PHYSICS

The following question given below consist of an "Assertion" (A) and "Reason" (R) Type questions. Use the following Key to choose the appropriate answer.

(A) If both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) If both (A) and (R) are true but (R) is not the correct explanation of (A).

(C) If (A) is true but (R) is false.

(D) If (A) is false but (R) is true.

Q. 1 **Assertion :** Due to frictional force acting on a body, the body is always retarded by friction.

Reason : Friction force opposes the slipping between the surfaces in contact. **[D]**

Q. 2 **Assertion :** Work done by static friction is always zero.

Reason : Static friction between two surface in contact acts when they are not slipping over each other but there is a tendency of slipping between them. **[D]**

Q.3 **Assertion :** Work done by frictional force may be sometimes path independent.

Reason : Frictional force is a non-conservative force. **[B]**

Q. 4 **Assertion :** Work done by frictional force can not be positive.

Reason : Work done is positive when force acts in the direction of displacement.

Sol. **[D]**

Work done by static friction may be positive.

Q. 5 **Assertion :** Due to frictional force acting on a body, the body is always retarded by friction.

Reason : Friction force opposes the slipping between the surfaces in contact. **[D]**

Q.6 Assertion : Work done by static friction acting on body is always zero.

Reason : Static friction on a body kept on a surfaces acts when the body is not slipping on it but there is a tandency of slipping.

[D]

Q.7 Assertion : When a body is at rest on a horizontal surface then the contact force on the body by the surface must be equal to the weight of body.

Reason : The contact force is the total force applied by the surface on the body kept on it.

Sol. **[D]**

Static friction may act even when body remain at rest

Q.8 **Assertion/Statement** : Pulling a lawn roller is easier than pushing it.

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

[A]

Q.9 **Assertion/Statement** : Static friction is a self adjusting force.

Reason/Statement : The magnitude of static friction is equal to the applied force and its direction is opposite to that of the applied force.

[C]

Q.10 **Assertion/Statement** : A horse has to pull a cart harder during the first few steps of his motion.

Reason/Statement : The first few steps are always difficult. **[C]**

Q.11 **Assertion/Statement** : Force of friction increases when surfaces in contact are too smooth.

Reason/Statement : Smoothness decreases friction. **[C]**

Q.12 **Assertion/Statement :** A block of mass m starts moving on a rough horizontal surface with a velocity v. It stops due to friction between the block and the surface after moving through a certain distance. The surface is now tilted to an angle of 30º with the horizontal and the same block is made to go up on the surface with the same initial velocity v. The decrease in the mechanical energy in the second situation is smaller than that in the first situation.

Reason/Statement : The coefficient of friction between the block and the surface decreases with the increase in the angle of inclination.

[IIT - 2007]

[C]

Q.13 **Assertion/Statement** : It is easier to pull a heavy object than to push it on a level ground.

Reason/Statement : The magnitude of frictional force depends on the nature of the two surfaces in contact. **[IIT-2008]**

[B]

Q.14 **Assertion :** Static friction acts between two surfaces in contact only when these surfaces are at rest with respect to ground.

Reason : Static friction opposes the slipping between surfaces. **[D]**

Q.15 **Statement I :** Pulling a lawn roller is easier than pushing it.

Statement II : Pushing increases the apparent weight and hence force of friction. **[A]**

Q.16 **Statement I :** The force of friction in the case of a disc rolling without slipping down an inclined plane is zero.

Statement II : When the disc rolls without slipping, friction is required because for rolling condition velocity of point of contact is zero.

[D]

Q.17 **Statement I :** Friction is self adjusting force.

Statement II : The magnitude of static friction is equal to the applied force and its direction is opposite to that of the applied force. **[D]**

Q.18 **Assertion :** A coin is placed on phonogram turn table. The motor is started, coin moves along the moving table.

Reason : Rotating table is providing necessary centripetal force to the coin.

(A) a (B) b

(C) c (D) d **[A]**

Q.19 **Assertion :** By pressing a block against a rough wall, one can balance it.

Reason : Smooth walls can not hold the block by pressing the block against the wall, however high the force is exerted.

(A) a (B) b

(C) c (D) d **[B]**

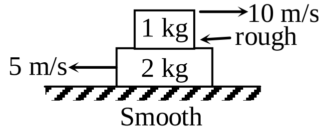
Q.20 **Assertion :** The value of dynamic friction is less than the limiting friction.

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

(A) a (B) b

(C) c (D) d **[A]**

Q.1 In a two block system shown in figure match the following :



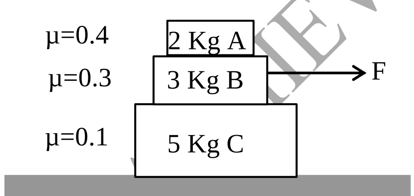
Column I	**Column II**
(A) velocity of centre of mass	(P) changing all the time
(B) Momentum of centre mass	(Q) First decreases then becomes zero
(C) momentum of 1kg block	(R) zero
(D) kinetic energy of 2 kg block	(S) constant

Sol. **A $\rightarrow$ R, S ; B $\rightarrow$ R, S; C $\rightarrow$ Q; D $\rightarrow$ Q**

As no external force is acting velocity of centre of mass will be constant.

Also due to friction speed of both blocks decreases and becomes zero.

Q.2 For the situation shown in the figure given below, match the entries of column I with the entries of column II.



Column-I	**Column-II**
(A) If F = 13 N, then	(P) relative motion between A and B is there
(B) If F = 15 N, then	(Q) relative motion between B and C is there
(C) If F = 25 N, then	(R) relative motion between C and the ground is there
(D) If F = 40 N, then	(S) relative motion is not there at any of the surface

Sol. **A $\rightarrow$ R ; B $\rightarrow$ R ; C $\rightarrow$ Q,R ; D $\rightarrow$ P,Q,R**

Let f_1, f_2 and f_3 represent the friction forces between three contact surface A – B, B – C and C – ground respectively. Limiting values of friction force at three surface are 8N, 15 N and 10N respectively.

For relative motion between C and ground, the minimum force needed is f = 10 N.

For F = 12 N

All the three blocks move together with same acceleration

i.e. $a_1 = a_2 = a_3 = a$

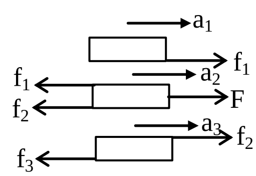
$F - f_3 = (2 + 3 + 5)a$

$\therefore a = \frac{12-10}{10} = \frac{2}{10}$ m/s^2

$f_1 = 2a = \frac{2}{5}$ N

$f_2 = 12 - f_1 - 3a = 11$N

$f_3 = 10$ N



For F = 15 N : The situation is similar.

For relative motion to start between B and C, $f_2 \geq f_{12}$

or $F - f_3 = 10$ a and $dF - f_2 = 5a$

or $f_2 = F - 5a = F - 5\left[\frac{F-f_3}{10}\right] = \frac{F+f_3}{2}$

or $\frac{F+10}{2} > 15$ or $F > 20$ N

[condition for relative motion to start between B and C].

For relative motion to start between A and B.

$f_1 \geq f_{L_1} = 8$ N

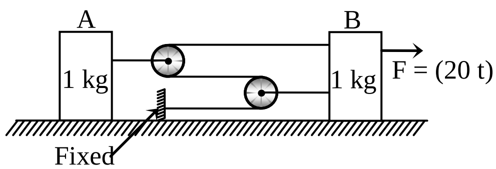
$F - f_1 - f_2 = 3a$ and $f_1 = 2a$

$f_1 = 2\left[\frac{F-15}{5}\right] > 8$

or f > 35 N [condition for relative motion between A and B].

Q.3 Two blocks of mass 1 kg each are connected through a light inextensible string as shown in figure. The friction coefficient between each block and horizontal surface is 0.2. A time varying force given by F = (20 N/s) t is applied to block B as shown, where t is time.

($g = 10\ m/s^2$)



Column-I	**Column-II (In SI unit)**
(A) At t = 1 s, acceleration of block B is	(P) Zero
(B) At $t = \frac{1}{10}$ s, tension in string in block B is	(Q) $\frac{90}{13}$
(C) At $t = \frac{3}{20}$ s, friction force on block B is	(R) $\frac{2}{3}$
(D) Motion will start at time t is given by	(S) $\frac{1}{4}$

Ans. **A → Q ; B → P ; C → R ; D → S**

Q.4 Figure-I shows a system of two blocks of masses M and 2M placed on a surface. There is no friction between the blocks and the surface. A force F is applied on the lower block as shown in figure. Coefficient of friction between two blocks is μ.

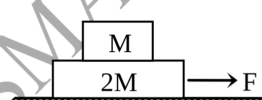


Figure-I

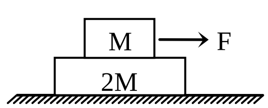


Figure-II

Figure-II shows a system of two blocks of masses M and 2M. There is no friction between the lower block and surface. A force F is applied on the upper blocks as shown in figure. Coefficient of friction between two surface is μ. Given for both figure.

($M = 5$ kg, $F = 20$ N, $\mu = 0.2$, $g = 10\ m/s^2$)

Column-I	**Column-II**
(A) For figure-II, acceleration of upper block is	(P) $\frac{20}{3}$ SI unit
(B) Force of friction between two blocks in Figure-II	(Q) $\frac{4}{3}$ SI unit
(C) For figure-I, acceleration of upper block is	(R) 10 SI unit
(D) For figure-I, force of friction between two blocks is	(S) 25 SI unit

Ans. **A → S ; B → R ; C → Q ; D → P**

Q.5 A cylinder, hollow sphere, solid sphere and a ring all having mass 1 kg are released from rest on a inclined plane having angle of inclination 37° (tan 37° = 3/4). Coefficient of friction between bodies and plane is 'μ', then match the following column.

Column I	**Column II**
(A) If $\mu < 0.25$ body which must not undergo pure rolling motion	(P) Ring
(B) If $\mu \le 0.3$ work done by friction must be negative for	(Q) Hollow sphere
(C) If $\mu = 0.4$, total mechanical energy will be conserved for	(R) Solid sphere
(D) If $\mu = 0.25$, friction force will be 2N for	(S) Cylinder

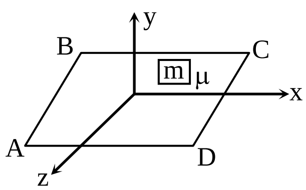
Sol. **A → P,Q,S ; B → P ; C → P,Q,R,S ; D → Q,R**

For pure rolling

$$\mu \ge \frac{\tan\theta}{\left(1+\frac{mr^2}{I}\right)} \text{ and } f = \frac{mg\sin\theta}{(1+\frac{mr^2}{I})}$$

Body	**Condition on μ**	**Friction force**
Ring	$\mu \ge 3/4$	3 N
Cylinder	$\mu \ge 1/4$	2 N
Hollow sphere	$\mu \ge 3/10$	12/5 N
Solid sphere	$\mu \ge 3/14$	12/7 N

Q.6 ABCD is a horizontal surface on which a block of mass m = 20 kg is placed and coefficient of friction between this body and surface is $\mu = 0.5$ as shown. y-axis is vertical axis and x-z plane is horizontal. The surface starts moving with an acceleration which depends on time as



$\vec{a} = (3t\hat{i} + 10\hat{j} + 4t\hat{k})$ m/s^2

Assuming at t = 0 block is at rest with respect to the surface. If -
't' is time when block stats slipping.
'a' is acceleration of surface when block starts slipping
F_L is limiting friction when block starts slipping
F is total force applied by surface on block at t = 1 sec.

Column I	Column II
(A) t	(P) 200
(B) a	(Q) $100\sqrt{17}$
(C) F_L	(R) $10\sqrt{2}$
(D) F	(S) 2

Sol. **A → S; B → R; C → P ; D → Q**

N = m (g + a) = 20 (10 +10) = 400 N

$F_{pseudo} = m\sqrt{(3t)^2 + (4t)^2} = 100\,t$

Also $F_L = \mu N = 0.5 \times 400 = 200$ N

$\therefore$ Slipping starts when 100 t = 200

$\Rightarrow$ t = 2 sec

Q.7 A man is standing on a ladder as shown in figure. N_1 and N_2 are the normal reactions and f the force of friction. Then match the following table:

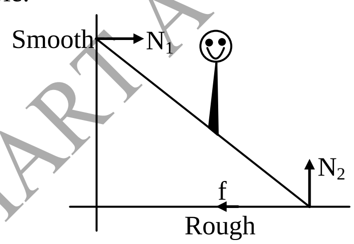
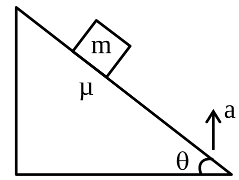


Table -1	Table -2
(A) As the man moves up the ladder	(P) N_1 will increase
(B) If weight of ladder is increased	(Q) N_1 will decrease
	(R) N_2 will increase
	(S) N_2 will decrease
	(T) f will increase

Ans. **A → P,T;** **B → P,T,R**

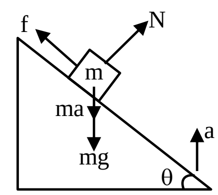
Q.8 A block of mass m = 1 kg is at rest with respect to a rough wedge as shown in figure.



The wedge starts moving up from rest with an acceleration of a = 2m/s^2 and the block remains at rest with respect to wedge then in 4 sec. of motion of wedge work done on block (assume angle of inclination of wedge is $\theta = 30^\circ$ and g = 10 m/s^2) -

Column I	Column II
(A) By gravity (in magnitude)	(P) 144 J
(B) By normal reaction	(Q) 32 J
(C) By friction	(R) 160 J
(D) By all the forces	(S) 48 J

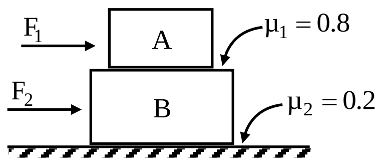
Sol. (A)→ R ; (B) → P; (C) → S; (D) → Q



N = m (g + a) cosθ

f = m (g + a) sin θ

Q.9 A block A of mass 5kg is placed on another block B of mass 10 kg placed on a horizontal rough surface. Horizontal force F_1 and F_2 acts on block A and B respectively as shown in figure. Coefficient of friction between two blocks is 0.8 while between block B and horizontal surface is 0.2. Let f_1 denote friction force acting on block B due to A and f_2 denote friction force on horizontal surface. Then match the following.



Column-I	Column-II
(A) If F_1 = 35N, F_2 = 0 then f_1	(P) Kinetic
(B) If F_1 = 50N, F_2 = 0 then f_2	(Q) Static
(C) If F_1 = 0, F_2 = 30 then f_1	(R) Zero
(D) If F_1 = 10 N, F_2 = 50N then f_1	(S) Towards right

Sol. A → Q,S; B → P, S ; C → R ; D → R

f_1^{max} = 40N

f_2^{max} = 30N

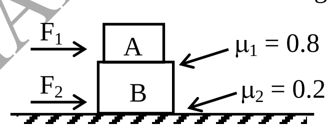
F_1 = 35N, F_2 = 0 : Block A will not slip over block B

F_1 = 50N, F_2 = 0 : Block B will slip over horizontal surface

F_1 = 0, F_2 = 30N : Block B will be at rest

F_1 = 10N, F_2 = 50N : Block A have no tendency of slipping over block B

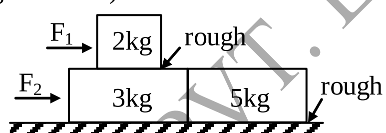
Q.10 A block 'A' of mass 5 kg is placed on other block 'B' of mass 10 kg placed on rough horizontal surface. F_1 and F_2 acts on block 'A' and 'B' respectively as shown in figure. Coefficient of friction between two blocks 0.8 while between block B & surface is 0.2. Let f_1 denote friction force acting on block B due to A and f_2 denote friction force on horizontal surface. Then match the following column -



Column-I	Column-II
(A) F_1 = 35 N, F_2 = 0 then f_2	(P) Static
(B) F_1 = 0, F_2 = 50 N then f_1	(Q) Kinetic
(C) F_1 = 20N, F_2 = 20N then f_2	(R) Towards left
(D) F_1 = 5N, F_2 = 55N then f_1	(S) Towards right

Sol. A → Q, S ; B → P, R ; C → Q, R ; D → P, R

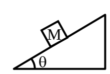
Q.11 In the given figure, coefficient of friction between the 2kg and 3kg blocks are $\mu_s = 0.3$ and $\mu_k = 0.2$, between the 5kg and surface are $\mu_s = \mu_k = 0.1$ and between 3 kg and surface is $\mu_s = \mu_k = 0$, (g = 10 m/s^2)



Column -I	Column-II
(A) For F_1 = 0, F_2 = 15 N	(P) acceleration of all blocks will be same
(B) For F_1 = 25/4N, F_2 = 0	(Q) acceleration of any two blocks will be different
(C) For F_1 = 8N, F_2 = 10 N	(R) frictional force between 2kg and 3 kg block is less than maximum static friction
(D) For F_1 = 16 N, F_2 = 9 N	(S) contact force between 3kg and 5kg block is less than 10 N

Sol. A → P,R ; B → P,S ; C → P,R; D → Q

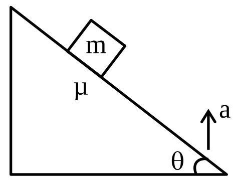
Q.12 Match the column-I with Column-II :

Column -I	Column-II
(A) Tension at each point of string is same if the string is	(P) Mg sin θ
(B)  A block of mass M is kept stationary on an inclined plane. Number of force acting on the block is	(Q) Mg cos θ
(C) The magnitude of normal reaction in B	(R) Massless
(D) Force of friction in B is	(S) 3

Sol. $A \to R$ $\quad$ $B \to S$

$C \to Q$ $\quad$ $D \to P$

Q.13 A block of mass m = 1 kg is at rest with respect to a rough wedge as shown in figure.



The wedge starts moving up from rest with an acceleration of $a = 2 m/s^2$ and the block remains at rest with respect to wedge then in 4 sec. of motion of wedge work done on block (assume angle of inclination of wedge is $\theta = 30^o$ and $g = 10 m/s^2$) –

Column I	**Column II**
(A) By gravity (in magnitude)	(P) 144 J
(B) By normal reaction	(Q) 32 J
(C) By friction	(R) 160 J
(D) By all the forces	(S) 48 J

Sol. **$A \to R$, $B \to P$, $C \to S$, $D \to Q$**

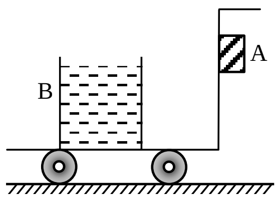
$S = \frac{1}{2} \times 2 \times 16 = 16$ m

$| W_g | = mg\, S =$

$W_N = m(g + a) \cos^2\theta .\, S$

$W_f = m(g + a) \sin^2\theta \,.\, S$

Q. 1 A trolley of mass m_1 is to be moved such as to keep block A of mass m_2 at rest with respect to it. A bucket of mass m_3 (with water) in it is placed on trolley. Coefficient of friction between the block A and trolley is μ. The trolley is moved with acceleration so that block does not slip –



(A) The minimum coefficient of friction between bucket and trolley is μ/2

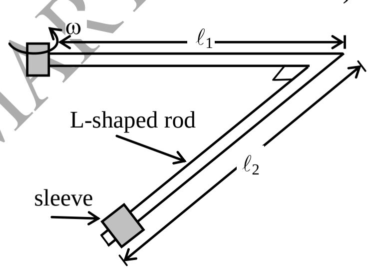
(B) The acceleration of trolley is g/μ

(C) The inclination of water surface in the bucket with horizontal in absence of any slipping is $\tan^{-1} 1/\mu$

(D) Force on trolley is $(m_1 + m_2 + m_3)\, g/\mu$

[B,C,D]

Q. 2 A rough L-shaped rod is located in a horizontal plane and a sleeve of mass m is inserted in the rod. The rod is rotated with a constant angular velocity ω in the horizontal plane. The lengths ℓ_1 and ℓ_2 are shown in figure. The normal reaction and frictional force acting on the sleeve when it just starts slipping are (μ = coefficient of friction between rod and sleeve) –



(A) $N = m\omega^2\ell_1$ (B) $f = m\omega^2\ell_2$

(C) $N = m\sqrt{g^2 + \omega^4\ell_1^2}$ (D) $f = \mu N$

[B,C,D]

Q.3 A prism of mass M with its smooth inclined face of inclination θ with horizontal is kept on a rough surface. When a body of mass m is released on its inclined face then its slips down but prism remains at rest then ,

(A) The acceleration of body is g sin θ

(B) Friction force on prism is $\frac{1}{2}$ mg sin 2θ

(C) Maximum friction force on prism is mg/2

(D) Friction force on prism is $\frac{1}{4}$ mg sin 2θ

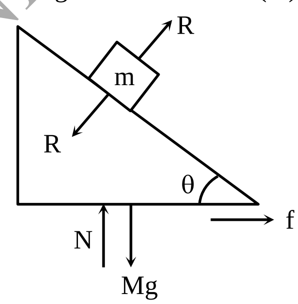
Sol. **[A, B, C]**

From FBD of prism and mass m

$N = Mg + R\cos\theta$ …. (i)

$f = R\sin\theta$ …. (ii)

$R = mg\cos\theta$ …. (iii)



Q.4 A block is placed over a plank. The coefficient of friction between the block and the plank is μ = 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 – ($g = 10 m/s^2$)

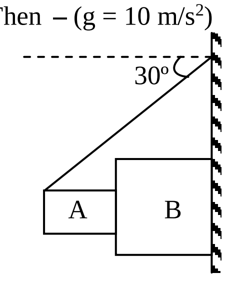
(A) 1 m relative to ground

(B) 1 m relative to plank

(C) zero relative to plank

(D) 2 m relative to ground **[A,B]**

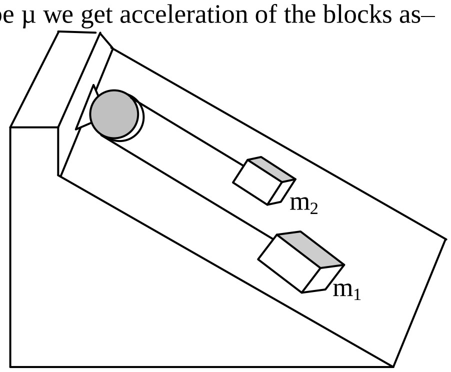
Q.5 Two blocks A and B of mass 10 kg and 20 kg respectively are placed as shown in figure. Coefficient of friction between all the surfaces is 0.2. Then – ($g = 10 m/s^2$)



(A) tension in the string is 306 N
(B) tension in the string is 132 N
(C) acceleration of block B is 2.6 m/s^2
(D) acceleration of block B is 4.7 m/s^2

[A,D]

Q.6 Two blocks on a rough incline are connected by a light string that passes over a frictionless light pulley as shown. Assuming $m_1 > m_2$ and taking the coefficient of kinetic friction for each block to be μ we get acceleration of the blocks as–



(A) $a = \dfrac{[(m_1 - m_2)\sin\theta - \mu(m_1 + m_2)\cos\theta]g}{(m_1 + m_2)}$

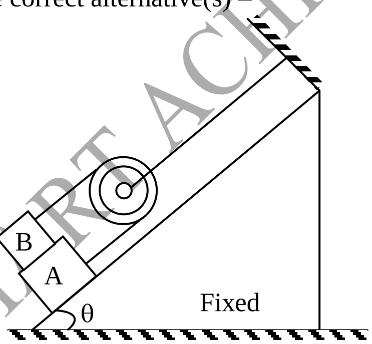
for m_1

(B) $a = \dfrac{[\mu(m_1 + m_2)\cos\theta - (m_1 - m_2)\sin\theta]g}{(m_1 + m_2)}$

for m_2

(C) $a = g(\sin\theta - \mu\cos\theta)$
(D) $a = g(\cos\theta - \mu\sin\theta)$ **[A,B]**

Q.7 In the arrangement shown in figure pulley is smooth and mass less and string is light. Friction coefficient between A and B is μ. Friction is absent between A and plane. Select the correct alternative(s) –



(A) acceleration of the system is zero if $\mu \geq \dfrac{(m_B - m_A)}{2m_B}\tan\theta$ and $m_B > m_A$
(B) force of friction between A and B is zero if $m_A = m_B$
(C) B moves upwards if $m_A < m_B$
(D) tension in the string is $mg(\sin\theta - \mu\cos\theta)$ if $m_A = m_B = m$ **[A,B]**

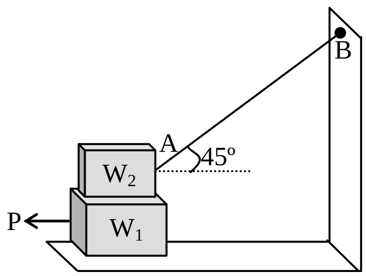
Q.8 Which of the following statement(s) is (are) correct about friction ?
(A) The coefficient of friction between two bodies is largely independent of area of contact
(B) The frictional force can never exceed the reaction force on a body from the supporting surface
(C) Rolling friction is generally smaller than sliding friction
(D) Friction is due to irregularities of the surfaces in contact **[All]**

Q.9 A lift is moving downwards. A body of mass m kept on the floor of the lift is pulled horizontally. If μ is the coefficient of friction between the surfaces in contact then –
(A) frictional resistance offered by the floor is μmg when lift moves up with a uniform velocity of 5 m/s
(B) frictional resistance offered by the floor is μmg when lift moves up with a uniform velocity of 3 m/s
(C) frictional resistance offered by the floor is 5μm when lift accelerates down with an acceleration of 4.8 m/s^2
(D) frictional resistance (f) offered by the floor must lie in the range $0 \leq f < \infty$

[All]

Q.10 A weight W can be just supported on a rough inclined plane by a force P either acting along the plane or horizontally. The angle of friction is ϕ and θ is the angle which incline makes with the horizontal. Then –
(A) the incline makes an angle with the horizontal twice the angle of friction i.e. $\theta = 2\phi$
(B) the incline makes an angle with the horizontal equal to the angle of friction i.e. $\theta = \phi$
(C) the ratio of the force to the weight is $\dfrac{P}{W} = \cot\phi$
(D) the ratio of the force to the weight is $\dfrac{P}{W} = \tan\phi$ **[A,D]**

Q.11 In the arrangement shown W_1 = 200 N, W_2 = 100 N, μ = 0.25 for all surfaces in contact. The block W_1 just slides under the block W_2. Then –



(A) A pull of 50 N is to be applied on W_1

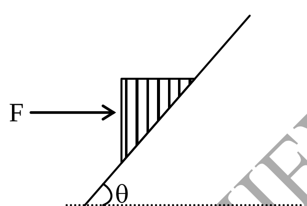
(B) A pull of 90 N is to be applied on W_1

(C) Tension in the string AB is $10\sqrt{2}$ N

(D) Tension in the string AB is $20\sqrt{2}$ N

[B,D]

Q.12 A block rests on a rough inclined plane as shown in figure. A horizontal force (F) is applied to it–



(A) Normal reaction on the block is $F \sin\theta + mg \cos\theta$

(B) Frictional force is zero when $F \cos\theta = mg \sin\theta$

(C) The value of limiting friction is $\mu(mg \sin\theta + F \cos\theta)$

(D) The value of limiting friction is $\mu(mg \sin\theta - F \cos\theta)$ **[A,D]**

Q.13 A uniform chain of length 1 m is placed on a rough horizontal table with a part of it hanging over the edge of the table. It is found that if the length of the hanging part is 25 cm or more, the chain starts sliding downwards. Which of the following is/are correct ?

(A) The coefficient of friction between the table and the chain is 1/3

(B) The coefficient of friction between the table and the chain is 1/4

(C) The chain will move with a uniform acceleration

(D) The acceleration of the chain will increase till it loses contact with the table

[A,D]

Q.14 Which of the following statements is/are true ?

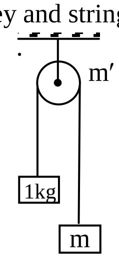
(A) Friction exerted by road on a man speeding up himself to the right, acts rightwards

(B) A wheel rolling down a rough inclined plane reaches bottom of the plane earlier than a block sliding down a smooth plane having same inclination

(C) A particle moving along a horizontal circle with constant speed has constant acceleration

(D) A particle moving with constant acceleration may traverse a parabolic path **[A,D]**

Q.15 Two blocks of mass 1 kg and mass 'm' is hanged over a pulley of mass 'm'. Friction coefficient between pulley and string is 'μ' such that $e^{\mu\pi} = 2$.



(A) There cannot be any slipping between string and pulley howsoever small m is

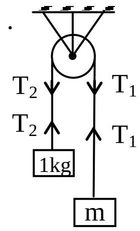
(B) If m′ = 4 kg, there cannot be any slipping between string and pulley howsoever large m (> 1kg) is

(C) If m' = 6 kg there will slipping between pulley and string if m = 8 kg

(D) If m' = 6 kg there will be slipping between string and pulley if m < $\frac{3}{8}$kg

[B,C,D]

Sol.



The string will not slip over pulley in clockwise direction till

$$\frac{T_1}{T_2} \le e^{\mu\pi} \Rightarrow \frac{T_1}{T_2} \le 2 \quad \text{... (i)}$$

$$\frac{T_1}{T_2} = \frac{mg - ma}{1.g + 1.a}$$

$$a = \frac{mg - 1.g}{m + m'/2 + 1}$$

By (i)

$$m \le \frac{2m'}{m' - 4}$$

String will not slip over pulley in anticlockwise direction till

$$\frac{T_2}{T_1} \le e^{\mu\pi} \Rightarrow \frac{T_2}{T_1} \le 2$$

Proceeding as above,

$$m \ge \frac{m'}{2(m'+2)}$$

Q.16 Choose the correct statement –

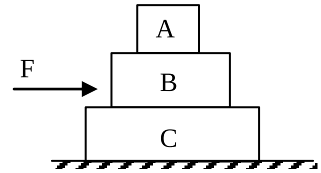
(A) Work done by Pseudo force in non-inertial frame itself cannot be positive

(B) Net work done by static friction on the system (consisting surfaces in contact) is always zero

(C) Net work done by kinetic friction on the system (consisting surfaces in contact) may be positive

(D) Work done by kinetic friction on a body may be positive **[B,D]**

Q.17 Force 'F' is applied on block 'B' and the system is at rest. All surface are rough. Which of the following statements is/are correct –



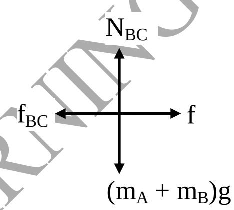
(A) Friction force on 'C' due to 'B' is zero

(B) Friction on 'C' due to ground is equal to friction force on 'B'

(C) Friction force on 'A' must be zero

(D) Friction force on 'A' depends upon force applied 'F' **[B,C]**

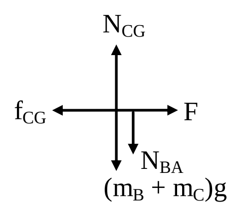
Sol. Free body diagram of (A + B) system



$f_{BC} = F \ne 0$

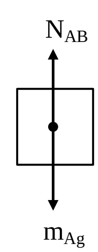
$\therefore\ f_{CB} \ne 0$

Free body diagram of (B + C) system



$f_{CG} = F = f_{BC}$

Free body diagram



No force acts on 'A' parallel to the surface in contact.

$\therefore\ f_{AB} = 0$

Q.18 A 10 kg block is placed on a horizontal surface. The coefficient of friction between them is 0.2. A horizontal force P = 15 N first acts on it in eastward direction. Later in addition to P a second horizontal force Q = 20 N acts on it in north direction -

(A) The block will not move when only P acts, but will move when both P & Q acts

(B) If the block moves, its acceleration will be $0.5\ m/s^2$

(C) When the block moves, its direction of motion will be $\tan^{-1}(4/3)$ east of north

(D) When both P & Q acts. The direction of force of friction will be $\tan^{-1}(3/4)$ west of south

[B, D]

Q. 19 A block is placed at the bottom of inclined plane and projected upward with some speed. Angle of inclination of plane is 'θ' & coefficient of friction b/w block and surface is 'μ'. If time of ascent & descent t_1 & t_2 respectively then –

(A) $t_1 > t_2$

(B) $t_1 < t_2$

(C) Retardation of block while moving up is $g(\sin\theta + \mu\cos\theta)$

(D) Acceleration of block is moving down is $g(\sin\theta - \mu\cos\theta)$ **[B, C, D]**

Q. 20 It block of mass 1 kg moves under influence of external force on a rough horizontal surface. At some instant, it has a speed of 1 m/s due east and acceleration is $1 m/s^2$ due north. The friction force acting on it is 'F' –

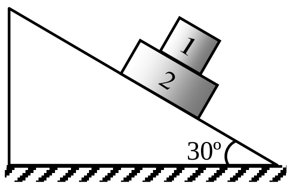
(A) F acts due west

(B) F acts due south

(C) F acts in south-west direction

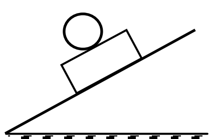
(D) The magnitude of F cannot be found from the given data **[A,D]**

Q.1 Two blocks 1 and 2 of mass 2kg and 4kg are kept over a frictionless inclined surface (angle of inclination = 30º). Coefficient of friction between two blocks is $\mu = 0.2$. Friction force on block 1 is equal to (in Newton) -



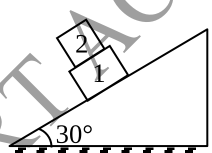
Sol. **[0]**
There is no tendency of relative slipping between blocks.

Q.2 A cylinder of mass 5 kg is kept over a block of mass 10 kg which is kept on a fixed inclined plane. The surface between cylinder and block is rough
($\mu = 0.2$) while that between block and inclined plane is smooth. Friction force acting on cylinder is -



Sol.[0] There is no tendency of slipping between cylinder and block.

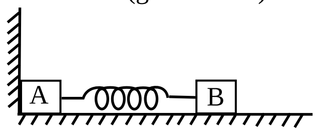
Q.3



Two blocks of mass 2kg each are kept over fixed frictionless inclined plane as shown. Coefficient of friction between blocks is $\mu = 0.4$
Friction force on block 2 is –

Sol.[0] As there is no tendency of slipping between block.

Q.4 Two blocks A and B, each of mass m = 2kg are connected to the ends of a ideal spring of force constant k = 1000 Nm^{-1} and this system is placed on rough floor. Coefficient of friction between these blocks and floor is $\mu = 0.5$. Block B is pressed towards left so that spring gets compressed. Then the initial minimum compression of spring in cm such that block A leaves contact with the wall when system is released is (g = 10 m/s^2)

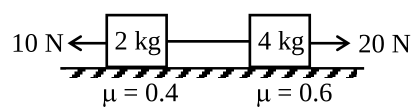


Sol.[3] x = final elongation, x_0 = initial compression
then, by conservation of energy

$$\frac{1}{2} k x_0^2 = \frac{1}{2} k x^2 + \mu mg (x_0 + x)$$

but to move the block kx = μmg

Q.5 Two blocks of mass 2 kg and 4 kg are connected through a massless inextensible string. Coefficient of friction between 2 kg block and ground is 0.4 and between 4 kg block and ground is 0.6. Two forces F_1 = 10 N and F_2 = 20 N are applied on the block as shown in figure. Friction force (in N)acting on 4 kg block minus 10 N is

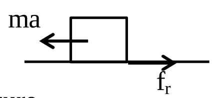


Sol. **[8]**
For equilibrium,
10 = 8 + T …(i)
T + f_2 = 20 …(ii)
$\Rightarrow$ f_2 = 18N

Q.6 A car begins to move at time t = 0 and then accelerates along a straight track with a velocity given by $V(t) = 2t^2$ ms^{-1} for $0 \le t \le 2$, where t is time in second. After the end of acceleration, the car continues to move at a constant speed. A small block initially at rest on the floor of the car begins to slip at t = 1 s and stops slipping at t = 3 s. The coefficient of static and kinetic friction between the block and the floor are μ_s and μ_k respectively. Find the value of $\frac{3\mu_s}{\mu_k}$

Sol.[4] $V = 2t^2$

$a = 4t$



at t = 1 sec, slipping occure

$ma = \mu_s mg$

$4t = \mu_s g$

$\mu_s = 0.4$

$t = 1 \rightarrow t = 3$ slipping occur

b/w t = 1 & t = 2sec

$(4t - \mu_k g) = \frac{dv}{dt}$

$v = \left[2t^2 - \mu_k gt\right]_1^2$, $v = 2 \times 3 - \mu_k g$

$\mu_k = 0.3$, $\frac{3\mu_s}{\mu_k} = 4$

Q.7 A 40 kg wooden crate is being pushed across a wooden floor with a force of 160 N. If $\mu_k = 0.3$, find the acceleration of the crate. ($g = 10$ m/s^2)

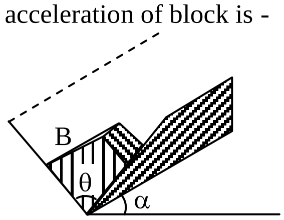
Sol. [1] $a = \frac{160\,N - 120\,N}{40\,kg} = 1$ m/s^2

Q.8 A car with its brakes locked is on a horizontal plane. It will remain stationary till the angle made by plane with horizontal is 45°. What is the coefficient of static friction of rubber tires on dry concrete?

Sol. [1] $\mu = \tan 45°$

PHYSICS

Q.1 A block 'B' is just fitting between two plane inclined at an angle 'θ'. The combination of plane is inclined at angle 'α' with horizontal. If coefficient of friction between block and the plane 'μ' is insufficient to stop slipping, then acceleration of block is -



(A) $g\{\sin \alpha - \mu \cos \alpha\}$

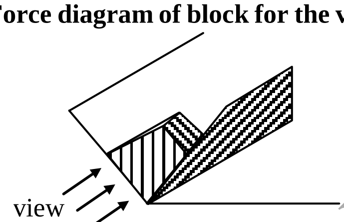
(B) $g\left\{\sin\alpha - \mu\dfrac{\cos\alpha}{\sin(\theta/2)}\right\}$

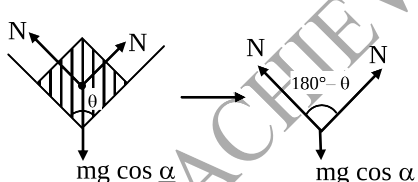
(C) $g\{\sin \alpha - 2\mu \cos \alpha \cos \theta/2\}$

(D) $g\{\sin \alpha - \mu \cos \alpha . \sin(\theta/2)\}$

[B]

Sol. **Force diagram of block for the view shown**





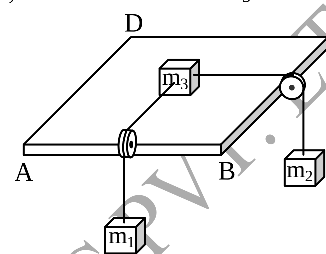
$$\Rightarrow N = \frac{mg\cos\alpha}{2\sin(\theta/2)}$$

$\therefore$ Net friction up the plane $= 2\,\mu N$

$$= \mu mg\ \frac{\cos\alpha}{\sin(\theta/2)}$$

$$\therefore\ a = g\left\{\sin\alpha - \mu\frac{\cos\alpha}{\sin(\theta/2)}\right\}$$

Q.2 Three blocks are arranged as shown in which ABCD is a horizontal plane. Strings are massless and both pulley stands vertical while the strings connecting blocks m_1 and m_2 are also vertical and are perpendicular to faces AB and BC which are mutually perpendicular to each other. If m_1 and m_2 are 3 kg and 4 kg respectively. Coefficient of friction between the block m_3 = 10 kg and surface is $\mu = 0.6$ then, frictional force on m_3 is -



(A) 30 N (B) 40 N

(C) 50 N (D) 60 N

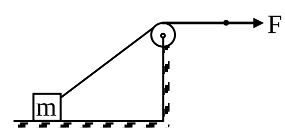
[C]

Sol. Net force on $m_3 = \sqrt{(30)^2 + (40)^2} = 50$ N

and limiting friction on $m_3 = \mu m_3 g = 60$N

$\therefore$ System remain in equilibrium and friction on m_3 = 50 N

Q.3 The block of mass m is placed on a rough horizontal floor and it is pulled by an ideal string by a constant force F as shown. As the block moves towards right on the floor, then the frictional force on block -



(A) remains constant

(B) increases

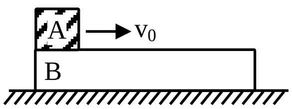
(C) decreases

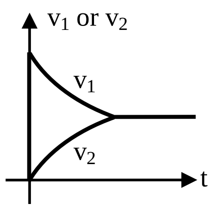
(D) can not be calculated

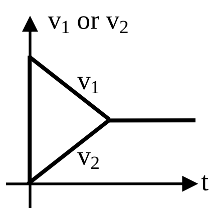
[C]

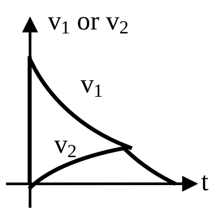
Sol. As the block moves towards right normal reaction on it decreases therefore frictional force on it decreases

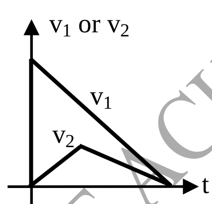
Q.4 A block A is placed over a long rough plank B of same mass as shown in figure. The plank is placed over a smooth horizontal surface. At time $t = 0$, block A is given a velocity v_0 in horizontal direction. Let v_1 and v_2 be the velocities of A and B at time t. Then choose the correct graph between $\mathbf{v_1}$ or $\mathbf{v_2}$ and $\mathbf{t}$:



(A)


(B)


(C)


(D)


[B]

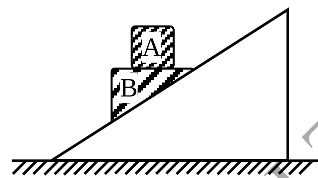
Sol. Friction force between A and B (= μmg) will accelerate B and retard A till slipping is stopped between the two and since mass of both are equal.

acceleration of B = retardation of A = μg

$\therefore v_1 = v_0 - \mu gt$ and $v_2 = \mu gt$

Hence, the correct graph is (B). After slipping is ceased the common velocity of both will become $\frac{v_0}{2}$, which can be obtained from conservation of linear momentum also.

Q.5 Block A is placed over the block B as shown in figure. Wedge is smooth and fixed. Force of friction on block A is :

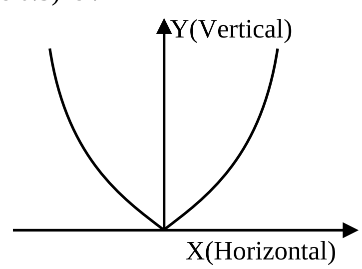


(A) towards right (B) towards left
(C) zero (D) always kinetic

[B]

Sol. Block A moves in horizontal direction only due to friction

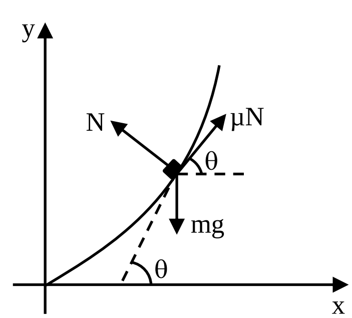
Q.6 A parabolic bowl with its bottom at origin has the shape $\mathbf{y} = x^2/20$. Here x and y are in metres. The maximum height at which a small mass **m** can be placed on the bowl without slipping (coefficient of static friction is 0.5) is :



(A) 2.5 m (B) 1.25 m
(C) 1.0 m (D) 4.0 m

[B]

Sol. $\frac{dy}{dx} = \frac{x}{10}$



or $\tan\theta = \frac{x}{10}$ … (i)

Equilibrium of mass in horizontal direction gives the equation,

$\mu N \cos\theta = N \sin\theta$

or $\tan\theta = \mu = \dfrac{1}{2}$ … (ii)

From Eqs. (i) and (ii)

$\dfrac{x}{10} = \dfrac{1}{2}$ or $x = 5$ m

$\therefore\ y = \dfrac{x^2}{20} = \dfrac{25}{20} = 1.25$ m

Q.7 A sphere is rotating between two rough inclined walls as shown in figure (a). Coefficient of friction between each wall and the sphere is 1/3. If $\mathbf{f_1}$ and $\mathbf{f_2}$ be the friction forces at P and Q. Then $\dfrac{f_1}{f_2}$ is –

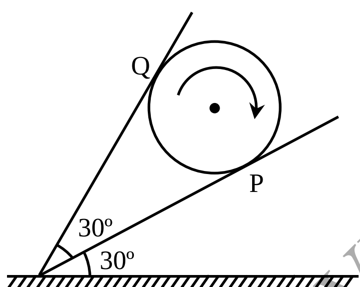


Fig. (a)

(A) $\dfrac{4}{\sqrt{3}} + 1$ (B) $\dfrac{1}{\sqrt{3}} + 2$

(C) $\dfrac{1}{2} + \sqrt{3}$ (D) $1 + 2\sqrt{3}$

[A]

Sol. Let μ be the friction coefficient between sphere and each wall. Free body diagram of sphere is

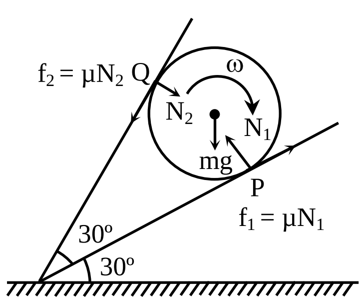


Fig.

Net force on the sphere in horizontal direction is zero.

$\therefore\ N_1 \cos 60^\circ + \mu N_2 \cos 60^\circ = N_2 \cos 30^\circ + \mu N_1 \cos 30^\circ$

or $N_1 + \mu N_2 = \sqrt{3}\,(N_2 + \mu N_1)$

or $N_1 (1 - \sqrt{3}\,\mu) = N_2\,(\sqrt{3} - \mu)$

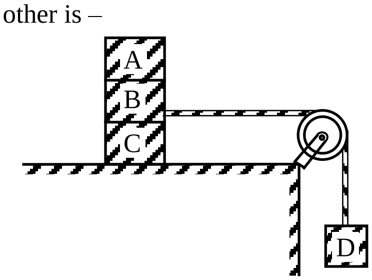
$\therefore\ \dfrac{N_1}{N_2} = \dfrac{\sqrt{3} - \mu}{1 - \sqrt{3}\,\mu}$

Substituting $\mu = \dfrac{1}{3}$ we get,

$$\frac{N_1}{N_2} = \frac{\sqrt{3} - \frac{1}{3}}{1 - \frac{\sqrt{3}}{3}} = \frac{3\sqrt{3} - 1}{3 - \sqrt{3}} = 1 + \frac{4}{\sqrt{3}}$$

Now $\dfrac{f_1}{f_2} = \dfrac{\mu N_1}{\mu N_2} = 1 + \dfrac{4}{\sqrt{3}}$

Q.8 Three blocks A, B and C of equal mass m are placed one over the other on a smooth horizontal ground as shown in figure. Coefficient of friction between any two blocks of A, B and C is ½. The maximum value of mass of block D so that the blocks A, B and C move without slipping over each other is –



(A) 6 m (B) 5 m

(C) 3 m (D) 4 m

[C]

Sol. Blocks A and C both move due to friction. But less friction is available to A as compared to C because normal reaction between A and B is less. Maximum friction between A and B can be:

$f_{max} = \mu\, m_A g = \left(\dfrac{1}{2}\right) mg$

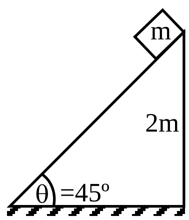
$\therefore$ Maximum acceleration of A can be:

$$a_{max} = \frac{f_{max}}{m} = \frac{g}{2}$$

further $a_{max} = \dfrac{m_D g}{3m + m_D}$

or $\dfrac{g}{2} = \dfrac{m_D g}{3m + m_D}$ or $m_D = 3m$

Q.9 A wedge of mass 2 m and a cube of mass m are shown in figure. Between cube and wedge, there is no friction. The minimum coefficient of friction between wedge and ground so that wedge does not move is –



(A) 0.10 (B) 0.20
(C) 0.25 (D) 0.50

[B]

Sol. Net horizontal force on wedge

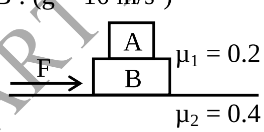
$F_H = mg \cos\theta \sin\theta$

Net normal reaction from the ground = 2 mg + mg $\cos^2\theta$

$\therefore \mu N = F_H$

$\Rightarrow \mu = 0.20$

Q.10 In the figure, $m_A = 2$ kg and $m_B = 4$ kg. For what minimum value of F, A starts slipping over B : ($g = 10$ m/s^2) –



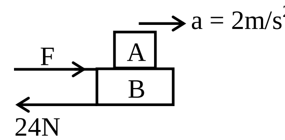
(A) 24 N (B) 36 N
(C) 12 N (D) 20 N

[B]

Sol. Maximum frictional force between A and B could be

$f_1 = \mu_1 m_A g = (0.2)(2)(10)$ N

$f_1 = 4$ N



Hence, maximum common acceleration till both the blocks move with same acceleration is

$$a = \frac{f_1}{m_A} = \frac{4}{2} = 2 \text{ m/s}^2$$

Now, taking (A + B) as the system:

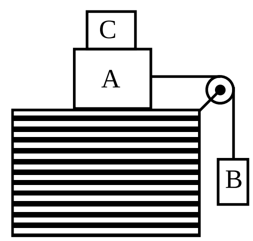
(From weight = upthrust)

$(f_2)_{max} = \mu_2(m_A + m_B)g = 24$ N

$F - 24 = (m_A + m_B)\, a = 6 \times 2 = 12$

$\therefore$ F = 36 N

Q.11 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 in figure. The coefficient of friction of A with the table is 0.2. The minimum mass of C that may be placed on A to prevent it from moving is –



(A) 15 kg (B) 5 kg (C) 10 kg (D) 0 kg

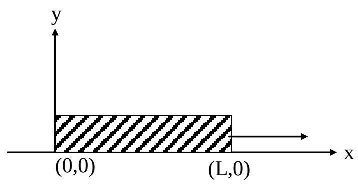
Sol. **[A]**

$5g = 0.2(10 + m)g \Rightarrow m = 15$ kg

Q.12 A uniform rod of length 'ℓ' and mass 'M' has been placed on rough horizontal surface as shown in figure. The rod is pulled by applying a horizontal force. Friction coefficient between surface and rod is 'μ' given by :

$$\mu = \begin{matrix} \mu_0 x & : & 0 \le x \le L \\ 0 & : & x > L \end{matrix}$$

Heat generated as rod moves by a distance 'L' is-



(A) $\frac{\mu MgL^2}{2}$ (B) μMgL^2

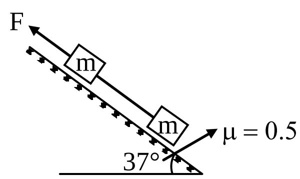
(C) $\frac{\mu MgL^2}{3}$ (D) $\frac{\mu MgL^2}{6}$

[A]

Sol. Heat generated = – (Work done by friction)

$$W_f = \int_0^L \mu\left(\frac{L-x}{L}.M\right)g = -\frac{\mu MgL^2}{2}$$

Q.13 Two identical blocks are kept on rough inclined plane (μ = 0.5). The blocks are connected with light string. If mg < F < 2mg, then -



(A) Friction force on block 'A' is in upward direction

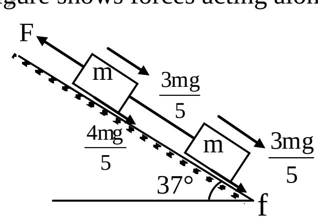
(B) Friction force on block B may be either in upward direction or downward direction

(C) Friction on block 'A' depends upon force 'F'

(D) Friction force on block 'B' may be zero

[B]

Sol. Figure shows forces acting along the string



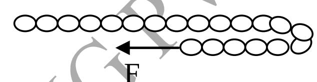
$$\therefore\ f + \frac{3mg}{5} = F - mg$$

$$\Rightarrow f = F - \frac{8mg}{5}$$

$\therefore$ If $F < \frac{8mg}{5} \Rightarrow f : -\text{ve} \Rightarrow$ Friction force on block 'B' is in upward direction.

$F > \frac{8mg}{5} \Rightarrow f : +\text{ve} \Rightarrow$ friction force on block 'B' is in downward direction.

Q.14 A chain of mass 'M' and length 'L' is put on a rough horizontal surface and is pulled by constant horizontal force 'F' as shown in figure. Velocity of chain as it turns completely: (Coefficient of friction = μ)

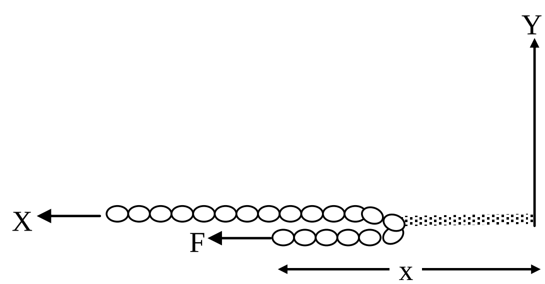


(A) $\left\{2\left(\frac{F}{M}-\mu g\right)L\right\}^{\frac{1}{2}}$ (B) $\left\{\left(\frac{2F}{M}-\mu g\right)\frac{L}{2}\right\}^{\frac{1}{2}}$

(C) $\left\{2\left(\frac{2F}{M}-\mu g\right)L\right\}^{\frac{1}{2}}$ (D) $\left\{\left(\frac{4F}{M}-\mu g\right)\frac{L}{2}\right\}^{\frac{1}{2}}$

[C]

Sol.



Let point of application of force have moved by distance 'dx'.

$\therefore$ Work done by friction

$$W_f = \int_0^{2L} -\mu\left(\frac{M}{L}.\,x\right)g\,dx$$

$\Rightarrow W_f = -Mg\ell$

$W_f = 2F\ell$

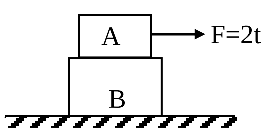
$\therefore W_{net} = 2FL - \mu MgL$

$\Rightarrow \frac{1}{2}Mv^2 = 2FL - \mu MgL$

$$\Rightarrow \mathbf{v} = \left\{2\left(\frac{2F}{M} - \mu g\right)L\right\}^{\frac{1}{2}}$$

Q.15 Two blocks A and B of mass 2 kg and 4 kg are placed one over the other. A horizontal force

F = 2t, which varies with time is applied on the upper block. If coefficient of friction between blocks A and B is 0.5 and horizontal surface is smooth. Then assuming t is in seconds, the total time upto which both blocks will move together without slipping over each other is -



(A) 5 sec (B) 7.5 sec
(C) 10 sec (D) 12.5 sec

[B]

Sol. If common maximum acceleration is a then,

$(m_A + m_B)a = f$

$(2 + 4)a = 2t$

$3a = t$ … (1)

For block B

$f_L = m_B \times a$

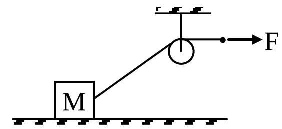
$0.5 \times 2 \times 10 = 4a$

$a = 2.5\ m/s^2$

From equation (1)

$t = 7.5$ sec

Q.16 The block of mass m is placed on a rough horizontal floor and it is pulled by an ideal string as shown by a constant force F. As the block moves towards right the frictional force on block-

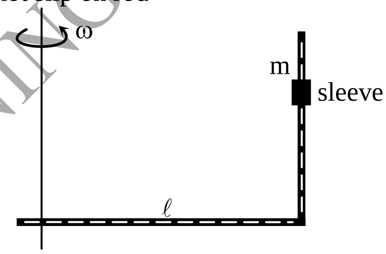


(A) remains constant (B) increases
(C) decreases (D) cannot be said

[C]

Sol. As block moves right normal reaction decreases

Q.17 A L shaped rod whose one end is horizontal and other is vertical is rotating about a vertical axis as shown with angular speed ω. The sleeve has mass m and friction coefficient between rod and sleeve is μ. The minimum angular speed ω for which sleeve cannot slip on rod –



(A) $\omega = \sqrt{\frac{g}{\mu\ell}}$ (B) $\omega = \sqrt{\frac{\mu g}{\ell}}$

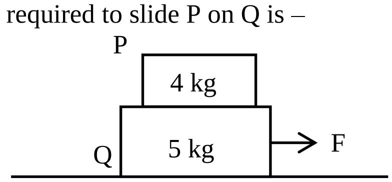
(C) $\omega = \sqrt{\frac{\ell}{\mu g}}$ (D) $\omega = \sqrt{\frac{\mu\ell}{g}}$

[A]

Sol. $N = m\ell\omega^2$ and $f_L = mg$

$\therefore\ \mu m\ell\omega^2 = mg \Rightarrow \omega = \sqrt{\frac{g}{\mu\ell}}$

Q.18 If the lower block is held fixed and force is applied to P, minimum horizontal force required to slide P on Q is 12 N. Now if Q is free to move on frictionless surface and force is applied to Q, then the minimum force F required to slide P on Q is –



(A) 12 N (B) 18 N
(C) 27 N (D) 36 N

[C]

Sol. $12 = \mu 4g \quad \Rightarrow \mu = 0.3$

a_{pmax} possible $= \mu g = 3\ m/s^2$

$F = (5 + 4) \times 3 = 27$ N

Q.19 The force of kinetic friction does not depend on–

(A) the relative velocity of the two surfaces in contact.

(B) nature of the surfaces in contact.

(C) normal reaction on the moving body

(D) all of the above **[A]**

Sol. μ_k depends upon nature of contact surfaces only

Q.20 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 ms^{-2}, the body will stop after covering a distance of –

(A) 10 m (B) 25 m

(C) 50 m (D) 250 m

[B]

Sol. u = 10, v = 0, a = – μg

Now $v^2 = u^2 + 2as$

Q.21 A blocks of mass 5.2 kg is placed on a rough plane inclined at an angle α to the horizontal where $\sin\alpha = 0.6$. The coefficient of friction between the block and the plane is 0.4. The block is just prevented from sliding down the plane by a horizontal force P. Then the value P is –

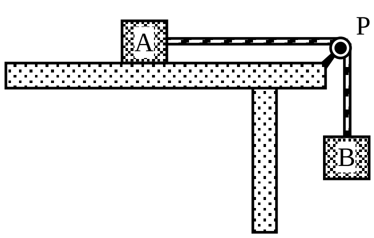
(A) 14 N (B) 15 N

(C) 13 N (D) 18 N

[A]

Sol. $Mg \sin\alpha = P \cos\alpha + \mu [Mg \cos\alpha + P \sin\alpha]$

Q.22 The block 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 –



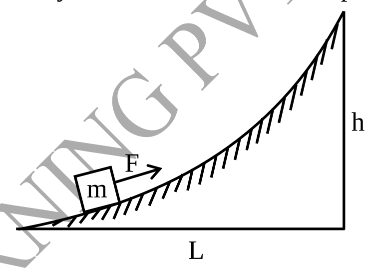
(A) 2 kg (B) 0.2 kg

(C) 5 kg (D) 10 kg

[A]

Sol. $\mu M_A g = M_B g \Rightarrow M_B = \mu M_A = .2 \times 10 = 2$ kg

Q.23 A body of mass m is hauled up the hill with constant speed v by a force such that the force at each point is directed along the tangent to the path. The length of base of hill is L and its height is h. The coefficient of friction between the body and path is μ. Then which of the following statement is incorrect when body moves from bottom to top -



(A) work done by gravity is –mgh

(B) work done by friction is – μmgL

(C) work done by gravity is path independen

(D) None of the above

[B]

Sol. Conceptual

Q.24 A bead of mass m is located on a parabolic wire with its axis vertical and vertex directed towards downward as in figure and whose equation is $x^2 = ay$. If the coefficient of friction is μ, the highest distance above the x-axis at which the particle will be in equilibrium is -

(A) μa (B) $\mu^2 a$

(C) $\frac{1}{4}\mu^2 a$ (D) $\frac{1}{2}\mu a$

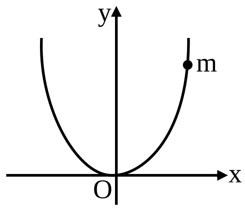
[C]

Sol. For the sliding not to occur when $\tan\theta \le \mu$

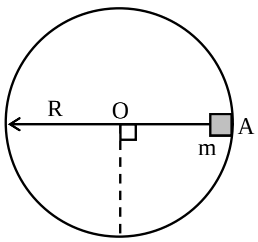
$$\tan\theta = \frac{dy}{dx} = \frac{2x}{a} = \frac{2\sqrt{ya}}{a} = 2\sqrt{\frac{y}{a}}$$

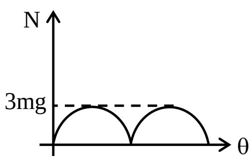
$$2\sqrt{\frac{y}{a}} \le \mu \text{ or } y \le \frac{a\mu^2}{4}$$

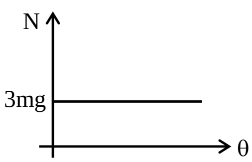
Q.25 A particle of mass m is released from point

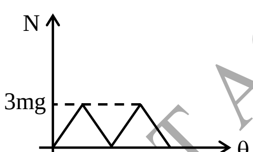


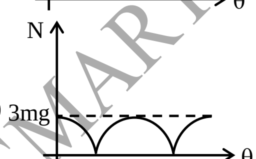
A on smooth fixed circular track as shown. If the particle is released from rest at t = 0, then variation of normal reaction N with (θ) angular displacement from initial position is -



(A)


(B)


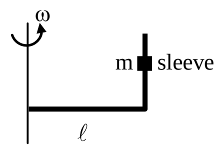
(C)


.(D)


Sol. **[A]**

$$N = mg \sin\theta + \frac{mv^2}{r} \text{ and } v^2 = 2g\, r \sin\theta$$

Q.26 A L shaped rod whose one rod is horizontal and other is vertical is rotating about a vertical axis as shown with angular speed ω. The sleeve shown in figure has mass m and friction coefficient between rod and sleeve is μ. The minimum angular speed ω for which sleeve cannot sleep on rod is -



(A) $\omega = \sqrt{\frac{g}{\mu\ell}}$ (B) $\omega = \sqrt{\frac{\mu g}{\ell}}$

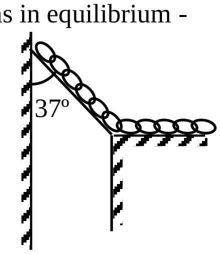
(C) $\omega = \sqrt{\frac{\ell}{\mu g}}$ (D) None of these

Sol. **[A]**

$N = m\ell\omega^2$ therefore $f = \mu N$

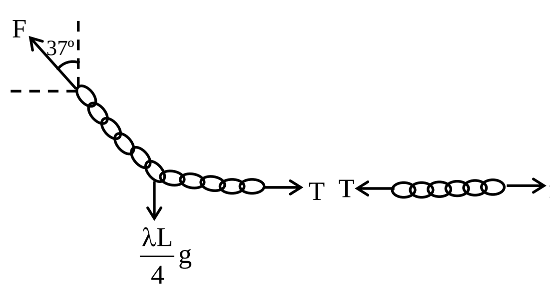
$\therefore\ \mu m\ell\omega^2 = mg$

Q.27 A uniform chain of length 'L' has one of its ends attached to the wall at point 'A', while $\frac{3L}{4}$ of the length of chain is lying on table as shown in figure. The minimum coefficient of friction between table and chain so that chain remains in equilibrium -



(A) $\frac{1}{3}$ (B) $\frac{1}{4}$ (C) $\frac{3}{4}$ (D) $\frac{1}{5}$

Sol. **[B]**



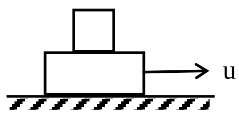
$$F \cos 37^\circ = \frac{\lambda L}{4} g$$

$F \sin 37^\circ = T = f$

$\therefore\ f = \dfrac{3\lambda Lg}{16} \le \mu N$

$\Rightarrow \mu \ge \dfrac{1}{4}$

Q.28 A block is resting on a horizontal plate in the XY plane and co-efficient of friction between block and the plate is 'μ'. The plate begins to move with velocity $u = bt^2$ in X-direction. At what time will the block starts sliding from plate -



(A) $\dfrac{\mu b}{g}$ (B) $\dfrac{\mu bg}{2}$ (C) $\dfrac{\mu g}{b}$ (D) $\dfrac{\mu g}{2b}$

Sol. **[D]**

$\mu\, mg = m.\ 2bt \Rightarrow t = \dfrac{\mu g}{2b}$

Q.29 The coefficient of friction between two surfaces is 0.2. The angle of friction is -

(A) $\sin^{-1}(0.2)$ (B) $\cos^{-1}(0.2)$

(C) $\tan^{-1}(0.1)$ (D) $\cot^{-1}(5)$

Sol. **[D]**

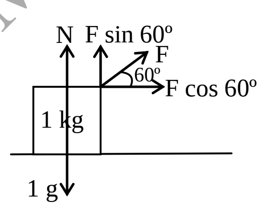
$\theta = \tan^{-1}(\mu)$

Q.30 A block of mass 1 kg is at rest on a horizontal table. The coefficient of static friction between the block and the table is 0.5. If g = 10 m s^{-2} , then the magnitude of the force acting upwards at an angle of 60º from the horizontal that will just start the block moving is -

(A) 5 N (B) 5.36 N

(C) 74.6 N (D) 10 N

Sol. **[B]**



$F \cos 60^\circ = f$ ...(i)

$f = \mu N = \mu\,(1\ g - F \sin 60^\circ)$ ...(ii)

Q.31 A block of mass 2 kg rests on a rough inclined plane making an angle of 30º with the horizontal. The coefficient of static friction between the block and the plane is 0.7. The frictional force on the block is -

(A) 9.8 N (B) $0.7 \times 9.8 \times \sqrt{3}$ N

(C) $9.8 \times \sqrt{3}$ N (D) 0.7×9.8 N

Sol. **[A]**

$f = \mu mg \cos\theta = 0.7 \times 2 \times g \times \dfrac{\sqrt{3}}{2} = 0.7 \times g \times \sqrt{3}$ Ext. force = $mg \sin\theta = 2 \times g \times \dfrac{1}{2} = 9.8$

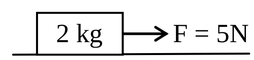
f > Ext. force. So particle will at rest

Q.32 A body of mass 2 kg is at rest on a horizontal table. The coefficient of friction between the body and the table is 0.3. A force of 5 N is applied on the body. The acceleration of the body is -

(A) 0 m s^{-2} (B) 2.5 m s^{-2}

(C) 5 m s^{-2} (D) 7.5 m s^{-2}

Sol. **[A]**



$\mu = 0.3$

friction $f = \mu\, mg = 0.3 \times 2 \times 10 = 6$ N, acce = 0

Q.33 A car starts from rest to cover a distance x. The coefficient of friction between the road and tyres is μ. The minimum time in which the car can cover distance x is proportional to -

(A) μ (B) $\dfrac{1}{\sqrt{\mu}}$

(C) $\sqrt{\mu}$ (D) $\dfrac{1}{\mu}$

Sol. **[B]**

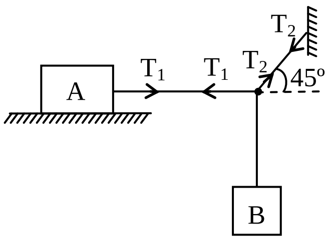
$V = u + at$ $v^2 = u^2 + 2as$

$0 = u + (-\mu g)t$ $0 = u^2 + 2(-\mu g)\, s$

$t = \dfrac{u}{\mu g}$ $u = \sqrt{2\mu gs}$

$t = \frac{\sqrt{2\mu g s}}{\mu g} \Rightarrow t \propto \frac{1}{\sqrt{\mu}}$

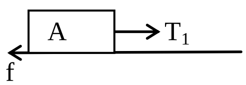
Q.34 The block A in Figure weighs 100 N. The coefficient of static friction between the block and the table is 0.25. The weight of the block B is maximum for the system to be in equilibrium. The value of T_1 is



(A) 0.25 N (B) 25 N

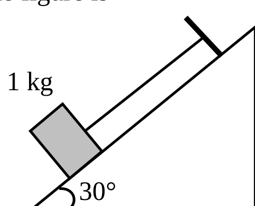
(C) 100 N (D) 100.25 N

Sol. **[B]**



$T_1 = f = 0.25 \times 100$; $T_1 = 25$ N

Q.35 The coefficient of friction between two surfaces is $\mu = 0.8$. The tension in the string shown in the figure is -



(A) 0 N (B) 6 N

(C) 4 N (D) 8 N

Sol. **[A]**

$\because \tan\theta < \mu$ $\therefore$ Body will not slide and string will be slack $\Rightarrow T = 0$

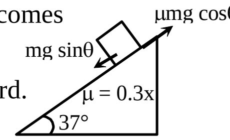
Q.36 A body is moving down a long inclined plane of slope 37°. The coefficient of friction between the body and plane varies as $\mu = 0.3x$, where x is the distance travelled down the plane. The body will have maximum speed -

(sin 37° = $\left(\frac{3}{5}\right)$ and g = 10 m/s^2)

(A) at x = 1.16 m (B) at x = 2 m

(C) at bottom of plane (D) at x = 2.5 m

Sol. **[D]**



After some time friction becomes more than $mg\sin\theta$, then body will retard. Thus speed is maximum when, total force or acc. is zero.

$mg\sin\theta - \mu mg\cos\theta = 0$

$\Rightarrow \mu = \tan\theta \Rightarrow 0.3x = 3/4$

$\Rightarrow x = 2.5$m

Q.37 A piece of ice slides down a 45° incline in twice the time it takes to slide down a frictionless 45° incline. What is the coefficient of friction between the ice and incline ?

(A) 0.25 (B) 0.50

(C) 0.75 (D) 0.40

Sol. **[C]**

$\mu = \tan\theta\left(1 - \frac{1}{n^2}\right)$ [discussed in class room]

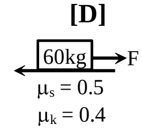
$= \tan 45\left(1 - \frac{1}{2^2}\right) = ¾$

Q.38 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

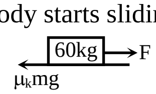
Sol. **[D]**



Force required to start the motion,

$F = \mu_s mg$

Once body starts sliding friction becomes kinetic.



$\therefore a = \frac{F - \mu_k mg}{m} = \frac{\mu_s mg - \mu_k mg}{m} = (\mu_s - \mu_k)g = 1\text{m/s}^2$

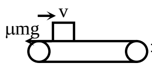
Q.39 A suitcase is gently dropped on a conveyor belt moving at 3 m/s. If the coefficient of friction between the belt and the suitcase is 0.5, find the displacement of the suitcase relative to conveyor belt before the slipping between the two is stopped : ($g = 10\ m/s^2$)

(A) 2.7 m (B) 1.8 m

(C) 0.9 m (D) 1.2 m

Sol. **[C]**

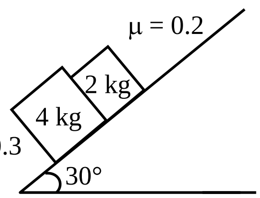
Relative to belt, $a = \dfrac{\mu mg}{m} = \mu g = 5 m/s^2$



$\Rightarrow 0 = u^2 - 2as \Rightarrow s =$

$\dfrac{u^2}{2a} = \dfrac{(3)^2}{2 \times 5} = 0.9m$

Q.40 Two blocks, 4 kg and 2 kg are sliding down an incline plane as shown in figure. The acceleration of 2 kg block is -



(A) $1.66\ m/s^2$ (B) $2.66\ m/s^2$

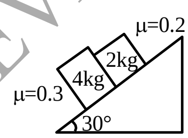
(C) $3.66\ m/s^2$ (D) $4.66\ m/s^2$

Sol. **[B]**

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

$\Rightarrow a = g\sin\theta - \left(\dfrac{\mu_1 m_1 + \mu_2 m_2}{m_1 + m_2}\right)$

$g\cos\theta$



$= g\left[\dfrac{1}{2} - \left(\dfrac{0.3 \times 4 + 0.2 \times 2}{4+2}\right) \times \dfrac{\sqrt{3}}{2}\right] = 2.66\ m/s^2$

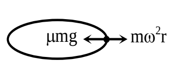
Q.41 A gramophone record is revolving with an angular velocity ω. A coin is placed at a distance R from the centre of the record. The static coefficient of friction is μ. The coin will revolve with the record if -

(A) $R > \dfrac{\mu g}{\omega^2}$ (B) $R = \dfrac{\mu g}{\omega^2}$ only

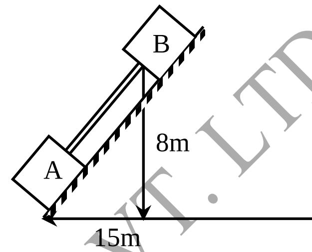
(C) $R < \dfrac{\mu g}{\omega^2}$ (D) $R \le \dfrac{\mu g}{\omega^2}$

Sol. **[D]**

$m\omega^2 r \le \mu mg \Rightarrow r \le \mu g/\omega^2$



Q.42 Blocks A and B in the figure are connected by a bar of negligible weight. If A = B = 170 kg & $\mu_A = 0.2$ and $\mu_B = 0.4$, where μ_A and μ_B are the coefficients of limiting friction between blocks and plane, calculate the force on the bar : ($g = 10\ m/s^2$)



(A) 150 N (B) 75 N

(C) 200 N (D) 250 N

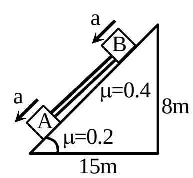
Sol. **[A]**

For (A) $\rightarrow mg\sin\theta - T - \mu_A mg\cos\theta = ma$ ....(1)

For (B) $\rightarrow T + mg\sin\theta - \mu_B mg\cos\theta = ma$ ....(2)

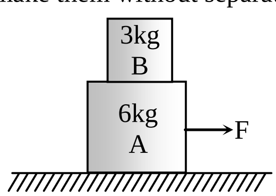
$\Rightarrow mg\sin\theta - T - \mu_A mg\cos\theta = T + mg\sin\theta - \mu_B mg\cos\theta$

$\Rightarrow T = \dfrac{mg\cos\theta}{2}(\mu_B - \mu_A)$



$= \dfrac{170 \times 10 \times 15/17}{2}(0.4 - 0.2) = 150N$

Q.43 Two blocks A and B of masses 6 kg and 3 kg rest on a smooth horizontal surface as shown in fig. If coefficient of friction between A and B is 0.4, the maximum horizontal force which can make them without separation is -



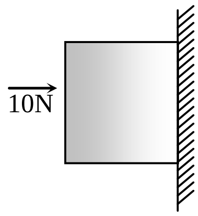
(A) 72 N (B) 40 N

(C) 36 N (D) 20 N

Sol. **[C]**

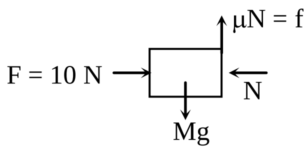
$F = \mu(m_A + m_B)\ g = 0.4\ (3 + 6) \times 10 = 36\ N$

Q.44 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 (fig.). The weight of the block is -



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

Sol. **[B]**



N = 10 N

f = μN = Mg = 20 N

Q.45 A car is moving along a straight horizontal road with a velocity of 72 km h^{-1}. If $\mu_s = 0.5$, then the shortest distance in which the car can be stopped is [Take g = 10 ms^{-2}].

(A) 40 m (B) 80 m (C) 100 m (D) 120 m

Sol. **[A]**

$v^2 = u^2 + 2as \Rightarrow 0 = u^2 + 2(-\mu g)s$

$$s = \frac{u^2}{2\mu g} = \frac{(20)^2}{2\times 0.5\times 10}.$$

Q.46 A mass m is placed on an inclined plane. If the mass is in equilibrium, the maximum inclination of the plane with the horizontal would be (where μ is the coefficient of friction between the mass and surface) -

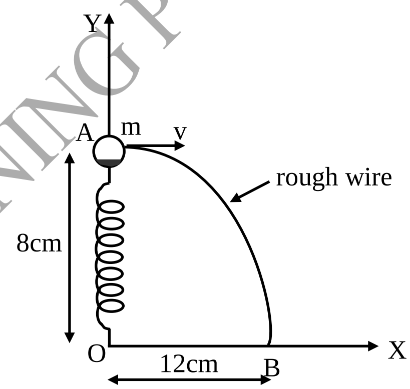
(A) $\tan^{-1}\mu$ (B) $\tan^{-1}\left(\frac{\mu}{2}\right)$

(C) $\tan^{-1}\left(\frac{\mu}{m}\right)$ (D) $\cos^{-1}\mu$

Sol. **[A]**

Repose angle = $\tan^{-1}(\mu)$ = maximum inclination of the plane with the horizontal if the mass is in equilibrium.

Q.47 A ring of mass 200 gram is attached to one end of a light spring of force constant 100 N/m and natural length 10 cm. The ring is constrained to move on a rough wire in the shape of quarter ellipse of major axis 24 cm and minor axis 16 cm with its centre at origin. The plane of ellipse is vertical and wire is fixed at points A and B as shown in figure. Initially ring is at A with other end of spring fixed at origin. Ring is given a horizontal velocity of 10 m/s towards right so that it just reaches point B, then select the correct alternative (s) (g = 10 m/s^2)



(A) Work done by friction is – 10 Joule

(B) At B energy stored in spring is more than energy stored at A.

(C) Work done by friction is –10.16 Joule

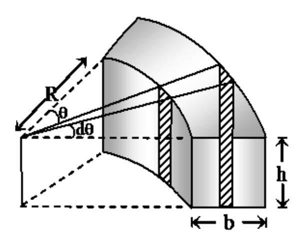
(D) Work done by spring force is positive

Sol.[C] Apply work energy theorem

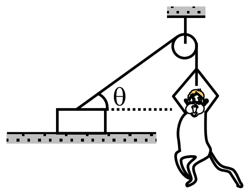
$W_g + W_N + W_{fr} + W_s = \Delta K$

$W_{fr} = -\frac{1}{2}mv^2 - mg(0.08)$

$W_{fr} = -10.16$



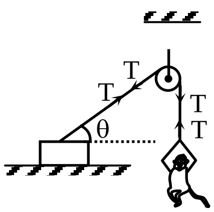
Q.48 A block of mass m rests on a rough horizontal surface with a rope tied to it. The co-efficient of friction between the surface and the block is μ. A monkey of the same mass climbs at the free end of the rope. The maximum acceleration with which the monkey can climb without moving the block is-



(A) $\dfrac{\mu g}{\mu\sin\theta+\cos\theta}-g$ (B) $\dfrac{\mu g}{\mu\sin\theta-\cos\theta}+g$

(C) $\dfrac{\mu g}{\tan\theta-\mu\cos\theta}+g$ (D) $\dfrac{\mu g}{\tan\theta+\mu\sec\theta}-g$

Sol.[A]



$T - mg = ma$ ……(1)

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

$$T=\frac{\mu mg}{(\cos\theta+\mu\sin\theta)}$$

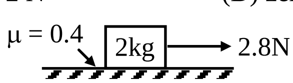
$$a=\frac{\mu g}{(\cos\theta+\mu\sin\theta)}$$

Q.49 A block of mass 2 kg is placed on the floor. The coefficient of static friction is 0.4. If a force of 2.8 N is applied on the block parallel to the floor, the force of friction between the block and the floor (taking $g = 10\ ms^{-2}$) is -

(A) 2.8 N (B) 8 N

(C) 2 N (D) zero

Sol. **[A]**

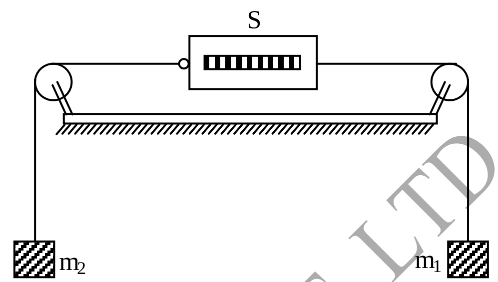


∵ 2.8 N is less than limiting force

∴ static friction f_S = 2.8 N

$f_L = (0.4)\,(2g) = 8$ N

Q.50 In the arrangement shown, the pulleys are fixed and ideal, the strings are light, $m_1 > m_2$, and S is a spring balance which is itself massless. The reading of S (in units of mass) is -



(A) $m_1 - m_2$ (B) $\dfrac{1}{2}\,(m_1 + m_2)$

(C) $\dfrac{m_1m_2}{m_1+m_2}$ (D) $\dfrac{2m_1m_2}{m_1+m_2}$

Sol. **[D]**

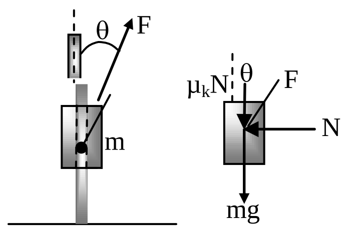
Acceleration of system = $\dfrac{m_1-m_2}{m_1+m_2}\,g$

Tension in string = $\dfrac{2m_1m_2}{m_1+m_2}\,g$

reading of spring balance is T.

PHYSICS

Q.1 The collar of mass **m** slides up the vertical shaft under the action of a force **F** of constant magnitude but variable direction. If $\theta = kt$, where k is a constant and if the collar starts from rest with $\theta = 0$, determine the magnitude F of the force which will result in the collar coming to rest as θ reaches $\pi/2$. The coefficient of kinetic friction between the collar and shaft is μ_k.



Sol. $[\Sigma F_y = ma_y]$ $F\cos\theta - \mu_k N - mg = m\dfrac{dv}{dt}$

Where equilibrium in the horizontal direction requires $N = F\sin\theta$. Substituting $\theta = kt$ and integrating first between general limits give

$$\int_0^t (F\cos kt - \mu_k F\sin kt - mg)dt = m\int_0^v dv$$

Which becomes $\dfrac{F}{k}[\sin kt + \mu_k(\cos kt - 1)] - mgt = mv$

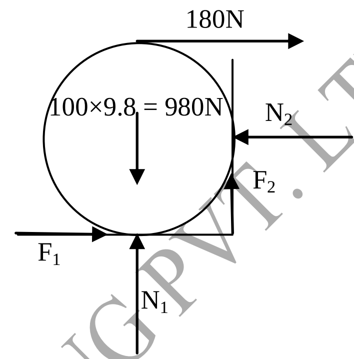
For $\theta = \pi/2$ the time becomes $t = \pi/2k$, and $v = 0$ so that

and $F = \dfrac{mg\pi}{2(1-\mu_k)}$ **Ans.**

Helpful Hints :

1. If θ were expressed as a function of the vertical displacement y instead of the time t, the acceleration would be come a function of the displacement and we would use v dv = a dy.
2. We see that the results do not depend on k, the rate at which the force changes direction.

Q.2 See fig. will the 180-N force cause the 100-kg cylinder to slip ? The coefficient of friction is 0.25.



Sol. Since it is unknown whether or not the cylinder slips, it is not possible to say $F_1 = \mu N_1$ and $F_2 = \mu N_2$. Therefore, consider F_1 and F_2 as unknowns together with N_1 and N_2. The equations of equilibrium are

$\Sigma F_h = 0 = F_1 - N_2 + 180$ …….(1)

$\Sigma F_v = 0 = N_1 + F_2 - 980$ …….(2)

$\Sigma M_A = 0 = -180 \times 2r + F_2 \times r + N_2 \times r$ …….(3)

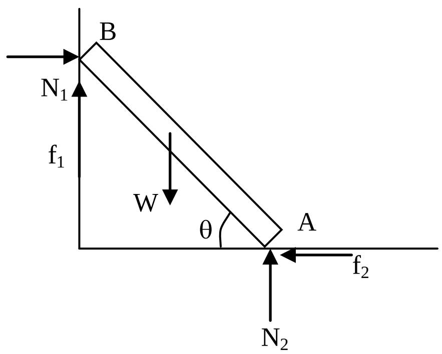
Solve for N_1, N_2 and F_1 in terms of F_2. These values are $N_1 = 980 - F_2$, $N_2 = 360 - F_2$ and $F_1 = 180 - F_2$

Let us assume F_2 is at its maximum value, that is $0.25N_2$ and solve for N_2, N_1, and F using equations (1), (2) and (3). Then N_1 = 288N , N2 = 908N, and F_1 = 108N.

This means that if F_2 assumes its maximum static value then F_1 must be 108N to hold the system in equilibrium. Since the maximum value of F_1 obtainable is $0.25N_1$ = 227N the cylinder will not rotate.

Q.3 Determine the smallest angle θ for equilibrium of a homogenous ladder of length 'ℓ' leaning against a wall. The coefficient of friction for all surfaces is μ.

Sol.



Translational equilibrium : $f_1 + N_2 - W = 0$ …..(1)

where $f_1 = \mu N_1$

$N_1 - f_2 = 0$ …..(2)

where $f_2 = \mu N_2$

Rotational equilibrium : net torque about A is zero

$$N_1\ell\sin\theta + f_1\ell\cos\theta - W\frac{\ell}{2}\cos\theta = 0$$

$$N_1\sin\theta + f_1\cos\theta - \frac{W}{2}\cos\theta = 0 \quad …..(3)$$

From (i) & (ii)

$N_2 = W - f_1 = W - \mu N_1$

$N_1 = f_2 = \mu N_2$

$N_1 = \mu [W - \mu N_1]$

$$N_1 = \frac{\mu W}{1+\mu^2}$$

From (3)

$$N_1\sin\theta + \mu N_1\cos\theta - \frac{W}{2}\cos\theta = 0$$

$$N_1[\sin\theta + \mu\cos\theta] = \frac{W}{2}\cos\theta$$

$$\frac{\mu W}{1+\mu^2}[\sin\theta + \mu\cos\theta] = \frac{W}{2}\cos\theta$$

$$[\tan\theta + \mu] = \frac{1}{2}\frac{(1+\mu^2)}{\mu}$$

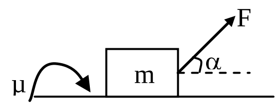
$$\tan\theta = \frac{1+\mu^2}{2\mu} - \mu$$

$$\tan\theta = \frac{1+\mu^2-2\mu^2}{2\mu}$$

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

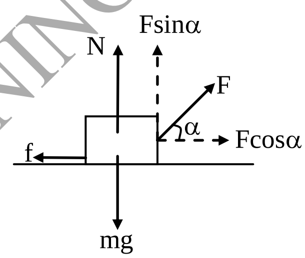
This is critical value of θ below which slip will occur.

Q.4



Find the minimum value of F required to move the block.

Sol. **First method :**



$F\cos\alpha - f = 0 \Rightarrow F\cos\alpha = f = \mu N$ …..(i)

$N + F\sin\alpha = mg \Rightarrow N = mg - F\sin\alpha$ …..(ii)

From (i) & (ii)

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

$$F = \frac{\mu mg}{\cos\alpha + \mu\sin\alpha} \quad ….(iii)$$

For minimum ‘F’

$$\frac{dF}{d\alpha} = \frac{-\mu mg(-\sin\alpha + \mu\cos\alpha)}{(\cos\alpha + \mu\sin\alpha)^2} = 0$$

$\tan\alpha = \mu$

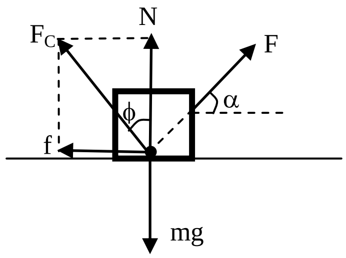
$\alpha = \tan^{-1}\mu$ …(iv)

If block is pulled at angle of friction ($\tan^{-1}\mu$). Then minimum force is required

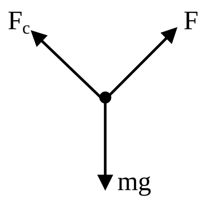
Putting (iv) in (iii)

$$\mathbf{F_{min} = \frac{\mu mg}{\sqrt{1+\mu^2}}}$$

Method II :



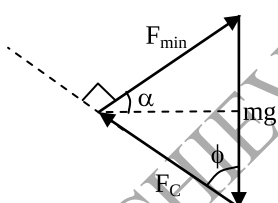
body is in equilibrium under action of three forces as shown.



$F_C \rightarrow$ contact force

Therefore $\vec{F} + \vec{F}_C + m\vec{g} = 0$

Vector triangle should be drawn such that 'F' is minimum. When body is about to move angle ϕ between N and F_C is angle of friction i.e., $\phi = \tan^{-1}\mu$.

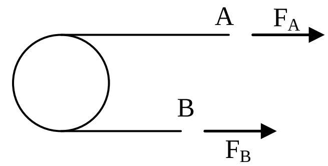


F is minimum in above triangle when a perpendicular is drawn from tail of mg on line of action of F_C.

From above figure $\alpha = \phi = \tan^{-1}\mu$

and $F_{min} = mg \sin\phi = mg\left(\dfrac{\mu}{\sqrt{1+\mu^2}}\right)$.

Q.5 A light inelastic thread is stretched round one-half of the circumference of a fixed cylinder as shown in the figure.



As a result of friction, the thread does not slip on the cylinder when the magnitudes of the forces acting on its ends fulfil the inequality

$$\frac{1}{2}F_A \le F_B \le 2F_A.$$

Determine the coefficient of friction between the thread and the cylinder.

Sol. When one end of the thread is pulled by a force F_0, let the maximum force with which the other end can be pulled without the thread slipping on the cylinder be F_{max} specify a general point of the thread in contact with the cylinder the angle α, which the radius of the cylinder at that point makes with a fixed radius. When the thread wound onto the cylinder is tightened, it exerts a normal force on the cylinder resulting in a frictional force which opposes any relative motion of the thread and the cylinder. The tension in the thread increases as α increases, but the excess tension at one end of a piece of the thread is balanced by the frictional force acting on that piece.

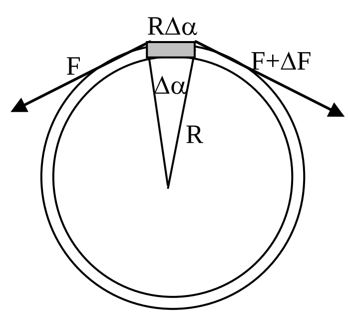


Fig.(a)

Consider a small length of thread that subtends an angle $\Delta\alpha$ at the centre of the cylinder. If as shown in fig.(a) the tension at one end of the small piece is F whilst it is F + ΔF at the other then the excess force ΔF is balanced by a frictional force, which can be calculated as

$\Delta F = \mu N$ ……..(i)

Where N is the exerted by the thread normal to the surface of the cylinder and μ is the required coefficient of friction.

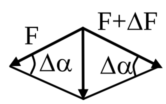


Fig.(b)

The normal force can be determined as the vector resultant of the forces F and F + ΔF $\approx$ F, shown in fig.(b) This is

$N = 2F \sin\frac{\Delta\alpha}{2} \approx F\Delta\alpha.$ ……(ii)

Substituting this into equation (1) shows the relationship between F and the angle α to be

$$\Delta F(\alpha) = \mu F(\alpha)\Delta\alpha.$$

This relationship is formally similar to the equation governing radioactive decay.

$$\Delta m(t) = -\lambda\, m(t)\, \Delta t,$$

Where m(t) is the mass of radioactive material, t the elapsed time, and λ the decay constant. As is well known, the mass of radioactive material decreases exponentially with time, i.e. $m(t) = m_0 e^{-\lambda t}$

Thus, using the established correspondence, with $-\lambda$ replaced by μ, the law of 'thread friction' can be expressed as

$F(\alpha) = F_0 e^{\mu x}$

………(3)

Both of the inequalities stated in the problem are equivalent to

$2F(0) = F(\pi) = F(0)\, e^{\mu\pi}$, which yields $\boldsymbol{\mu = \frac{1}{\pi}\ell n\, 2 \approx 0.22.}$

Q.6 Two blocks are connected by a light, flexible cable that passes over a frictionless pulley (see fig.1). Block A weights 500N, and block B weighs 200N. The coefficient of static friction between block A and the ramp is μ_s = 0.30.

(a) Determine whether the blocks are in equilibrium.

(b) Determine whether block A will slide down the ramp after the cable in cut

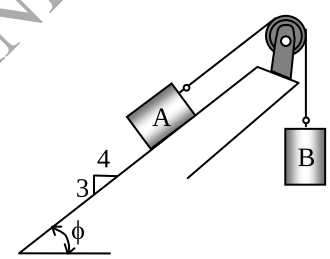


Fig.1

Sol. **(a)** Neither the magnitude nor the sense of the frictional force is known. Therefore, we assume that the blocks are in equilibrium, and drawn the free-body diagram of block B (see fig.2). Summing forces in the y direction. We have T – 200 = 0, or T = 200N. Since the sense of the frictional force that acts on black A is not immediately obvious, we draw the free-body diagram of block A, and assume that the frictional force F acts down the ramp (see fig.3). Since the pulley is frictionless the force that the cable exerts on block A is t = 200 N. From fig.3 the equations of equilibrium for block A are

$\sum F_x = T - F - 500\sin\phi = 0$ …… (a)

$$\sum F_y = N - 500\cos\phi = 0 \qquad \text{...... (b)}$$

The solutions of Eqs. (a) and (b) are N = 400N and F = –100N. Since the sign of F is negative, the assumed sense of F is wrong. The correct sense of F is up the ramp fig.4 The block are in equilibrium, since F = 100N does not exceed the minimum static frictional force, $F_s = \mu_s N$ = (0.3) (400) = 120N.

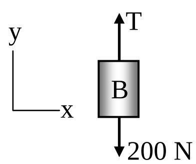


Fig. 2

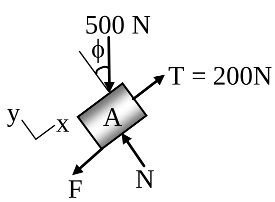


Fig. 3

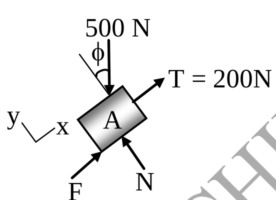


Fig. 4

(**b**) To determine whether or not block A slides down the ramp after the cable is cut, we solve eq. (a) for F, with –F replaced by +F and T = 0. Then F = 300N. Since the frictional force (F = 300N) required to keep block A from sliding is greater than the maximum static frictional force (F_s = 120N), block A will slide down the ramp.

Information Item : The result of part of could have been obtained by comparing the ramps angle of inclination ϕ to the angle of repose ϕ. From fig. a, $\phi = \tan^{-1}(3/4) = 36.87^o$ with $\mu_x = 0.3$, we find $\phi_s = \tan^{-1}(0.3) = 16.70^o$. Since $\phi > \phi_s$ the ramp is inclined at an angle greater than the angle of repose. Therefore, block A will slide down the ramp after the cable is cut.

Q.7 A large rectangular shipping crate of height **h** and width **b** is at rest on a floor. It is a acted on by a horizontal force P, as illustrated in Fig.1 Assume that the material in the crate is uniformly distributed so that the weights acts at the centroid of the crate.

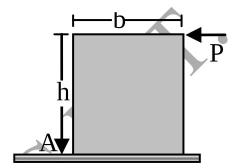


Fig.1

(a) Determine the conditions for which the crate is on the verge of sliding.

(b) Determine the conditions under which the crate will tip about point A.

Sol. Before we consider whether the crate will tip or slide, we consider the normal reaction of the floor on the crate, and draw a general free-body diagram of the crate (see fig.2) We assume that the normal reaction is distributed over the bottom of the crate, as indicated by the dashed arrows. The resultant of these distributed parallel normal forces is a normal force N that acts at some distance x from point A. For both parts **a** and **b**, we know oppose P. Under these general conditions, the equilibrium equations for the crate are

Q.8 A sphere, made of two non-identical homogeneous hemispheres stuck together, is placed on a plane inclined at an angle of 30º to the horizontal. Can the sphere remain in equilibrium on the inclined plane ?

Sol. If static friction is large enough, the sphere will not slide down the slope. However, this by itself is not sufficient for equilibrium; it is also necessary that the sphere does not roll down the inclined plane.

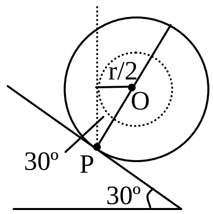


Fig.1

The sphere is made of two hemispheres, implying an inhomogeneous mass distribution. If the distance between its centre of mass and geometrical centre is less than $\frac{1}{2}$ r, where r is the radius of the sphere, then whatever the orientation of the sphere, its weight will produce a torque about P, the point of contact with the inclined plane (see fig.1) which will make the sphere roll.

It will now be shown that this is the situation for any sphere made of two homogeneous hemispheres – whatever the densities of the two halves.

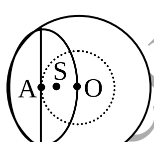


Fig.2

Consider the shaded area in fig.2 By symmetry, the centre of mass of this part is obviously at point A, i.e. at a distance $\frac{1}{2}$ r from the centre O. The rest of the sphere moves the centre of mass S of the whole even closer to point O, i.e. OS < $\frac{1}{2}$ r.

From our previous considerations, this implies that the sphere cannot remain in equilibrium on the 30º inclined plane. In obtaining the solution, we have assumed that rolling resistance is small i.e., no resistance torque can act at point P. In the case of a surface covered with Velcro, this is obviously not true, and the sphere may even adhere to a vertical surface.

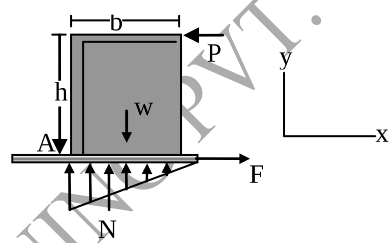


Fig.2

$$\sum F_x = F - P = 0 \qquad \ldots\ldots(a)$$

$$\sum F_y = N - W = 0 \qquad \ldots\ldots(b)$$

$$\sum M_A = Nx - (0.5)(Wb) + Ph = 0 \qquad \ldots\ldots(c)$$

Consequently, if the crate is in equilibrium, Eqs. (a), (b) and (c) yield

$$F = P \qquad \ldots\ldots (d)$$

$$N = W \qquad \ldots\ldots (e)$$

$$X = \frac{b}{2} - \frac{Ph}{W} \qquad \ldots\ldots (f)$$

(a) If the crate is on the verge of sliding, F = $F_s = \mu_s N$, where μ, is the coefficient of static friction. By Eqs. (d) and (e) the value of P corresponding to this condition is

$$P_{sliding} = F_s = \mu_s W \qquad \ldots\ldots (g)$$

(b) If the crate is on the verge of tipping, it is on the verge of rotating about point A; that is, the crate and the floor are in contact only at point A. Consequently, the normal force is concentrated at A, and x = 0 (see fig.2) For x = 0, Eq.(f) yields

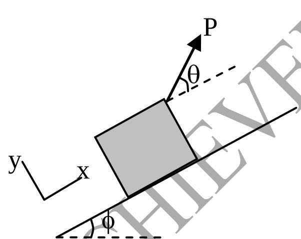
$P_{tipping} = \dfrac{Wb}{2h}$ ……(h)

Note that tipping will occur before sliding, provided that $P_{sliding} > P_{tipping}$. Therefore, by Eqs.(g) and (h), if P increases until motion occurs, tipping will occur before sliding provided that

$\mu_s > \dfrac{b}{2h}$

On the other hand, sliding will occur without tipping if $\mu_s < b/2h$. For $\mu_s = b/2h$, tipping and sliding occur simultaneously.

Q.9 The friction of a block moves on an inclined plane utilized in various machines. To develop the general theory of this phenomenon. Let's consider a block of weight W that is pulled up an inclined plane by a force P that forms an angle θ with the plane. The plane is inclined at an angle ϕ to the horizontal (see fig.)



(a) Determine the force P, in terms of W and angles θ and ϕ, that will cause sliding of the block up the plane.

(b) Determine the value of ϕ for which the block will be on the verge of sliding down the plane under the action of its own weight.

Sol. In both parts **a** and **b**, the sense of the frictional force is known by inspection (Case I of the Problem-Solving Technique).

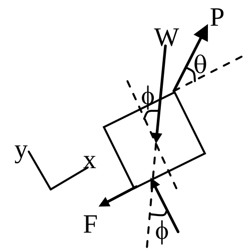


Fig.1

(a) The free-body diagram of the block is shown in fig. With respect to the xy axes in Fig.1 the equilibrium equations for the block are

$$\sum F_x = P\cos\theta - W\sin\phi - F = 0 \quad .....(a)$$

$$\sum F_y = P\sin\theta + N - W\cos\phi = 0$$

When sliding is impending, the frictional force is $F = F_s = \mu_s N$. Substituting this relation into Eqs. (a) and solving for N and P, we obtain

$$P = W\left[\frac{\sin\phi + \mu_s\cos\phi}{\cos\theta + \mu_s\sin\theta}\right] \quad ....(b)$$

$$N = W\left[\frac{\cos(\theta+\phi_s)}{\cos\theta + \mu_s\sin\theta}\right] \quad ......(c)$$

Introducing the angle of static friction ϕ_s, defined by $\tan\phi_s = \mu_s$ [see question 2 eq. (b)] we can express Eqs. (b) and (c) in alternative forms, as follows :

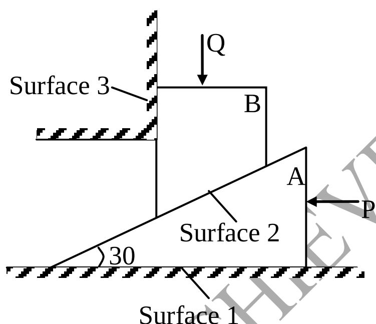
$$P = W\left[\frac{\sin(\phi+\phi_s)}{\cos(\phi_s-\theta)}\right] \quad ....(d)$$

$$N = W\left[\frac{\cos\phi_s\cos(\theta+\phi)}{\cos\theta(\phi_s-\theta)}\right] \quad ....(e)$$

Equation (b) or (d) defines the force P that will cause impending sliding of the block up the plane at an angle θ. Note that if ϕ = 0, the plane on which the block slides is horizontal and impending sliding of the block is the right.

(b) To determine the value of ϕ at which the block will slide under the action of its own weight, we set P = 0 in Eq. (b). Then, $\tan\phi = -\mu_s$. Note that the minus sign is due to the fact that, in part a, motion impends up the plane and $F = F_s$ is directed down the plane fig.1, but here motion impends down the plane and $F = F_s$ is directed up the plane. In other words, in either case, $F = F_s$ opposes the impending motion.

Q.10 A wedge A and a block B are subject to a known load Q and a force P, as shown in Fig. If the force P is sufficiently large, the block is raised; if it is small, the block may be lowered. The individual weights of the wedge and the block are negligible compared to Q. The coefficients of static friction for surfaces 1, 2 and 3 are 0.1, 0.2, 0.3, respectively. The angle of the wedge is 30º. Determine the range of the force P, in terms of Q, for which there is no motion.



Sol. Since the sense of the impending motion of the wedge, either to the left or to the right, is known, the frictional force has the opposite sense; that is, the sense of the frictional force is known.

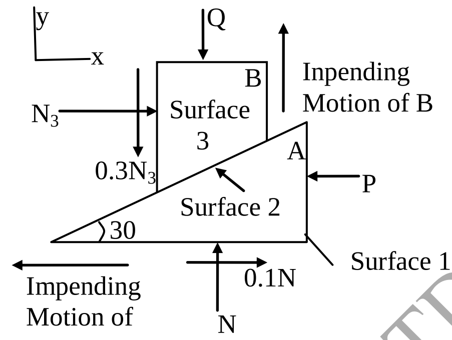


Fig.1

First we consider the case in which the block tends to move upwards; that is , motion of the block is impending upward, and motion of the wedge is impending to the left. Figure 1 is the free-body diagram of the block and wedge considered as a unit. As noted in the problem statement, the weights of the bodies are negligible compared to the given load Q. Hence they are ignored in Fig. 1. The frictional forces at surfaces 1 and 3 are directed so as to resist the impending movement. The magnitudes of these forces are the maximum static frictional values. The equations of equilibrium of forces, from fig.1 are

$$\sum F_x = N_3 + 0.1N_1 - P = 0 \qquad \ldots\ldots(a)$$

$$\sum F_y = N_1 - 0.3N_3 - Q = 0 \qquad \ldots\ldots(b)$$

Since these two equations contain three unknowns, N_1, N_3 and P, additional equations are needed. We can obtain them from the free-body diagram of the wedge (see fig. 2) (Alternatively we could use the free-body diagram of the block). Note that the frictional force $0.2N_2$ that acts on the inclined face of the wedge opposes the impending sliding. From fig.2.

$$\sum F_x = 0.1N_1 + 0.2N_2\cos30^o + N_2\sin30^o - P = 0 \qquad \ldots\ldots (c)$$

$$\sum F_y = N_1 + 0.2N_2 \sin 30^o - N_2 \cos 30^o = 0$$
……(d)

The four equations. Eqs. (a), (b), (c) and (d) contain the four unknowns; N_1, N_2, N_3 and P. Solving for P in terms of Q, we obtain

P = 1.329Q` ……..(e)

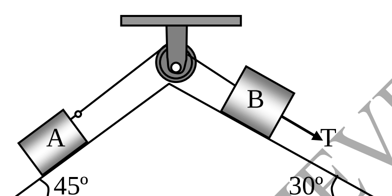
If the block B is on the verge of moving downward.

P = 0.2163Q ……..(f)

Hence, by Eqs. (e) and (f) the range of values that the force P may take without resulting motion is

$0.2163Q \leq P \leq 1.329Q$.

Q.11 The boxes shown in fig. are connected by a light flexible cord that passes over a frictionless pulley. A pull T is exerted on box B. Box A weighs 600N and box B weighs 900N. The coefficients of static and kinetic friction between the bodies and the planes are $\mu_s = 0.5$ and $\mu_k = 0.2$. respectively.



(a) Determine the force $T = T_s$ required to produce impending motion of box B down the

plane

(b) Assume that sufficient force is applied to box B to start the boxes sliding. Determine the force $T = T_s$ required to produce impending motion of box B down the plane.

Sol. **(a)** Since the sense of impending motion of each of the boxes is known, the sense of each frictional force that acts on the boxes is known; it is opposite to the sense of impending motion.

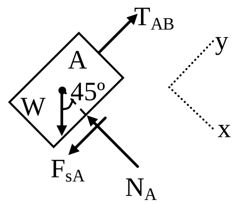


Fig.1

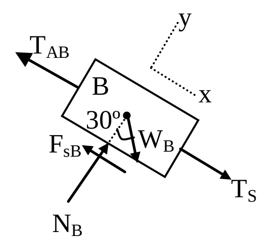


Fig.2

For impending motion, the free-body diagrams of boxes A and B are shown in Fig 1 & 2 respectively. From fig. 1 summation of forces yields

$$\sum F_x = W_A \cos 45^o - N_A = 0$$

$$N_A = \frac{W_A}{\sqrt{2}}$$

$$\sum F_y = T_{AB} - F_{sA} - W_A \sin 45^o = 0$$

$$T_{AB} = F_{SA} + \frac{W_A}{\sqrt{2}}$$

Therefore,

$$F_{SA} = \mu_s N_A = \mu_s \frac{W_A}{\sqrt{2}} \quad ……(a)$$

$$T_{AB} = (1 + \mu_s) \frac{W_A}{\sqrt{2}}$$

Similarly, from Fig.2 we have

$$\sum F_x = T_s + W_B \sin 30^o - F_{sB} - T_{AB} = 0$$
…....(b)

$$\sum F_y = N_B - W_B \cos 30^o = 0$$

$$N_B = W_B \frac{\sqrt{3}}{2}$$

Therefore, $F_{sB} = \mu_B N_B = \mu_s W_B \frac{\sqrt{3}}{2}$ … (c)

Then, by eqs. (a), (b) and (c) we find

$$T_s = \frac{W_A}{\sqrt{2}}(1+\mu_s) - \frac{W_B}{2}(1-\sqrt{3}\mu_s) \quad …… (d)$$

Inserting numerical values into Eq. (d), we obtain the required pull for impending motion $T_s = 576N$

(b) As the boxes slide with constant speed equilibrium conditions hold. Hence, the analysis of part a is valid for sliding, except that μ_s in Eq. (d) must be replaced by μ_k. Substitution of the value $\mu_k = 0.2$, with the other values, into Eq. (e) yields the required pull for sliding with constant speed :

T = 215N

Q.12 An escaped prisoner, was noted for his ability to climb up the corner formed by the intersection of two vertical perpendicular walls. Find the minimum force with which he had to push on the walls whilst climbing. What is the minimum coefficient of static friction required for him to be able to perform such a feat ?

Sol. Fig.1 shows prisoner's location on the wall. Figure 2 is a sketch showing his weight (mg) the normal reactions of the walls (N) and the static frictional force (F_{fr}) acting on his limbs.

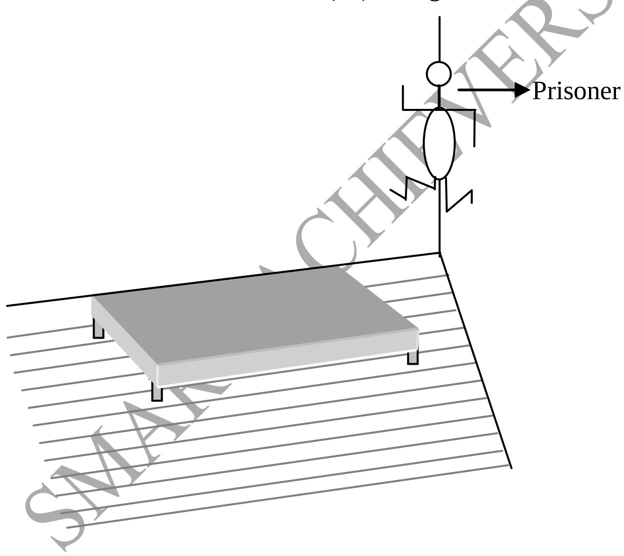


Fig. 1

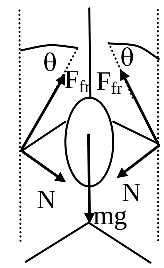


Fig.2

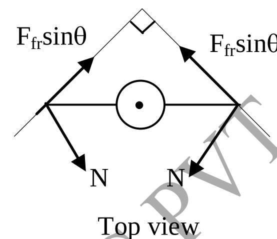


Fig.3

Let the static frictional forces make a common angle θ with the vertical.

The conditions for static equilibrium (see fig.3) are

$Mg = 2F_{fr} \cos\theta$ and $N = F_{fr} \sin\theta$.

From these equations we can express the normal component, N, of the force exerted by the prisoner on the wall whilst climbing as

$$N = \frac{1}{2} mg \tan\theta$$

Thus the total force required, F, is given by

$$F^2 = N^2 + F_{fr}^2 = \left(\frac{mg}{2}\right)^2 \frac{1+\sin^2\theta}{\cos^2\theta}.$$

We can also find the minimal force using the inequality

$F_{fr} \le \mu_0 N$.

From which it follows that

$$\sin\theta \ge \frac{1}{\mu_0} \text{ or } \tan\theta \ge \frac{1}{\sqrt{\mu_0^2 - 1}}$$

where μ_0 is the coefficient of static friction. Using either of these inequalities we find the minimal force to be

$$F_{min} = \frac{mg}{2}\sqrt{\frac{\mu_0^2+1}{\mu_0^2-1}}.$$

This expression shows that the coefficient of static friction must be greater than unity if prisoner is not to fall off the wall. If the coefficient of static friction approaches infinity, the force on each of his hands is equal to half of his body weight; this situation corresponds to his being glued to the wall.

Q.13 A sphere, made of two non-identical homogeneous hemispheres stuck together, is placed on a plane inclined at an angle of 30º to the horizontal. Can the sphere remain in equilibrium on the inclined plane ?

Sol. If static friction is large enough, the sphere will not slide down the slope. However, this by itself is not sufficient for equilibrium; it is also necessary that the sphere does not roll down the inclined plane.

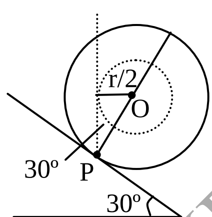


Fig.1

The sphere is made of two hemispheres, implying an inhomogeneous mass distribution. If the distance between its centre of mass and geometrical centre is less than $\frac{1}{2}$ r, where r is the radius of the sphere, then whatever the orientation of the sphere, its weight will produce a torque about P, the point of contact with the inclined plane (see fig.1) which will make the sphere roll.

It will now be shown that this is the situation for any sphere made of two homogeneous hemispheres – whatever the densities of the two halves.

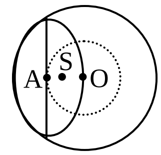
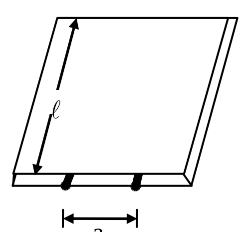


Fig.2

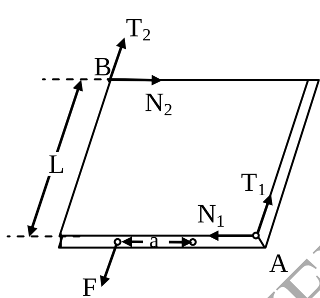
Consider the shaded area in fig.2 By symmetry, the centre of mass of this part is obviously at point A, i.e. at a distance $\frac{1}{2}$ r from the centre O. The rest of the sphere moves the centre of mass S of the whole even closer to point O, i.e. OS < $\frac{1}{2}$ r.

From our previous considerations, this implies that the sphere cannot remain in equilibrium on the 30º inclined plane. In obtaining the solution, we have assumed that rolling resistance is small i.e., no resistance torque can act at point P. In the case of a surface covered with Velcro, this is obviously not true, and the sphere may even adhere to a vertical surface.

Q.14 A sideboard has a sliding board in it for cutting bread on. For convenience in pulling out the board there are two handles in the front edge distance **a** part and placed symmetrically in relation to the centre (Fig.). The length of the leaf is **L**. What is the least coefficient of friction **k** between the side of the leaf and the wall of the sideboard which will prevent the leaf being pulled out by one handle only, no matter how much force is applied ?



Sol. Let force F be applied to the left handle of the board. It produces a reaction in the sides of the sideboard at points A and B (Fig.) Each of the reactions can be resolved into two components: N_1 and N_2, normal to the sides of the sideboard, and T_1 and T_2, acting along the same sides of the sideboard (the force of friction). Assuming that the board cannot be pulled out, we must have the following equalities. The force F must equal to sum of the forces of friction, so that there should be no motion in a straight line on the part of the board, i.e. $F = T_1 + T_2$; and the moment of the force F about the centre of the board must equal the sum of the moments of the normal reactions about the same point for the board not to rotate, i.e.



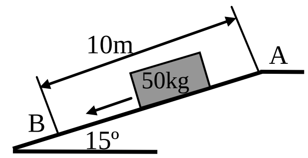
$$F\,\frac{a}{2} = (N_1 + N_2)\,\frac{L}{2}$$

Further, by definition, we have:

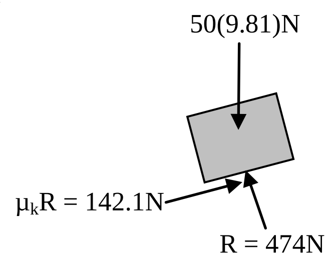
$$\frac{N_1}{T_1} = \frac{N_2}{T_2} = k.$$

Getting rid of force F from both equations, we find that the least value for the coefficient of friction must be **L/a**. If it has a greater value than this, it is impossible to pull the board out of the sideboard by pulling on one handle only.

Q.15 Calculate the velocity **v** of the 50 kg crate when it reaches the bottom of the chute at B if it is given an initial velocity of 4 m/s down the chute at A. The coefficient of kinetic friction is 0.30.



Sol. The free-body diagram of the crate is drawn and includes the normal force R and the kinetic friction force F calculated in the usual manner. The work done by the component of the weight down the plane is positive, whereas that done by the friction force is negative. The total work done on the crate during the motion is



$[U = Fs]$ $U_{1-2} = [50(9.81)\sin 15^\circ - 142.1]10 = -151.9$ J

The change in kinetic energy is $T_2 - T_1 = \Delta T$

$\left[T = \frac{1}{2}mv^2\right]$ $\Delta T = \frac{1}{2}(50)(v^2 - 4^2)$

The work-energy equation gives

$[U_{1\text{-}2} = \Delta T]$ $-151.9 = 25(v^2 - 16)$

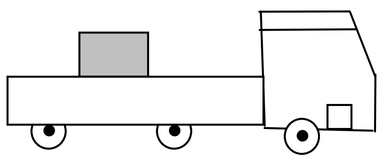
$v^2 = 9.93\ (m/s)^2$ **v = 3.15 m/s** **Ans.**

Since the net work done is negative, we obtain a decrease in the kinetic energy.

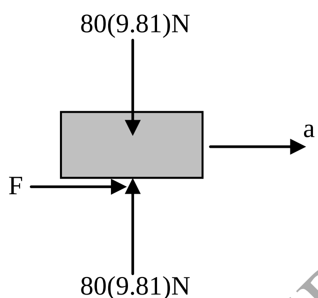
Helpful Hint :

Since the net work done is negative we obtain a decrease in the kinetic energy.

Q.16 The flatbed truck, which carries an 80 kg crate, starts from rest and attains a speed of 72 km/h in a distance of 75m on a level road with constant acceleration. Calculate the work done by the friction force acting on the crate during this interval if the static and kinetic coefficients of friction between the crate and the truck bed are (a) 0.30 and 0.28, respectively, or (b) 0.25 and 0.20, respectively.



Sol.



If the crate does not slip on the bed, its acceleration will be that of the truck, which is

$$[v^2 = 2as]\ a = \frac{v^2}{2s} = \frac{(72/3.6)^2}{2(75)} = 2.67 \text{ m/s}^2$$

Case (a). This acceleration requires a friction force on the block of

$[F = ma]$ $F = 80\ (2.67) = 213$ N

Which is less than the maximum possible value of $\mu_s N = 0.30(80)\ (9.81) = 235$ N.

Therefore, the crate does not slip and the work done by the actual static friction force of 213N is

$[U = F_s]$ $U_{1-2} = 213(75) = 16000$ J or **16 kJ**

Case (b). For $\mu_s = 0.25$, the maximum possible friction force is 0.25 (80) (9.81) = 235 N. which is slightly less than the value of 213N required for no slipping. Therefore, we conclude that the crate slips, and the friction force is governed by the kinetic coefficient and is F = 0.20(80)(9.81) = 157.0N. The acceleration becomes

$[F = ma]$ $a = F/m = 157.0/80 =$ **1.962 m/s²**

The distance traveled by the crate and the truck are in proportion to their accelerations. Thus, the crate has a displacement of (1.962/2.67)75 = 55.2m, and the work done by kinetic friction is

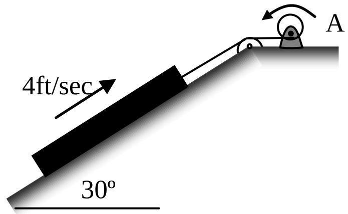
$[U = F_s]$ $U_{1-2} = 157.0(55.2) = 8660$ J or **8.66 kJ Ans.**

Helpful Hint :

(i) We note that static friction forces do no work when the contacting surfaces are both at rest. When they are in motion, however, as in this problem, the static friction force acting on the rate does positive work and that acting on the truck bed does negative work.

(ii) This problem shows that a kinetic friction force can do positive work when the surface which supports the object and generates the friction force is in motion. If the supporting surface is at rest, then the kinetic friction force acting on the moving part always does negative work.

Q.17 The power winch A hoists the 800-ℓb long up the 30º incline at a constant speed of 4ft/sec. If the power output of the winch is 6 hp, compute the coefficient of kinetic friction μ_k between the log and the incline. If the power is suddenly increased to 8 hp, what is the corresponding instantaneous acceleration **a** of the log ?

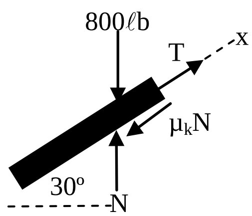


Sol. From the free-body diagram of the log, we get N = 800 cos 30º = 693 lb, and the kinetic friction force becomes $693\mu_{k.}$ For constant speed, the forces are in equilibrium so that

$[\Sigma F_x = 0]$ $T - 693\mu_k - 800 \sin 30º = 0$

$T = 693\mu_k + 400$

The power output of the winch gives the tension in the cable



(i) [P = Tv] T = P/v = 6(550)/4 = 825 ℓb

Substituting T gives 825 = $693\mu_k$ + 400 **μ_k = 0.613 Ans.**

When the power is increased, the tension momentarily becomes

[P = Tv] T = P/v = 8(550)/4 = 1100 ℓb

and the corresponding acceleration is given by

$[\Sigma F_x = ma_x]$ $1100 - 693\,(0.613) - 800 \sin 30º = \frac{800}{32.2} a$

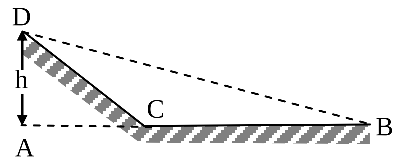
(ii) a = 11.07 ft/sec^2 Ans.

Helpful Hints

(i) Note the conversion from horse power to ft-lb/sec.

(ii) As the speed increases, the acceleration will drop until the speed stabilizes at a value higher than 4 ft/sec.

Q.18 A sledge slides down an icy hill of height **h** (Fig.) and stops after covering a distance CB. The distance AB is equal to S.



Determine the coefficient of friction **k** between the sledge and the icy surface. Calculate the acceleration of the sledge over the path DC and over the path CB.

Sol. The sledge at the top of the hill has a potential energy **E = mgh.** During motion this energy is expended on the work A_1 to overcome the force of friction over the path DC and on the work A_2 to overcome these force over the path CB, i.e.,

$$E = mgh = A_1 + A_2$$

The force of friction F_1 over the path DC

$$F_1 = kmg\,\frac{\ell}{\sqrt{\ell^2 + h^2}}$$

Where ℓ is the length of AC. The work will be

$$A_1 = F_1 DC = k\ell mg$$

For the path CB the force of friction F_2 = kmg and the work is

$A_2 = F_2 CB = kmg\,(S - \ell)$

Hence, $mgh = A_1 + A_2 = mgkS$

And $k = \frac{h}{S}$

The equation of Newton's second law for the motion of the sledge over the path DC will be

$$m\,\frac{h}{\sqrt{\ell^2 + h^2}} - F_1 = ma_1$$

and therefore $\mathbf{a_1} = \frac{gh}{\sqrt{\ell^2 + h^2}}\left(\ell - \frac{\ell}{S}\right)$ Since $\frac{\ell}{S} < 1$, $a_1 > 0$ and the sledge will move over the path DC with a uniformly accelerated motion.

The acceleration over the path CB **is a_2 = – kg** and the sledge move with a uniformaly retarded motion.

Q.19 A train weighs 3,000 tons. The coefficient of friction k = 0.02. What should the tractive force of the locomotive be for the train to acquire a speed of 60 km/hr two minutes after the motion has commenced ?

Sol. The momentum imparted to the train during time **t** by the tractive force of the locomotive will be **Ft** and by the force of friction –kPt. By Newton's second law,

$$Ft - kPt = \frac{P}{g}v$$

Hence, $F = \frac{Pv}{gt} + kP$.

Q.20 A body of weight **P** slides down a rough inclined surface. The angle of inclination is $\alpha = 30^\circ$, the length of the inclined surface ℓ = 167 cm and the coefficient of friction k = 0.2. The initial velocity of the body is zero. How long does it take for the body to reach the bottom of inclined surface ?

Sol. The force exerted by the body on the surface is $N = P\cos\alpha$, the force of friction $F_1 = kN = kP\cos\alpha$ and the resultant force of gravity acting along the inclined surface is $F = P\sin\alpha$.

According to Newton's second law,

$$(F - F_1)\,t = \frac{P}{g}v \qquad \text{.....(i)}$$

Where v is the velocity of the body at the end of descent and **t** is the time of descent. Since the initial velocity is zero,

$$\ell = \frac{at^2}{2} = \frac{vt}{2}$$

Hence $v = \frac{2\ell}{t}$.

Inserting the calculated value of **v** is equation (i) we find that

$$\mathbf{t} = \sqrt{\frac{2\ell}{g(\sin\alpha - k\cos\alpha)}}$$