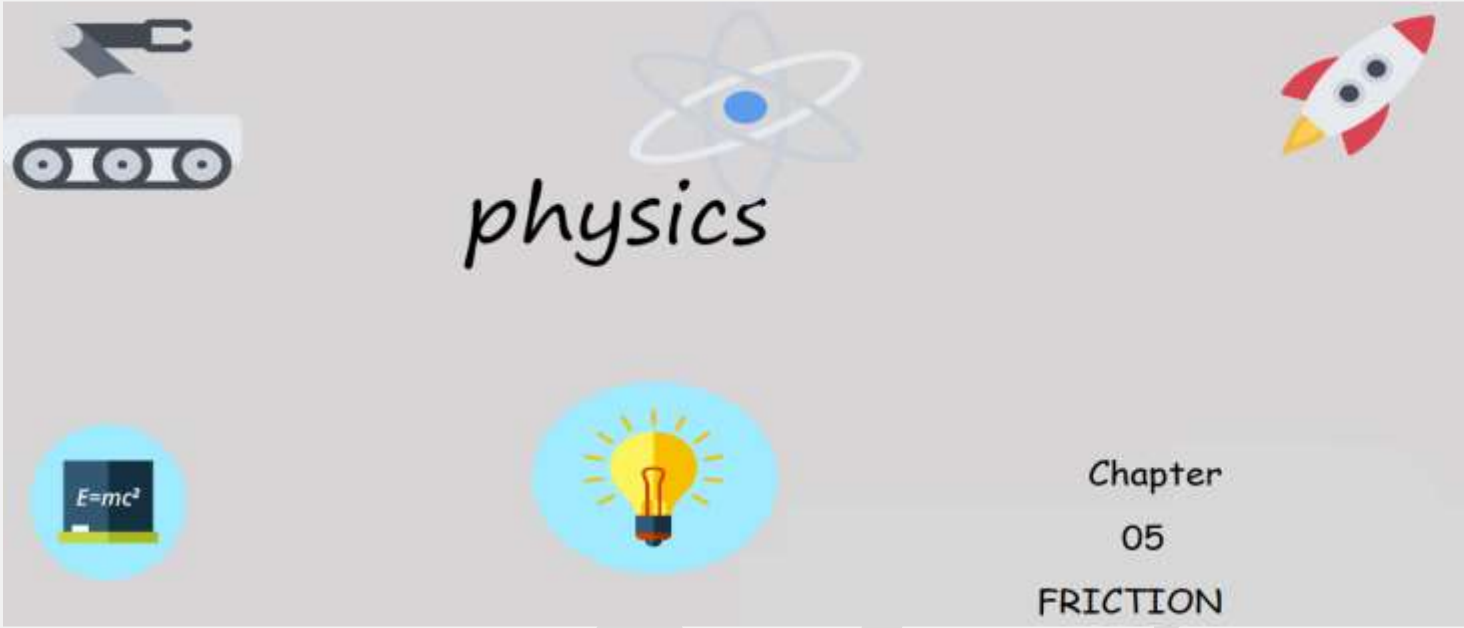


Introduction

If we slide or try to slide a body over a surface, the motion is resisted by a bonding between the body and the surface. This resistance is represented by a single force and is called friction force.

The force of friction is parallel to the surface and opposite to the direction of intended motion.

Types of Friction

(1) **Static friction :** The opposing force that comes into play when one body tends to move over the surface of another, but the actual motion has yet not started is called static friction.

(i) If applied force is P and the body remains at rest then static friction F = P.

(ii) If a body is at rest and no pulling force is acting on it, force of friction on it is zero.

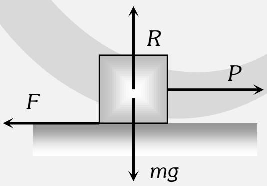


Fig. 5.1

(iii) Static friction is a self-adjusting force because it changes itself in accordance with the applied force and is always equal to net external force.

(2) **Limiting friction :** If the applied force is increased, the force of static friction also increases. If the applied force exceeds a certain (maximum) value, the body starts moving. This maximum value of static friction upto which body does not move is called limiting friction.

(i) The magnitude of limiting friction between any two bodies in contact is directly proportional to the normal reaction between them.

$F_l \propto R$ or $F_l = \mu_s R$

(ii) Direction of the force of limiting friction is always opposite to the direction in which one body is at the verge of moving over the other

(iii) Coefficient of static friction : (a) μ_s is called coefficient of static friction and is defined as the ratio of force of limiting friction and normal reaction $\mu_s = \frac{F}{R}$

(b) Dimension : $[M^0L^0T^0]$

(c) Unit : It has no unit.

(d) Value of μ depends on material and nature of surfaces in contact that means whether dry or wet ; rough or smooth polished or non-polished.

(e) Value of μ does not depend upon apparent area of contact.

(3) **Kinetic or dynamic friction :** If the applied force is increased further and sets the body in motion, the friction opposing the motion is called kinetic friction.

(i) Kinetic friction depends upon the normal reaction.

$F_k \propto R$ or $F_k = \mu_k R$ where μ_k is called the coefficient of kinetic friction

(ii) Value of μ_k depends upon the nature of surface in contact.

(iii) Kinetic friction is always lesser than limiting friction

$F_k < F_l \ \therefore \ \mu_k < \mu_s$

i.e. coefficient of kinetic friction is always less than coefficient of static friction. Thus we require more force to start a motion than to maintain it against friction. This is because once the motion starts actually ; inertia of rest has been overcome. Also when motion has actually started, irregularities of one surface have little time to get locked again into the irregularities of the other surface.

(iv) Kinetic friction does not depend upon the velocity of the body.

(v) Types of kinetic friction

(a) **Sliding friction** : The opposing force that comes into play when one body is actually sliding over the surface of the other body is called sliding friction. *e.g.* A flat block is moving over a horizontal table.

(b) **Rolling friction** : When objects such as a wheel (disc or ring), sphere or a cylinder rolls over a surface, the force of friction that comes into play is called rolling friction.

❑ Rolling friction is directly proportional to the normal reaction (R) and inversely proportional to the radius (r) of the rolling cylinder or wheel.

$$F_{rolling} = \mu_r \frac{R}{r}$$

μ_r is called coefficient of rolling friction. It would have the dimensions of length and would be measured in *metre*.

❑ Rolling friction is often quite small as compared to the sliding friction. That is why heavy loads are transported by placing them on carts with wheels.

❑ In rolling the surfaces at contact do not rub each other.

❑ The velocity of point of contact with respect to the surface remains zero all the times although the centre of the wheel moves forward.

Graph Between Applied Force and Force of Friction

(1) Part OA of the curve represents static friction (F_s). Its value increases linearly with the applied force

(2) At point A the static friction is maximum. This represent limiting friction (F_l).

(3) Beyond A, the force of friction is seen to decrease slightly. The portion BC of the curve represents the kinetic friction (F_k).

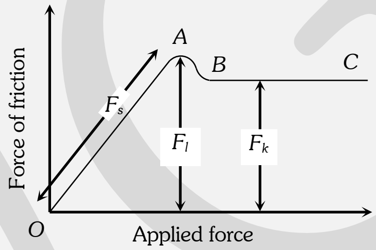


Fig. 5.2

(4) As the portion BC of the curve is parallel to x-axis therefore kinetic friction does not change with the applied force, it remains constant, whatever be the applied force.

Friction is a Cause of Motion

It is a general misconception that friction always opposes the motion. No doubt friction opposes the motion of a moving body but in many cases it is also the cause of motion. For example :

(1) While moving, a person or vehicle pushes the ground backwards (action) and the rough surface of ground reacts and exerts a forward force due to friction which causes the motion. If there had been no friction there will be slipping and no motion.

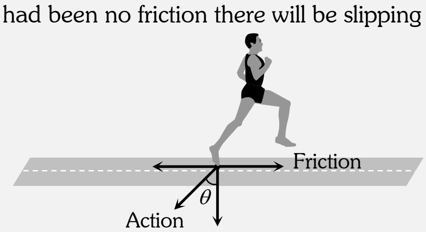


Fig. 5.3

(2) During cycling, the rear wheel moves by the force communicated to it by pedalling while front wheel moves by itself. So, when pedalling a bicycle, the force exerted by rear wheel on ground makes force of friction act on it in the forward direction (like walking). Front wheel moving by itself experience force of friction in backward direction (like rolling of a ball). [However, if pedalling is stopped both wheels move by themselves and so experience force of friction in backward direction].

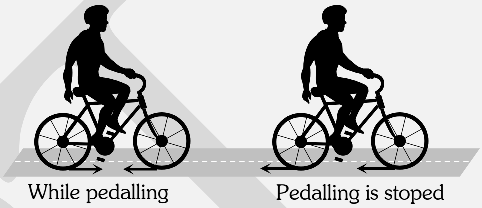


Fig. 5.4

(3) If a body is placed in a vehicle which is accelerating, the force of friction is the cause of motion of the body along with the vehicle (*i.e.*, the body will remain at rest in the accelerating vehicle until $ma < \mu_s mg$). If there had been no friction between body and vehicle, the body will not move along with the vehicle.

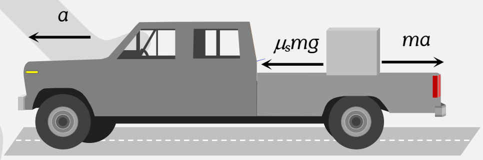


Fig. 5.5

From these examples it is clear that without friction motion cannot be started, stopped or transferred from one body to the other.

Advantages and Disadvantages of Friction

(1) **Advantages of friction**

(i) Walking is possible due to friction.

(ii) Two body sticks together due to friction.

Fig. 5.6

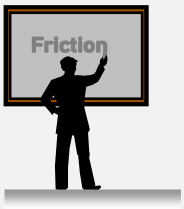


Fig. 5.7

(iii) Brake works on the basis of friction.

(iv) Writing is not possible without friction.

(v) The transfer of motion from one part of a machine to other part through belts is possible by friction.

(2) **Disadvantages of friction**

(i) Friction always opposes the relative motion between any two bodies in contact. Therefore extra energy has to be spent in over coming friction. This reduces the efficiency of machine.

(ii) Friction causes wear and tear of the parts of machinery in contact. Thus their lifetime reduces.

(iii) Frictional force result in the production of heat, which causes damage to the machinery.

Methods of Changing Friction

We can reduce friction

(1) By polishing.

(2) By lubrication.

(3) By proper selection of material.

(4) By streamlining the shape of the body.

(5) By using ball bearing.

Also we can increase friction by throwing some sand on slippery ground. In the manufacturing of tyres, synthetic rubber is preferred because its coefficient of friction with the road is larger.

Angle of Friction

Angle of friction may be defined as the angle which the resultant of limiting friction and normal reaction makes with the normal reaction.

By definition angle θ is called the angle of friction

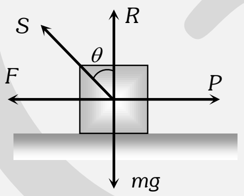


Fig. 5.8

$$\tan\theta = \frac{F_l}{R}$$

$\therefore$ $\tan\theta = \mu_s$

[As we know $\frac{F_l}{R} = \mu_s$]

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

Hence coefficient of static friction is equal to tangent of the angle of friction.

Resultant Force Exerted by Surface on Block

In the above figure resultant force $S = \sqrt{F^2 + R^2}$

$$S = \sqrt{(\mu mg)^2 + (mg)^2}$$

$$S = mg\sqrt{\mu^2 + 1}$$

when there is no friction $(\mu = 0)$ S will be minimum

i.e. $S = mg$

Hence the range of S can be given by, $mg \le S \le mg\sqrt{\mu^2 + 1}$

Angle of Repose

Angle of repose is defined as the angle of the inclined plane with horizontal such that a body placed on it is just begins to slide.

By definition, α is called the angle of repose.

In limiting condition $F = mg\sin\alpha$ and $R = mg\cos\alpha$

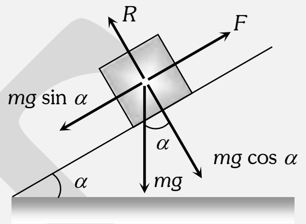


Fig. 5.9

So $\frac{F}{R} = \tan\alpha$

$\therefore$ $\frac{F}{R} = \mu_s = \tan\theta = \tan\alpha$ [As we know $\frac{F}{R} = \mu_s = \tan\theta$]

Thus the coefficient of limiting friction is equal to the tangent of angle of repose.

As well as $\alpha = \theta$ i.e. angle of repose = angle of friction.

Calculation of Required Force in Different Situation

If W = weight of the body, θ = angle of friction, $\mu = \tan\theta =$ coefficient of friction

Then we can calculate required force for different situation in the following manner :

(1) **Minimum pulling force P at an angle α from the horizontal**

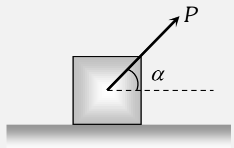


Fig. 5.10

By resolving P in horizontal and vertical direction (as shown in figure)

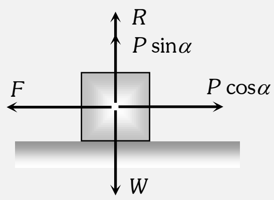


Fig. 5.11

For the condition of equilibrium

$F = P\cos\alpha$ and $R = W - P\sin\alpha$

By substituting these value in $F = \mu R$

$P\cos\alpha = \mu(W - P\sin\alpha)$

$\Rightarrow$ $P\cos\alpha = \frac{\sin\theta}{\cos\theta}(W - P\sin\alpha)$ [As $\mu = \tan\theta$]

$$\Rightarrow \quad P = \frac{W\sin\theta}{\cos(\alpha - \theta)}$$

(2) **Minimum pushing force P at an angle α from the horizontal**

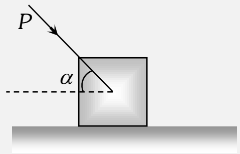


Fig. 5.12

By Resolving P in horizontal and vertical direction (as shown in the figure)

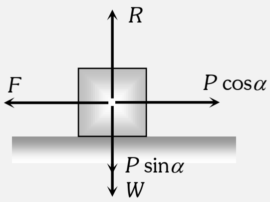


Fig. 5.13

For the condition of equilibrium

$F = P\cos\alpha$ and $R = W + P\sin\alpha$

By substituting these value in $F = \mu R$

$\Rightarrow \quad P\cos\alpha = \mu(W + P\sin\alpha)$

$\Rightarrow \quad P\cos\alpha = \dfrac{\sin\theta}{\cos\theta}(W + P\sin\alpha)$ [As $\mu = \tan\theta$]

$\Rightarrow \quad P = \dfrac{W\sin\theta}{\cos(\alpha+\theta)}$

(3) **Minimum pulling force P to move the body up on an inclined plane**

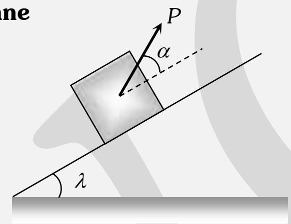


Fig. 5.14

By Resolving P in the direction of the plane and perpendicular to the plane (as shown in the figure)

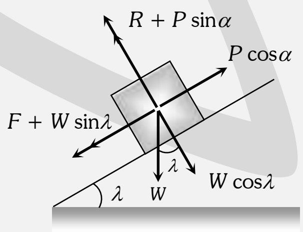


Fig. 5.15

For the condition of equilibrium

$R + P\sin\alpha = W\cos\lambda$

$\therefore \quad R = W\cos\lambda - P\sin\alpha$ and $F + W\sin\lambda = P\cos\alpha$

$\therefore \quad F = P\cos\alpha - W\sin\lambda$

By substituting these values in $F = \mu R$ and solving we get

$P = \dfrac{W\sin(\theta+\lambda)}{\cos(\alpha-\theta)}$

(4) **Minimum force to move a body in downward direction along the surface of inclined plane**

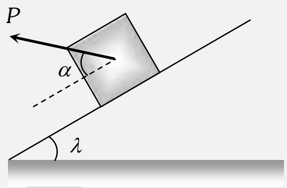


Fig. 5.16

By Resolving P in the direction of the plane and perpendicular to the plane (as shown in the figure)

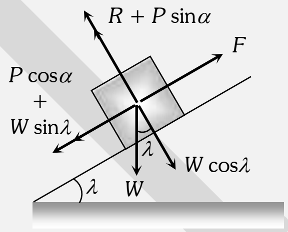


Fig. 5.17

For the condition of equilibrium

$R + P\sin\alpha = W\cos\lambda$

$\therefore \quad R = W\cos\lambda - P\sin\alpha$ and $F = P\cos\alpha + W\sin\lambda$

By substituting these values in $F = \mu R$ and solving we get

$P = \dfrac{W\sin(\theta-\lambda)}{\cos(\alpha-\theta)}$

(5) **Minimum force to avoid sliding of a body down on an inclined plane**

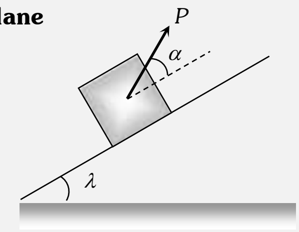


Fig. 5.18

By Resolving P in the direction of the plane and perpendicular to the plane (as shown in the figure)

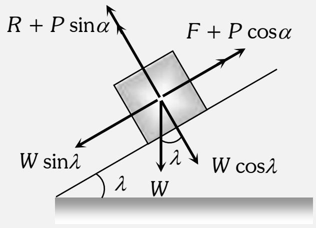


Fig. 5.19

For the condition of equilibrium

$R + P\sin\alpha = W\cos\lambda$

$\therefore \quad R = W\cos\lambda - P\sin\alpha$ and $P\cos\alpha + F = W\sin\lambda$

$\therefore \quad F = W\sin\lambda - P\cos\alpha$

By substituting these values in $F = \mu R$ and solving we get

$P = W\left[\dfrac{\sin(\lambda-\theta)}{\cos(\theta+\alpha)}\right]$

(6) **Minimum force for motion along horizontal surface and its direction**

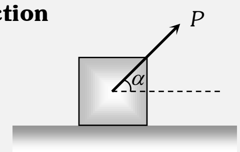


Fig. 5.20

Let the force P be applied at an angle α with the horizontal.

By resolving P in horizontal and vertical direction (as shown in figure)

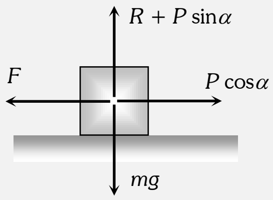


Fig. 5.21

For vertical equilibrium

$R + P\sin\alpha = mg$

$\therefore \; R = mg - P\sin\alpha$ ...(i)

and for horizontal motion

$P\cos\alpha \geq F$

i.e. $P\cos\alpha \geq \mu R$ ...(ii)

Substituting value of R from (i) in (ii)

$P\cos\alpha \geq \mu(mg - P\sin\alpha)$

$$P \geq \frac{\mu mg}{\cos\alpha + \mu\sin\alpha} \quad \text{...(iii)}$$

For the force P to be minimum $(\cos\alpha + \mu\sin\alpha)$ must be maximum *i.e.*

$$\frac{d}{d\alpha}[\cos\alpha + \mu\sin\alpha] = 0$$

$\Rightarrow \; -\sin\alpha + \mu\cos\alpha = 0$

$\therefore \quad \tan\alpha = \mu$

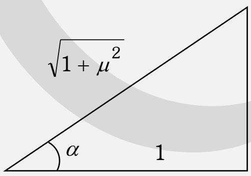


Fig. 5.22

or $\quad \alpha = \tan^{-1}(\mu) = \text{angle of friction}$

i.e. For minimum value of P its angle from the horizontal should be equal to angle of friction

As $\tan\alpha = \mu$ so from the figure, $\sin\alpha = \dfrac{\mu}{\sqrt{1+\mu^2}}$

and $\cos\alpha = \dfrac{1}{\sqrt{1+\mu^2}}$

By substituting these value in equation (iii)

$$P \geq \frac{\mu mg}{\dfrac{1}{\sqrt{1+\mu^2}} + \dfrac{\mu^2}{\sqrt{1+\mu^2}}} \geq \frac{\mu mg}{\sqrt{1+\mu^2}}$$

$$\therefore \quad P_{\min} = \frac{\mu mg}{\sqrt{1+\mu^2}}$$

Acceleration of a Block Against Friction

(1) **Acceleration of a block on horizontal surface**

When body is moving under application of force P, then kinetic friction opposes its motion.

Let a is the net acceleration of the body

From the figure

$ma = P - F_k$

$\therefore \; a = \dfrac{P - F_k}{m}$

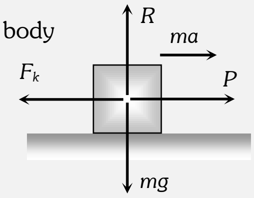


Fig. 5.23

(2) **Acceleration of a block sliding down over a rough inclined plane**

When angle of inclined plane is more than angle of repose, the body placed on the inclined plane slides down with an acceleration a.

From the figure $ma = mg\sin\theta - F$

$\Rightarrow \; ma = mg\sin\theta - \mu R$

$\Rightarrow \; ma = mg\sin\theta - \mu mg\cos\theta$

$\therefore$ Acceleration $a = g[\sin\theta - \mu\cos\theta]$

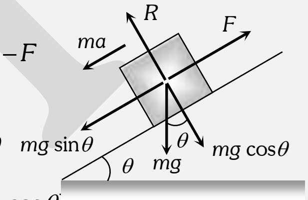


Fig. 5.24

Note : ❑ For frictionless inclined plane $\mu = 0$ $\therefore a = g\sin\theta$.

(3) **Retardation of a block sliding up over a rough inclined plane**

When angle of inclined plane is less than angle of repose, then for the upward motion

$ma = mg\sin\theta + F$

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

Retardation $a = g[\sin\theta + \mu\cos\theta]$

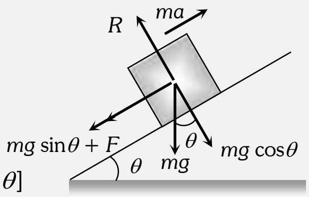


Fig. 5.25

Note : ❑ For frictionless inclined plane $\mu = 0$ $\therefore a = g\sin\theta$

Work done against friction

(1) **Work done over a rough inclined surface**

If a body of mass m is moved up slowly on a rough inclined plane through distance s, then

Work done = force × distance

$= ma \times s = mg[\sin\theta + \mu\cos\theta]s = mgs[\sin\theta + \mu\cos\theta]$

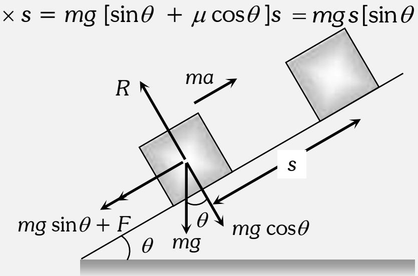


Fig. 5.26

(2) **Work done over a horizontal surface**

In the above expression if we put $\theta = 0$ then

Work done = force × distance = $F \times s = \mu\, mg\, s$

It is clear that work done depends upon

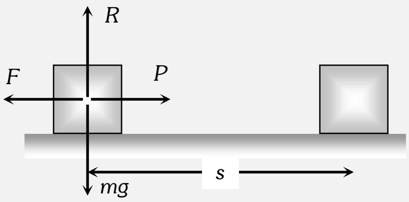


Fig. 5.27

(i) Weight of the body.

(ii) Material and nature of surface in contact.

(iii) Distance moved.

Motion of Two Bodies one Resting on the Other

When a body A of mass m is resting on a body B of mass M then two conditions are possible

(1) A force F is applied to the upper body, (2) A force F is applied to the lower body

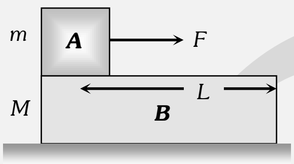


Fig. 5.28

We will discuss above two cases one by one in the following manner :

(1) **A force *F* is applied to the upper body, then following four situations are possible**

(i) **When there is no friction**

(a) The body A will move on body B with acceleration (F/m).

$$a_A = F/m$$

(b) The body B will remain at rest

$$a_B = 0$$

(c) If L is the length of B as shown in figure, A will fall from B after time t

$$t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2mL}{F}} \qquad \left[\text{As } s = \frac{1}{2}at^2 \text{ and } a = F/m\right]$$

(ii) **If friction is present between *A* and *B* only and applied force is less than limiting friction ($F < F_l$)**

(F = Applied force on the upper body, F_l = limiting friction between A and B, F_k = Kinetic friction between A and B)

(a) The body A will not slide on body B till $F < F_l$ *i.e.* $F < \mu_s mg$

(b) Combined system ($m + M$) will move together with common acceleration $a_A = a_B = \dfrac{F}{M+m}$

(iii) **If friction is present between *A* and *B* only and applied force is greater than limiting friction ($F > F_l$)**

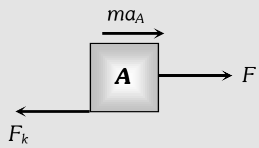
In this condition the two bodies will move in the same direction (*i.e.* of applied force) but with different acceleration. Here force of kinetic friction $\mu_k mg$ will oppose the motion of A while cause the motion of B.

$$F - F_k = ma_A$$

i.e. $$a_A = \frac{F - F_k}{m}$$

$$a_A = \frac{(F - \mu_k mg)}{m}$$

Free body diagram of A

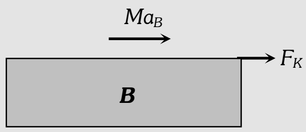


$$F_k = M a_B$$

i.e. $$a_B = \frac{F_k}{M}$$

$\therefore$ $$a_B = \frac{\mu_k mg}{M}$$

Free body diagram of B



Note : ❑ As both the bodies are moving in the same direction.

Acceleration of body A relative to B will be

$$a = a_A - a_B = \frac{MF - \mu_k mg(m+M)}{mM}$$

So, A will fall from B after time

$$t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2mML}{MF - \mu_k mg(m+M)}}$$

(iv) **If there is friction between *B* and floor**

(where $F_l' = \mu'(M+m)g$ = limiting friction between B and floor, F_k = kinetic friction between A and B)

B will move only if $F_k > F_l'$ and then $F_k - F_l' = M a_B$

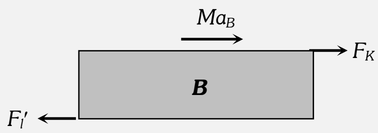


Fig. 5.29

However if B does not move then static friction will work (not limiting friction) between body B and the floor *i.e.* friction force = applied force (= F_k) not F_l'.

(2) **A force *F* is applied to the lower body, then following four situations are possible**

(i) **When there is no friction**

(a) B will move with acceleration (F/M) while A will remain at rest (relative to ground) as there is no pulling force on A.

$$a_B = \left(\frac{F}{M}\right) \text{ and } a_A = 0$$

(b) As relative to B, A will move backwards with acceleration (F/M) and so will fall from it in time t.

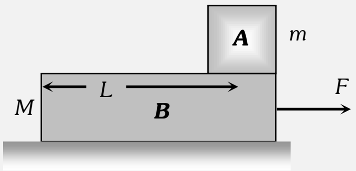


Fig. 5.30

$$\therefore \quad t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2ML}{F}}$$

(ii) **If friction is present between A and B only and $F' < F_l$**

(where F' = Pseudo force on body A and F_l = limiting friction between body A and B)

(a) Both the body will move together with common acceleration $a = \dfrac{F}{M+m}$

(b) Pseudo force on the body A,

$$F' = ma = \frac{mF}{m+M} \text{ and } F_l = \mu_s mg$$

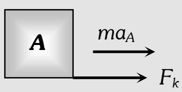
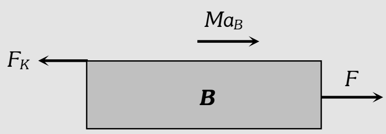
(c) $F' < F_l \;\Rightarrow\; \dfrac{mF}{m+M} < \mu_s mg \;\Rightarrow\; F < \mu_s(m+M)g$

So both bodies will move together with acceleration $a_A = a_B = \dfrac{F}{m+M}$ if $F < \mu_s[m+M]g$

(iii) **If friction is present between A and B only and $F > F_l'$**

(where $F_l' = \mu_s mg$ = limiting friction between body A and B)

Both the body will move with different acceleration. Here force of kinetic friction $\mu_k mg$ will oppose the motion of B while will cause the motion of A.

$ma_A = \mu_k mg$ i.e. $a_A = \mu_k g$	Free body diagram of A 
$F - F_k = Ma_B$ i.e. $a_B = \dfrac{[F - \mu_k mg]}{M}$	Free body diagram of B 

Note : ❑ As both the bodies are moving in the same direction

Acceleration of body A relative to B will be

$$a = a_A - a_B = -\left[\frac{F - \mu_k g(m+M)}{M}\right]$$

Negative sign implies that relative to B, A will move backwards and will fall it after time

$$t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2ML}{F - \mu_k g(m+M)}}$$

(iv) **If there is friction between B and floor and $F > F_l''$:**

(where $F_l'' = \mu_s(m+M)g$ = limiting friction between body B and surface)

The system will move only if $F > F_l''$ then replacing F by $F - F_l''$. The entire case (iii) will be valid.

However if $F < F_l''$ the system will not move and friction between B and floor will be F while between A and B is zero.

Motion of an Insect in the Rough Bowl

The insect crawl up the bowl, up to a certain height h only till the component of its weight along the bowl is balanced by limiting frictional force.

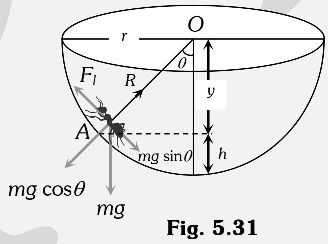


Fig. 5.31

Let m = mass of the insect, r = radius of the bowl, μ = coefficient of friction

for limiting condition at point A

$R = mg\cos\theta$ ......(i) and $F_l = mg\sin\theta$ ......(ii)

Dividing (ii) by (i)

$$\tan\theta = \frac{F_l}{R} = \mu \qquad [\text{As } F_l = \mu R]$$

$$\therefore \frac{\sqrt{r^2 - y^2}}{y} = \mu \quad \text{or} \quad y = \frac{r}{\sqrt{1+\mu^2}}$$

So $h = r - y = r\left[1 - \dfrac{1}{\sqrt{1+\mu^2}}\right]$, $\therefore\; h = r\left[1 - \dfrac{1}{\sqrt{1+\mu^2}}\right]$

Minimum Mass Hung from the String to Just Start the Motion

(1) **When a mass m_1 placed on a rough horizontal plane**

Another mass m_2 hung from the string connected by frictionless pulley, the tension (T) produced in string will try to start the motion of mass m_1.

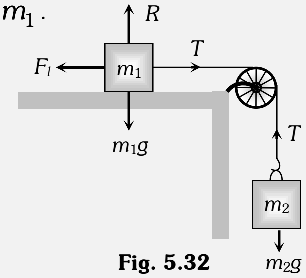


Fig. 5.32

At limiting condition $T = F_l$

$\Rightarrow \quad m_2 g = \mu R \;\Rightarrow\; m_2 g = \mu\, m_1 g$

$\therefore\; m_2 = \mu m_1$ this is the minimum value of m_2 to start the motion.

Note : ❑ In the above condition Coefficient of friction $\mu = \dfrac{m_2}{m_1}$

(2) **When a mass m_1 placed on a rough inclined plane** Another mass m_2 hung from the string connected by frictionless pulley, the tension (T) produced in string will try to start the motion of mass m_1.

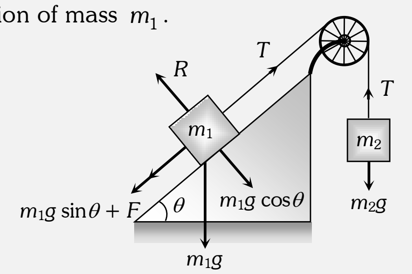


Fig. 5.33

At limiting condition

For $m_2 \quad T = m_2 g$ ...(i)

For $m_1 \quad T = m_1 g\sin\theta + F$

$\Rightarrow \quad T = m_1 g \sin\theta + \mu R$

$\Rightarrow\; T = m_1 g\sin\theta + \mu m_1 g\cos\theta$ ...(ii)

From equation (i) and (ii) $\quad m_2 = m_1[\sin\theta + \mu\cos\theta]$

this is the minimum value of m_2 to start the motion

Note : ❑ In the above condition Coefficient of friction

$$\mu = \left[\frac{m_2}{m_1\cos\theta} - \tan\theta\right]$$

Maximum Length of Hung Chain

A uniform chain of length l is placed on the table in such a manner that its l' part is hanging over the edge of table without sliding. Since the chain have uniform linear density therefore the ratio of mass and ratio of length for any part of the chain will be equal.

We know $\quad \mu = \dfrac{m_2}{m_1} = \dfrac{\text{mass hanging from the table}}{\text{mass lying on the table}}$

$\therefore$ For this case we can rewrite above expression in the following manner

$\mu = \dfrac{\text{length hanging from the table}}{\text{length lying on the table}}$ [As chain have uniform linear density]

$\therefore \qquad \mu = \dfrac{l'}{l - l'}$

by solving $l' = \dfrac{\mu\, l}{(\mu + 1)}$

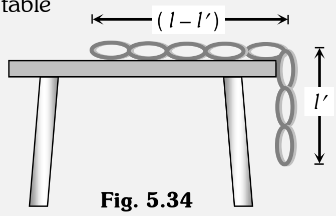


Fig. 5.34

Coefficient of Friction Between a Body and Wedge

A body slides on a smooth wedge of angle θ and its time of descent is t.

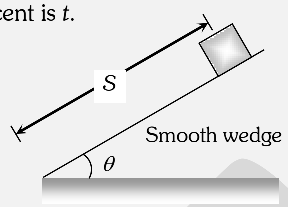


Fig. 5.35

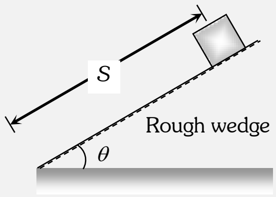


Fig. 5.36

If the same wedge made rough then time taken by it to come down becomes n times more (*i.e.* nt)

The length of path in both the cases are same.

For smooth wedge, $S = ut + \dfrac{1}{2}at^2$

$$S = \frac{1}{2}(g\sin\theta)t^2 \qquad \text{...(i)}$$

[As $u = 0$ and $a = g\sin\theta$]

For rough wedge, $S = ut + \dfrac{1}{2}at^2$

$$S = \frac{1}{2}g(\sin\theta - \mu\cos\theta)(nt)^2 \qquad \text{...(ii)}$$

[As $u = 0$ and $a = g(\sin\theta - \mu\cos\theta)$]

From equation (i) and (ii)

$$\frac{1}{2}(g\sin\theta)t^2 = \frac{1}{2}g(\sin\theta - \mu\cos\theta)(nt)^2$$

$\Rightarrow\; \sin\theta = (\sin\theta - \mu\cos\theta)n^2$

$\Rightarrow\; \mu = \tan\theta\left[1 - \dfrac{1}{n^2}\right]$

Stopping of Block Due to Friction

(1) **On horizontal road**

(i) **Distance travelled before coming to rest :** A block of mass m is moving initially with velocity u on a rough surface and due to friction, it comes to rest after covering a distance S.

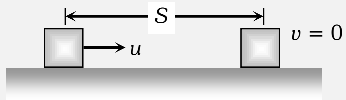


Fig. 5.37

Retarding force $F = ma = \mu R \;\Rightarrow\; ma = \mu mg$

$\therefore\; a = \mu g$

From $\; v^2 = u^2 - 2aS \;\Rightarrow\; 0 = u^2 - 2\mu g S$

[As $v = 0$, $a = \mu g$]

$\therefore \quad S = \dfrac{u^2}{2\mu g}$ or $S = \dfrac{P^2}{2\mu m^2 g}$

[As momentum $P = mu$]

(ii) **Time taken to come to rest**

From equation $v = u - at \;\Rightarrow\; 0 = u - \mu g t$

[As $v = 0, a = \mu g$]

$\therefore\; t = \dfrac{u}{\mu g}$

(2) **On inclined road :** When block starts with velocity u its kinetic energy will be converted into potential energy and some part of it goes against friction and after travelling distance S it comes to rest *i.e.* $v = 0$.

We know that retardation $a = g[\sin\theta + \mu\cos\theta]$

By substituting the value of v and a in the following equation

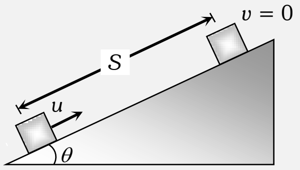


Fig. 5.38

$v^2 = u^2 - 2aS$

$\Rightarrow \quad 0 = u^2 - 2g[\sin\theta + \mu\cos\theta]S$

$\therefore \quad S = \dfrac{u^2}{2g(\sin\theta + \mu\cos\theta)}$

Stopping of Two Blocks Due to Friction

When two masses compressed towards each other and suddenly released then energy acquired by each block will be dissipated against friction and finally block comes to rest

i.e., $F \times S = E$ [Where F = Friction, S = Distance covered by block, E = Initial kinetic energy of the block]

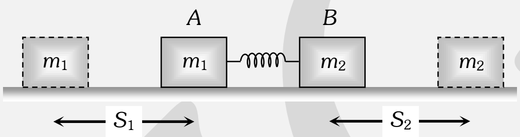


Fig. 5.39

$\Rightarrow \quad F \times S = \dfrac{P^2}{2m}$ [Where P = momentum of block]

$\Rightarrow \quad \mu mg \times S = \dfrac{P^2}{2m}$ [As $F = \mu mg$]

$\Rightarrow \quad S = \dfrac{P^2}{2\mu m^2 g}$

In the given condition P and μ are same for both the blocks.

So, $S \propto \dfrac{1}{m^2}$; $\therefore \dfrac{S_1}{S_2} = \left[\dfrac{m_2}{m_1}\right]^2$

Velocity at the Bottom of Rough Wedge

A body of mass m which is placed at the top of the wedge (of height h) starts moving downward on a rough inclined plane.

Loss of energy due to friction = FL (Work against friction)

PE at point $A = mgh$

KE at point $B = \dfrac{1}{2}mu^2$

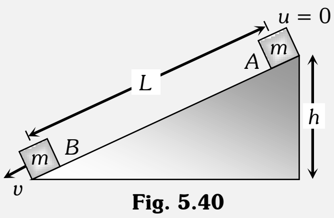


Fig. 5.40

By the law of conservation of energy

i.e. $\dfrac{1}{2}mv^2 = mgh - FL$

$v = \sqrt{\dfrac{2}{m}(mgh - FL)}$

Sticking of a Block With Accelerated Cart

When a cart moves with some acceleration toward right then a pseudo force (ma) acts on block toward left.

This force (ma) is action force by a block on cart.

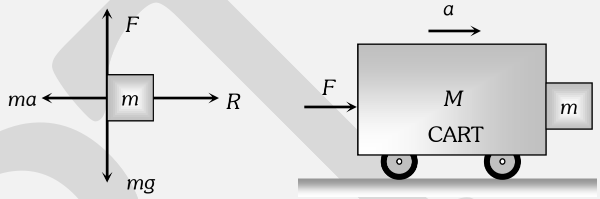


Fig. 5.41

Now block will remain static *w.r.t.* cart. If friction force $\mu R \geq mg$

$\Rightarrow \quad \mu ma \geq mg$ [As $R = ma$]

$\Rightarrow \quad a \geq \dfrac{g}{\mu}$

$\therefore \quad a_{min} = \dfrac{g}{\mu}$

This is the minimum acceleration of the cart so that block does not fall.

and the minimum force to hold the block together

$F_{min} = (M + m)a_{min}$

$F_{min} = (M + m)\dfrac{g}{\mu}$

Sticking of a Person with the Wall of Rotor

A person with a mass m stands in contact against the wall of a cylindrical drum (rotor). The coefficient of friction between the wall and the clothing is μ.

If Rotor starts rotating about its axis, then person thrown away from the centre due to centrifugal force at a particular speed ω, the person stuck to the wall even the floor is removed, because friction force balances its weight in this condition.

From the figure.

Friction force (F) = weight of person (mg)

$\Rightarrow \mu R = mg \Rightarrow \mu F_c = mg$

[Here, F_c= centrifugal force]

$\Rightarrow \quad \mu m\omega_{min}^2 r = mg$

$\therefore \quad \omega_{min} = \sqrt{\dfrac{g}{\mu r}}$

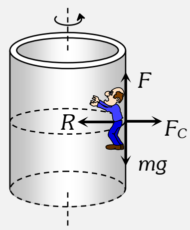


Fig. 5.42

Tips & Tricks

- Force of friction is non-conservative force.
- Force of friction always acts in a direction opposite to that of the relative motion between the surfaces.
- Rolling friction is much less than the sliding friction. This knowledge was used by man to invent the wheels.
- The friction between two surfaces increases (rather than to decrease), when the surfaces are made highly smooth.
- The atomic and molecular forces of attraction between the two surfaces at the point of contact give rise to friction between the surfaces.

Ordinary Thinking

Objective Questions

Static and limiting friction

1. The coefficient of friction μ and the angle of friction λ are related as

(a) $\sin\lambda = \mu$ (b) $\cos\lambda = \mu$

(c) $\tan\lambda = \mu$ (d) $\tan\mu = \lambda$

2. A force of 98 N is required to just start moving a body of mass 100 kg over ice. The coefficient of static friction is

(a) 0.6 (b) 0.4

(c) 0.2 (d) 0.1

3. A block weighs W is held against a vertical wall by applying a horizontal force F. The minimum value of F needed to hold the block is **[MP PMT 1993]**

(a) Less than W (b) Equal to W

(c) Greater than W (d) Data is insufficient

4. The maximum static frictional force is

(a) Equal to twice the area of surface in contact

(b) Independent of the area of surface in contact

(c) Equal to the area of surface in contact

(d) None of the above

5. Maximum value of static friction is called **[BHU 1995; RPET 2000]**

(a) Limiting friction (b) Rolling friction

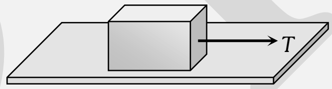
(c) Normal reaction (d) Coefficient of friction

6. Pulling force making an angle θ to the horizontal is applied on a block of weight W placed on a horizontal table. If the angle of friction is α, then the magnitude of force required to move the body is equal to **[EAMCET 1987]**

(a) $\dfrac{W\sin\alpha}{g\tan(\theta-\alpha)}$ (b) $\dfrac{W\cos\alpha}{\cos(\theta-\alpha)}$

(c) $\dfrac{W\sin\alpha}{\cos(\theta-\alpha)}$ (d) $\dfrac{W\tan\alpha}{\sin(\theta-\alpha)}$

7. In the figure shown, a block of weight 10 N resting on a horizontal surface. The coefficient of static friction between the block and the surface $\mu_s = 0.4$. A force of 3.5 N will keep the block in uniform motion, once it has been set in motion. A horizontal force of 3 N is applied to the block, then the block will **[MP PET 1993]**



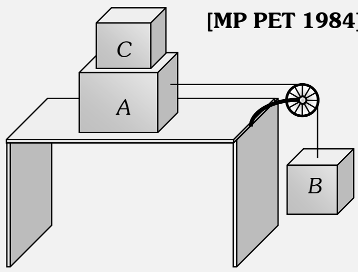
(a) Move over the surface with constant velocity

(b) Move having accelerated motion over the surface

(c) Not move

(d) First it will move with a constant velocity for some time and then will have accelerated motion

8. Two masses A and B of 10 kg and 5 kg respectively are connected with a string passing over a frictionless pulley fixed at the corner of a table as shown. The coefficient of static friction of A with table is 0.2. The minimum mass of C that may be placed on A to prevent it from moving is **[MP PET 1984]**



(a) 15 kg

(b) 10 kg

(c) 5 kg

(d) 12 kg

9. The limiting friction is

(a) Always greater than the dynamic friction

(b) Always less than the dynamic friction

(c) Equal to the dynamic friction

(d) Sometimes greater and sometimes less than the dynamic friction

10. Which is a suitable method to decrease friction

(a) Ball and bearings (b) Lubrication

11. (c) Polishing (d)

A uniform rope of length l lies on a table. If the coefficient of friction is μ, then the maximum length l_1 of the part of this rope which can overhang from the edge of the table without sliding down is

(a) $\frac{l}{\mu}$ (b) $\frac{l}{\mu+l}$

(c) $\frac{\mu l}{1+\mu}$ (d) $\frac{\mu l}{\mu-1}$

12. Which of the following statements is not true

[CMC Vellore 1989]

(a) The coefficient of friction between two surfaces increases as the surface in contact are made rough

(b) The force of friction acts in a direction opposite to the applied force

(c) Rolling friction is greater than sliding friction

(d) The coefficient of friction between wood and wood is less than 1

13. A block of 1 kg is stopped against a wall by applying a force F perpendicular to the wall. If $\mu = 0.2$ then minimum value of F will be

(a) 980 N (b) 49 N

(c) 98 N (d) 490 N

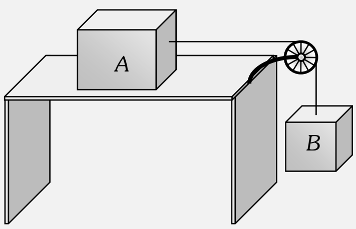
14. A heavy uniform chain lies on a horizontal table-top. If the coefficient of friction between the chain and table surface is 0.25, then the maximum fraction of length of the chain, that can hang over one edge of the table is **[CBSE PMT 1990]**

(a) 20% (b) 25%

(c) 35% (d) 15%

15. The blocks A and B are arranged as shown in the figure. The pulley is frictionless. The mass of A is 10 kg. The coefficient of friction of A with the horizontal surface is 0.20. The minimum mass of B to start the motion will be

[MP PET 1994]



(a) 2 kg

(b) 0.2 kg

(c) 5 kg

(d) 10 kg

16. Work done by a frictional force is

(a) Negative (b) Positive

[DPMT 2001]

(c) Zero (d) All of the above

17. A uniform chain of length L changes partly from a table which is kept in equilibrium by friction. The maximum length that can withstand without slipping is l, then coefficient of friction between the table and the chain is

[EAMCET (Engg.) 1995]

(a) $\frac{l}{L}$ (b) $\frac{l}{L+l}$

(c) $\frac{l}{L-l}$ (d) $\frac{L}{L+l}$

18. When two surfaces are coated with a lubricant, then they

[AFMC 1998, 99; AIIMS 2001]

(a) Stick to each other (b) Slide upon each other

(c) Roll upon each other (d) None of these

19. A 20 kg block is initially at rest on a rough horizontal surface. A horizontal force of 75 N is required to set the block in motion. After it is in motion, a horizontal force of 60 N is required to keep the block moving with constant speed. The coefficient of static friction is

[MP PMT 2003]

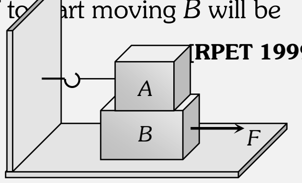
[AMU 1999]

(a) 0.38 (b) 0.44

(c) 0.52 (d) 0.60

20. A block A with mass 100 kg is resting on another block B of mass 200 kg. As shown in figure a horizontal rope tied to a wall holds it. The coefficient of friction between A and B is 0.2 while coefficient of friction between B and the ground is 0.3. The minimum required force F to start moving B will be

[RPET 1999]



(a) 900 N

(b) 100 N

(c) 1100 N

(d) 1200 N

21. To avoid slipping while walking on ice, one should take smaller steps because of the

(a) Friction of ice is large

(b) Larger normal reaction

(c) Friction of ice is small

(d) Smaller normal reaction

22. A box is lying on an inclined plane what is the coefficient of static friction if the box starts sliding when an angle of inclination is 60° **[KCET 2000]**

(a) 1.173 (b) 1.732

(c) 2.732 (d) 1.677

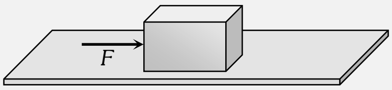
23. A block of mass 2 *kg* is kept on the floor. The coefficient of static friction is 0.4. If a force *F* of 2.5 *Newtons* is applied on the block as shown in the figure, the frictional force between the block and the floor will be **[MP PET 2000]**

(a) 2.5 *N*

(b) 5 *N*

(c) 7.84 *N*

(d) 10 *N*



24. Which one of the following is not used to reduce friction **[Kerala (Engg.) 2001]**

(a) Oil (b) Ball bearings

(c) Sand (d) Graphite

25. If a ladder weighing 250*N* is placed against a smooth vertical wall having coefficient of friction between it and floor is 0.3, then what is the maximum force of friction available at the point of contact between the ladder and the floor **[AIIMS 2002]**

(a) 75 *N* (b) 50 *N* (c) 35 *N* (d) 25 *N*

26. A body of mass 2 *kg* is kept by pressing to a vertical wall by a force of 100 *N*. The coefficient of friction between wall and body is 0.3. Then the frictional force is equal to **[Orissa JEE 2003]**

(a) 6 *N* (b) 20 *N* (c) 600 *N* (d) 700 *N*

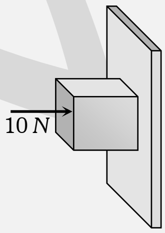
27. A horizontal force of 10 *N* is necessary to just hold a block stationary against a wall. The coefficient of friction between the block and the wall is 0.2. the weight of the block is **[AIEEE 2003]**

(a) 2 *N*

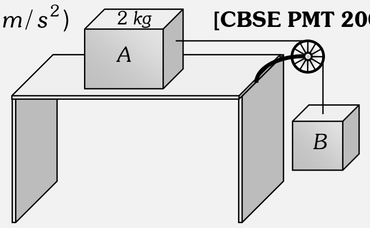
(b) 20 *N*

(c) 50 *N*

(d) 100 *N*



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



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

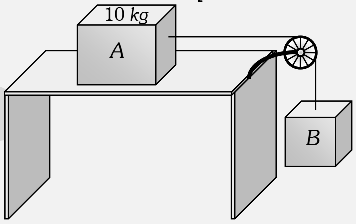
29. If mass of $A = 10\ kg$, coefficient of static friction = 0.2, coefficient of kinetic friction = 0.2. Then mass of *B* to start motion is **[Orissa PMT 2004]**

(a) 2 *kg*

(b) 2.2 *kg*

(c) 4.8 *kg*

(d) 200 *gm*



30. A uniform metal chain is placed on a rough table such that one end of chain hangs down over the edge of the table. When one-third of its length hangs over the edge, the chain starts sliding. Then, the coefficient of static friction is **[Kerala PET 2005]**

(a) $\frac{3}{4}$ (b) $\frac{1}{4}$ (c) $\frac{2}{3}$ (d) $\frac{1}{2}$

31. A lift is moving downwards with an acceleration equal to acceleration due to gravity. A body of mass *m* kept on the floor of the lift is pulled horizontally. If the coefficient of friction is μ, then the frictional resistance offered by the body is **[DPMT 2004]**

(a) mg (b) μmg (c) $2\mu mg$ (d) Zero

32. If a ladder weighing 250 *N* is placed against a smooth vertical wall having coefficient of friction between it and floor is 0.3, then what is the maximum force of friction available at the point of contact between the ladder and the floor **[BHU 2004]**

(a) 75 *N* (b) 50 *N* (c) 35 *N* (d) 25 *N*

Kinetic Friction

1. Which one of the following statements is correct

(a) Rolling friction is greater than sliding friction

(b) Rolling friction is less than sliding friction

(c) Rolling friction is equal to sliding friction

(d) Rolling friction and sliding friction are same

2. The maximum speed that can be achieved without skidding by a car on a circular unbanked road of radius *R* and coefficient of static friction μ, is

(a) μRg (b) $Rg\sqrt{\mu}$

(c) $\mu\sqrt{Rg}$ (d) $\sqrt{\mu Rg}$

3. A car is moving along a straight horizontal road with a speed v_0. If the coefficient of friction between the tyres and the road is μ, the shortest distance in which the car can be stopped is **[MP PET 1985; BHU 2002]**

(a) $\frac{v_0^2}{2\mu g}$ (b) $\frac{v_0}{\mu g}$

(c) $\left(\frac{v_0}{\mu g}\right)^2$ (d) $\frac{v_0}{\mu}$

4. A block of mass 5 *kg* is on a rough horizontal surface and is at rest. Now a force of 24 *N* is imparted to it with negligible impulse. If the coefficient of kinetic friction is 0.4 and $g = 9.8 m/s^2$, then the acceleration of the block is

(a) $0.26 m/s^2$ (b) $0.39 m/s^2$

(c) $0.69 m/s^2$ (d) $0.88 m/s^2$

5. A body of mass 2 *kg* is being dragged with uniform velocity of 2 *m/s* on a rough horizontal plane. The coefficient of friction between the body and the surface is 0.20. The amount of heat generated in 5 sec is $(J = 4.2\, joule/cal$ and $g = 9.8 m/s^2)$

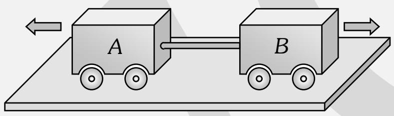
[MH CET (Med.) 2001]

(a) 9.33 *cal* (b) 10.21 *cal*

(c) 12.67 *cal* (d) 13.34 *cal*

6. Two carts of masses 200 *kg* and 300 *kg* on horizontal rails are pushed apart. Suppose the coefficient of friction between the carts and the rails are same. If the 200 *kg* cart travels a distance of 36 *m* and stops, then the distance travelled by the cart weighing 300 *kg* is

[CPMT 1989; DPMT 2002]



(a) 32 *m* (b) 24 *m*

(c) 16 *m* (d) 12 *m*

7. A body *B* lies on a smooth horizontal table and another body *A* is placed on *B*. The coefficient of friction between *A* and *B* is μ. What acceleration given to B will cause slipping to occur between *A* and *B*

(a) μg (b) g/μ

(c) μ/g (d) $\sqrt{\mu g}$

8. A 60 *kg* body is pushed with just enough force to start it moving across a floor and the same force continues to act afterwards. The coefficient of static friction and sliding friction are 0.5 and 0.4 respectively. The acceleration of the body is

(a) $6 m/s^2$ (b) $4.9 m/s^2$

(c) $3.92 m/s^2$ (d) $1 m/s^2$

9. A car turns a corner on a slippery road at a constant speed of $10 m/s$. If the coefficient of friction is 0.5, the minimum radius of the arc in meter in which the car turns is

(a) 20 (b) 10

(c) 5 (d) 4

10. A motorcyclist of mass *m* is to negotiate a curve of radius *r* with a speed *v*. The minimum value of the coefficient of friction so that this negotiation may take place safely, is

[Haryana CEE 1996]

(a) $v^2 rg$ (b) $\frac{v^2}{gr}$

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

11. On a rough horizontal surface, a body of mass 2 *kg* is given a velocity of 10 *m/s*. If the coefficient of friction is 0.2 and $g = 10 m/s^2$, the body will stop after covering a distance of

[MP PMT 1999]

(a) 10 *m* (b) 25 *m*

(c) 50 *m* (d) 250 *m*

12. A block of mass 50 *kg* can slide on a rough horizontal surface. The coefficient of friction between the block and the surface is 0.6. The least force of pull acting at an angle of 30° to the upward drawn vertical which causes the block to just slide is

(a) 29.43 *N* (b) 219.6 *N*

(c) 21.96 *N* (d) 294.3 *N*

13. A body of 10 *kg* is acted by a force of 129.4 *N* if $g = 9.8 m/sec^2$. The acceleration of the block is $10 m/s^2$. What is the coefficient of kinetic friction**[EAMCET 199**

(a) 0.03 (b) 0.01

(c) 0.30 (d) 0.25

14. Assuming the coefficient of friction between the road and tyres of a car to be 0.5, the maximum speed with which the car can move round a curve of 40.0 *m* radius without slipping, if the road is unbanked, should be **[AMU 1995]**

(a) 25 *m/s* (b) 19 *m/s*

(c) 14 *m/s* (d) 11 *m/s*

15. Consider a car moving along a straight horizontal road with a speed of 72 *km/h*. If the coefficient of kinetic friction between the tyres and the road is 0.5, the shortest distance in which the car can be stopped is $[g = 10 ms^{-2}]$

[CBSE PMT 1992]

(a) 30 m (b) 40 m

(c) 72 m (d) 20 m

16. A 500 kg horse pulls a cart of mass 1500 kg along a level road with an acceleration of $1 ms^{-2}$. If the coefficient of sliding friction is 0.2, then the force exerted by the horse in forward direction is

(a) 3000 N (b) 4000 N

(c) 5000 N (d) 6000 N

17. The maximum speed of a car on a road turn of radius 30m; if the coefficient of friction between the tyres and the road is 0.4; will be **[MH CET (Med.) 1999]**

(a) 9.84 m/s (b) 10.84 m/s

(c) 7.84 m/s (d) 5.84 m/s

18. A block of mass 50 kg slides over a horizontal distance of 1 m. If the coefficient of friction between their surfaces is 0.2, then work done against friction is

[BHU 2001; CBSE PMT 1999, 2000; AIIMS 2000]

(a) 98 J (b) 72J

(c) 56 J (d) 34 J

19. On the horizontal surface of a truck (μ = 0.6), a block of mass 1 kg is placed. If the truck is accelerating at the rate of 5m/sec^2 then frictional force on the block will be

[CBSE PMT 2001]

(a) 5 N (b) 6 N

(c) 5.88 N (d) 8 N

20. A vehicle of mass m is moving on a rough horizontal road with momentum P. If the coefficient of friction between the tyres and the road be μ, then the stopping distance is

[CBSE PMT 2001]

(a) $\frac{P}{2\mu m g}$ (b) $\frac{P^2}{2\mu m g}$

(c) $\frac{P}{2\mu m^2 g}$ (d) $\frac{P^2}{2\mu m^2 g}$

21. A body of weight 64 N is pushed with just enough force to start it moving across a horizontal floor and the same force continues to act afterwards. If the coefficients of static and dynamic friction are 0.6 and 0.4 respectively, the acceleration of the body will be (Acceleration due to gravity = g)

[EAMCET 2001]

(a) $\frac{g}{6.4}$ (b) 0.64 g

(c) $\frac{g}{32}$ (d) 0.2 g

22. When a body is moving on a surface, the force of friction is called **[MP PET 2002]**

(a) Static friction (b) Dynamic friction

(c) Limiting friction (d) Rolling friction

[SCRA 1998]

23. A block of mass 10 kg is placed on a rough horizontal surface having coefficient of friction μ = 0.5. If a horizontal force of 100 N is acting on it, then acceleration of the block will be

(a) 0.5 m/s^2 (b) 5 m/s^2

(c) 10 m/s^2 (d) 15 m/s^2

24. It is easier to roll a barrel than pull it along the road. This statement is **[BVP 2003]**

(a) False (b) True

(c) Uncertain (d) Not possible

25. A marble block of mass 2 kg lying on ice when given a velocity of 6 m/s is stopped by friction in 10s. Then the coefficient of friction is

(a) 0.01 (b) 0.02

(c) 0.03 (d) 0.06

26. A horizontal force of 129.4 N is applied on a 10 kg block which rests on a horizontal surface. If the coefficient of friction is 0.3, the acceleration should be

(a) $9.8 m/s^2$ (b) $10 m/s^2$

(c) $12.6 m/s^2$ (d) $19.6 m/s^2$

27. A 60 kg weight is dragged on a horizontal surface by a rope upto 2 $metres$. If coefficient of friction is $\mu = 0.5$, the angle of rope with the surface is 60° and $g = 9.8 m/sec^2$, then work done is

(a) 294 $joules$ (b) 315 $joules$

(c) 588 $joules$ (d) 197 $joules$

28. A car having a mass of 1000 kg is moving at a speed of 30 $metres/sec$. Brakes are applied to bring the car to rest. If the frictional force between the tyres and the road surface is 5000 $newtons$, the car will come to rest in **[MP PMT 1995]**

(a) 5 $seconds$ (b) 10 $seconds$

(c) 12 $seconds$ (d) 6 $seconds$

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

(a) $\mu_s < \mu_k < \mu_r$ (b) $\mu_k < \mu_r < \mu_s$

(c) $\mu_r < \mu_k < \mu_s$ (d) $\mu_r = \mu_k = \mu_s$

30. A body of mass 5*kg* rests on a rough horizontal surface of coefficient of friction 0.2. The body is pulled through a distance of 10*m* by a horizontal force of 25 *N*. The kinetic energy acquired by it is (g = 10 ms^2)

[EAMCET (Med.) 2000]

(a) 330 *J* (b) 150 *J*

(c) 100 *J* (d) 50 *J*

31. A motorcycle is travelling on a curved track of radius 500*m*. If the coefficient of friction between road and tyres is 0.5, the speed avoiding skidding will be

(a) 50 *m/s* (b) 75 *m/s*

(c) 25 *m/s* (d) 35 *m/s*

32. A fireman of mass 60 *kg* slides down a pole. He is pressing the pole with a force of 600 *N*. The coefficient of friction between the hands and the pole is 0.5, with what acceleration will the fireman slide down (g = 10 m/s^2)

[Pb. PMT 2002]

(a) 1 m/s^2 (b) 2.5 m/s^2

(c) 10 m/s^2 (d) 5 m/s^2

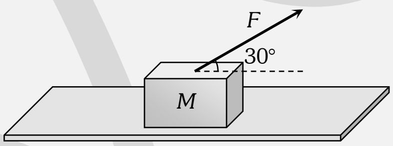
33. A block of mass $M = 5\,kg$ is resting on a rough horizontal surface for which the coefficient of friction is 0.2. When a force $F = 40\,N$ is applied, the acceleration of the block will be $(g = 10\,m/s^2)$

(a) 5.73 $m/\sec^2$

(b) 8.0 $m/\sec^2$

(c) 3.17 $m/\sec^2$

(d) 10.0 $m/\sec^2$



34. A body is moving along a rough horizontal surface with an initial velocity $6\,m/s$. If the body comes to rest after travelling 9 *m*, then the coefficient of sliding friction will be

[BCECE 2004]

(a) 0.4 (b) 0.2

(c) 0.6 (d) 0.8

35. Consider a car moving on a straight road with a speed of 100 *m/s*. The distance at which car can be stopped is [$\mu_k = 0.5$] **[AIEEE 2005]**

(a) 100 *m* (b) 400 *m*

(c) 800 *m* (d) 1000 *m*

36. A cylinder of 10 *kg* is sliding in a plane with an initial velocity of 10 *m/s*. If the coefficient of friction between the surface and cylinder is 0.5 then before stopping, it will cover. $(g = 10\,m/s^2)$ **[Pb. PMT 2004]**

(a) 2.5 *m* (b) 5 *m*

(c) 7.5 *m* (d) 10 *m*

Motion on Inclined Surface

1. When a body is lying on a rough inclined plane and does not move, the force of friction

[MH-CET (Med.) 2002]

(a) is equal to μR (b) is less than μR

(c) is greater than μR (d) is equal to R

2. When a body is placed on a rough plane inclined at an angle θ to the horizontal, its acceleration is

(a) $g(\sin\theta - \cos\theta)$ (b) $g(\sin\theta - \mu\cos\theta)$

(c) $g(\mu\sin\theta 1 - \cos\theta)$ (d) $g\mu(\sin\theta - \cos\theta)$

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

A body starts sliding down at an angle θ to horizontal. Then coefficient of friction is equal to **[CBSE PMT 19**

[MP PMT 2004]

(a) $\sin\theta$ (b) $\cos\theta$

(c) $\tan\theta$ (d) Independent of θ

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

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

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

5. The force required just to move a body up an inclined plane is double the force required just to prevent the body sliding down. If the coefficient of friction is 0.25, the angle of inclination of the plane is

(a) 36.8° (b) 45°

(c) 30° (d) 42.6°

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

(a) 0.33 (b) 0.25

(c) 0.75 (d) 0.80

7. The coefficient of friction between a body and the surface of an inclined plane at 45° is 0.5. If $g = 9.8\,m/s^2$, the acceleration of the body downwards in m/s^2 is

[EAMCET 1994]

(a) $\frac{4.9}{\sqrt{2}}$ (b) $4.9\sqrt{2}$

(c) $19.6\sqrt{2}$ (d) 4.9

8. A box is placed on an inclined plane and has to be pushed down. The angle of inclination is

(a) Equal to angle of friction

(b) More than angle of friction

(c) Equal to angle of repose

(d) Less than angle of repose

9. A force of 750 *N* is applied to a block of mass 102 *kg* to prevent it from sliding on a plane with an inclination angle 30° with the horizontal. If the coefficients of static friction and kinetic friction between the block and the plane are 0.4 and 0.3 respectively, then the frictional force acting on the block is **[SCRA 1994]**

(a) 750 *N* (b) 500 *N*

(c) 345 *N* (d) 250 *N*

10. A block is lying on an inclined plane which makes 60° with the horizontal. If coefficient of friction between block and plane is 0.25 and $g = 10\,m/s^2$, then acceleration of the block when it moves along the plane will be **[RPET 1997]**

(a) $2.50\,m/s^2$ (b) $5.00\,m/s^2$

(c) $7.4\,m/s^2$ (d) $8.66\,m/s^2$

11. A body of mass 100 *g* is sliding from an inclined plane of inclination 30°. What is the frictional force experienced if $\mu = 1.7$ **[BHU 1998]**

(a) $1.7 \times \sqrt{2} \times \frac{1}{\sqrt{3}}\,N$ (b) $1.7 \times \sqrt{3} \times \frac{1}{2}\,N$

(c) $1.7 \times \sqrt{3}\,N$ (d) $1.7 \times \sqrt{2} \times \frac{1}{3}\,N$

12. A body takes just twice the time as long to slide down a plane inclined at 30° to the horizontal as if the plane were frictionless. The coefficient of friction between the body and the plane is **[CBSE PMT 1990]** **[JIPMER 1999]**

(a) $\frac{\sqrt{3}}{4}$ (b) $\sqrt{3}$

(c) $\frac{4}{3}$ (d) $\frac{3}{4}$

13. A brick of mass 2 *kg* begins to slide down on a plane inclined at an angle of 45° with the horizontal. The force of friction will be **[CPMT 2000]**

(a) 19.6 *sin* 45° (b) 19.6 cos 45°

(c) 9.8 *sin* 45° (d) 9.8 cos 45°

14. The upper half of an inclined plane of inclination θ is perfectly smooth while the lower half is rough. A body starting from the rest at top comes back to rest at the bottom if the coefficient of friction for the lower half is given by **[EAMCET 1994]**

[Pb. PMT 2000]

(a) $\mu = \sin\theta$ (b) $\mu = \cot\theta$

(c) $\mu = 2\cos\theta$ (d) $\mu = 2\tan\theta$

15. A body is sliding down an inclined plane having coefficient of friction 0.5. If the normal reaction is twice that of the resultant downward force along the incline, the angle between the inclined plane and the horizontal is

[EAMCET (Engg.) 2000]

(a) 15° (b) 30°

(c) 45° (d) 60°

16. A body of mass 10 *kg* is lying on a rough plane inclined at an angle of 30° to the horizontal and the coefficient of friction is 0.5. the minimum force required to pull the body up the plane is

(a) 914 *N* (b) 91.4 *N*

(c) 9.14 *N* (d) 0.914 *N*

17. A block of mass 1 *kg* slides down on a rough inclined plane of inclination 60° starting from its top. If the coefficient of kinetic friction is 0.5 and length of the plane is 1 *m*, then work done against friction is (Take $g = 9.8\,m/s^2$)

[AFMC 2000; KCET 2001]

(a) 9.82 *J* (b) 4.94 *J*

(c) 2.45*J* (d) 1.96 *J*

18. A block of mass 10 *kg* is placed on an inclined plane. When the angle of inclination is 30°, the block just begins to slide down the plane. The force of static friction is

[Kerala (Engg.) 2001]

(a) 10 *kg wt* (b) 89 *kg w*

(c) 49 *kg wt* (d) 5 *kg wt*

19. A body of 5 *kg* weight kept on a rough inclined plane of angle 30° starts sliding with a constant velocity. Then the coefficient of friction is (assume $g = 10\ m/s^2$)

(a) $1/\sqrt{3}$ (b) $2/\sqrt{3}$

(c) $\sqrt{3}$ (d) $2\sqrt{3}$

20. 300 *Joule* of work is done in sliding up a 2 *kg* block on an inclined plane to a height of 10 *metres*. Taking value of acceleration due to gravity '*g*' to be 10 m/s^2, work done against friction is

(a) 100 *J* (b) 200 *J*

(c) 300 *J* (d) Zero

21. A 2 *kg* mass starts from rest on an inclined smooth surface with inclination 30° and length 2 *m*. How much will it travel before coming to rest on a frictional surface with frictional coefficient of 0.25

(a) 4 *m* (b) 6 *m*

(c) 8 *m* (d) 2 *m*

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

(a) 2.0 (b) 4.0

(c) 1.6 (d) 2.5

23. A body takes time *t* to reach the bottom of an inclined plane of angle θ with the horizontal. If the plane is made rough, time taken now is 2*t*. The coefficient of friction of the rough surface is

(a) $\frac{3}{4}\tan\theta$ (b) $\frac{2}{3}\tan\theta$

(c) $\frac{1}{4}\tan\theta$ (d) $\frac{1}{2}\tan\theta$

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

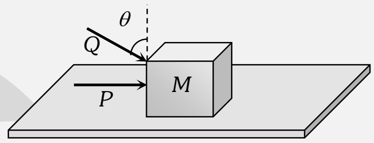
(a) $\sqrt{2gl(\mu\cos\theta - \sin\theta)}$ (b) $\sqrt{2gl(\sin\theta - \mu\cos\theta)}$

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

Critical Thinking

Objective Questions

1. A block of mass *m* lying on a rough horizontal plane is acted upon by a horizontal force *P* and another force *Q* inclined at an angle θ to the vertical. The block will remain in equilibrium, if the coefficient of friction between it and the surface is



(a) $\frac{(P + Q\sin\theta)}{(mg + Q\cos\theta)}$

[JIPMER 2002]

(b) $\frac{(P\cos\theta + Q)}{(mg - Q\sin\theta)}$

(c) $\frac{(P + Q\cos\theta)}{(mg + Q\sin\theta)}$

(d) $\frac{(P\sin\theta - Q)}{(mg - Q\cos\theta)}$

[MP PMT 2002]

2. Which of the following is correct, when a person walks on a rough surface **[IIT 1981]**

(a) The frictional force exerted by the surface keeps him moving

(b) The force which the man exerts on the floor keeps him moving

[UPSEAT 2003]

(c) The reaction of the force which the man exerts on floor keeps him moving

(d) None of the above

3. A block of mass 0.1 *kg* is held against a wall by applying a horizontal force of 5 *N* on the block. If the coefficient of friction between the block and the wall is 0.5, the magnitude of the frictional force acting on the block is **[IIT 1994]**

[AIEEE 2004]

(a) 2.5 *N* (b) 0.98 *N*

(c) 4.9 *N* (d) 0.49 *N*

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

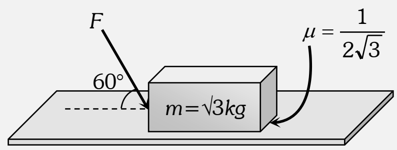
[MP PET 1997]

(a) $F = Mg$ (b) $F = \mu Mgf$

(c) $Mg \le F \le Mg\sqrt{1+\mu^2}$ (d) $Mg \ge F \ge Mg\sqrt{1+\mu^2}$

5. What is the maximum value of the force *F* such that the block shown in the arrangement, does not move

[IIT-JEE Screening 2003]

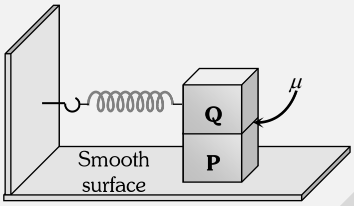


(a) 20 *N* (b) 10 *N*

(c) $12\,N$ (d) $15\,N$

6. A block P of mass m is placed on a frictionless horizontal surface. Another block Q of same mass is kept on P and connected to the wall with the help of a spring of spring constant k as shown in the figure. μ_s is the coefficient of friction between P and Q. The blocks move together performing SHM of amplitude A. The maximum value of the friction force between P and Q is

[IIT-JEE (Screening) 2004]



(a) kA

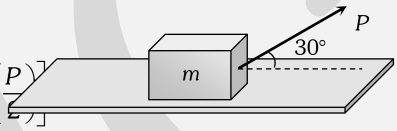
(b) $\frac{kA}{2}$

(c) Zero

(d) $\mu_s\, mg$

7. A body of mass m rests on horizontal surface. The coefficient of friction between the body and the surface is μ. If the mass is pulled by a force P as shown in the figure, the limiting friction between body and surface will be

[BHU 2004]



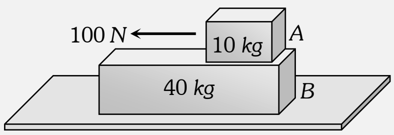
(a) μmg

(b) $\mu\left[mg+\left(\frac{P}{2}\right)\right]$

(c) $\mu\left[mg-\left(\frac{P}{2}\right)\right]$

(d) $\mu\left[mg-\left(\frac{\sqrt{3}\,P}{2}\right)\right]$

8. A 40 kg slab rests on a frictionless floor as shown in the figure. A 10 kg block rests on the top of the slab. The static coefficient of friction between the block and slab is 0.60 while the kinetic friction is 0.40. The 10 kg block is acted upon by a horizontal force 100 N. If $g = 9.8\,m/s^2$, the resulting acceleration of the slab will be **[NCERT 1982]**



(a) $0.98\,m/s^2$

(b) $1.47\,m/s^2$

(c) $1.52\,m/s^2$

(d) $6.1\,m/s^2$

9. A block of mass 2 kg rests on a rough inclined plane making an angle of 30° with the horizontal. The coefficient of static friction between the block and the plane is 0.7. The frictional force on the block is **[IIT 1980; J & K CET 2004]**

(a) $9.8\,N$

(b) $0.7 \times 9.8 \times \sqrt{3}\,N$

(c) $9.8 \times \sqrt{3}\,N$

(d) $0.8 \times 9.8\,N$

10. When a bicycle is in motion, the force of friction exerted by the ground on the two wheels is such that it acts

[IIT 1990; Manipal MEE 1995; MP PET 1996]

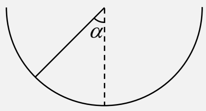
(a) In the backward direction on the front wheel and in the forward direction on the rear wheel

(b) In the forward direction on the front wheel and in the backward direction on the rear wheel

(c) In the backward direction on both front and the rear wheels

(d) In the forward direction on both front and the rear wheels

11. An insect crawls up a hemispherical surface very slowly (see the figure). The coefficient of friction between the insect and the surface is 1/3. If the line joining the centre of the hemispherical surface to the insect makes an angle α with the vertical, the maximum possible value of α is given by



(a) $\cot\alpha = 3$

(b) $\tan\alpha = 3$

(c) $\sec\alpha = 3$

(d) $\mathrm{cosec}\,\alpha = 3$

AR Assertion & Reason

For AIIMS Aspirants

Read the assertion and reason carefully to mark the correct option out of the options given below:

(a) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(b) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(c) If assertion is true but reason is false.

(d) If the assertion and reason both are false.

(e) If assertion is false but reason is true.

1. Assertion : On a rainy day, it is difficult to drive a car or bus at high speed.

Reason : The value of coefficient of friction is lowered due to wetting of the surface.

2. Assertion : When a bicycle is in motion, the force of friction exerted by the ground on the two wheels is always in forward direction.

Reason : The frictional force acts only when the bodies are in contact.

3. Assertion : Pulling a lawn roller is easier than pushing it.

Reason : Pushing increases the apparent weight and hence the force of friction.

4. Assertion : Angle of repose is equal to angle of limiting friction.

Reason : When the body is just at the point of motion, the force of friction in this stage is called as limiting friction.

5. Assertion : Two bodies of masses M and m $(M > m)$ are allowed to fall from the same height if the air resistance for each be the same then both the bodies will reach the earth simultaneously.

Reason : For same air resistance, acceleration of both the bodies will be same.

6. Assertion : Friction is a self adjusting force.

Reason : Friction does not depend upon mass of the body.

7. Assertion : The value of dynamic friction is less than the limiting friction.

Reason : Once the motion has started, the inertia of rest has been overcome.

8. Assertion : The acceleration of a body down a rough inclined plane is greater than the acceleration due to gravity.

Reason : The body is able to slide on a inclined plane only when its acceleration is greater than acceleration due to gravity.

Answers

Static and Limiting Friction

1	c	2	d	3	c	4	b	5	a
6	c	7	c	8	a	9	a	10	d
11	c	12	c	13	b	14	a	15	a
16	d	17	c	18	b	19	a	20	c
21	c	22	b	23	a	24	c	25	a
26	b	27	a	28	d	29	a	30	d
31	d	32	a						

Kinetic Friction

1	b	2	d	3	a	4	d	5	a
6	c	7	a	8	d	9	a	10	b
11	b	12	d	13	c	14	c	15	b
16	d	17	b	18	a	19	a	20	d
21	d	22	b	23	b	24	b	25	d
26	b	27	b	28	d	29	c	30	b
31	a	32	d	33	a	34	b	35	d
36	d								

Motion on Inclined Surface

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

Critical Thinking Questions

1	a	2	c	3	b	4	c	5	a
6	b	7	c	8	a	9	a	10	ac
11	a								

Assertion & Reason

1	a	2	e	3	a	4	b	5	d
6	d	7	a	8	d				