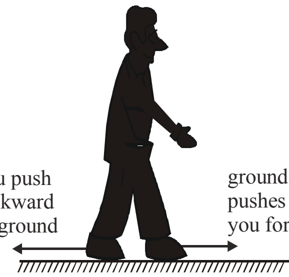
FRICTION

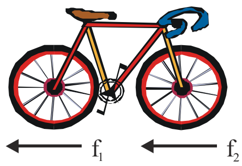
INTRODUCTION

Friction is the force of two surfaces in contact, or the force of a medium acting on a moving object. (i.e. air on aircraft.). Frictional forces may also exist between surfaces when there is no relative motion. Frictional forces arise due to molecular interactions. In some cases friction acts as a supporting force and in some cases it acts as opposing force.



- **Supporting :** Walking process can only take place because there is friction between the shoes and ground.
- **Opposing :** When a block slides over a surface the force of friction acts as an opposing force in the opposite direction of the motion
- **Both Supporting and Opposing :**
- **Pedaling :** When cyclist pedals the friction force on rear wheel acts as a supporting force and on front wheel as a opposing force.

Force of friction when pedaling



Force of friction when not pedaling

- **Non–Pedaling :** When cyclist not pedals the friction force on rear wheel & front wheel act as a opposing force.

CAUSE OF FRICTION

- **Old View :** When two bodies are in contact with each other, the irregularities in the surface of one body set interlocked in the irregularites of another surface. This locking opposes the tendency of motion.
- **Modern View :** Friction is arises on account of strong atomic or molecular forces of attraction between the two surfaces at the point of actual contact.

TYPES OF FRICTION

Friction

- Static friction (No relative motion between objects)
- Dynamic friction (Kinetic friction) (There is relative motion between objects)

STATIC FRICTION

- It is the frictional force which is effective before motion starts between two planes in contact with each other.
- It's nature is self adjusting.
- Numerical value of static friction is equal to external force which creates the tendency of motion of body.
- Maximum value of static friction is called limiting friction. $0 \le f_s \le \mu_s N$, $\vec{f}_s = -\vec{F}_{applied}$

LAWS OF LIMITING FRICTION

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

DYNAMIC FRICTION

The friction opposing the relative motion between two bodies is called dynamic or kinetic friction

$$\vec{f}_k = -(\mu_k N)$$

- This is always slightly less than the limitng friction

COEFFICIENT OF FRICTION

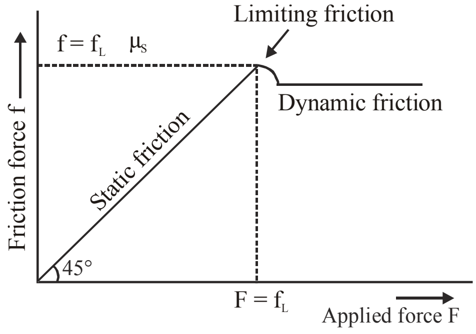
The frictional coefficient is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together.

- Static friction coefficient $\mu_s = \frac{F}{N}$
- Sliding friction coefficient $\mu_k = \frac{F_k}{N}$

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

GRAPH BETWEEN APPLIED FORCE AND FORCE OF FRICTION

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



- When two highly polished surfaces are pressed hard, then a situation similar to welding occurs. It is called **cold welding.**
- When two copper plates are highly polished and placed in contact with each other, then instead of decreasing, the force of friction increases. This arises due to the fact that for two highly polished surfaces in contact, the number of molecules coming in contact increases and as a result the cohesive/adhesive forces increases. This in turn, increases the force of friction.

  Net contact force is the resultant of normal reaction and frictional force.

APPROXIMATE COEFFICIENTS OF FRICTION

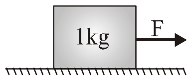
Materials	**Coefficient of static friction, μ_s**	**Coefficien of kinetic friction, μ_k**
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Copper on cast iron	1.05	0.29
Brass on steel	0.51	0.44
Teflon on teflon	0.04	0.04
Rubber on concrete (dry)	1.0	0.8
Rubber on concrete (wet)	0.30	0.25

Ex. A block of mass 1 kg is at rest on a rough horizontal surface having coefficient of static friction 0.2 and kinetic friction 0.15, find the frictional forces if a horizontal force,

(a) F = 1N

(b) F = 1.96 N

(c) F = 2.5 N , is applied on a block



Sol. Maximum force of friction $f_{max} = 0.2 \times 1 \times 9.8\text{ N} = 1.96\text{ N}$

(a) for $F_{ext} = 1\text{ N}$, $F_{ext} < f_{max}$

So, body is in rest means static friction is present and hence $f_s = F_{ext} = 1\text{ N}$

(b) for $F_{ext} = 1.96\text{ N}$, $F_{ext} = f_{max} = 1.96\text{ N}$ so $f = 1.96\text{ N}$

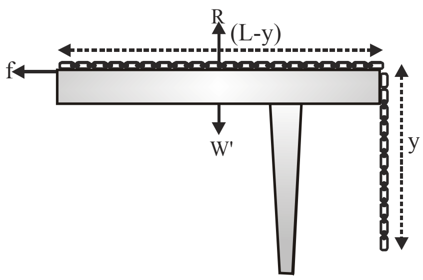
(c) for $F_{ext} = 2.5\text{ N}$, so $F_{ext} > f_{max.}$

now body is in moving condition

$\therefore\ f_{max.} = f_k = \mu_k N = \mu_k\, mg = 0.15 \times 1 \times 9.8 = 1.47\text{ N}$

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

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



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

Weight of part of the chain on table $W' = \frac{M}{L}(L-y)g$

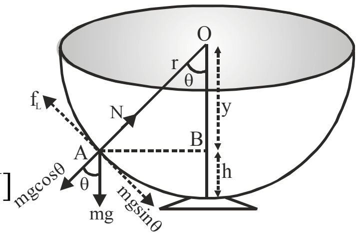
Weight of hanging part of the chain $W = \frac{M}{L}yg$

For equlibrium : limiting force of friction = weight of hanging part of the chain

$\mu R = W \Rightarrow \quad \mu W' = W \quad \Rightarrow \mu\frac{M}{L}(L-y)g = \frac{M}{L}yg \Rightarrow \mu L - \mu y = y \Rightarrow y = \frac{\mu L}{1+\mu}$

Ex. If the coefficient of friction between an insect and bowl is μ and the radius of the bowl is r, find the maximum height to which the insect can crawl up in the bowl.

Sol. The insect will crawl up the bowl till the component of its weight along the bowl is balanced by limiting frictional force. So, resolving weight perpendicular to the bowl and along the bowl,



$N = mg\cos\theta$, $f_L = mg\sin\theta \Rightarrow \tan\theta = \frac{f_L}{N} \Rightarrow \tan\theta = \mu$ $[\because f_L = \mu N]$

$$\Rightarrow \sqrt{\frac{(r^2 - y^2)}{y}} = \mu \Rightarrow y = \frac{r}{\sqrt{1+\mu^2}} \quad \text{So } h = r - y = r\left[1 - \frac{1}{\sqrt{1+\mu^2}}\right]$$

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

Sol. Let f is the force of friction and N is the normal reaction,

then the net force by the surface on the body is $F = \sqrt{N^2 + f^2}$

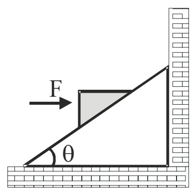
Let the applied force is F′ (varying), applied horizontally then $f \le \mu_s N$ (adjustable with f = F′). Now if F′ is zero, f = 0 and $F_{min} = N = Mg$

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

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

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

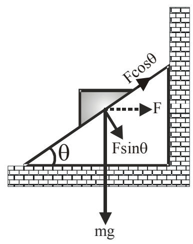
Ex. A block rest on a rough inclined plane as shown in fig. A horizontal force F is applied to it (a) Find out the force of reaction, (b) Can the force of friction be zero if yes when? and (c) Assuming that friction is not zero find its magnitude and direction of its limiting value.



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

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

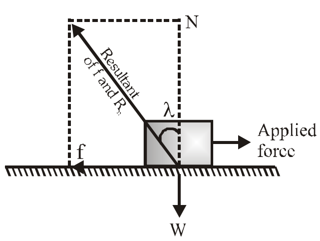
(c) $f = \mu R = \mu\,(mg\cos\theta + F\sin\theta)$; up the plane if the body has tendency to slide down and down the plane if the body has tendency to move up.



ANGLE OF FRICTION

The angle of friction is the angle which the resultant of limiting friction f_S and normal reaction N makes with the normal reaction. It is

represented by λ $\tan\lambda = \frac{f_S}{N} = \frac{\mu N}{N} = \mu$



- For smooth surface $\lambda = 0$

ANGLE OF REPOSE (θ)

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

F_S = mg sinθ and N = mg cosθ

so $\frac{F_S}{N} = \tan\theta \Rightarrow \mu = \tan\theta$

Relation between angle of friction (λ) and angle of repose (θ)

tan λ = μ and μ = tan θ, hence tan λ = tan θ ⇒ θ = λ

Thus, angle of repose = angle of friction

Ex. A block of mass 2 kg slides down an inclined plane which makes an angle of 30° with the horizontal.

The coefficient of friction between the block and the surface is $\frac{\sqrt{3}}{2}$.

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

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

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

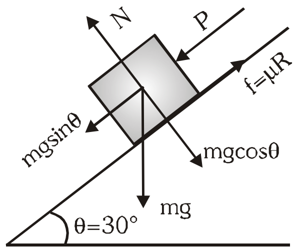
(i) Project forces along and perpendicular to the plane

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

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

(∵ there is no acceleration along the plane)

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



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

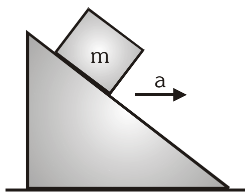
$$= 19.6\left(\frac{\sqrt{3}}{2} \times \frac{\sqrt{3}}{2} - \frac{1}{2}\right) = 19.6\left(\frac{3}{4} - \frac{1}{2}\right) = 4.9\text{ N}$$

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

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

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

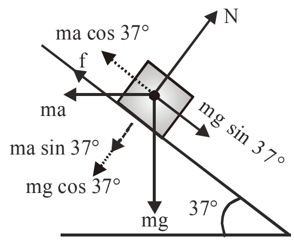
Ex. A block of mass 1 kg sits on an incline as shown in figure.



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

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

Sol. N = m (g cos37° + a sin37°) = 1(9.8 × 0.8 + 3 × 0.6) = 9.64 N



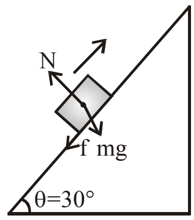
mg sin 37° = ma cos 37° + f

(a) f = 1(9.8 × 0.6 – 3 × 0.8) = 3.48

(b) $\because$ f = μN $\qquad \therefore \mu = \frac{f}{N} = \frac{3.48}{9.64} = 0.36$

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

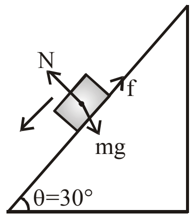
Sol. For upward motion: upward retardation $a_1 = \frac{\mu N + mg\sin\theta}{m}$



$a_1 = \mu g\cos30° + g\sin30° = (\sqrt{3}\mu + 1)\frac{g}{2}$

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

For downward motion: downward acceleration $a_2 = \frac{mg\sin\theta - \mu N}{m}$



$a_2 = g\sin30° - g\cos30° = (1 - \sqrt{3}\mu)\frac{g}{2}$

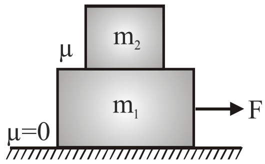
$\Rightarrow t_2 = \sqrt{\frac{2s}{a_2}} = \sqrt{\frac{4s}{(1-\sqrt{3}\mu)g}}$

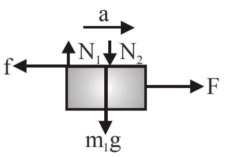
Now according to question $2t_1 = t_2$

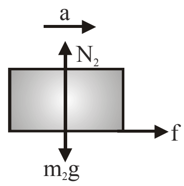
$\Rightarrow 2\sqrt{\frac{4s}{(\sqrt{3}\mu+1)g}} = \sqrt{\frac{4s}{(1-\sqrt{3}\mu)g}}$

$\Rightarrow \frac{1-\sqrt{3}\mu}{1+\sqrt{3}\mu} = \frac{1}{4} \Rightarrow \mu = \frac{\sqrt{3}}{5}$

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



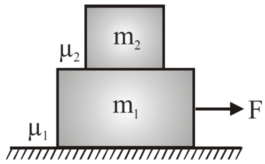
Sol. For m_1 

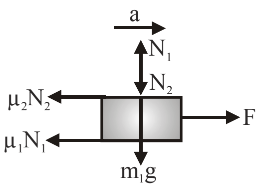
for m_2 

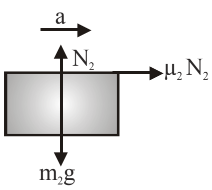
For system acceleration $a = \dfrac{F}{m_1 + m_2}$

For m_2 $f = m_2a \Rightarrow \mu m_2 g = m_2\left(\dfrac{F}{m_1 + m_2}\right) \Rightarrow F_{min} = \mu(m_1 + m_2)\ g$

Ex. When force F applied on m_1 and the coefficient of friction between m_1 and surface. is μ_1 and the coefficient of friction between m_1 and m_2 is μ_2. What should be the minimum value of F so that there is no relative motion between m_1 and m_2 .



Sol. For m_1 

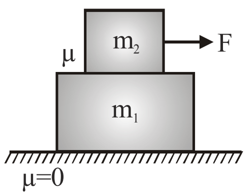
for m_2 

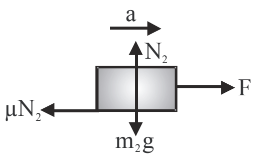
For system $a = \dfrac{F - \mu_1(m_1 + m_2)g}{m_1 + m_2}$

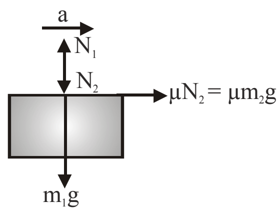
For m_2, $\mu_2\ (m_2g) = m_2a = m_2\left(\dfrac{F - \mu_1(m_1 + m_2)g}{m_1 + m_2}\right)$

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

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



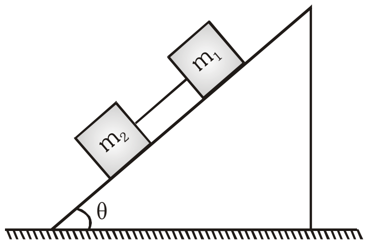
Sol. For m_2 

For m_1 

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

for m_1 : $\mu m_2 g = m_1 a = m_1\left(\dfrac{F}{m_1 m_2}\right)$, $F_{min} = (m_1 + m_2)\left(\dfrac{\mu m_2 g}{m_1}\right)$

Ex. Two blocks with masses m_1 = 1 kg and m_2 = 2 kg are connected by a string and side down a plane inclined at an angle $\theta = 45^0$ with the horizontal. The coefficient of sliding friction between m_1 and plane is μ_1 = 0.4, and that between m_2 and plane is μ_2 = 0.2. Calculate the common acceleration of the two blocks and the tension in the string.



Sol. As $\mu_2 < \mu_1$, block m_2 has greater acceleration than m_1 if we separately consider the motion of blocks. But they are connected so they move together as a system with common acceleration. So acceleration of the blocks :

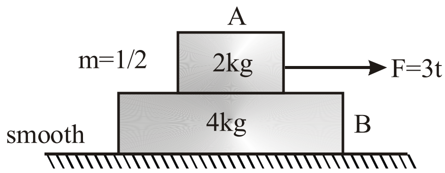
$$a = \frac{(m_1+m_2)g\sin\theta - \mu_1 m_1 g\cos\theta - \mu_2 m_2 g\cos\theta}{m_1+m_2}$$

$$= \frac{(1+2)(10)\left(\frac{1}{\sqrt{2}}\right) - 0.4\times1\times10\times\frac{1}{\sqrt{2}} - 0.2\times2\times10\times\frac{1}{\sqrt{2}}}{1+2} = \frac{22}{3\sqrt{2}}\ ms^{-2}$$

For block m_2 : $m_2 g\sin\theta - \mu_2 m_2 g\cos\theta - T = m_2 a \Rightarrow T = m_2 g\sin\theta - \mu_2 m_2 g\cos\theta - m_2 a$

$$= 2\times10\times\frac{1}{\sqrt{2}} - 0.2\times2\times10\times\frac{1}{\sqrt{2}} - 2\times\frac{22}{3\sqrt{2}} = \frac{2}{3\sqrt{2}}N$$

Ex. For shown situation draw a graph showing accelerations of A and B on y–axis and time on x–axis. ($g=10ms^{-2}$)



Sol. Limiting friction between A & B, $f_L = \mu m_A g = \left(\frac{1}{2}\right)(2)(10) = 10$ N

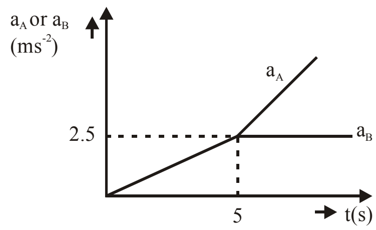
Block B moves due to friction only. So maximum acceleration of B,

$$a_{max} = \frac{f_L}{m_B} = \frac{10}{4} = 2.5\ ms^{-2}.$$

So both the blocks move together till the common acceleration becomes 2.5 ms^{-2}, after that acceleations of B will become constant while that of A will go on increasing. Slipping will starts between A & B at 2.5 ms^{-2}

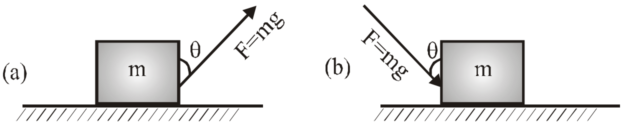
$$\Rightarrow 2.5 = \frac{F}{m_A+m_B} = \frac{3t}{6} \Rightarrow t = 5\ s$$

Hence for $t \leq 5s$, $a_A = a_B = \frac{F}{m_A+m_B} = \frac{3t}{6} = \frac{t}{2}$



and for t > 5 s $a_B = 2.5\ ms^{-2}$, $a_A = \frac{F-f_L}{m_A} = \frac{3t-10}{2} = \frac{3}{2}t - 5$

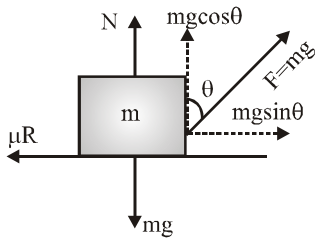
Ex. A block of mass m rests on a rough horizontal surface as shown in figure (a) and (b). Coefficient of friction between block and surface is μ. A force $F = mg$ acting at an angle θ with the vertical side of the block. Find the condition for which block will move along the surface.



Sol. For (a) : normal reaction $N = mg - mg\cos\theta$, frictional force $= \mu N = \mu(mg - mg\cos\theta)$

Now block can be pulled when : Horizontal component of force $\geq$ frictional force

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



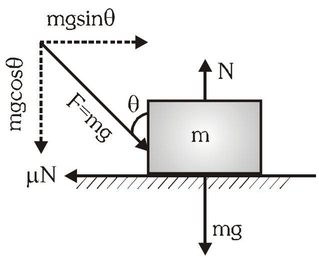
or $2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq \mu(1-\cos\theta)$

or $2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq 2\mu\sin^2\frac{\theta}{2}$ or $\cot\frac{\theta}{2} \geq \mu$

For (b) **:** Normal reaction $N = mg + mg\cos\theta = mg(1+\cos\theta)$

Hence, block can be pushed along the horizontal surface when horizontal component of force $\geq$ frictional force

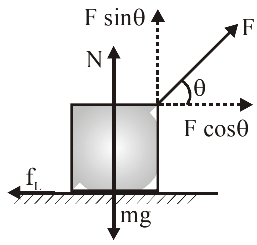
i.e. $mg\sin\theta \geq \mu\, mg(1+\cos\theta)$



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

Ex. A body of mass m rests on a horizontal floor with which it has a coefficient of static friction μ. It is desired to make the body move by applying the minimum possible force F. Find the magnitude of F and the direction in which it has to be applied.

Sol. Let the force F be applied at an angle θ with the horizontal as shown in figure.



For vertical equilibrium,

$R + F\sin\theta = mg \Rightarrow N = mg - F\sin\theta$ (i)

for horizontal motion $F\cos\theta \geq f_L \Rightarrow F\cos\theta \geq \mu N$ [as $f_L = \mu N$] (ii)

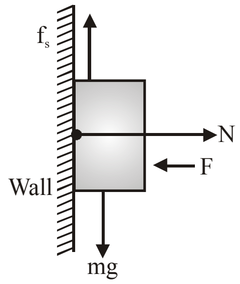
substituting value of R from equation (i) in (ii),

$F\cos\theta \geq \mu(mg - F\sin\theta) \Rightarrow F \geq \dfrac{\mu mg}{(\cos\theta + \mu\sin\theta)}$ (iii)

For the force F to be minimum $(\cos\theta + \mu\sin\theta)$ must be maximum,

maximum value of $\cos\theta + \mu\sin\theta$ is $\sqrt{1+\mu^2}$ so that $F_{min} = \dfrac{\mu mg}{\sqrt{1+\mu^2}}$ with $\theta = \tan^{-1}(\mu)$

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



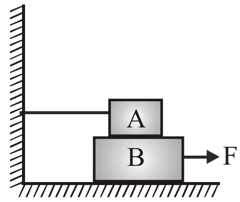
Sol. The situation is shown in fig. The forces acting on the book are–

For book to be at rest it is essential that $Mg = f_s$

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

$\therefore\ Mg = \mu_S F \Rightarrow F = \frac{Mg}{\mu_s} = \frac{1 \times 9.8}{0.2} = 49\ N$

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

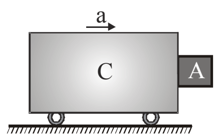


Sol. When B is tied to move, by applying a force F, then the frictional forces acting on the block B are f_1 and f_2 with limiting values, $f_1 = (\mu_S)_A m_A g$ and $f_2 = (\mu_S)_B (m_A + m_B)g$

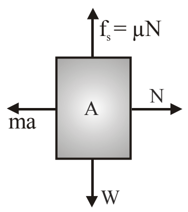
then minimum value of F should be (for just tending to move),

$F = f_1 + f_2 = 0.2 \times 100\ g + 0.3 \times 300\ g = 110\ g = 1100\ N$

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



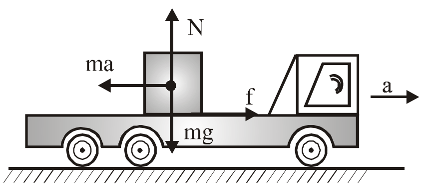
Sol. The forces acting on the block A (in block A's frame (i.e. non inertial frame) are :



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

we require $W = f_s$ $\Rightarrow mg = \mu(ma)$ Thus $a = \frac{g}{\mu}$

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



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

While the limiting friction force

$F = \mu_s N = \mu_S mg = 0.6 \times 1 \times 9.8 = 5.88\ N$

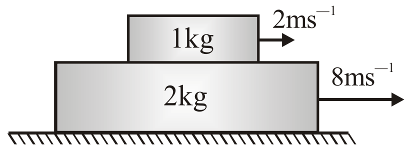
As required force F lesser than limiting friction force. The block will remain at rest in the truck and the force of friction will be equal to 5N and in the direction of acceleration of the truck.

Ex. Coefficient of friction between two blocks shown in figure is $\mu = 0.4$ The blocks are given velocities of $2ms^{-1}$ and $8\ ms^{-1}$ in the directions shown in figure. Find

(i) The time when relative motion between them will stop.

(ii) The common velocities of blocks upto that instant.

(iii) Displacement of blocks upto that instant ($g = 10\ ms^{-2}$)



Sol. (i) Frictional force between two blocks will oppose the relative motion. For 1 kg block friction support the motion & for 2 kg friction oppose the motion. Let common velocity be v then

for 1 kg $v = 2 + a_1 t$ where $a_1 = \frac{\mu(1g)}{1} = \frac{0.4 \times 10}{1} = 4\ ms^{-2}$

for 2 kg $v = 8 - a_2\ t$ where $a_2 = \frac{\mu(1g)}{2} = \frac{0.4 \times 10}{2} = 2\ ms^{-2} \Rightarrow 2 + 4t = 8 - 2\ t \Rightarrow 6t = 6 \Rightarrow t = 1s$

(ii) $v = 2 + 4\ t = 2 + 4 \times 1 = 6\ ms^{-1}$

(iii) Displacement of 1 kg block from rest

$$s = ut + \frac{1}{2}at^2 \Rightarrow s_1 = 2 \times 1 + \frac{1}{2} \times 4 \times 1^2 = 2 + 2 = 4m$$

Displacement of 2 kg block from rest

$$s = ut + \frac{1}{2}at^2 \Rightarrow s_2 = 8 \times 1 - \frac{1}{2} \times 2 \times 1^2 = 8 - 1 = 7\ m$$

Friction is a Necessary Evil :

Friction is a necessary evil. It means it has advantage as well as disadvantages. In other words, friction is not desirable but without friction, we cannot think of survival.

Disadvantages :

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

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

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

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

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

Advantages :

(i) The force of friction helps us to move on the surface of earth. In the absence of friction, we cannot think of walking on the surface. That is why, we fall down while moving on a smooth surface.

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

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

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

(v) The force of friction between a chalk and the black board helps us to write on the board.

Thus, we observe that inspect of various disadvantages of the friction, it is very difficult to part with it. So, friction is a necessary evil.

METHODS OF REDUCING FRICTION

As friction causes the wastage of energy so it becomes necessary to reduce the friction. Friction can be reduced by the following methods.

(i) Polishing the surface. We know, friction between rough surface is much more than between the polished surfaces. So we polish the surface to reduce the friction. The irregularities on the surface are filled with polish and hence the friction decreases.

(ii) Lubrication. To reduce friction, lubricants like oil or greese are used. When the oil or greese is put in between the two surfaces, the irregularities remain apart and do not interlock tightly. Thus, the surface can move over each other with less friction between them.

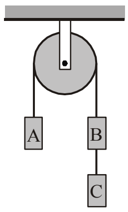
(iii) By providing the streamlined shape. When a body (e.g. bus, train, aeroplane etc.) moves with high speed, air resistance (friction) opposes its motion. The effect of air resistance on the motion of the objects (stated above) is decreased by providing them a streamlined shape.

EXERCISE (S-1)

1. A force F applied to an object of mass m_1 produces an acceleration of 3.00 m/s^2. The same force applied to a second object of mass m_2 produces an acceleration of 1.00 m/s^2.
(i) What is the value of the ratio m_1/m_2 ?
(ii) If m_1 and m_2 are combined, find their acceleration under the action of the force F.

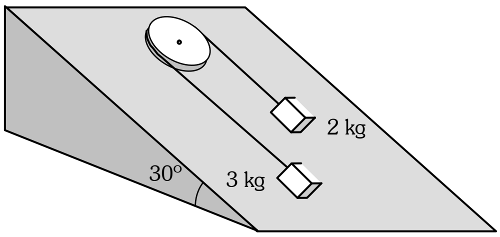
NL0001

2. 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



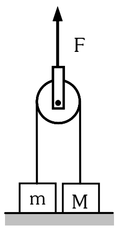
NL0002

3. 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 axel on a smooth incline plane as shown in the figure. When the blocks are released, find magnitude of their accelerations.



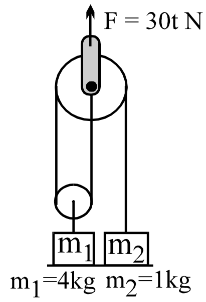
NL0003

4. 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.



NL0004

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

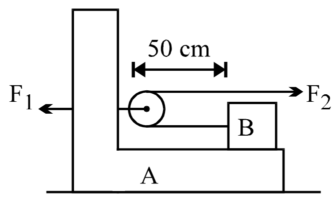


NL0005

6. A 40 kg boy 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 boy can have without lifting the weight? If he climbs the rope with upward acceleration 2 g, with what acceleration the weight will rise up?

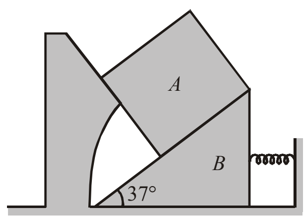
NL0006

7. A 1kg block B rests as shown on a bracket A of same mass. Constant forces F_1 = 20N and F_2 = 8N start to act at time t = 0 when the distance of block B from pulley is 50cm. Time when block B reaches the pulley is _________.



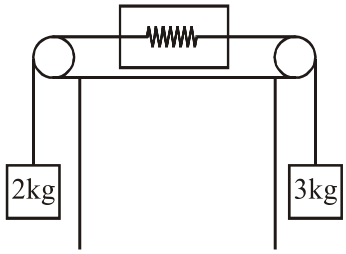
NL0007

8. 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 & B, spring force and normal reaction of ground on block B. (g= 10 m/s^2).



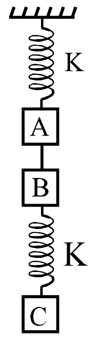
NL0008

9. Find the reading of the massless spring balance in the given condition



NL0009

10. The system shown adjacent is in equilibrium. Find the acceleration of the blocks *A, B* & *C* all of equal masses *m* at the instant when



(Assume springs to be ideal)

(i) The spring between ceiling & *A* is cut.

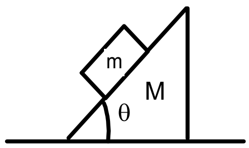
(ii) The string (inextensible) between *A* & *B* is cut.

(iii) The spring between *B* & *C* is cut.

Also find the tension in the string when the system is at rest and in the above 3 cases.

NL0010

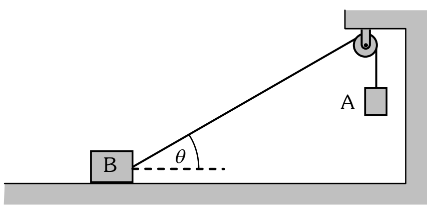
11. A block of mass *m* lies on wedge of mass *M* as shown in figure.



With what minimum acceleration must the wedge be moved towards right horizontally so that block m falls freely.

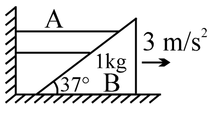
NL0011

12. 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



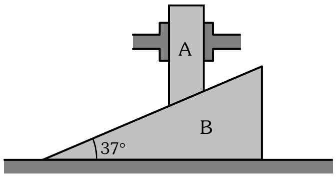
NL0012

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



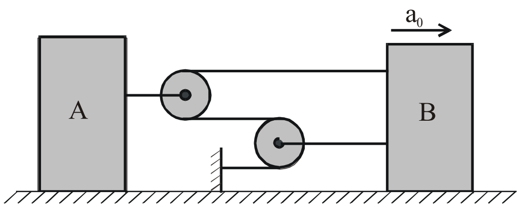
NL0013

14. Rod A can slide in vertical direction pushing the triangular wedge B towards right. The wedge is moving toward right with uniform acceleration a_B. Find acceleration of the rod A.



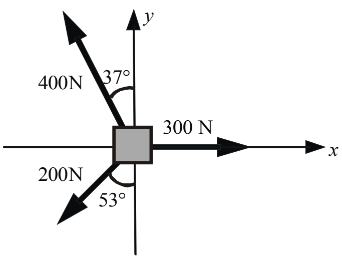
NL0014

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



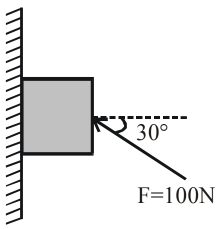
NL0015

16. A block is placed on a rough horizontal plane. Three horizontal forces are applied on the block as shown in the figure. If the block is in equilibrium, find the friction force acting on the block.



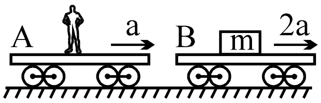
NL0016

17. 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 acting on the block.



NL0017

18. Two trolley A and B are moving with accelerations a and 2a respectively in the same direction. To an observer in trolley A, the magnitude of pseudo force acting on a block of mass m on the trolley B is



NL0018

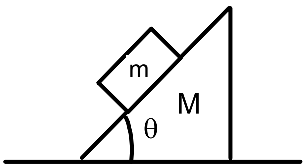
19. A thin rod of length 1 m is fixed in a vertical position inside a train, which is moving horizontally with constant acceleration 4 m/s^2. A bead can slide on the rod, and friction coefficient between them is 1/2. If the bead is released from rest at the top of the rod, find the time when it will reach at the bottom.[g = 10 m/s^2]

NL0019

20. 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 μ = 0.5. Plank rests on frictionless surface. Find the time when block comes to rest w.r.t. plank.

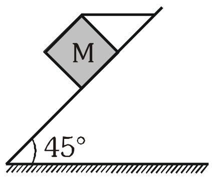
NL0020

21. 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.



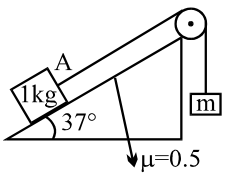
NL0021

22. A block of mass 15 kg is resting on a rough inclined plane as shown in figure.The block is tied up by a horizontal string which has a tension of 50 N. Calculate the minimum coefficient of friction between the block and inclined plane.



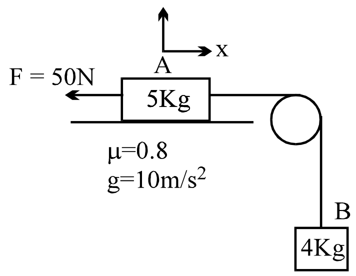
NL0022

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



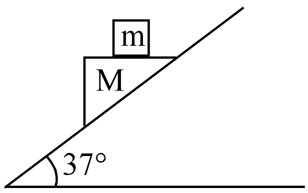
NL0023

24. Find the acceleration of the blocks and magnitude & direction of frictional force between block *A* and table, if block *A* is pulled towards left with a force of 50 N.



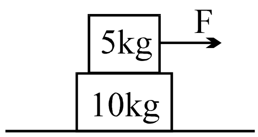
NL0024

25. Block *M* slides down on frictionless incline as shown. Find the minimum friction coefficient so that *m* does not slide with respect to *M*.



NL0025

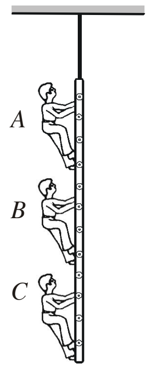
26. Coefficient of friction between 5 kg and 10 kg block is 0.5. If friction between them is 20 N. What is the value of force being applied on 5 kg. The floor is frictionless.



NL0026

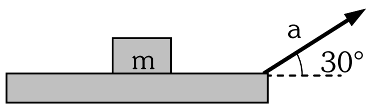
EXERCISE (S-2)

1. 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. [g = 9.8 m/s^2]



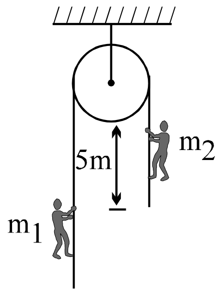
NL0027

2. 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 3*mg*/2. Find the magnitude of the acceleration.



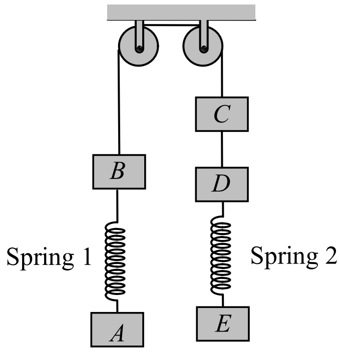
NL0028

3. 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 mann 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.



NL0029

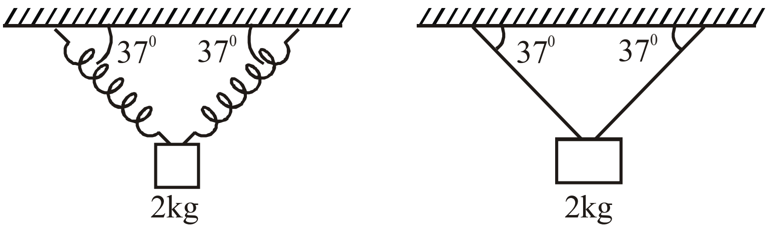
4. The system shown in the figure is initially in equilibrium. A is of mass $2m$ and B,C, D and E are of mass m. Certain actions are performed on the system. Every action has been taken individually when the system is intact. Find the direction and magnitude of acceleration of the blocks after each action of the following actions has been taken



(i) Spring 1 is cut
(ii) Spring 2 is cut
(iii) String between C and D is cut.
(iv) String between B and C is cut.

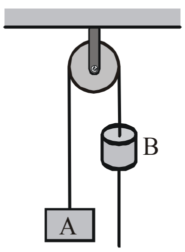
NL0030

5. The blocks are of mass 2 kg shown is in equilibrium. At $t = 0$ right spring in figure (i) and right string in figure (ii) breaks. Find the ratio of instantaneous acceleration of blocks?



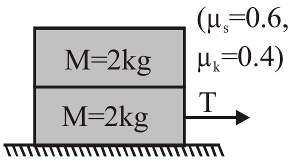
NL0031

6. A 2 kg block A is attached to one end of a light string that passes over an 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. [g = 10 m/s^2]



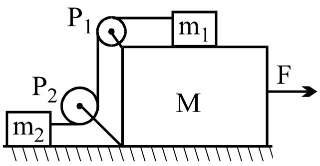
NL0032

7. 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.



NL0033

8. 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 $g = 10\ m/s^2$.

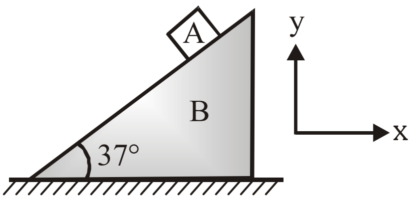


(i) Draw a free-body diagram for mass M, clearly showing all the forces.

(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.

NL0034

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.

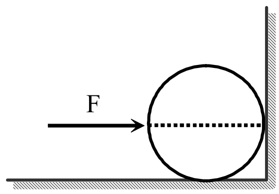


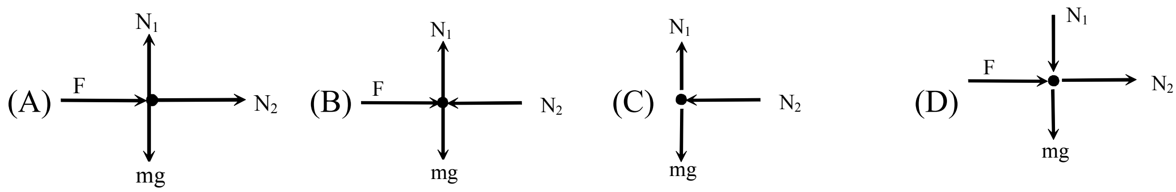
NL0035

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

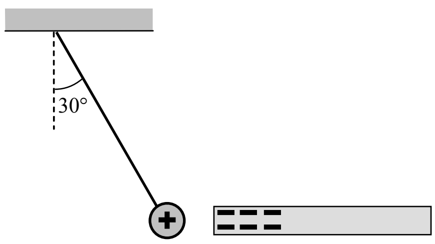
1. A ball of mass m kept at the corner as shown in the figure, is acted by a horizontal force F. The correct free body diagram of ball is

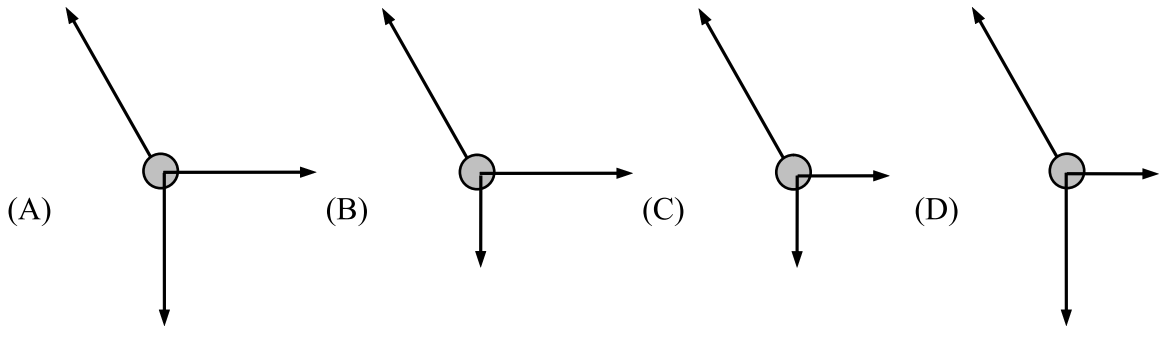




NL0036

2. 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?



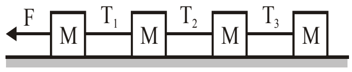


NL0037

3. Under what condition(s) will an object be in equilibrium ?
(A) Only if it is at rest
(B) Only if it is moving with constant velocity
(C) Only if it is moving with constant acceleration
(D) If it is either at rest or moving with constant velocity

NL0038

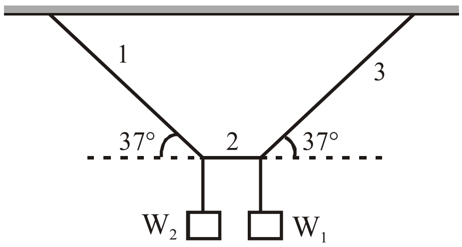
4. Four blocks of same mass connected by cords are pulled by force F on a smooth horizontal surface, as in figure. The tension T_1, T_2 and T_3 will be



(A) $T_1 = F/4$, $T_2 = 3F/2$, $T_3 = F/4$
(B) $T_1 = F/4$, $T_2 = F/2$, $T_3 = F/2$
(C) $T_1 = 3F/4$, $T_2 = F/2$, $T_3 = F/4$
(D) $T_1 = 3F/4$, $T_2 = F/2$, $T_3 = F/2$

NL0039

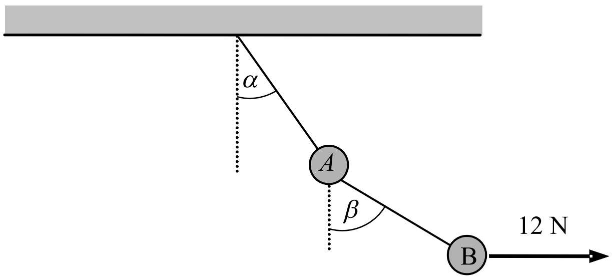
5. In a given figure system is in equilibrium. If $W_1 = 300$ N. Then W_2 is approximately equal to



(A) 500 N
(B) 400 N
(C) 670 N
(D) 300 N

NL0040

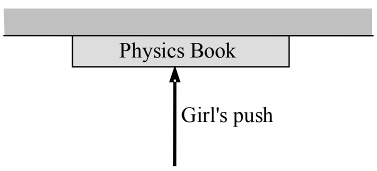
6. Two balls A and B weighing 7 N and 9 N are connected by a light cord. The system is suspended from a fixed support by connecting the ball A with another light cord. The ball B is pulled aside by a horizontal force 12 N and equilibrium is established. Angles α and β respectively are



(A) 30° and 60°
(B) 60° and 30°
(C) 37° and 53°
(D) 53° and 37°

NL0041

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

NL0042

8. 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.

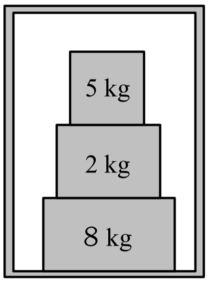
(B) Both accelerate towards each other with equal accelerations of equal modulus.

(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.

NL0043

9. 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



(A) 80 N (B) 48 N (C) 40 N (D) 32 N

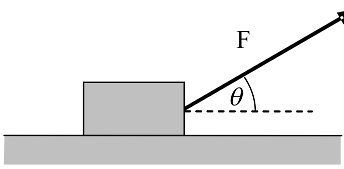
NL0044

10. A man is standing on a weighing machine with a block in his hand. The machine records w. When he takes the block upwards with some acceleration the machine records w_1. When he takes the block down with some acceleration, the machine records w_2.Then choose correct option

(A) $w_1 = w = w_2$ (B) $w_1 < w < w_2$ (C) $w_2 < w < w_1$ (D) $w_2 = w_1 > w$

NL0045

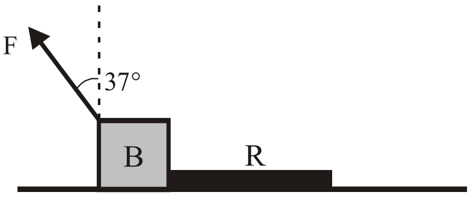
11. A block is being pulled by a force F on a long frictionless level floor. Magnitude of the force is gradually increases from zero until the block lifts off the floor. Immediately before the block leaves the floor, its acceleration is



(A) $g\cos\theta$ (B) $g\cot\theta$ (C) $g\sin\theta$ (D) $g\tan\theta$

NL0046

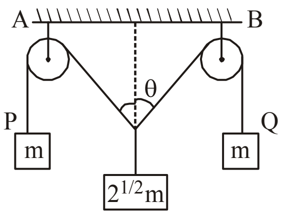
12. A block B is tied to one end of a uniform rope R as shown. The mass of block is 2 kg and that of rope is 1 kg. A force F = 15 N is applied at angle 37° with vertical. The tension at the mid-point of rope is



(A) 1.5 N (B) 2 N (C) 3N (D) 4.5 N

NL0047

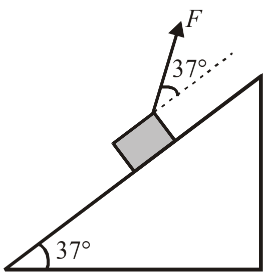
13. The pulleys and strings shown in the figure are smooth and of negligible mass. For the system to remain in equilibrium, the angle θ should be **[JEE (Scr) 2001]**



(A) 0° (B) 30° (C) 45° (D) 60°

NL0048

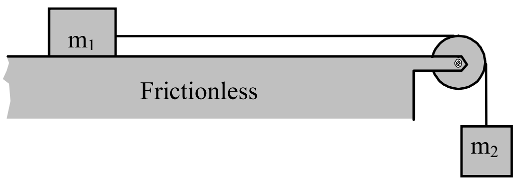
14. A block resting on a smooth inclined plane is acted upon by a force *F* as shown. If mass of block is 2 kg and *F* = 20 N and sin 37°= 3/5, the acceleration of block is



(A) 2 m/s^2 (B) 6 m/s^2 (C) 8 m/s^2 (D) zero

NL0049

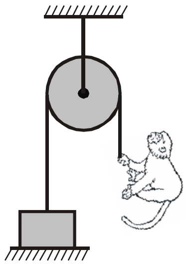
15. In the arrangement shown, the blocks of unequal masses are held at rest. When released, acceleration of the blocks is



(A) g/2. (B) g.
(C) a value between zero and g. (D) a value that could be greater than g.

NL0050

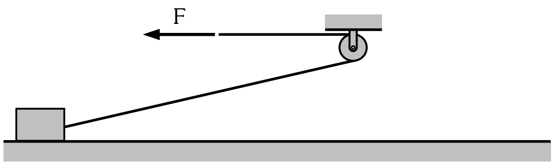
16. A monkey weighing 10 kg is climbing up a light rope and frictionless pulley attached to 15 kg mass at other end as in figure. In order to raise the 15 kg mass off the ground the monkey must climb-up



(A) with constant acceleration g/3.
(B) with an acceleration greater than g/2.
(C) with an acceleration greater than g/4.
(D) It is not possible because weight of monkey is lesser than the block.

NL0051

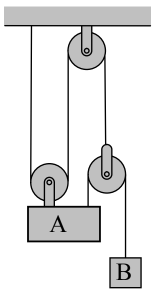
17. A heavy cart is pulled by a constant force F along a horizontal track with the help of a rope that passes over a fixed pulley, as shown in the figure. Assume the tension in the rope and the frictional forces on the cart remain constant and consider motion of the cart until it reaches vertically below the pulley. As the cart moves to the right, its acceleration



(A) decreases. (B) increases. (C) remains constant. (D) is zero

NL0052

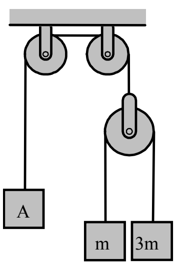
18. In arrangement shown the block A of mass 15 kg is supported in equilibrium by the block B. Mass of the block B is closest to



(A) 2 kg (B) 3 kg (C) 4 kg (D) 5 kg

NL0053

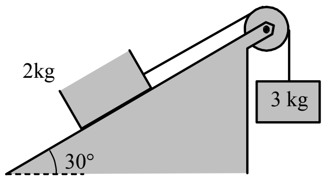
19. In the given figure, find mass of the block A, if it remains at rest, when the system is released from rest. Pulleys and strings are massless. [$g = 10\ m/s^2$]



(A) m (B) 2m (C) 2.5m (D) 3m

NL0054

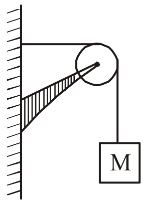
20. In the arrangement shown, the 2 kg block is held to keep the system at rest. The string and pulley are ideal. When the 2 kg block is set free, by what amount the tension in the string changes? [$g = 10\ m/s^2$]



(A) Increase of 12 N (B) Decrease of 12 N (C) Increase of 18 N (D) Decrease of 18 N

NL0055

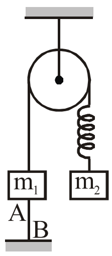
21. A string of negligible mass going over a clamped pulley of mass *m* supports a block of mass *M* as shown in the figure. The force on the pulley by the clamp is given **[JEE (Scr) 2001]**



(A) $\sqrt{2}\,Mg$ (B) $\sqrt{2}\,mg$ (C) $\sqrt{(M+m)^2+m^2}\ g$ (D) $\sqrt{(M+m)^2+M^2}\ g$

NL0056

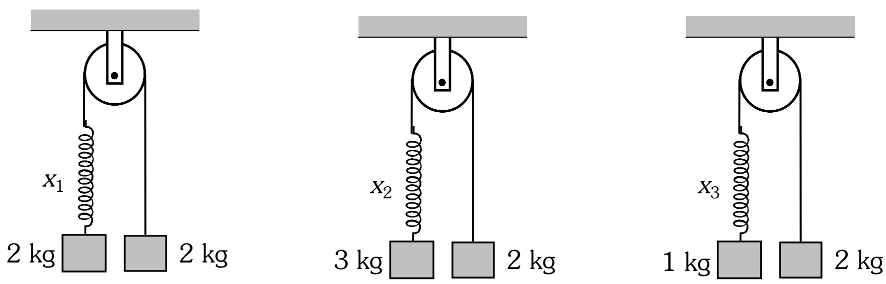
22. In a given figure two masses m_1 & m_2 ($m_2 > m_1$) are at rest in equilibrium position. Find the tension in string AB



(A) m_1g (B) m_2g (C) $(m_1+m_2)g$ (D) $(m_2-m_1)g$

NL0057

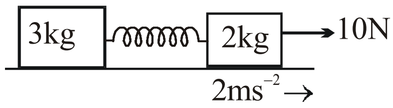
23. Same spring is attached with 2 kg, 3 kg and 1 kg blocks in three different cases as shown. If x_1, x_2 and x_3 be the extensions in the spring in these three cases, when acceleration of both the blocks have same magnitude, then



(A) $x_2 > x_3 > x_1$ (B) $x_2 > x_1 > x_3$ (C) $x_3 > x_1 > x_2$ (D) $x_1 > x_2 > x_3$

NL0058

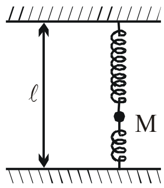
24. Find the acceleration of 3 kg mass when acceleration of 2 kg mass is 2 ms^{-2} as shown in figure.



(A) 3 ms^{-2} (B) 2 ms^{-2} (C) 0.5 ms^{-2} (D) zero

NL0059

25. A small ball of mass M is held in equilibrium with two identical springs as shown in the figure . Force constant of each spring is k and relaxed length of each spring is $\ell/2$. What is distance between the ball and roof?



(A) $\frac{\ell}{2}+\frac{Mg}{k}$ (B) $\frac{\ell}{2}-\frac{Mg}{k}$ (C) $\frac{\ell}{2}+\frac{Mg}{2k}$ (D) $\frac{\ell}{2}-\frac{Mg}{2k}$

NL0060

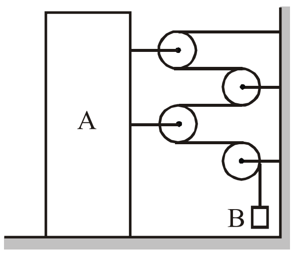
26. An elastic spring of relaxed length ℓ_o and force constant k is cut into two parts of lengths ℓ_1 and ℓ_2. The force constants of these parts are respectively

(A) $\frac{k\ell_o}{\ell_1}$ and $\frac{k\ell_o}{\ell_2}$ (B) $\frac{k\ell_1}{\ell_0}$ and $\frac{k\ell_2}{\ell_o}$

(C) $\frac{k\ell_0}{\ell_2}$ and $\frac{k\ell_0}{\ell_1}$ (D) $\frac{k\ell_2}{\ell_0}$ and $\frac{k\ell_1}{\ell_0}$

NL0061

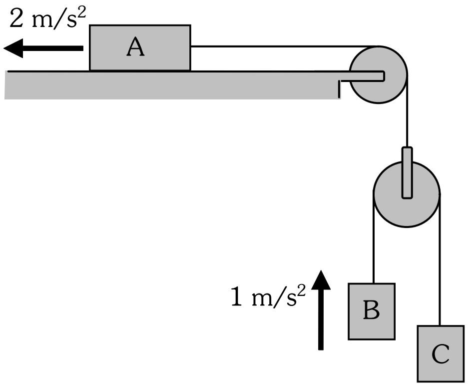
27. Block A is moving away from the wall at a speed v and acceleration a.



(A) Velocity of B is v with respect to A.
(B) Acceleration of B is a with respect to A.
(C) Acceleration of B is 4a with respect to A.
(D) Acceleration of B is $\sqrt{17}$a with respect to A.

NL0062

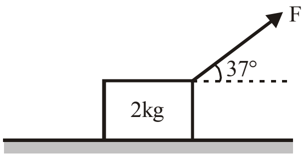
28. In the setup shown, find acceleration of the block C.



(A) 3 m/s² ↑ (B) 3 m/s² ↓ (C) 5 m/s² ↑ (D) 5 m/s² ↓

NL0063

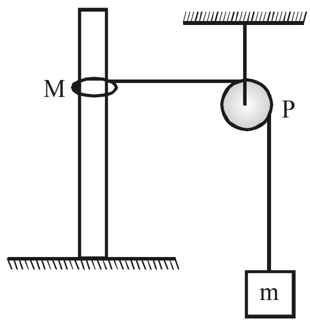
29. A block of mass 2 kg is kept on a rough horizontal floor and pulled with a force F. If the coefficient of friction is 0.5. then the minimum force required to move the block is :-



(A) 10 N (B) $\frac{100}{11}$ N (C) $\frac{100}{8}$ N (D) 20 N

NL0064

30. 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

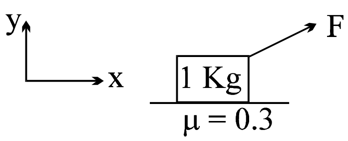
(B) μ*mg* directed up

(C) (*M* –*m*)g directed down

(D) μ*mg* directed down

NL0065

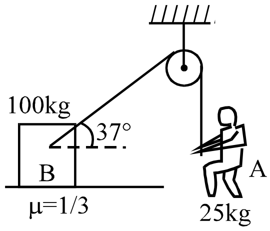
31. A force $\vec{F} = \hat{i} + 4\hat{j}$ acts on block shown. The force of friction acting on the block is :



(A) $-\hat{i}$ (B) $-1.8\hat{i}$ (C) $-2.4\hat{i}$ (D) $-3\hat{i}$

NL0066

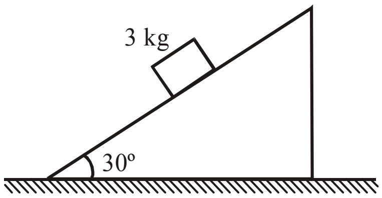
32. Block *B* of mass 100 kg rests on a rough surface of friction coefficient $\mu = 1/3$. A rope is tied to block *B* as shown in figure. The maximum acceleration with which boy *A* of 25 kg can climbs on rope without making block move is :



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

NL0067

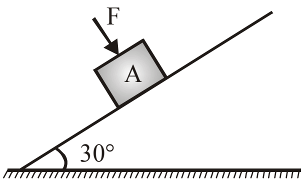
33. A block of mass 3 kg is at rest on a rough inclined plane as shown in the figure. The magnitude of net force exerted by the surface on the block will be ($g = 10\ m/s^2$)



(A) 26 N (B) 19.5 N (C) 10 N (D) 30 N

NL0068

34. 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 $\mu = 0.5$. What minimum force F should be applied perpendicular to the plane on the block, so that block does not slip on the plane ($g=10m/s^2$)

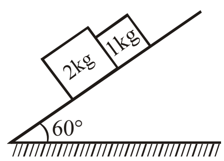


(A) zero (B) 6.24 N (C) 2.68 N (D) 4.34 N

NL0069

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

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



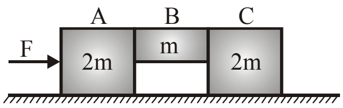
NL0070

36. 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

(A) $\frac{9}{20}$ (B) $\frac{7}{5}$ (C) $\frac{7}{12}$ (D) $\frac{5}{7}$

NL0071

37. 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 :-

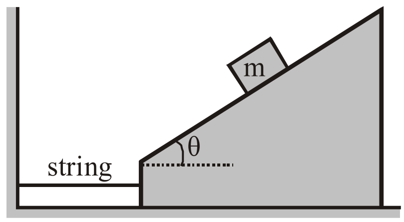


(A) $\left(\frac{3}{2\mu}\right)mg$ (B) $\left(\frac{5}{2\mu}\right)mg$ (C) $\left(\frac{5}{2}\right)\mu mg$ (D) $\left(\frac{3}{2}\right)\mu mg$

NL0072

MULTIPLE CORRECT TYPE QUESTIONS

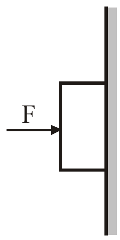
38. Refer the system shown in the figure. Block is sliding down the wedge. All surfaces are frictionless. Find correct statement(s)



(A) Acceleration of block is $g\sin\theta$
(B) Acceleration block is $g\cos\theta$
(C) Tension in the string is $mg\cos^2\theta$
(D) Tension in the string is $mg\sin\theta.\cos\theta$

NL0073

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

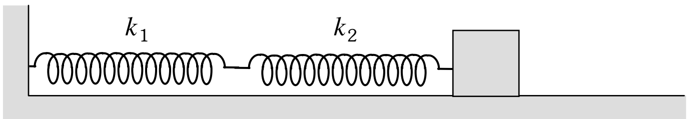
NL0074

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

(A) $F = 4$ N, acceleration is zero.
(B) $F = 4$ N, friction is 10 N and acceleration is 3 m/s^2.
(C) $F = 14$ N, acceleration is 2 m/s^2.
(D) $F = 14$ N, friction is 14 N.

NL0075

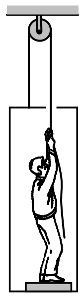
41. The mass in the figure can slide on a frictionless surface. When the mass is pulled out, spring 1 is stretched a distance x_1 and spring 2 is stretched a distance x_2. The spring constants are k_1 and k_2 respectively. Magnitude of spring force pulling back on the mass is



(A) k_1x_1 (B) k_2x_2 (C) $(k_1x_1 + k_2x_2)$ (D) $0.5\,(k_1 + k_2)\,(x_1 + x_2)$

NL0076

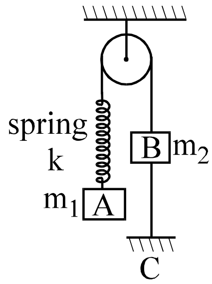
42. A carpenter of mass 50 kg is standing on a weighing machine placed in a lift of mass 20 kg. A light string is attached to the lift. The string passes over a smooth pulley and the other end is held by the carpenter as shown. When carpenter keeps the lift moving upward with constant velocity :- ($g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



(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

NL0077

43. In the system shown in the figure $m_1 > m_2$. System is held at rest by thread BC. Just after the thread BC is burnt :



(A) initial acceleration of m_2 will be upwards

(B) magnitude of initial acceleration of both blocks will be equal to $\left(\dfrac{m_1 - m_2}{m_1 + m_2}\right)$ g.

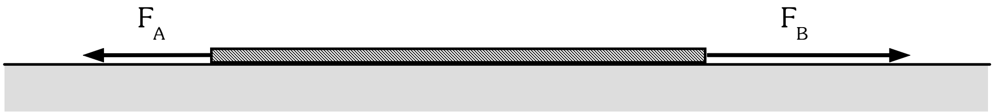
(C) initial acceleration of m_1 will be equal to zero
(D) magnitude of initial acceleration of two blocks will be non-zero and unequal.

NL0078

COMPREHENSION TYPE QUESTIONS

Paragraph for Question No. 44 to 47

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.



44. 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) $a=\frac{F_B-F_A}{m}$

NL0079

45. 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) $T=\frac{1}{2}(F_A+F_B)$

NL0079

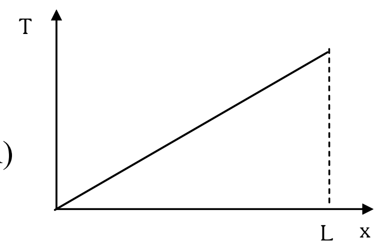
46. Expression (T_x) of tension at a point at distance x from the end A is

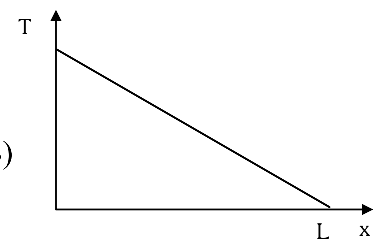
(A) $T_x=\left(\frac{F_B-F_A}{L}\right)x+F_A$ (B) $T_x=\left(\frac{F_B-F_A}{L}\right)x-F_A$

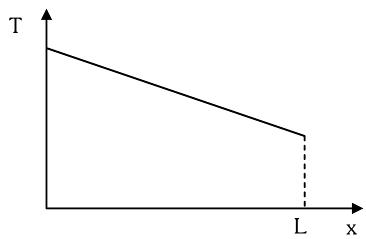
(C) $T_x=\left(\frac{F_B-F_A}{L}\right)x+F_B$ (D) $T_x=\left(\frac{F_B-F_A}{L}\right)x-F_B$

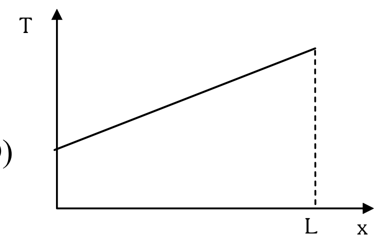
NL0079

47. 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?

(A)


(B)


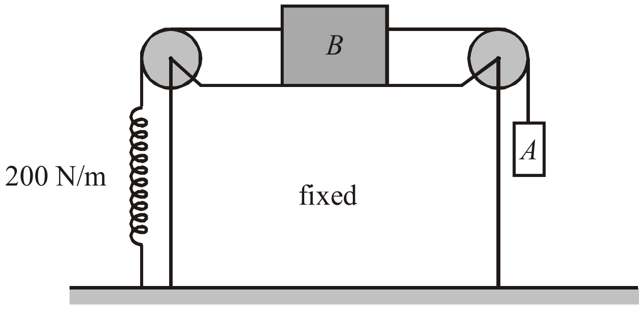
(C)


(D)


NL0079

Paragraph for Question No. 48 to 50

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 = 10m/s^2)



48. The elongation of the spring is

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

NL0080

49. 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

NL0080

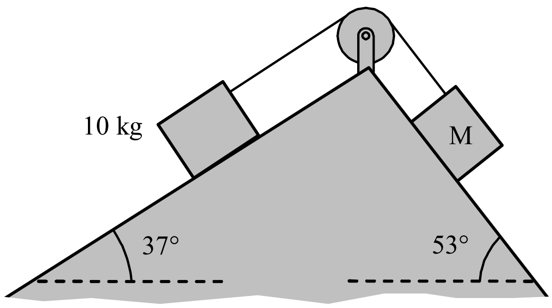
50. Now the force on A is suddenly removed. The acceleration of block B becomes :-

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

NL0080

Paragraph for Question No. 51 to 53

The blocks are on frictionless inclined ramp and connected by a massless cord. The cord passes over an ideal pulley. [g = 10 m/s^2]



51. When set free, the 10 kg block slides down the ramp with acceleration of 2 m/s^2. Mass M is closest to

(A) 13 kg (B) 8 kg (C) 5 kg (D) 4 kg

NL0081

52. When the 10 kg block slides down the ramp with acceleration of 2 m/s^2, tension in the cord is closest to :-

(A) 80 N (B) 60 N (C) 40 N (D) 30 N

NL0081

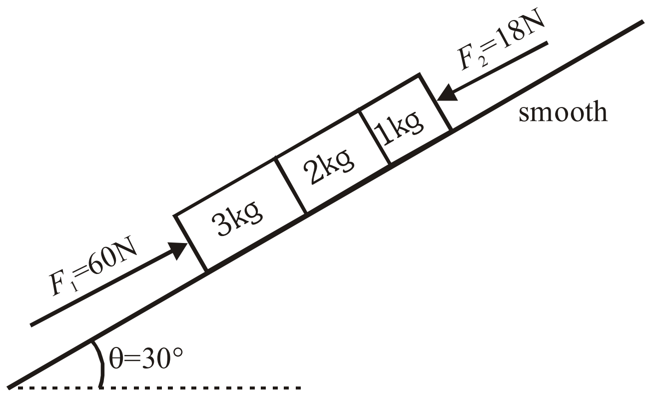
53. What value of M would keep the system at rest.

(A) 10 kg (B) 8 kg (C) 7.5 kg (D) 6 kg

NL0081

MATRIX MATCH TYPE QUESTION

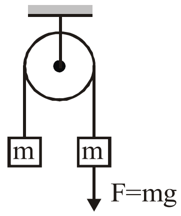
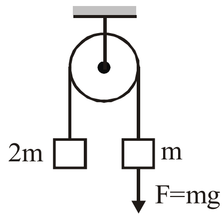
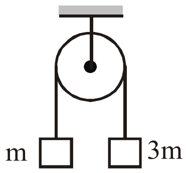
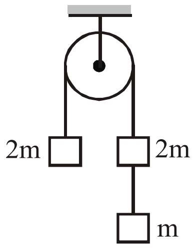
54. In the diagram shown in figure ($g = 10$ m/s^2)



	Column I		Column II
(A)	Acceleration of 2 kg block in m/s^2	(P)	8
(B)	Net force on 3 kg block in newton	(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

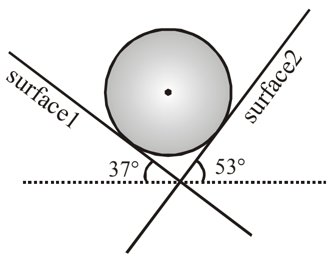
NL0082

55. Match the situations in column I to the accelerations of blocks in the column II (acceleration due to gravity is g and F is an additional force applied to one of the blocks ?

Column I	Column II
(A) 	(P) $\frac{g}{5}$
(B) 	(Q) $\frac{g}{3}$
(C) 	(R) $\frac{g}{2}$
(D) 	(S) $\frac{2g}{3}$
	(T) zero

NL0083

56. 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. ($g = 10\ ms^{-2}$)



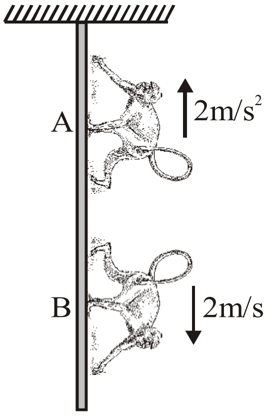
Column I	Column II
(A) Normal reaction by Surface 1	(P) Zero
(B) Normal reaction by surface 2	(Q) 60 N
(C) Force on sphere by Earth	(R) 80 N
(D) Net force on sphere	(S) 100 N
	(T) 120 N

NL0084

EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

1. 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.

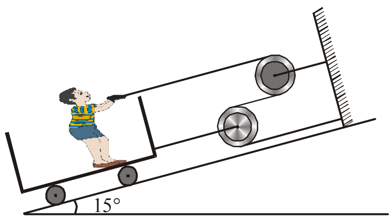


(A) 180 N (B) 200 N (C) 80 N (D) 216 N

NL0085

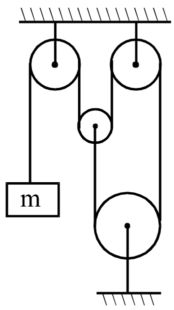
2. A trolley is being pulled up an incline plane by a man sitting on it (as shown in figure). He applies a force of 250 N. If the combined mass of the man and trolley is 100 kg, the acceleration of the trolley will be [sin15° = 0.26]

(A) 2.4 m/s^2 (B) 9.4 m/s^2
(C) 6.9 m/s^2 (D) 4.9 m/s^2



NL0086

3. If the string & all the pulleys are ideal, acceleration of mass *m* is :-



(A) $\frac{g}{2}$ (B) 0 (C) g (D) dependent on m

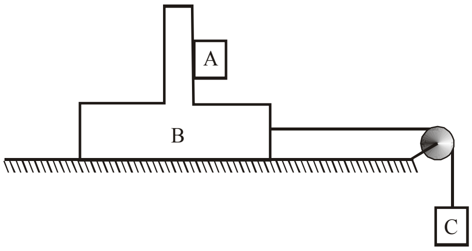
NL0087

4. 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, $\mu = 0.15$ 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 starts fall down is :-

(A) 4 m (B) 8 m (C) 16 m (D) 32 m

NL0088

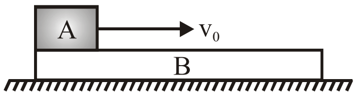
5. In the arrangement shown in the figure, mass of the block *B* and *A* is 2m and *m* respectively. Surface between *B* and floor is smooth. The block *B* is connected to the block *C* by means of a string-pulley system. If the whole system is released, then find the minimum value of mass of block *C*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

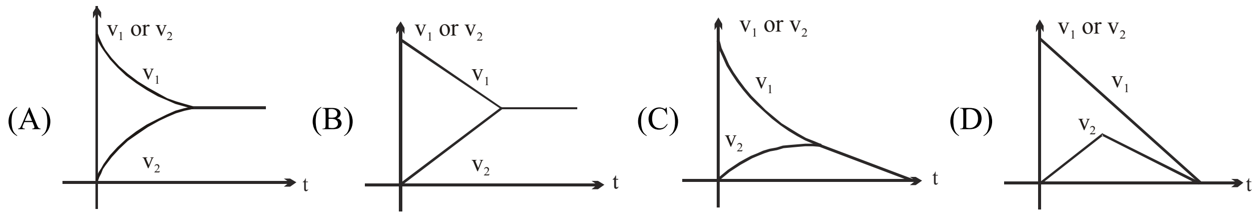


(A) $\frac{m}{\mu}$ (B) $\frac{2m+1}{\mu+1}$ (C) $\frac{3m}{\mu-1}$ (D) $\frac{6m}{\mu+1}$

NL0089

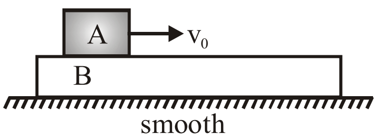
6. A block *A* is placed over a long rough plank *B* of same mass as shown in figure. The plank is placed over a smooth horizontal surface. At time t = 0, block *A* is given a velocity v_0 in horizontal direction. Let v_1 and v_2 be the velocities of *A* and *B* at time *t*. Then choose the correct graph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





NL0090

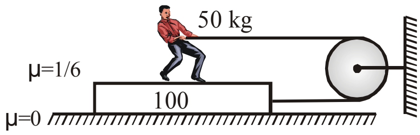
7. A block *A* of mass *m* is placed over a plank *B* of mass 2 m. Plank *B* is placed over a smooth horizontal surface. The coefficient of friction between *A* and *B* is 0.5. Block *A* is given a velocity v_0 towards right. Acceleration of *B* relative to *A* is :-



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

NL0091

8. 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 & plank move together, find force of friction acting on man.

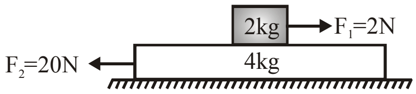


(A) $\frac{100}{3}$ N towards left (B) $\frac{100}{3}$ N towards right

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

NL0092

9. 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) 4 N

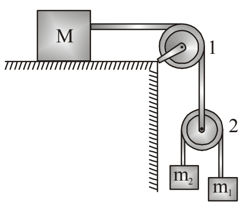
NL0093

10. 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) $\frac{W}{2} . cosec\, \theta$ (B) $\frac{W}{2} . \tan \theta$ (C) $\frac{W}{2} \cot \theta$ (D) none

NL0094

11. 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)

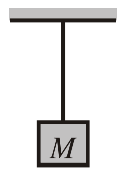


(A) 6 kg (B) 4 kg (C) 8 kg (D) 10 kg

NL0095

MULTIPLE CORRECT TYPE QUESTIONS

12. 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

NL0096

13. If a horizontal support exerts an upward force of 10 N on a block of weight 9.8 N placed on it, which of the following statements is/are correct. Assume acceleration due to gravity to be 9.8 m/s^2.

(A) The block exerts a force of 10 N on the support.

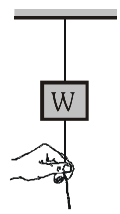
(B) The block exerts a force of 9.8 N on the support.

(C) The block has an upward acceleration.

(D) The block has a downward acceleration.

NL0097

14. A block of mass m is suspended from a fixed support with the help of a cord. Another identical cord is attached to the bottom of the block. Which of the following statement is /are true?



(A) If the lower cord is pulled suddenly, only the upper cord will break.

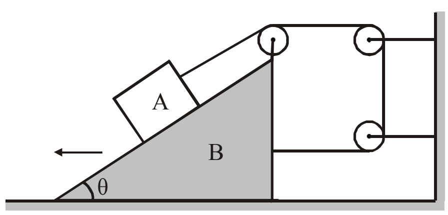
(B) If the lower cord is pulled suddenly, only the lower cord will break.

(C) If pull on the lower cord is increased gradually, only the lower cord will break.

(D) If pull on the lower cord is increased gradually, only the upper cord will break.

NL0098

15. 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 vertical upwards. Then



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

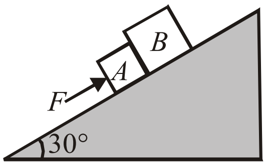
(B) Acceleration of A with respect to B is $2\sqrt{3}$ m/s^2.

(C) Angle θ is 60°.

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

NL0099

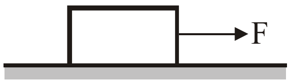
16. Two blocks A and B of mass 2 kg and 4 kg respectively are placed on a smooth inclined plane and 2 kg block is pushed by a force F acting parallel to the plane as shown. If N be the magnitude of contact force applied on B by A, which of the following is/are correct?



(A) if $F = 0$ N, $N = 10$ N
(B) if F=15 N, N=10 N
(C) If $F = 30$ N, $N = 20$ N
(D) if F=45 N, N=30 N

NL0100

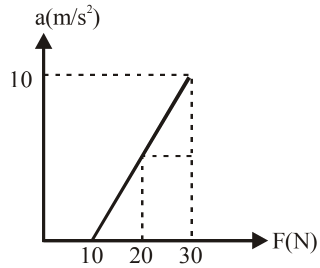
17. A block is kept on a rough surface and applied with a horizontal force as shown which is gradually increasing from zero. The coefficient of static and kinetic friction are $1/\sqrt{3}$ then



(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.

NL0101

18. 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 $F = 8$ N, friction between block and surface is 10 N.

NL0102

19. 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 (g=10 m/s^2)

(A) 1 m relative to ground
(B) 1 m relative to plank
(C) zero relative to plank
(D) 2 m relative to ground

NL0103

20. A block is released from rest from a point on a rough inclined place 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.

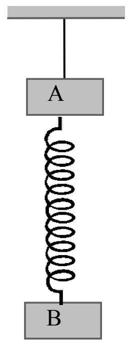
(B) The velocity of block after moving 4 m is 4 m/s.

(C) The block travels equal distances in equal intervals of time.

(D) The velocity of block increases linearly.

NL0104

21. 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.

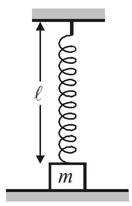
(D) Relative to the ground, accelerations of the blocks A and B are 2g downwards and zero respectively.

NL0105

COMPREHENSION TYPE QUESTIONS

Paragraph for Question No. 22 to 24

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.



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

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

NL0106

23. Force constant of the spring is :-

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

NL0106

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

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

NL0106

Paragraph for Question No. 25 to 29

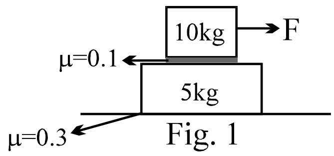


Fig. 1

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

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

NL0107

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

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

NL0107

27. 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

NL0107

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

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

NL0107

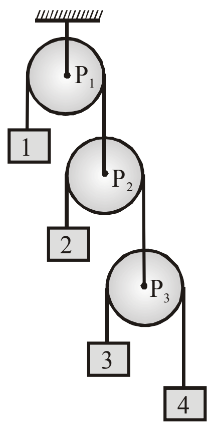
29. The acceleration of 10 kg block when $F = 30$ N is

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

NL0107

MATRIX MATCH TYPE QUESTION

30. 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		Column II	
(A)	Absolute acceleration of 2	(P)	(y–x) downwards
(B)	Absolute acceleration of 3	(Q)	(z–x–y) upwards
(C)	Absolute acceleration of 4	(R)	(x+y+z) downwards
		(S)	None

NL0108

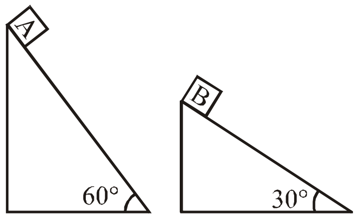
31. Velocity of three particles A, B and C varies with time t as, $\vec{v}_A = (2t\hat{i} + 6\hat{j})$ m/s; $\vec{v}_B = (3\hat{i} + 4\hat{j})$ m/s and $\vec{v}_C = (6\hat{i} - 4t\hat{j})$ m/s. Regarding the pseudo force match the following table

	Column I		**Column II**
(A)	On A as observed by B	(P)	Along positive x–direction
(B)	On B as observed by C	(Q)	Along negative x–direction
(C)	On A as observed by C	(R)	Along positive y–direction
(D)	On C as observed by A	(S)	Along negative y–direction
		(T)	Zero

NL0109

EXERCISE (JM)

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



(1) 4.9 ms^{-2} in vertical direction.
(2) 4.9 ms^{-2} in horizontal direction
(3) 9.8 ms^{-2} in vertical direction
(4) Zero

NL0110

2. The minimum force required to start pushing a body up a rough (frictional coefficient μ) inclined plane is F_1 while the minimum force needed to prevent it from sliding down is F_2. If the inclined plane makes an angle θ from the horizontal such that $\tan\theta = 2\mu$ then the ratio $\frac{F_1}{F_2}$ is :- **[AIEEE - 2011]**

(1) 4 (2) 1 (3) 2 (4) 3

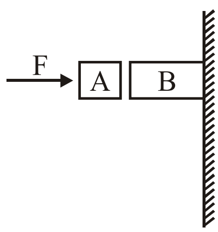
NL0111

3. 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

NL0112

4. 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

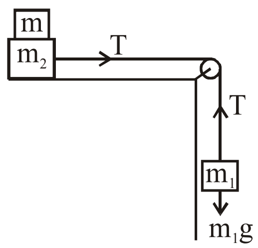
NL0113

5. 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 Online-2016]**

(1) 2 tan θ (2) 3 tan θ (3) tan θ (4) tan 2θ

NL0114

6. Two masses $m_1 = 5kg$ and $m_2 = 10kg$, 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

NL0115

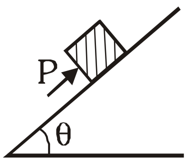
EXERCISE (JA)

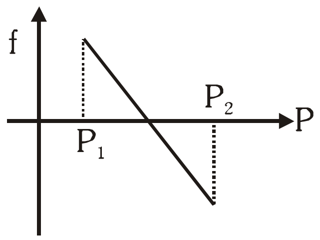
1. A piece of wire is bent in the shape of a parabola $y = kx^2$ (y-axis vertical) with a bead of mass m on it. The bead can slide on the wire without friction. It stays at the lowest point of the parabola when the wire is at rest. The wire is now accelerated parallel to the x-axis with a constant acceleration a. The distance of the new equilibrium position of the bead, where the bead can stay at rest with respect to the wire, from the y-axis is **[IIT-JEE-2009]**

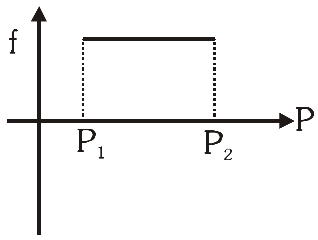
(A) $\frac{a}{gk}$ (B) $\frac{a}{2gk}$ (C) $\frac{2a}{gk}$ (D) $\frac{a}{4gk}$

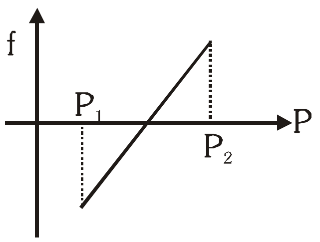
NL0116

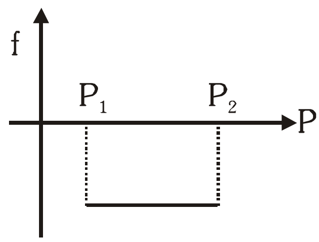
2. A block of mass m is on an inclined plane of angle θ. The coefficient of friction between the block and the plane is μ and $\tan\theta > \mu$. The block is held stationary by applying a force P parallel to the plane. The direction of force pointing up the plane is taken to be positive. As P is varied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



(A)


(B)


(C)


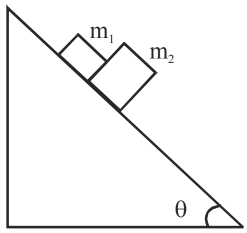
(D)


NL0117

3. 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 **[IIT-JEE-2011]**

NL0118

4. 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 :** $\tan(5.5°) \approx 0.1$; $\tan(11.5°) \approx 0.2$; $\tan(16.5°) \approx 0.3$] **[IIT-JEE-2014]**



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

NL0119

ANSWER KEY

EXERCISE (S-1)

1. Ans. (i) $\frac{m_1}{m_2} = \frac{1}{3}$ (ii) $a = 3/4$ m/s^2 **2. Ans.** $\frac{4}{3}W$ **3. Ans.** $\frac{g}{10} m/s^2$ **4. Ans.** 200 N, 10 m/s^2

5. Ans. 2 sec **6. Ans.** $0.5g, g$ **7. Ans.** 0.5 s **8. Ans.** 80 N, 48 N, 264 N **9. Ans. 24 N**

10. Ans. (i) $a_A = \frac{3g\downarrow}{2} = a_B$; $a_C = 0$; T = $mg/2$; **(ii)** $a_A = 2g\uparrow$, $a_B = 2g\downarrow$, $a_c = 0$, $T = 0$;

(iii) $a_A = a_B = g/2\uparrow$, $a_c = g\downarrow$, $T = \frac{3mg}{2}$;

11. Ans. $a = g \cot\theta$ **12. Ans.** $v_0/\cos\theta$ **13. Ans.** 5N, 16/31 kg **14. Ans.** $3a_B/4$

15. Ans. $\frac{a_0}{2}$ **16. Ans.** $(100\hat{i} - 200\hat{j})$ N **17. Ans.** 20 N vertically downward

18. Ans. (ma) **19. Ans.** 1/2 s **20. Ans.** 4/3 s **21. Ans.** $\mu_{min} = \frac{m\sin\theta\cos\theta}{m\cos^2\theta + M}$

22. Ans. 0.5 **23. Ans.** 1 kg **24. Ans.** $10\hat{i}$ **25. Ans.** 3/4 **26. Ans.** 30 N

EXERCISE (S-2)

1. Ans. 1440 N **2. Ans.** g m/s^2 **3. Ans.** 556.8 N, 1.47 s

4. Ans. (i) $a_A = g\downarrow$, $a_B = \frac{2g}{3}\uparrow$, $a_c = \frac{2g}{3}\downarrow$, $a_D = \frac{2g}{3}\downarrow$, $a_E = 0$

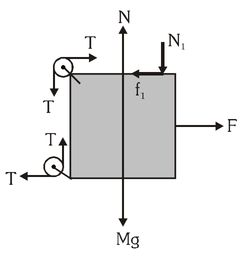
(ii) $a_A = 0$, $a_B = \frac{g}{3}\downarrow$, $a_C = \frac{g}{3}\uparrow$, $a_D = \frac{g}{3}\uparrow$, $a_E = g\downarrow$

(iii) $a_A = 0, a_B = g\downarrow, a_C = g\uparrow, a_D = 2g\downarrow, a_E = 0$

(iv) $a_A = 0, a_B = 3g\downarrow, a_C = \frac{3g}{2}\downarrow, a_D = \frac{3g}{2}\downarrow, a_E = 0$

5. Ans. $\frac{25}{24}$ **6. Ans.** 5 m/s^2 downwards, 0 m/s^2, 10 N **7. Ans.** 40 N

8. Ans. (i)



(ii) a = 3/5 m/s^2 , T = 18 N, F = 60N **9. Ans.** $-5\,\hat{i}$ m/s^2

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

1. Ans. (B)	2. Ans. (D)	3. Ans. (D)	4. Ans. (C)	5. Ans. (D)	6. Ans. (C)
7. Ans. (C)	8. Ans. (C)	9. Ans. (D)	10. Ans. (C)	11. Ans. (B)	12. Ans. (A)
13. Ans. (C)	14. Ans. (A)	15. Ans. (C)	16. Ans. (B)	17. Ans. (A)	18. Ans. (B)
19. Ans. (D)	20. Ans. (B)	21. Ans. (D)	22. Ans. (D)	23. Ans. (B)	24. Ans. (B)
25. Ans. (C)	26. Ans. (A)	27. Ans. (D)	28.Ans. (A)	29. Ans. (B)	30. Ans. (A)
31. Ans. (A)	32. Ans. (B)	33. Ans. (D)	34. Ans. (C)	35. Ans. (B)	36. Ans. (A)
37. Ans. (B)					

MULTIPLE CORRECT TYPE QUESTIONS

38. Ans. (A,D)	39. Ans. (B,C,D)	40. Ans. (A,C)	41. Ans. (A,B)	42. Ans. (A,B)	43. Ans. (A,C)

COMPREHENSION TYPE QUESTIONS

44. Ans. (D)	45. Ans. (D)	46. Ans. (A)	47. Ans. (D)	48. Ans. (B)	49. Ans. (C)
50. Ans. (B)	51. Ans. (D)	52. Ans. (C)	53. Ans. (C)		

MATRIX MATCH TYPE QUESTION

54. Ans. (A) - (R); (B) - (T); (C) - (Q); (D) - (T)

55. Ans. (A) - (R); (B) - (T); (C) - (R); (D) - (P)

56. Ans. (A)-R; (B)-Q; (C)-S; (D)-P

EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

1. Ans. (B)	2. Ans. (D)	3. Ans. (C)	4. Ans. (C)	5. Ans. (C)	6. Ans. (B)
7. Ans. (C)	8. Ans. (A)	9. Ans. (A)	10. Ans. (C)	11. Ans. (C)	

MULTIPLE CORRECT TYPE QUESTIONS

12. Ans. (C,D) 13. Ans. (A,C) 14. Ans. (B,D) 15. Ans. (A,C,D) 16. Ans. (B,C,D)

17. Ans. (A,B,C,D) 18. Ans. (A,B,C) 19. Ans. (A,B) 20. Ans. (A,B,D)

21. Ans. (A,B,D)

COMPREHENSION TYPE QUESTIONS

22. Ans. (B)	23. Ans. (A)	24. Ans. (B)	25. Ans. (A)	26. Ans. (A)	27. Ans. (A)
28. Ans. (C)	29. Ans. (A)				

MATRIX MATCH TYPE QUESTION

30. Ans. (A) - (S) ; (B) - (R) ; (C) - (Q)

31. Ans. (A) - (T); (B) - (R); (C) - (R); (D) - (Q)

EXERCISE (JM)

1. Ans. (1)	2. Ans. (4)	3. Ans. (3)	4. Ans. (1)	5. Ans. (3)	6. Ans. (1)

EXERCISE (JA)

1. Ans. (B)	2. Ans. (A)	3. Ans. 5	4. Ans. (D)