and A is $2m$ and m respectively. Surface between B and floor is smooth. The block B is connected to the block C by means of a string-pulley system. If the whole system is released, then find the minimum value of mass of block C so that A remains stationary w.r.t. B.

Coefficient of friction between A and B is μ.



(A) $\frac{m}{\mu}$ (B) $\frac{2m+1}{\mu+1}$ (C) $\frac{3m}{\mu-1}$ (D) $\frac{6m}{\mu+1}$

SECTION-II

- This section contains EIGHT questions.
- Each question has FOUR options for correct answer(s). ONE OR MORE THAN ONE of these four option(s) is (are) correct option(s).
- For each question, choose the correct option(s) to answer the question.
- Answer to each question will be evaluated according to the following marking scheme:

Full Marks : + 4 if only (all) the correct option(s) is (are) chosen.
Partial Marks : +3 if all the four options are correct but ONLY three options are chosen.
Partial Marks : + 2 if three or more options are correct but ONLY two options are chosen, both of which are correct options.
Partial Marks : +1 if two or more options are correct but ONLY one option is chosen and it is a correct option.
Zero Marks : 0 if none of the options is chosen (i.e. the question is unanswered).
Negative Marks : -2 in all other cases.
For Example : If first, third and fourth are the ONLY three correct options for a question with second option being an incorrect option; selecting only all the three correct options will result in +4 marks. Selecting only two of the three correct options (e.g. the first and fourth options), without selecting any incorrect option (second option in this case), will result in +2 marks. Selecting only one of the three correct options (either first or third or fourth option), without selecting any incorrect option (second option in this case), will result in +1 marks. Selecting any incorrect option(s) (second option in this case), with or without selection of any correct option(s) will result in -2 marks.

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6. Refer the system shown in the figure. Block is sliding down the wedge. All surfaces are frictionless. Find correct statement(s)

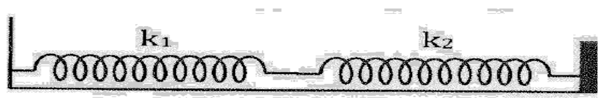
(A) Acceleration of block is $gsin\theta$

(B) Acceleration of block is $gcos\theta$

(C) Tension in the string is $mgcos2\theta$

(D) Tension in the string is $mgsin\theta \cdot cos\theta$

7. The mass in the figure can slide on a frictionless surface. When the mass is pulled out, spring 1 is stretched a distance x_1 and spring 2 is stretched a distance x_2. The spring constants are k_1 and k_2 respectively. Total magnitude of spring force pulling back on the mass is



(A) k_1X_1

(B) k_2X_2

(C) $\left(k_1X_1 + k_2X_2\right)$

(D) $0.5\left(k_1 + k_2\right)\left(x_1 + x_2\right)$

8. In the given figure both the blocks have equal mass. When the thread is cut, which of the following statements give correct description immediately after the thread is cut?

(A) Relative to the block A, acceleration of block B is $2g$ upwards.

(B) Relative to the block B, acceleration of block A is $2g$ downwards.

(C) Relative to the ground, accelerations of the blocks A and B are both g downwards.

(D) Relative to the ground, accelerations of the blocks A and B are $2g$ downwards and zero respectively.

9. A block is kept on a rough horizontal surface as shown. Its mass is 2 kg and coefficient of friction between block and surface $(\mu) = 0.5$. A horizontal force F is acting on the block. When

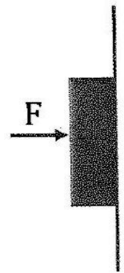
(A) $F = 4N$, acceleration is zero.

(B) $= 4\ N$, friction is 10 N and acceleration is $3\ m/s^2$.

(C) $= 14\ N$, acceleration is $2\ m/s^2$.

(D) $= 14\ N$, friction is 14 N .

10. A block of mass 1 kg is held at rest against a rough vertical surface by pushing by a force F horizontally. The coefficient of friction is 0.5 . When

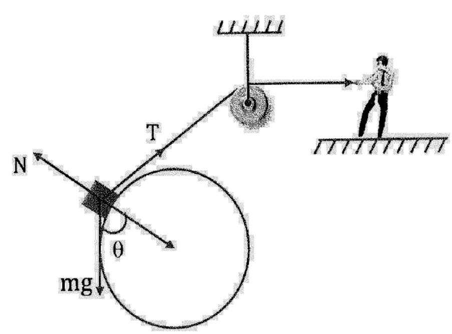


(A) $=$ 40 N, friction on the block is 20 N .
(B) $=$ 30 N, friction on the block is 10 N .
(C) $=$ 20 N, friction on the block is 10 N .
(D) Minimum value of force F to keep block at rest is 20 N .

11. A block is released from rest from a point on a rough fixed inclined plane of inclination 37°. The coefficient of friction is 0.5 .
(A) The time taken to slide down 9 m on the plane is 3 s .
(B) The velocity of block after moving 4 m is 4 m/s.
(C) The block travels equal distances in equal intervals of time.
(D) The velocity of block increases linearly.

12. A block is placed over a plank. The coefficient of friction between the block and the plank is $\mu = 0.2$. Initially both are at rest, suddenly the plank starts moving with acceleration $a_0 = 4\ m/s^2$. The displacement of the block in $1s$ is $\left(g = 10\ m/s^2\right)$
(A) displacement of plank is 2 m
(B) displacement of block is 1 m
(C) displacement of plank is 4 m
(D) displacement of block is 2 m

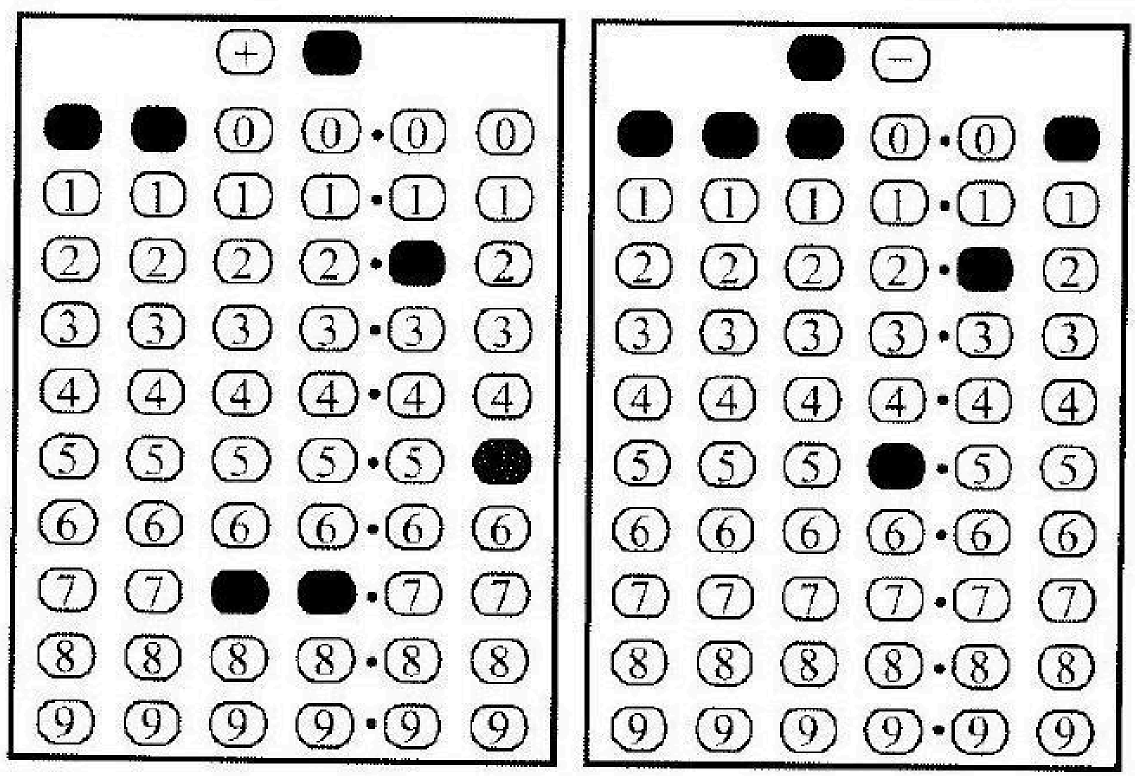
13. Block on the sphere shown in figure is in equilibrium (it implies that net force is zero). If sphere applies a force (N) of $3N$ on the block in the direction perpendicular to the surface of the sphere and weight of the block (mg) is 5 N vertically downward. The force applied by the string on the block (T) and angle θ if it acts tangentially is -



(A) 4
(B) 5
(C) 37°
(D) 53°

SECTION-III

- This section contains **FIVE** questions.
- The answer to each question is a NUMERICAL VALUE.
- For each question, enter the correct numerical value (in decimal notation, truncated/rounded-off to the second decimal place; e.g. 6. 25, 7. 00, − 0. 33, −. 30, 30. 27, − 127. 30, if answer is 11. 36777.... then both 11.36 and 11.37 will be correct) by darken the corresponding bubbles in the ORS.
  For Example : If answer is − 77. 25, 5. 2 then fill the bubbles as follows:



- Answer to each question will be evaluated according to the following marking scheme:
  Full Marks : +3 if ONLY the correct numerical value is entered as answer.
  Zero Marks : 0 in all other cases.

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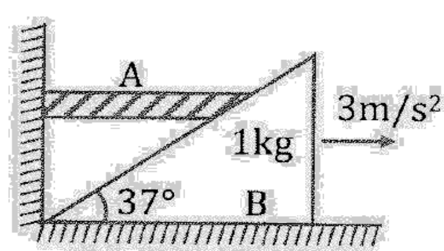
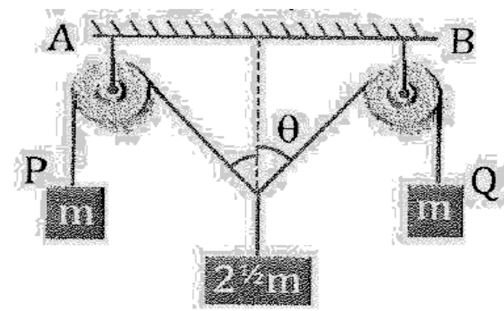
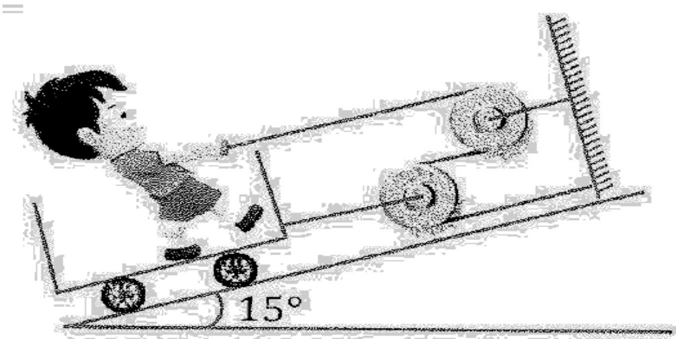
14. Find force in newton which mass A exerts on mass B if B is moving towards right with 3 m/s^2. (All surfaces are smooth)



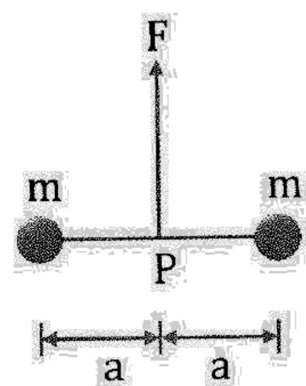
15. The pulleys and strings shown in the figure are smooth and of negligible mass. For the system to remain in equilibrium, the angle θ (in degrees) should be



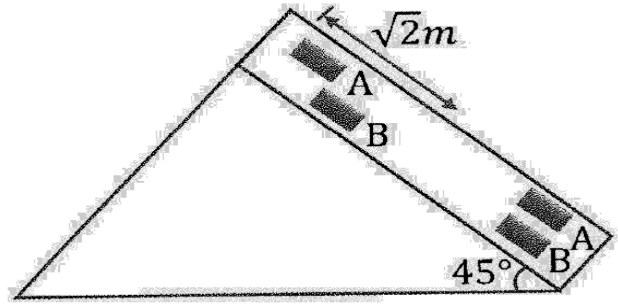
16. A trolley is being pulled up an incline plane by a man sitting on it (as shown in figure). He applies a force of 250 N . If the combined mass of the man and trolley is 100 kg , the acceleration $\left(m/s^2\right)$ of the trolley will be $\left[sin15^{\circ} = 0.26\right]$



17. Two particles of mass m each are tied at the ends of a light string of length $2a$. The whole system is kept on a frictionless horizontal surface with the string held tight so that each mass is at a distance a from the center P (as shown in the figure). Now, the mid-point of the string is pulled vertically upwards with a small but constant force F. As a result, the particles move towards each other on the surface. The magnitude of acceleration, when the separation between them is $\frac{F}{Pm}\frac{Qx}{\sqrt{a^2-x^2}}$, $P + Q$ is equal to -



18. Two blocks A and B equal masses are placed on rough inclined plane as shown in figure. When will the two blocks come on the same line on the inclined plane if they are released simultaneously. Initially the block A is $\sqrt{2}m$ behind the block B. Coefficient of kinetic friction for the blocks A and B are 0.2 and 0.3 respectively $\left(g = 10\, m/s^2\right)$



ANSWER KEY

EXERCISE - 0

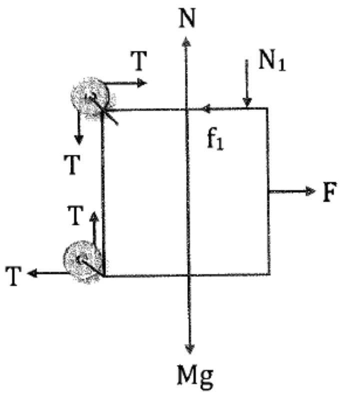
Que.	1	2	3	4	5	6	7	8	9	10
Ans.	B	C	B	D	A	C	B	C	C	B
Que.	11	12	13	14	15	16	17	18	19	20
Ans.	C	C	B	C	C	D	B	C	C	B
Que.	21	22	23	24	25	26	27	28	29	30
Ans.	C	B	B	D	B	C	C	A	C	A
Que.	31	32	33	34	35	36	37	38	39	40
Ans.	A	A	B	B	B	C	A	A	CD	ABCD
Que.	41	42	43	44	45	46	47	48	49	50
Ans.	BD	AB	ABCD	AB	ABCD	ABD	AD	ACD	ABCD	ABC
Que.	51	52	53	54	55	56	57	58	59	60
Ans.	ACD	D	D	A	D	B	A	B	B	C
Que.	61	62	63	64	65	66	67	68	69	70
Ans.	B	A	B	C	A	A	A	C	A	B
Que.	71	72			73			74		
Ans.	C	(A-R), (B-Q), (C-S), (D-P)			(A-T), (B-R), (C-R), (D-Q)			(A-S), (B-R), (C-Q)		

Que.	75							
Ans.	(A-R), (B-T), (C-Q), (D-T)							

EXERCISE - S

1.
2. 1440 N
3. $0.5g, g$
4. $556.8N, 1.47s$
5. $200\ N, 10\ /s^2$
6. 2 sec
7. $80\ N, 48\ N, 264\ N$
8. $\frac{(M+m)gsin\theta}{M+msin^2\theta}$
9. $-\ 5\hat{i}\ m/s^2$
10. $v_0/cos\theta$
11. $\frac{a_0}{2}$
12. 4
13. 10
14. 2
15. $V_{P_1} = 5\ m/s$ downward, $V_C = 25\ m/s$ upward
16. $a_A = \frac{9g}{25}, a_B = \frac{12g}{25}$
17. u tan θ
18. $a = \frac{mgsin\theta}{M+2m(1-cos\theta)}$
19. 5 m/s^2 downwards, 0 m/s^2, 10 N
20. 1.4s
21. 1 kg
22. $\mu_{min} = \frac{msi\theta\ coscos\ \theta}{\theta\ +M}$
23. 6
24. 3
25. 5
26. 10 m/s^2
27. 1
28. 30 N
29.

(i)



(ii) $a = 3/5\ m/s^2$, T = 18 N , F = 60 N

30. 1/2

EXERCISE - JEE (Main) PYQ

Que.	1	2	3	4	5	6	7	8	9	10
Ans.	3	1	3	1	1	2	3	3	4	1
Que.	11	12	13	14	15	16	17	18	19	20
Ans.	3	4	25	3	2	30	3	4	1	36
Que.	21	22	23	24						
Ans.	2	3	2	1						

EXERCISE - JEE (Advanced) PYQ

Que.	1	2
Ans.	D	A

JEE (Main) Practice Paper

	Q.	1	2	3	4	5	6	7	8	9	10
Section -A	A.	4	1	2	4	2	1	3	2	1	4
	Q.	11	12	13	14	15	16	17	18	19	20

	A.	2	4	2	2	1	2	3	1	2	3
Section-B	Q.	1	2	3	4	5	6	7	8	9	10
	A.	1	2	40	4	9	24	1	67	20	4

JEE (Advanced) Practice Paper

Section-I	Q.	1	2	3	4	5			
	A.	C	D	A	A	C			
Section-II	Q.	6	7	8	9	10	11	12	13
	A.	AD	AB	ABD	AC	BCD	ABD	AB	AD
Section-III	Q.	14	15	16	17	18			
	A.	5	45	4.9	3	2			