

Laws of Motion

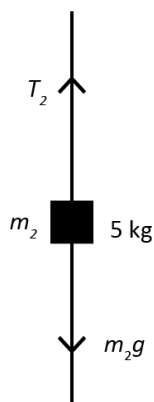
Answers

Module 1 Laws of Motion Part -1

A. 5.1.1 (B)

Free Body Diagram for $m_2 = 5 \text{ kg}$ is shown in Fig.A.5.1.1(a)

We have



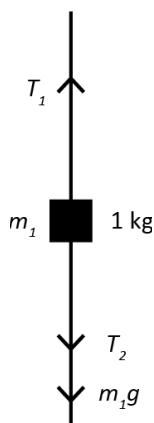
$$m_2 g - T_2 = m_2 a$$

$$5 \times 10 - T_2 = 5 \times 0 \quad [\because a = 0]$$

$$50 - T_2 = 0 \quad \text{or } T_2 = 50 \text{ N}$$

Fig A.5.1.1(a)

Fig. A.5.1.1(b) shows free body diagram for $m_1 = 1 \text{ kg}$. From Newton's law



$$m_1 g + T_2 - T_1 = m_1 a$$

As the body is at rest, $a = 0$. Therefore,

$$10 + 50 - T_1 = 0$$

$$\text{or, } T_1 = 60 \text{ N}$$

Fig. A.5.1.1(b)

A.5.1.2 (A) True

When the driver suddenly applies brakes, the car comes to rest almost immediately. If he is not wearing the seat belt, the lower part of the body of the driver on the seat also comes to rest with the car but the upper part of the body continues moving with the initial momentum (which was there at the time of application of the brakes) and hence he hits against the steering wheel almost instantly. However, when the driver is wearing a seatbelt, the belt increases the time taken by the body to reach the steering wheel while continuously slowing it down. Hence by the time the body reaches the steering wheel, it has already either come to rest or the impact is negligible. In other words the seat belt facilitates towards increasing the time of impact,

(C) False. The tensile strength of the seat belt is not a factor that is used here as the seat belt gets pulled out while continuously slowing down the body of the driver.

(D) False. If the seat belt would keep the driver fixed to the seat then the seat belt will cause an impact on the body and there shall be a whiplash on the body due to the seat belt.

A.5.1.3 (B)

There is no relative motion in horizontal direction between Ram and coin. Therefore , Ram catches the coin. There is relative motion between Sham and coin in horizontal direction due to acceleration of bus B. Therefore, Sham will not be able to catch the coin.

A.5.1.4 (A) Refer to Figure A.5.1.2

Let F_H be the horizontal force required to keep the body in equilibrium. For equilibrium in horizontal direction,

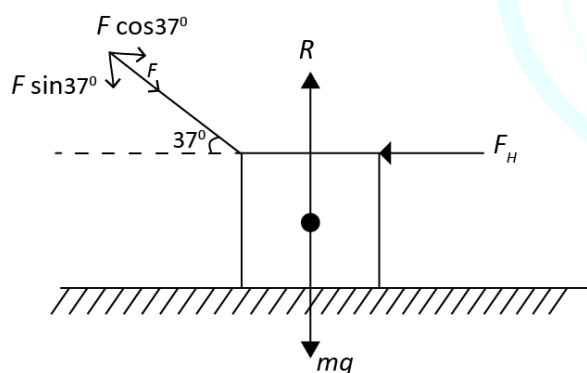


Fig.A.5.1.2

$$[20 \cos 37^\circ \hat{i} + (-F_H \hat{i})] = \vec{0}$$

$$F_H = 20 \times \frac{4}{5} = 16 \text{ N}$$

For equilibrium in vertical direction,

$$\vec{R} = \hat{j} (20 \sin 37^\circ + 13 \times g)$$

$$\begin{aligned} \vec{R} &= \hat{j} \left(20 \times \frac{3}{5} + 130 \right) \text{ N} \\ &= (142 \hat{j}) \text{ N} \end{aligned}$$

A.5.1.5 (B)

Resolving T_1 into rectangular components (Fig A.5.1.3),

$$T_1 = -T_1 \cos 37^\circ \hat{i} + T_1 \sin 37^\circ \hat{j}$$

As the system is in equilibrium ($a = 0$)

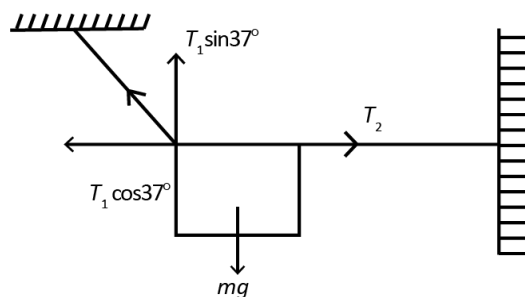


Fig.A.5.1.3

Along x-axis,

$$T_2 \hat{i} - T_1 \cos 37^\circ \hat{i} = \vec{0}$$

$$T_2 \hat{i} = T_1 \cos 37^\circ \hat{i} = T_1 \frac{4}{5} \hat{i}$$

Along y- axis

$$T_1 \sin 37^\circ \hat{j} = mg$$

$$T_1 \frac{3}{5} = 10 \times 10 \quad (g = 10 \text{ m/s}^2)$$

$$T_1 = \frac{500}{3} \text{ N} = 166.7 \text{ N}$$

$$T_2 = T_1 \frac{4}{5} = \frac{500}{3} \times 0.8 = 133.3 \text{ N}$$

A.5.1.6 (A)

Fig.A.5.1.4 shows the force diagram.

Resolving, T_1 and T_2 into rectangular components as shown, for equilibrium we get,

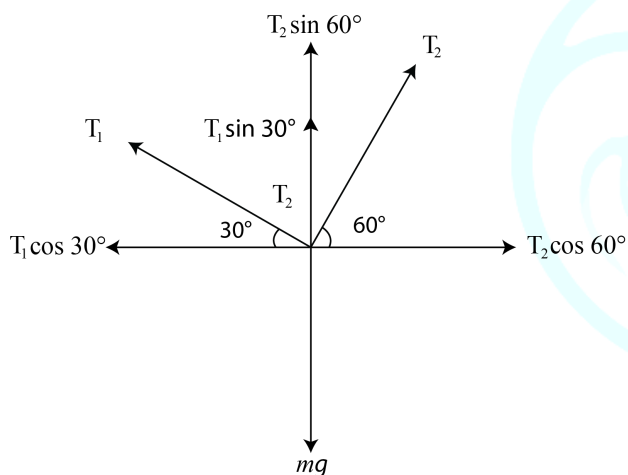


Fig.A.5.1.4

Along x axis

$$T_1 \cos 30^\circ = T_2 \cos 60^\circ \quad (5.1.6.1)$$

$$T_1 \frac{\sqrt{3}}{2} = T_2 \frac{1}{2} \quad (5.1.6.1)$$

Along y-axis

$$T_2 \sin 60^\circ + T_1 \sin 30^\circ = mg \quad (5.1.6.2)$$

$$T_2 \frac{\sqrt{3}}{2} + T_1 \frac{1}{2} = 5 \times 10 \quad (5.1.6.3)$$

Therefore $T_1 + \sqrt{3} T_2 = 100$.

So, from Eq. (5.1.6.2) , $4 T_1 = 100$, $T_1 = 25$ N,

and $T_2 = 25 \sqrt{3}$ N

A.5.1.7 (A)

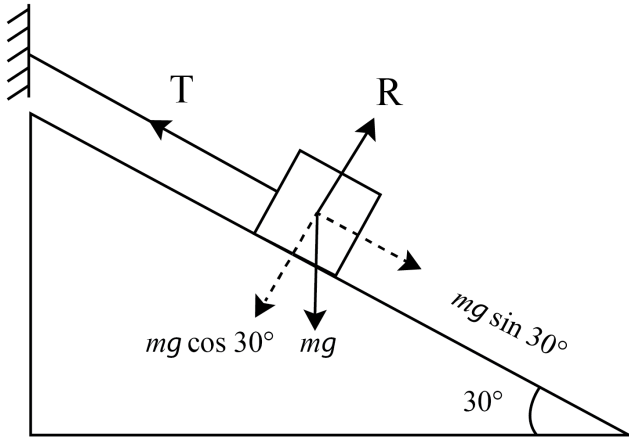


Fig.A.5.1.5

Fig. A.5.1.5 shows the force diagram.

For equilibrium

(i) Along the plane

$$mg \sin 30^\circ - T = 0$$

$$T = 4 \times 10 \times \frac{1}{2} = 20 \text{ N}$$

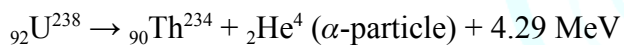
(ii) Perpendicular to plane

$$R = mg \cos 30^\circ$$

$$R = 4 \times 10 \times \frac{\sqrt{3}}{2} = 20\sqrt{3} \text{ N}$$

A.5.1.8 (C)

Given



Initially, ${}_{92}\text{U}^{238}$ is at rest. Initial momentum is zero.

From the law of conservation of momentum, after splitting, the total momentum of the system (α -particle + ${}_{90}\text{Th}^{234}$) must be equal to zero. Therefore,

$$m_\alpha v_\alpha + m_{Th} v_{Th} = 0$$

$$\text{Or, Magnitude of } v_{Th} = \frac{m_\alpha v_\alpha}{m_{Th}} \quad (5.1.8.1)$$

From the law of conservation of energy,

KE of α -particle + KE of Th = 4.29 MeV

$$\frac{1}{2}m_{\alpha}v_{\alpha}^2 + \frac{1}{2}m_{Th}\left(\frac{m_{\alpha}v_{\alpha}}{m_{Th}}\right)^2 = 4.29 \text{ MeV}$$

$$\frac{1}{2}m_{\alpha}v_{\alpha}^2\left(1 + \frac{m_{\alpha}}{m_{Th}}\right) = 4.29 \text{ MeV}$$

$$\frac{1}{2}m_{\alpha}v_{\alpha}^2\left(\frac{m_{Th}+m_{\alpha}}{m_{Th}}\right) = 4.29 \text{ MeV}$$

$$\frac{1}{2}m_{\alpha}v_{\alpha}^2\left(\frac{238}{234}\right) = 4.29 \text{ MeV}$$

$$\frac{1}{2}m_{\alpha}v_{\alpha}^2 = 4.29 \left(\frac{234}{238}\right) \text{ MeV}$$

$$= 98\% \text{ of } 4.29 \text{ MeV}$$

A.5.1.9 (D) Fig. A.5.1.6 shows the force diagram. For equilibrium of mass M

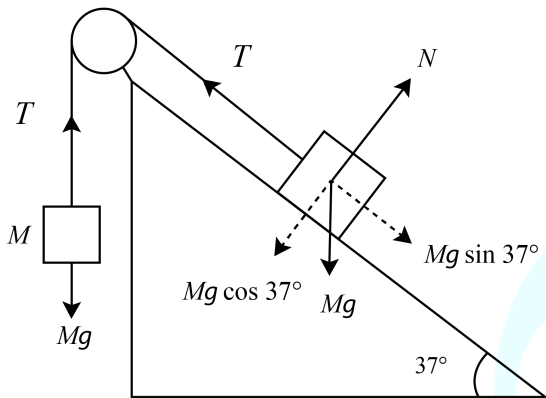


Fig A.5.1.6

$$Mg \sin 37^\circ = T \quad (5.1.9.1)$$

For equilibrium of mass m ;

$$T = mg \quad (5.1.9.2)$$

From Eq. (5.1.9.1) and Eq. (5.1.9.2)

$$Mg \sin 37^\circ = mg$$

$$\therefore M = 2 \times \frac{5}{3} = \frac{10}{3} \text{ kg}$$

A.5.1.10 (D)

Refer to Fig A.5.1.7(a).

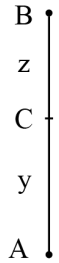


Fig. A.5.1.7(a)

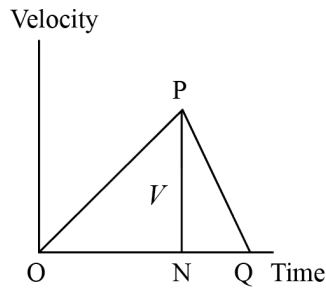


Fig. A.5.1.7(b)

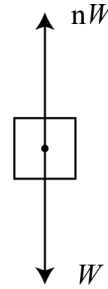


Fig. A.5.1.7(c)

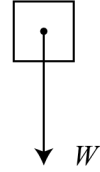


Fig. A.5.1.7(d)

A is the initial position of rest from where the load is lifted, and it is taken up to B, which is its final position of rest. C is an intermediate point upto which it accelerates due to the net unbalanced force, resulting out of the tension in the rope and the load, and thereafter it decelerates.

Let, AC and CB be equal to y and z respectively

$$\text{So, } h = y + z \quad (5.1.10.1)$$

Now, we shall relate h with time. For that we shall draw the velocity versus time graph. The load starts from rest, accelerates uniformly, attains a highest velocity V , and then decelerates and finally comes to rest. So, the graph will be like what has been shown at Fig.A.5.1.7(b), as we know that the velocity versus time graph of a particle moving under uniform acceleration is a straight line.

The total displacement is equal to the area under the triangle OPQ, which is equal to $\frac{1}{2} \text{OQ} \times \text{PN} = \frac{1}{2} Vt = h$.

$$\text{So, } t = \frac{2h}{V} \quad (5.1.10.2)$$

For the time being least, value of V must be the highest possible, and this happens when the tension in the rope due to the pull is highest ($= nW$, where W is the load and $n=10$).

Correspondingly, we have the FBDs for the parts AC and CB; which are Fig A.5.1.8 (c) and (d) respectively.

We have

$$\begin{aligned} nW - W &= \frac{Wf}{g}; \text{ where } f \text{ is the acceleration} \\ f &= (n - 1)g \end{aligned} \quad (5.1.10.3)$$

And the deceleration takes place at the rate of acceleration due to gravity. So, the square of the highest velocity can be expressed in two ways, which are as follows.

$$V^2 = 2(n - 1)gy \quad (5.1.10.4)$$

$$\text{And also, } V^2 = 2gz \quad (5.1.10.5)$$

So, from Eqns. (5.1.10.1; 10.4 and 10.5), we get,

$$h = \frac{V^2}{2g} \left(1 + \frac{1}{n-1}\right) = \frac{V^2}{2g} \left(\frac{n}{n-1}\right) \quad (5.1.10.6)$$

Hence, from Eqn. (5.1.10.2), we get

$$t = \sqrt{\frac{2nh}{(n-1)g}} \quad (5.1.10.7)$$

So, putting $n = 10, g = 10$, we get $t = \sqrt{\frac{2h}{9}}$

Module 2 Laws of Motion Part -2

A.5.2.1 (A)

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

At $t = 2$ s

$$\vec{p} = 2x (4\hat{i} + 4\hat{j}) = 8(\hat{i} + \hat{j})$$

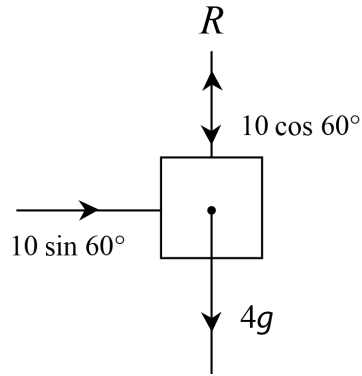
$$\vec{F} = \frac{d\vec{p}}{dt} = m \frac{d\vec{v}}{dt} = m \frac{d(2t\hat{i} + t^2\hat{j})}{dt}$$

$$\vec{F} = m 2\hat{i} + m 2t\hat{j}$$

At $t = 2$ sec,

$$\vec{F} = (4\hat{i} + 8\hat{j}) \text{ N}$$

A.5.2.2 (C) Fig A.5.2.1 shows force diagram.



FigA.5.2.1

Resolving $\vec{F}$, the applied force, we get

$$\vec{F} = \hat{i} F_x + \hat{j} F_y$$

$$\vec{F} = \hat{i} 10 \sin 60^\circ + \hat{j} 10 \cos 60^\circ$$

$$F_x = 10 \times \sqrt{3}/2 = 5\sqrt{3} \text{ N and } F_y = 10 \times 1/2 = 5 \text{ N}$$

We have no net force in the vertical direction.

$$\text{So, } R = 10 \cos 60^\circ + 4g = 5 + 40 = 45 \text{ N.}$$

The net unbalanced force in the horizontal direction is

$$F_x = ma, \quad \text{So, } a = \frac{5}{4}\sqrt{3} \text{ m/s}^2$$

A.5.2.3 (C)

Suppose X is 5 kg block and Y is 10 kg block placed as shown in Fig. A.5.2.2(a)

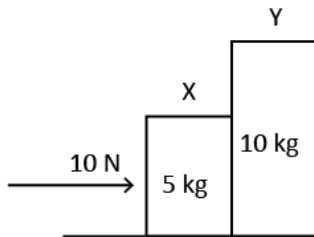


Fig. A.5.2.2(a)

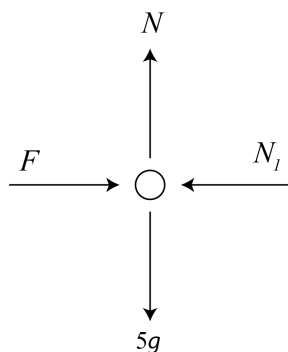


Fig. A.5.2.2(b)

FBD for X

(Refer Fig. A.5.2.2(b))

N_1 is normal reaction of Y on X

$$N = 5g,$$

$$F - N_1 = 5a \quad (5.2.3.1)$$

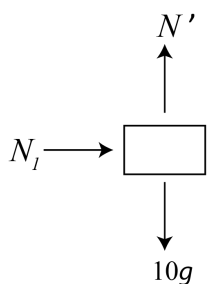


Fig. A.5.2.2(c)

FBD for Y

(Refer Fig. A.5.2.2(c))

$$N_1 = 10a \quad (5.2.3.2)$$

Adding equations (5.2.3.1) and (5.2.3.2),

$$F = (5 + 10) a$$

$$10 = 15a$$

$$a = 10/15 \text{ m/s}^2 = \frac{2}{3} \text{ m/s}^2$$

Normal reaction of X on Y or Y on X

$$N_1 = 10 \times 10/15 = 20/3 \text{ N}$$

A.5.2.4 (D) OX is the original direction of the ball. With symbols having their usual meanings,

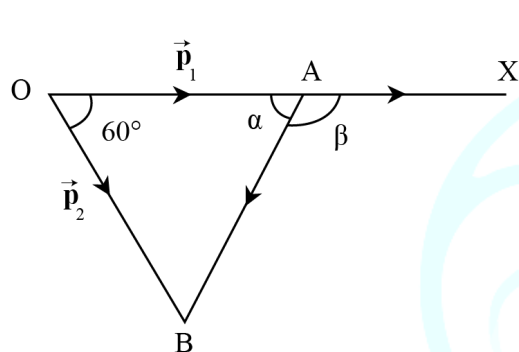


Fig. A.5.2.3

$$\vec{OA} = \vec{p}_1, \quad \vec{OB} = \vec{p}_2$$

$$\Delta \vec{p} = \vec{OB} - \vec{OA} = \vec{AB}$$

$$AB^2 + OB^2 - 2 OA \cdot OB \cos \angle AOB$$

$$= p_1^2 + p_2^2 - 2p_1 p_2 \cos 60^\circ$$

$$p_1 = p_2 = p = (160 \text{ g}) (120 \text{ km/h})$$

$$= (0.16 \text{ kg}) (120 \times \frac{5}{18} \text{ m/s})$$

$$= \frac{16}{3} \text{ kg m/s}$$

$$AB^2 = 2p^2 (1 - \cos 60^\circ) = 2p^2 (1 - \frac{1}{2}) = p^2$$

$$\therefore AB = p$$

$$\text{Let } \angle AOB = \alpha$$

$$\therefore \frac{OB}{\sin \alpha} = \frac{AB}{\sin 60^\circ}$$

But, $OB = AB = p$

$$\therefore \sin \alpha = \sin 60^\circ, \quad \alpha = 60^\circ$$

$$\angle OAX = \beta = 180^\circ - 60^\circ = 120^\circ$$

A.5.2.5 (B)

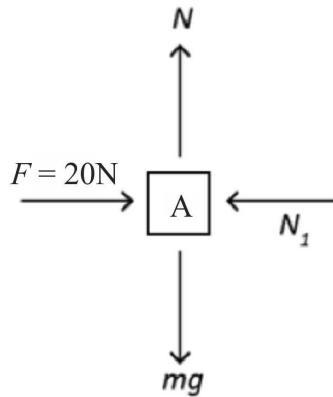


Fig. A.5.2.4 (a)

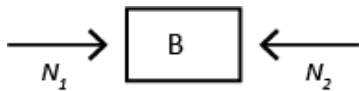


Fig.A.5.2.4(b)

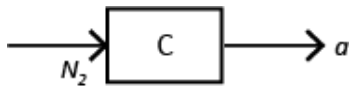


Fig.A.5.2.4(c)

FBD for A [Fig. A.5.2.4 (a)].

a = Acceleration along the horizontal direction

$$20 - N_1 = 5a \quad (5.2.5.1)$$

FBD for B [Fig. A.5.2.4 (b)].

$$N_1 - N_2 = 10a \quad (5.2.5.2)$$

(Since three blocks behave as one)

FBD for C [Fig. A.5.2.4 (c)].

$$N_2 = 15a \quad (5.2.5.3)$$

Adding (5.2.5.1), (5.2.5.2) and (5.2.5.3)

$$20 = 5a + 10a + 15a$$

$$a = 20/30 \text{ m/s}^2 = 2/3 \text{ m/s}^2$$

$$N_2 = 15 \times 2/3 = 10 \text{ N}$$

$$N_1 = 10 \times \frac{2}{3} + 10 = \frac{50}{3} \text{ N}$$

A.5.2.6 (D)

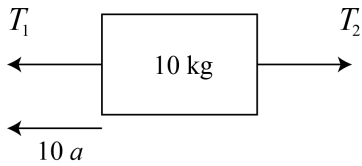


Fig.A.5.2.5(a)

FBD for Block A [Fig.A.5.2.5(a)]

$$T_1 - T_2 = 10a \quad (5.2.6.1)$$

FBD for Block B [Fig.A.5.2.5(b)]

$$T_2 = 20a \quad (5.2.6.2)$$

Adding Eq.(5.2.6.1) and (5.2.6.2),

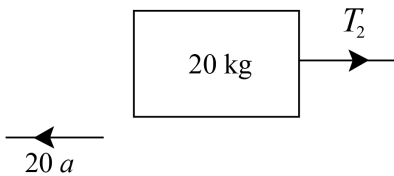


Fig.A.5.2.5(b)

$$T_1 = 30a \text{ (since } T_1 = 10 \text{ N)}$$

$$10 \text{ N} = 30a$$

$$a = \frac{1}{3} \text{ m/s}^2$$

$$T_2 = 20 \times \frac{1}{3} = \frac{20}{3} \text{ N}$$

A.5.2.7 (A) Refer Fig.A.5.2.6.

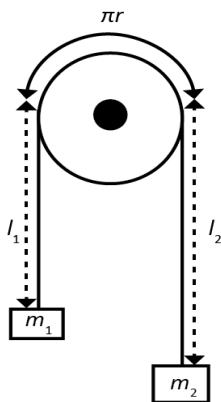


Fig.A.5.2.6

$$L = l_1 + l_2 + \pi r$$

$$\frac{dL}{dt} = \frac{dl_1}{dt} + \frac{dl_2}{dt} + \frac{d(\pi r)}{dt}$$

πr and L are constant. Therefore,

$$0 = v_1 + v_2$$

$$\text{Or, } v_1 = -v_2$$

$$\frac{dv_1}{dt} = -\frac{dv_2}{dt},$$

$$\text{Or, } a_1 = -a_2$$

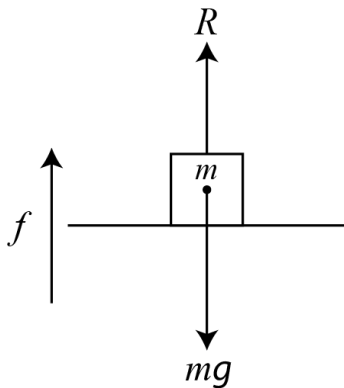
A.5.2.8 (A) with symbol their usual having meaning ,

we have

$$v^2 - \frac{2Rd}{m} = 0$$

$$\therefore v^2 = \frac{2Rd}{m}, v = \sqrt{\frac{2Rd}{m}}$$

A.5.2.9 (C) Refer to Fig.A.5.2.7. Let R be the normal reaction. If the acceleration of the system is f upward, then the equation of motion of m is



$$R - mg = mf$$

$$R = m(g + f)$$

$$\text{When } f = 1.25 \text{ m/s}^2, \quad R = (12.5)g$$

$\therefore$ The required value of the mass is given by

$$m = \frac{12.5 \times 10}{10 + 1.25} = \frac{12.5}{11.25} = 11\frac{1}{9} = 11.1$$

Fig.A.5.2.7

A.5.2.10 (A) With symbols having their usual meanings, $v^2 = g^2 t^2$. So, the retarding force required to bring it to rest within a length $l = \frac{mv^2}{2l} = \frac{mg^2 t^2}{2l}$. This retarding force will have to overcome the weight of the body. So, the required upward force $= mg + \frac{mg^2 t^2}{2l} = mg\left(1 + \frac{g t^2}{2l}\right)$



Module 3 Laws of Motion Part- 3

A.5.3.1 (A) Refer [Fig.A.5.3.1]

The component of the force that tends to bring it down the incline

$$F_d = mg \sin 53^\circ = 5 \times 10 \times \frac{4}{5} = 40 \text{ N}$$

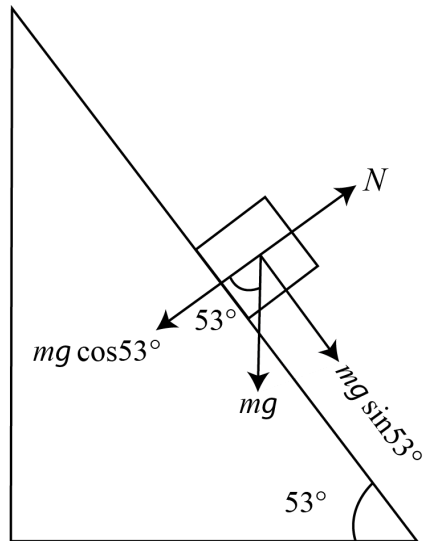


Fig.A.5.3.1

A.5.3.2 (B) Refer [Fig.A.5.3.1].

Force of limiting friction

$$F_l = \mu_s mg \cos 53^\circ = 0.2 \times 10 \times 10 \times \frac{3}{5} = 12 \text{ N}$$

A..5.3.3 (C) Refer [Fig.A.5.3.1].

Force of limiting friction

$$f_l = \mu_s mg \cos 53^\circ = 0.2 \times 2.5 \times 10 \times \frac{3}{5} = 3 \text{ N}$$

The component of the force that tends to bring it down the incline

$$f_d = mg \sin 53^\circ = 2.5 \times 10 \times \frac{4}{5} = 20 \text{ N}$$

As $f_d > f_l$ the body will slide down along the incline with acceleration and friction will no

longer be static, but kinetic. And the following equation will hold good-

$$f_k = \mu_k \times mg \cos 53^\circ = 0.1 \times 2.5 \times 10 \times \frac{3}{5} = 1.5 \text{ N}$$

To get the acceleration let's consider the following FBD

$$mg \sin 53^\circ - f_k = ma$$

$$a = \frac{20-1.5}{2.5} = 7.4 \text{ m/s}^2$$

A.5.3.4 (A) Refer [Fig.A.5.3.2]. The body is at rest on the plane and is on brink of sliding down.

F is the force required to keep the body at rest on an inclined plane.

$$F + f_l = mg \sin \theta = 5 \times 10 \times \frac{4}{5} = 40$$

$$f_l = \mu_s mg \cos 53^\circ = 0.2 \times 5 \times 10 \times \left(\frac{3}{5}\right) = 6 \text{ N}$$

F is the minimum force required to keep the body at rest. Obviously,

$$F = 40 - 6 = 34 \text{ N}$$

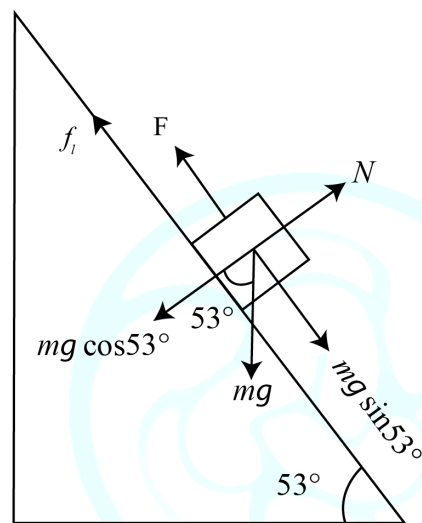


Fig. A.5.3.2

A.5.3.5 (D) Refer [Fig.A.5.3.2].

Force applied to keep the object at rest $F = 62 \text{ N}$

The component of the force that tends to bring the mass down the inclined plane

$$f_d = mg \sin 53^\circ = 10 \times 10 \times \frac{4}{5} = 80 \text{ N}$$

The force of friction

$$f_l = 80 - 62 = 18 \text{ N}$$

We have, $f_l = 18 = \mu_s mg \cos 53^\circ = \mu_s \times 5 \times 10 \times \frac{3}{5}$

$$\mu_s = \frac{18 \times 5}{10 \times 10 \times 3} = 0.3$$

A.5.3.6 (C). refer [Fig.A.5.3.3].

Let F be the force required to move the body up with constant velocity. The net force on the body is zero.

Therefore,

$$F = f_k + mg \sin 53^\circ$$

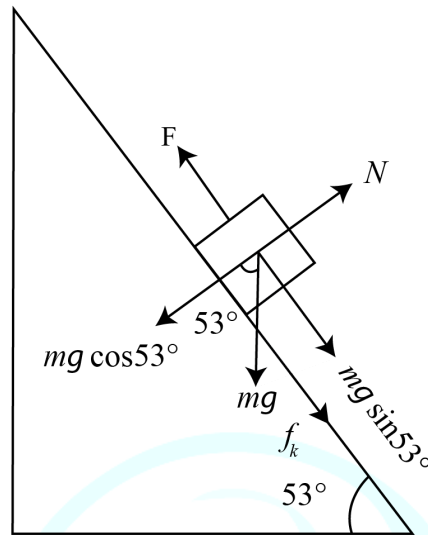


Fig.A.5.3.3

$$f_k = \mu_k mg \cos 53^\circ = 0.2 \times 2.5 \times 10 \times \frac{3}{5} = 3 \text{ N}$$

$$mg \sin 53^\circ = 2.5 \times 10 \times \frac{4}{5} = 20 \text{ N}$$

$$F = (3 + 20) \text{ N} = 23 \text{ N}$$

A.5.3.7 (C) Refer [Fig.A.5.3.3].

Let F be the force required in moving the body up the inclined with an acceleration of 1 m/s^2

The equation of motion is

$$F - (f_k + mg \sin 53^\circ) = ma$$

We have,

$$f_k = \mu_k \times mg \cos 53^\circ = 0.1 \times 5 \times 10 \times \frac{3}{5} = 3 \text{ N}$$

$$\text{And } mg \sin 53^\circ = 5 \times 10 \times \frac{4}{5} = 40 \text{ N}$$

$$\therefore F = 3 + 40 + (5 \times 1) = 48 \text{ N}$$

A.5.3.8 (A). Refer [Fig.A.5.3.4].

Let F be the force required to move the body down the plane with a constant velocity.

We have,

$$F = mg \sin 53^\circ - f_k$$

Also,

$$f_k = \mu_k mg \cos 53^\circ = 0.1 \times 10 \times 10 \times \frac{3}{5} = 6 \text{ N}$$

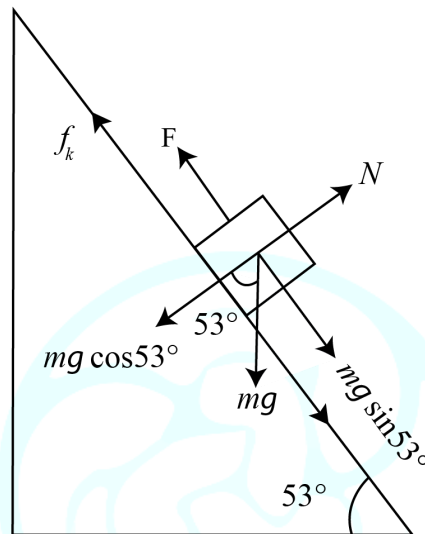


Fig.A.5.3.4

$$\text{and } mg \sin 53^\circ = 10 \times 10 \times \frac{4}{5} = 80 \text{ N}$$

Therefore ,

$$F = (80 - 6) \text{ N} = 74 \text{ N}$$

A.5.3.9 (B)

1. True, because for the two bodies to start moving together the minimum value of $F = 0.15 mg$.

2. True, because the limiting value of F beyond which A will slip over B is $0.45 \, mg$.
3. False, because for values of $F > 0.45 \, mg \, N$, A will slip over B True, because the minimum value of F for which the two blocks start moving is $F = 0.15 \, mg$.
4. True, because $0.45 \, mg$ happens to be the maximum value of F for which there is no relative motion between A and B.

The solution is given below with the help of Fig.A.5.3.5.

F_{sB} = The limiting frictional force acting on B when A does not move with respect to B.

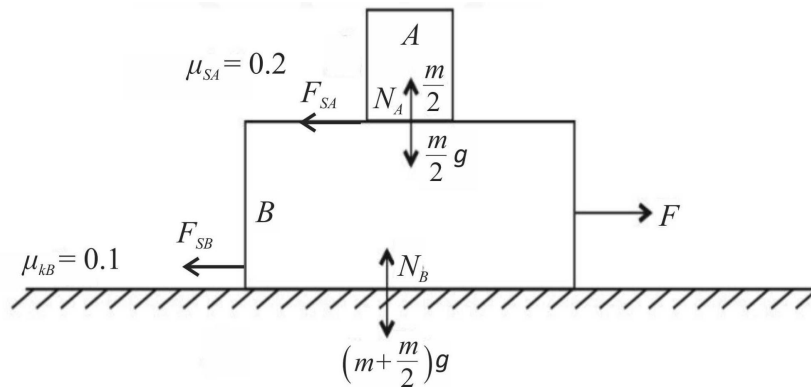


Fig.A.5.3.5

$$\begin{aligned}
 F_{sB} &= \mu_{sB} N_B = 0.1 \left(m + \frac{m}{2} \right) g \\
 &= \frac{0.3}{2} mg = 0.15 \, mg \\
 F_{sA} &= \text{Limiting force of friction on A} = \mu_{sA} N_A \\
 &= 0.2 \left(\frac{m}{2} \right) g = 0.1 \, mg
 \end{aligned}$$

The minimum value of F for system to move = $0.15 \, mg$

For A to remain at rest w.r.t. B, A should move with the same acceleration as B. For A not to slip the maximum acceleration a_A will be due to the limiting static frictional force acting on A.

Therefore,

$$\begin{aligned}
 \frac{m}{2} a_A &= F_{sA} = 0.1 \, mg \\
 \therefore a_A &= 0.2 \, g \, \text{m/s}^2
 \end{aligned}$$

If A moves with an acceleration greater than a_A then A will slip over block B.

From FBD of block B, the net force acting on B is

$$f = F - F_{sA} - F_{sB}$$

$$f = F - 0.15 mg - 0.1 mg = ma_B$$

A is stationary w.r.t. B. if $a_A = a_B$.

Therefore,

$$m \times 0.2g = F - 0.25 mg$$

$$\text{Or, } F = 0.45 mg$$

This is the maximum value of F so that there is no relative motion between A and B.

A.5.3.10 (A)

- (A) Correct. The net force is zero, which is the condition for motion with uniform speed. $\tau = 0$, which means that the net torque is zero, ensures that there would not be any relative motion between different parts of the body about P.
- (B) False, if there is a non-zero torque at point P then there will be motion between different parts of the body.
- (C) False, if forces are not coplanar then there will be a net force acting, and the body will not move with uniform speed.
- (D) False, both one and two are essential conditions for a body to move with uniform speed.



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