

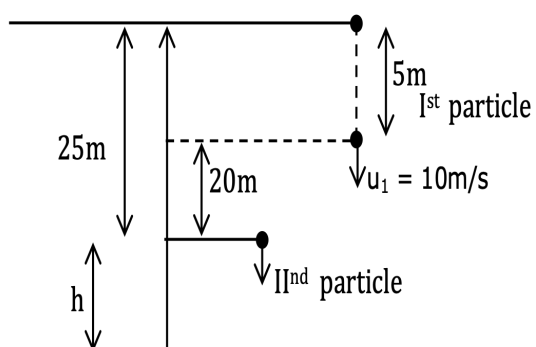
Topic : Unit and Dimension,  
Kinematics

---

1. A particle is dropped from the top of a building. When it crosses a point 5 m below the top, another particles starts to fall from a point 25 m below the top, both particles reach the bottom of the building simultaneously. The height of the building is :

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

- ☒ **A.** 45 m  
☐ **B.** 35 m  
☐ **C.** 25 m  
☐ **D.** 50 m



Let the speed of the particle 1 be  $u_1$ , 5 m below the top of the building.

Using kinematic equation,  $v^2 - u^2 = 2as$

$$v^2 = (2) (10) (5) \quad [u = 0]$$

$$v = 10 \text{ m/s}$$

For particle 1 using second kinematic equation,

$$s = ut + \frac{1}{2}at^2$$

we have:

$$20 + h = 10t + gt^2 \quad \dots\dots (1)$$

For particle 2, using second kinematic equation we have:

$$h = gt^2 \quad \dots\dots (2)$$

Using equations (1) and (2) we have

$$20 + gt^2 = 10t + gt^2$$

$$t = 2 \text{ s}$$

Using this value in equation (1) we get

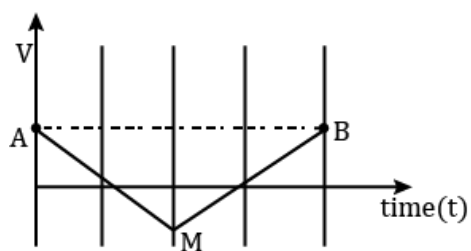
$$h = 20 \text{ m}$$

$\therefore$  The height of the building is,

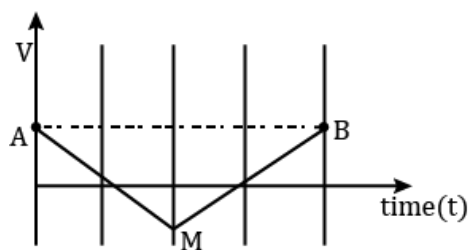
$$25 + 20 = 45 \text{ m}$$

Hence, option (A) is the correct answer.

2. If the velocity-time graph has the shape AMB, what would be the shape of the corresponding acceleration-time graph?



- ☒ A.
- ☐ B.
- ☐ C.
- ☐ D.



We know that the slope of  $v - t$  curve gives acceleration.

For AM, slope is constant and negative. Therefore, acceleration is constant and negative.

Similarly, for MB, slope is constant and positive. Therefore, acceleration is constant and positive.

This situation is best represented by the curve in option (A).

Hence, option (A) is the correct answer.

3. The velocity of a particle is  $v = v_0 + gt + Ft^2$ . Its position is  $x = 0$  at  $t = 0$ ; then its displacement after time ( $t = 1$  s) is:  
( $g$  and  $F$  are constants)

- ☐ A.  $v_0 + \frac{g}{2} + F$
- ☐ B.  $v_0 + 2g + 3F$
- ☐ C.  $v_0 + g + F$
- ☒ D.  $v_0 + \frac{g}{2} + \frac{F}{3}$

Given,  $v = v_0 + gt + Ft^2$

We know that,  $v = \frac{dx}{dt}$

$$\Rightarrow \frac{dx}{dt} = v_0 + gt + Ft^2$$

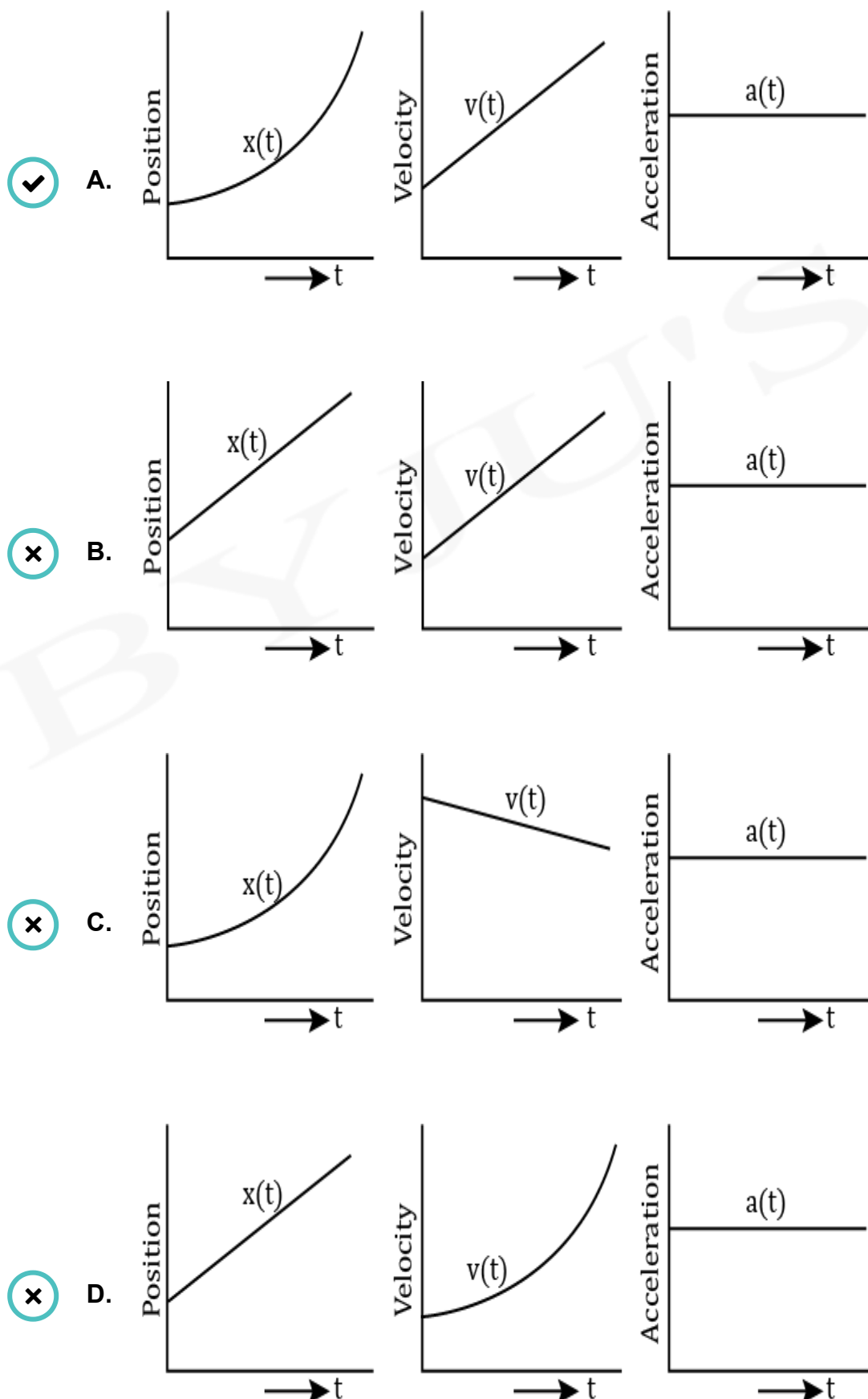
$$\Rightarrow \int_{x=0}^x dx = \int_{t=0}^{t=1} (v_0 + gt + Ft^2) dt$$

$$\Rightarrow x = \left[ v_0 t + \frac{gt^2}{2} + \frac{Ft^3}{3} \right]_{t=0}^{t=1}$$

$$\Rightarrow x = v_0 + \frac{g}{2} + \frac{F}{3}$$

Hence, (D) is the correct answer.

4. The position, velocity and acceleration of a particle moving with a constant acceleration can be represented by:



In all the options, acceleration is constant and positive.

Acceleration  $a = \frac{dv}{dt}$  is the slope of the  $v - t$  graph.

So,  $v - t$  graph should be linear and it should be increasing (to have positive slope).

Velocity  $v = \frac{dx}{dt}$  is slope of the  $x - t$  graph. So  $x - t$  graph should be quadratic.

$x \propto t^2$  (parabolic graph)

Hence, (A) is the correct answer.

5. Water droplets are coming from an open tap at a particular rate. The spacing between a droplet observed at 4<sup>th</sup> second after its fall, to the next droplet, is 34.3 m. At what rate the droplets are coming from the tap ? (Take  $g = 9.8 \text{ m/s}^2$ )

☒ A. 3 drops/s

☒ B. 2 drops/s

☒ C. 1 drop/s

☒ D.  $\frac{1}{7}$  drops/s

The distance travelled by a freely falling drop is,

$$h = ut + \frac{1}{2}at^2 = \frac{1}{2}at^2 \quad (\because u = 0)$$

In 4 sec, 1<sup>st</sup> drop will travel,

$$h_1 = \frac{1}{2} \times (9.8) \times (4)^2 = 78.4 \text{ m}$$

$\therefore$  2<sup>nd</sup> drop would have travel,

$$h_2 = 78.4 - 34.3 = 44.1 \text{ m}$$

So, time taken by 2<sup>nd</sup> drop is,

$$h_2 = \frac{1}{2}(9.8)t^2 = 44.1$$

$$\therefore t = 3 \text{ sec}$$

It means each drop have time gap of 1 sec.

So, drops are falling at a rate of 1 drop/s

Hence, (C) is the correct answer.



6. The trajectory of a projectile in a vertical plane is,  $y = \alpha x - \beta x^2$ , where  $\alpha, \beta$  are constants,  $x$  and  $y$  are respectively the horizontal and vertical distances of the projectile from the point of projection. The angle of projection and the maximum height attained are respectively given by :

☒ A.  $\tan^{-1} \alpha, \frac{\alpha^2}{4\beta}$

☐ B.  $\tan^{-1} \beta, \frac{\alpha^2}{2\beta}$

☐ C.  $\tan^{-1} \alpha, \frac{\alpha^2}{2\beta}$

☐ D.  $\tan^{-1} \beta, \frac{\alpha^2}{4\beta}$

Given:

$$y = \alpha x - \beta x^2$$

$$\text{Also, } y = x \tan \theta - \frac{g}{2u^2 \cos^2 \theta} x^2$$

On comparing, we get,

$$\tan \theta = \alpha \quad \dots (1), \quad \text{and}$$

$$\frac{g}{2u^2 \cos^2 \theta} = \beta \Rightarrow \frac{u^2}{g} = \frac{1}{2\beta \cos^2 \theta} \quad \dots (2)$$

So, angle of projection,  $\theta = \tan^{-1} \alpha$   
[From (1)]

Now, maximum height attained,

$$H_{\max} = \frac{u^2 \sin^2 \theta}{2g}$$

$$\Rightarrow H_{\max} = \frac{\sin^2 \theta}{4\beta \cos^2 \theta}$$

[From (2)]

$$\Rightarrow H_{\max} = \frac{\tan^2 \theta}{4\beta} = \frac{\alpha^2}{4\beta}$$

[From (1)]

7. A player kicks a football with an initial speed of  $25 \text{ ms}^{-1}$  at an angle of  $45^\circ$  from the ground. What are the maximum height and the time taken by the football to reach at the highest point during motion ? (Take  $g = 10 \text{ ms}^{-2}$ )

- ☒ A.  $h_{max} = 10 \text{ m}, T = 2.5 \text{ s}$
- ☒ B.  $h_{max} = 15.625 \text{ m}, T = 1.77 \text{ s}$
- ☐ C.  $h_{max} = 15.625 \text{ m}, T = 3.54 \text{ s}$
- ☐ D.  $h_{max} = 3.54 \text{ m}, T = 0.125 \text{ s}$

Given :

$$u = 25 \text{ m/s}$$

$$\theta = 45^\circ$$

The maximum height is given by :

$$h_{max} = \frac{u^2 \sin^2 \theta}{2g}$$

$$h_{max} = \frac{25^2 \sin^2 45^\circ}{2 \times 10} = 15.625 \text{ m}$$

The time taken to reach the maximum height is :

$$T = \frac{u \sin \theta}{g} = \frac{25 \sin 45^\circ}{10} = 1.77 \text{ s}$$

Hence, (B) is the correct answer.

8. A particle starts from the origin at  $t = 0$  with an initial velocity of  $3.0\hat{i}$  m/s and moves in the  $x - y$  plane with a constant acceleration  $(6.0\hat{i} + 4.0\hat{j})$  m/s<sup>2</sup>. The  $x$ -coordinate of the particle at the instant when its  $y$ -coordinate is 32 m is  $D$  meters. The value of  $D$  is:

☒ A. 32

☒ B. 50

☒ C. 60

☒ D. 40

Given,  $\vec{u} = (3\hat{i} + 0\hat{j})$  m/s and

$$\vec{a} = (6\hat{i} + 4\hat{j}) \text{ m/s}^2$$

Using,  $s = ut + \frac{1}{2}at^2$ , for  $y$  - axis

$$y = u_y t + \frac{1}{2}a_y t^2$$

$$\Rightarrow 32 = 0 \times t + \frac{1}{2}(4)t^2$$

$$\Rightarrow \frac{1}{2} \times 4 \times t^2 = 32$$

$$\Rightarrow t = 4 \text{ s}$$

For  $x$ -axis,

$$x = u_x t + \frac{1}{2}a_x t^2$$

$$\Rightarrow x = 3 \times 4 + \frac{1}{2} \times 6 \times 4^2 = 60 \text{ m}$$

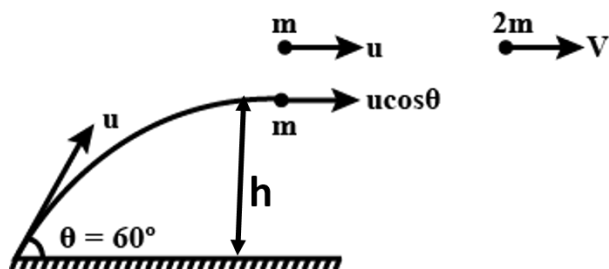
$$\therefore D = 60$$

Hence, (C) is the correct answer.

9. A particle of mass  $m$  is projected with a speed of  $u$  from the ground at an angle  $\theta = \frac{\pi}{3}$  w.r.t. horizontal (x-axis). When it has reached its maximum height, it collides completely inelastically with another particle of the same mass and velocity  $u\hat{i}$ . The horizontal distance covered by the combined mass before reaching the ground is:

- ☒ A.  $\frac{3\sqrt{3} u^2}{8 g}$
- ☐ B.  $\frac{3\sqrt{2} u^2}{4 g}$
- ☐ C.  $\frac{5 u^2}{8 g}$
- ☐ D.  $2\sqrt{2} \frac{u^2}{g}$

Image for the given problem,



Using the principle of conservation of linear momentum for horizontal motion, we have

$$p_i = p_f$$

$$mu + mu \cos 60^\circ = 2mv$$

$$\therefore v = \frac{3u}{4}$$

For vertical motion,

$$h = 0 + \frac{1}{2}gT^2 \Rightarrow T = \sqrt{\frac{2h}{g}}$$

Using maximum height formula,

$$h = \frac{u^2 \sin^2 60^\circ}{2g} = \frac{u^2 \left(\frac{\sqrt{3}}{2}\right)^2}{2g} = \frac{3u^2}{8g}$$

Let  $R$  is the horizontal distance travelled by the body.

$$R = vT + \frac{1}{2}(0)(T)^2 \text{ (For horizontal motion, } a=0\text{)}$$

$$= vT = \frac{3u}{4} \times \sqrt{\frac{2h}{g}}$$

$$\Rightarrow R = \frac{3u}{4} \times \sqrt{\frac{2 \times \frac{3u^2}{8g}}{g}} = \frac{3\sqrt{3}u^2}{8g}$$

Hence, (A) is the correct answer.

10. Starting from the origin at time  $t = 0$ , with initial velocity  $5\hat{j} \text{ ms}^{-1}$ , the particle moves in the  $x - y$  plane with a constant acceleration of  $(10\hat{i} + 4\hat{j}) \text{ m/s}^2$ . At time  $t$ , its coordinates are  $(20 \text{ m}, y_0 \text{ m})$ . The values of  $t$  and  $y_0$  are, respectively:

- ☒ A. 2 s and 18 m
- ☐ B. 4 s and 52 m
- ☐ C. 2 s and 24 m
- ☐ D. 5 s and 25 m

Given:  $\vec{u} = 5\hat{j} \text{ m/s}$

Acceleration,  $\vec{a} = 10\hat{i} + 4\hat{j}$  and final coordinates  $(20, y_0)$  in time  $t$ .

Using equation of motion along x-axis,

$$x = u_x t + \frac{1}{2} a_x t^2$$

$$[\because u_x = 0]$$

$$\Rightarrow 20 = 0 + \frac{1}{2} \times 10 \times t^2$$

$$\Rightarrow t = 2 \text{ s}$$

Using equation of motion along y-axis,

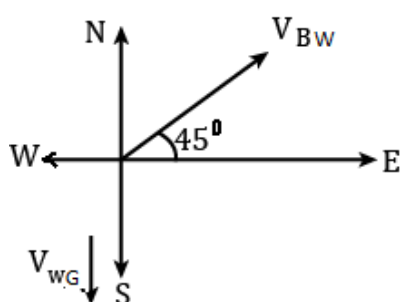
$$y = u_y \times t + \frac{1}{2} a_y t^2$$

$$y = y_0 = 5 \times 2 + \frac{1}{2} \times 4 \times 2^2 = 18 \text{ m}$$

Hence, (A) is the correct answer.

11. A butterfly is flying with a velocity  $4\sqrt{2}$  m/s in North-East direction. Wind is slowly blowing at 1 m/s from North to South. The resultant displacement of the butterfly in 3 seconds is :

- ☒ A. 3 m
- ☒ B. 20 m
- ☒ C.  $12\sqrt{2}$  m
- ☒ D. 15 m



In the figure,

$\vec{V}_{BW}$  = Velocity of butterfly in the frame of wind

$\vec{V}_{WG}$  = Velocity of wind in the frame of ground

We know that,

$$\vec{V}_{BW} = \vec{V}_{BG} - \vec{V}_{WG}$$

$$\Rightarrow \vec{V}_{BG} = \vec{V}_{BW} + \vec{V}_{WG}$$

$$\therefore V_{BG} = \sqrt{V_{BW}^2 + V_{WG}^2 + 2V_{BW}V_{WG}\cos\theta}$$

$$\Rightarrow V_{BG} = \sqrt{(4\sqrt{2})^2 + 1^2 + 2(4\sqrt{2})(1)\cos(90^\circ + 45^\circ)}$$

$$\Rightarrow V_{BG} = 5 \text{ m/s}$$

So, displacement in 3 seconds,

$$d = V_{BG}t = 5 \times 3 = 15 \text{ m}$$

Hence, option (D) is the correct answer.

12. A boy reaches the airport and finds that the escalator is not working. He walks up the stationary escalator in time  $t_1$ . If he remains stationary on a moving escalator, then the escalator takes him up in time  $t_2$ . The time taken by him to walk up on the moving escalator will be:

- ☒ A.  $\frac{t_1 t_2}{t_2 - t_1}$   
☒ B.  $\frac{t_1 + t_2}{2}$   
☒ C.  $\frac{t_1 t_2}{t_2 + t_1}$   
☒ D.  $t_2 - t_1$

Let  $L$  be the length of the escalator.

When only boy is walking,

$$v_b = \frac{L}{t_1}$$

And when only escalator is moving,

$$v_{esc} = \frac{L}{t_2}$$

Now let  $t$  be the time taken by boy to walk up on the moving escalator.

$$\therefore t = \frac{L}{v_b + v_{esc}} = \frac{L}{(L/t_1) + (L/t_{esc})}$$

$$\Rightarrow t = \frac{t_1 t_2}{t_1 + t_2}$$

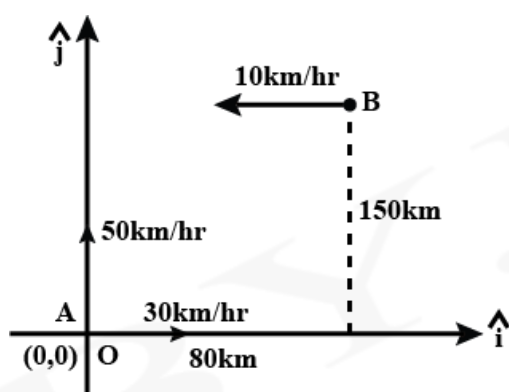
Hence, option (C) is correct.



13. Ship A is sailing towards north-east with velocity vector  $\vec{v} = 30\hat{i} + 50\hat{j}$  km/hr where  $\hat{i}$  points east and  $\hat{j}$  north. Ship B is at a distance of 80 km east and 150 km north of Ship A and is sailing towards west at 10 km/hr. A will be at minimum distance from B in,

- ☒ A. 2.2 hrs  
☒ B. 4.2 hrs  
☒ C. 2.6 hrs  
☒ D. 3.2 hrs

Given data is represented in the figure,



From figure,

$$\vec{V}_{AB} = \vec{V}_A - \vec{V}_B = (30\hat{i} + 50\hat{j}) - (-10\hat{i})$$

$$\Rightarrow \vec{V}_{AB} = 40\hat{i} + 50\hat{j} \text{ and}$$

$$\vec{r}_{AB} = -80\hat{i} - 150\hat{j}$$

Now, A will be at minimum distance from B in time,

$$t = \frac{\vec{r}_{AB} \cdot \vec{V}_{AB}}{|\vec{V}_{AB}|^2}$$

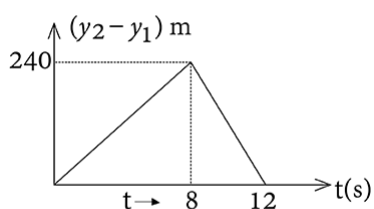
$$\Rightarrow t = -\frac{(-80\hat{i} - 150\hat{j}) \cdot (40\hat{i} + 50\hat{j})}{(\sqrt{40^2 + 50^2})^2}$$

$$\Rightarrow t = -\frac{-3200 - 7500}{4100} = 2.6 \text{ hr}$$

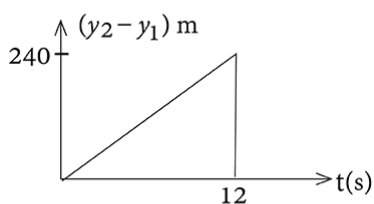
Hence, (C) is the correct answer.

14. Two stones are thrown up simultaneously from the edge of a cliff 240 m high with initial speed 10 m/s and 40 m/s respectively. Which of the following graph best represents the time variation of relative position of the second stone with respect to the first? (Assume stones do not rebound after hitting the ground and neglect air resistance, take  $g = 10 \text{ m/s}^2$ )  
(The figures are schematic and not drawn to scale.)

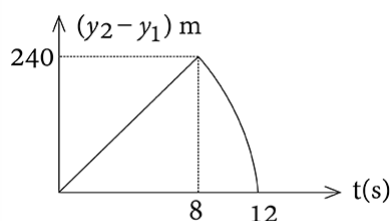
☒ A.



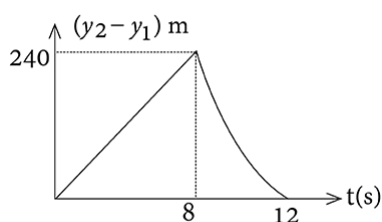
☒ B.



☒ C.



☒ D.



Using equation of motion for the first stone,

$$-240 = 10t - \frac{1}{2}gt^2$$

$$\Rightarrow 5t^2 - 10t - 240$$

$$\Rightarrow t^2 - 2t - 48 = 0$$

$$\Rightarrow t = 8, -6$$

$\therefore$  The 1st stone will reach the ground in 8 secs.

Upto 8 secs, the relative velocity between the particles is 30 m/sec and the relative acceleration is zero.

For the 2nd stone,

$$-240 = 40t - 5t^2$$

$$\Rightarrow t^2 - 8t - 48 = 0$$

$$t = 12 \text{ secs}$$

The second stone will strike the ground in 12 secs.

Now, relative position

$$\Delta y = y_1 - y_2 = 40t - \frac{1}{2}gt^2 - 10t + \frac{1}{2}gt^2 = 30t$$

$$\Delta y = 30t$$

After 8 second stone 1 reaches ground

$$y_1 = -240 \text{ m}$$

$$\therefore \Delta y = y_2 - y_1$$

$$= 40t - \frac{1}{2}gt^2 + 240$$

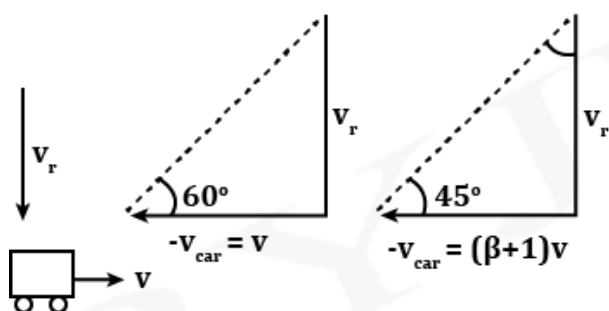
$\therefore$  It will be a parabolic curve after 8 secs.

So, the correct option is (C).

15. When a car is at rest, its driver sees raindrops falling on it vertically. When driving the car with speed  $v$ , he sees that raindrops are coming at an angle  $60^\circ$  from the horizontal. On further increasing the speed of the car to  $(1 + \beta)v$ , this angle changes to  $45^\circ$ . The value of  $\beta$  is close to :

- ☐ A. 0.50  
☐ B. 0.41  
☐ C. 0.37  
☒ D. 0.73

The given situation is shown in the diagram. Here  $v_r$  be the velocity of rain drop.



When car is moving with speed  $v$ ,

$$\tan 60^\circ = \frac{v_r}{v} \dots (i)$$

When car is moving with speed  $(1 + \beta)v$ ,

$$\tan 45^\circ = \frac{v_r}{(\beta + 1)v} \dots (ii)$$

Dividing (i) by (ii) we get,

$$\sqrt{3} = (\beta + 1)$$

$$\Rightarrow \beta = \sqrt{3} - 1 = 0.732.$$

Hence, (D) is the correct answer.

16. If  $e$  is the electric charge of an electron,  $c$  is the speed of light in free space, and  $h$  is planck's constant,  $\epsilon_0$  is permittivity of free space. The dimension of  $\frac{e^2}{4\pi\epsilon_0 hc}$  is

- ☒ A.  $[LC^{-1}]$
- ☒ B.  $[M^0 L^0 T^0]$
- ☒ C.  $[MLT^0]$
- ☒ D.  $[MLT^{-1}]$

Given,

$e$  = Electric charge of an electron =  $[TI]$

$c$  = Speed of Light =  $[M^0 L^1 T^{-1}]$

$h$  = Planck's constant =  $[ML^2 T^{-1}]$

$\epsilon_0$  =  $[M^{-1} L^{-3} T^4 I^2]$

Therefore dimension of  $\frac{e^2}{4\pi\epsilon_0 hc}$  is  $[M^0 L^0 T^0]$

17. The work done by a gas molecule in an isolated system is given by,

$$W = \alpha\beta^2 e^{-x^2/\alpha kT}$$

Where  $x$  is the displacement,  $k$  is the Boltzmann constant,  $T$  is the temperature,  $\alpha$  and  $\beta$  are constants, then the dimension of  $\beta$  will be :

- ☒ A.  $[M^0 L T^0]$
- ☒ B.  $[M^2 L T^2]$
- ☒ C.  $[MLT^{-2}]$
- ☒ D.  $[ML^2 T^{-2}]$

Given:

Work done,  $W = \alpha\beta^2 e^{-x^2/\alpha kT}$

Where,

$x$  = Displacement

$k$  = Boltzmann constant

$T$  = Temperature

$\alpha, \beta$  = Constants

We know that,

$$-\frac{x^2}{\alpha kT} = \text{dimensionless}$$

$$\Rightarrow \left[ \frac{x^2}{\alpha kT} \right] = [M^0 L^0 T^0]$$

$$[kT] = [PV] = [ML^2 T^{-2}]$$

$$[x^2] = [L^2]$$

$$\therefore [\alpha] = [M^{-1} T^2]$$

Also,

$$[W] = [\alpha\beta^2]$$

$$\Rightarrow [ML^2 T^{-2}] = [M^{-1} T^2] [\beta^2]$$

$$\Rightarrow [\beta^2] = [M^2 L^2 T^{-4}]$$

$$\Rightarrow [\beta] = [MLT^{-2}]$$

18. Match List - I with List - II.

List - I	List - II
a. $h$ (Planck's Constant)	i. $[MLT^{-1}]$
b. $E$ (Kinetic Energy)	ii. $[ML^2T^{-1}]$
c. $V$ (Electric Potential)	iii. $[ML^2T^{-2}]$
d. $P$ (Linear Momentum)	iv. $[ML^2I^{-1}T^{-3}]$

Choose the correct answer from the options given below.

- ☒ **A.**  $(a) \rightarrow (ii), (b) \rightarrow (iii), (c) \rightarrow (iv), (d) \rightarrow (i)$
- ☐ **B.**  $(a) \rightarrow (i), (b) \rightarrow (ii), (c) \rightarrow (iv), (d) \rightarrow (iii)$
- ☐ **C.**  $(a) \rightarrow (iii), (b) \rightarrow (ii), (c) \rightarrow (iv), (d) \rightarrow (i)$
- ☐ **D.**  $(a) \rightarrow (iii), (b) \rightarrow (iv), (c) \rightarrow (ii), (d) \rightarrow (i)$

(i). Planck Constant,  $h = \frac{E}{f}$

$$\Rightarrow [h] = \left[ \frac{E}{f} \right] = [ML^2T^{-1}]$$

(ii). Kinetic Energy,  $E = \frac{1}{2}mv^2$

$$\Rightarrow [E] = \left[ \frac{1}{2}mv^2 \right] = [ML^2T^{-2}]$$

(iii). Electric Potential,  $V = \frac{W}{q} = \frac{W}{It}$

$$\Rightarrow [V] = \left[ \frac{W}{It} \right] = [ML^2I^{-1}T^{-3}]$$

(iv). Linear Momentum,  $P = mv$

$$\Rightarrow [P] = [mv] = [MLT^{-1}]$$

19. The pitch of the screw gauge is 1 mm and there are 100 divisions on the circular scale. When nothing is put in between the jaws, the zero of the circular scale lies 8 divisions below the reference line. When a wire is placed between the jaws, the first linear scale division is clearly visible while 72<sup>nd</sup> division on circular scale coincides with the reference line. The radius of the wire is :

- ☒ A. 1.64 mm
- ☒ B. 1.80 mm
- ☒ C. 0.82 mm
- ☒ D. 0.90 mm

$$\text{Least count, LC} = \frac{\text{Pitch}}{\text{Number of divisions on circular scale}}$$

$$\Rightarrow \text{LC} = \frac{1}{100} = 0.01 \text{ mm}$$

$$\text{Also, positive zero error } e = +8 \times \text{LC} = +8 \times 0.01 = +0.08 \text{ mm}$$

Now,

True reading

$$= \text{Measured reading} - e$$

$$= 1 + 72 \times 0.01 - 0.08 = 1.64 \text{ mm}$$

$$\text{Hence, radius} = \frac{1.64}{2} = 0.82 \text{ mm}$$



20. In a typical combustion engine, the work done by a gas molecule is given by,

$$W = \alpha^2 \beta e^{-\beta x^2 / kT}$$

Where  $x$  is the displacement,  $k$  is the Boltzmann constant,  $T$  is the temperature,  $\alpha$  and  $\beta$  are constants, then the dimension of  $\alpha$  will be :

- ☒ A.  $[M^0 L T^0]$
- ☐ B.  $[M^2 L T^0]$
- ☐ C.  $[M L T^{-2}]$
- ☐ D.  $[M L^2 T^{-2}]$

Given:

Work done,  $W = \alpha^2 \beta e^{-\beta x^2 / kT}$

Where,

$x$  = Displacement

$k$  = Boltzmann constant

$T$  = Temperature

$\alpha, \beta$  = Constants

We know that,

$$-\frac{\beta x^2}{kT} = \text{dimensionless}$$

$$\Rightarrow \left[ \frac{\beta x^2}{kT} \right] = [M^0 L^0 T^0]$$

$$[kT] = [PV] = [M L^2 T^{-2}]$$

$$[x^2] = [L^2]$$

$$\therefore [\beta] = [M^1 T^{-2}]$$

Also,

$$[W] = [\alpha^2 \beta]$$

$$\Rightarrow [M L^2 T^{-2}] = [M^1 T^{-2}] [\alpha^2]$$

$$\Rightarrow [\alpha^2] = [L^2]$$

$$\Rightarrow [\alpha] = [M^0 L T^0]$$

21. If  $C$  and  $V$  represent capacitance and voltage respectively then what is the dimension of  $\lambda$  where  $\lambda = \frac{C}{V}$ ?

- ☒ A.  $[M^{-2}L^{-4}I^3T^7]$
- ☐ B.  $[M^{-2}L^{-3}I^2T^6]$
- ☐ C.  $[M^{-1}L^{-3}I^{-2}T^{-7}]$
- ☐ D.  $[M^{-3}L^{-4}I^3T^7]$

We know that,

$$V = \frac{w}{q} \text{ and } C = \frac{q}{V} = \frac{q^2}{w}$$

$$\text{So, } \lambda = \frac{C}{V} = \frac{\frac{q^2}{w}}{\frac{w}{q}}$$

$$\Rightarrow \lambda = \frac{q^3}{w^2}$$

$$\Rightarrow \lambda = \frac{I^3 t^3}{w^2} \quad [\because I = q/t]$$

$$\Rightarrow [\lambda] = \left[ \frac{I^3 t^3}{w^2} \right]$$

$$\Rightarrow [\lambda] = \left[ \frac{I^3 T^3}{(ML^2 T^{-2})^2} \right]$$

$$\Rightarrow [\lambda] = [M^{-2}L^{-4}I^3T^7]$$

22. In order to determine the Young's Modulus of a wire of radius 0.2 cm (measured using a scale of least count = 0.001 cm) and length 1 m (measured using a scale of least count = 1 mm), a weight of mass 1 kg (measured using a scale of least count = 1 g) was hanged to get the elongation of 0.5 cm (measured using a scale of least count 0.001 cm). What will be the fractional error in the value of Young's Modulus determined by this experiment.

- ☒ A. 9%
- ☒ B. 1.4%
- ☒ C. 0.9%
- ☒ D. 0.14%

In this case, Young's modulus will be given as:

$$\gamma = \frac{mgL}{A.l}$$

$$\frac{\Delta\gamma}{\gamma} = \left(\frac{\Delta m}{m}\right) + \left(\frac{\Delta g}{g}\right) + \left(\frac{\Delta A}{A}\right) + \left(\frac{\Delta l}{l}\right) + \left(\frac{\Delta L}{L}\right)$$

$$\frac{\Delta\gamma}{\gamma} = \left(\frac{1 \text{ g}}{1 \text{ kg}}\right) + 0 + 2\left(\frac{\Delta r}{r}\right) + \left(\frac{\Delta l}{l}\right) + \left(\frac{\Delta L}{L}\right)$$

$$= \left(\frac{1 \text{ g}}{1 \text{ kg}}\right) + 2\left(\frac{0.001 \text{ cm}}{0.2 \text{ cm}}\right) + \left(\frac{0.001 \text{ cm}}{0.5 \text{ cm}}\right) + \left(\frac{0.001 \text{ m}}{1 \text{ m}}\right)$$

$$= \left(\frac{1}{1000}\right) + 2\left(\frac{1 \times 10}{2 \times 10^3}\right) + \left(\frac{1}{5} \times \frac{10}{10^3}\right) + \left(\frac{1}{10^3}\right)$$

$$= \frac{1}{1000} + \frac{1}{100} + \frac{2}{10^3} + \frac{1}{10^3}$$

$$= \frac{1 + 10 + 2 + 1}{1000} = \frac{14}{1000}$$

$$= 1.4\%$$

23. The vernier scale used for measurement has a positive zero error of 0.2 mm . If while taking a measurement it was noted that 0 on the vernier scale lies between 8.5 cm and 8.6 cm, vernier coincidence is 6, then the correct value of measurement is \_\_\_\_\_cm.

(Least count = 0.01 cm)

- ☒ A. 8.36 cm
- ☒ B. 8.56 cm
- ☒ C. 8.58 cm
- ☒ D. 8.54 cm

Correct Reading

$$= (\text{MSR} + \text{VSR} \times \text{LC}) - \text{Zero Error}$$

$$= (8.5 + 6 \times 0.01) - 0.2 \times 10^{-1}$$

$$= 8.54 \text{ cm}$$

24. In the experiment of Ohm's law, a potential difference of 5.0 V is applied across the end of a conductor of length 10.0 cm and diameter of 5.00 mm. The measured current in the conductor is 2.00 A. The maximum permissible percentage error in the resistivity of the conductor is:

☐ A. 7.5

☒ B. 3.9

☐ C. 8.4

☐ D. 3.0

We know that  $V = IR$  and  $R = \rho \frac{l}{A}$

$$\text{So, } V = I \left( \frac{\rho l}{A} \right)$$

$$\Rightarrow \rho = \frac{VA}{Il}$$

$$\text{Also, } A = \frac{\pi d^2}{4}$$

$$\text{So } \Rightarrow \rho = \frac{V\pi d^2}{4Il}$$

$$\text{Now, } \frac{\Delta \rho}{\rho} = \frac{\Delta V}{V} + \frac{\Delta I}{I} + \frac{\Delta l}{l} + 2 \frac{\Delta d}{d}$$

Since  $V = 5.0$  V There is one zero after decimal, so  $\Delta V = 0.1$  V

$$\frac{\Delta \rho}{\rho} = \frac{0.1}{5} + \frac{0.01}{2} + \frac{0.1}{10} + 2 \times \frac{0.01}{5}$$

$$\frac{\Delta \rho}{\rho} = 0.02 + 0.005 + 0.01 + 0.004$$

$$\frac{\Delta \rho}{\rho} = 0.039$$

$$\frac{\Delta \rho}{\rho} \times 100 = 0.039 \times 100 = 3.9\%$$

25. The time period of a simple pendulum is given by  $T = 2\pi\sqrt{\frac{l}{g}}$ . The measured value of the length of pendulum is 10 cm known to 1 mm accuracy. The time for 200 oscillations of the pendulum is found to be 100 second using a clock of 1 s resolution. The percentage accuracy in the determination of  $g$  using this pendulum is  $x$ . The value of  $x$  to the nearest integer is.

☐ A. 5%

☐ B. 4%

☒ C. 3%

☐ D. 2%

$$T = 2\pi\sqrt{\frac{l}{g}} \Rightarrow g = 4\pi^2 \frac{l}{T^2}$$

$$\text{Now, } \frac{\Delta g}{g} = \frac{\Delta l}{l} + \frac{2\Delta T}{T}$$

$$\Rightarrow \frac{\Delta g}{g} = \frac{1 \times 10^{-3}}{10 \times 10^{-2}} + \frac{2 \times 1}{100}$$

$$\Rightarrow \frac{\Delta g}{g} = 0.01 + 0.02 = 0.03$$

$$\Rightarrow \frac{\Delta g}{g} \times 100 = 0.03 \times 100 = 3\%$$

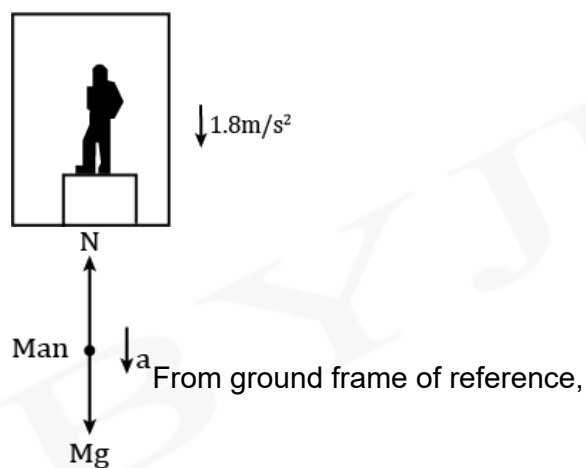
## Topic : NLM and Friction

1. A man standing on a spring balance inside a stationary lift measures 60 kg. The weight of that person if the lift descends with a uniform downward acceleration of  $1.8 \text{ m/s}^2$  will be \_\_\_\_N.  
[ $g = 10 \text{ m/s}^2$ ]

Accepted Answers

492 492.0 492.00

Solution:

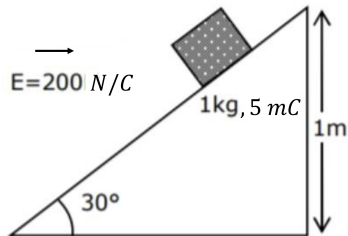


$$Mg - N = Ma$$

$$\Rightarrow N = M(g - a)$$

$$\Rightarrow N = 60(10 - 1.8) = 492 \text{ N}$$

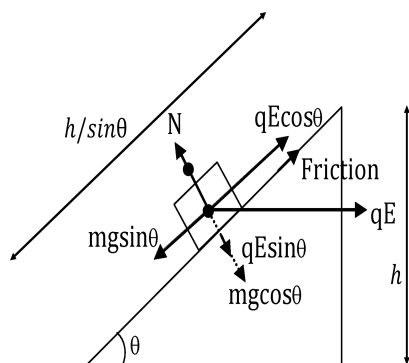
2. An inclined plane making an angle of  $30^\circ$  with the horizontal is placed in a uniform horizontal electric field  $200 \text{ N/C}$  as shown in the figure. A body of mass  $1 \text{ kg}$  and charge  $5 \text{ mC}$  is allowed to slide down from rest from a height of  $1 \text{ m}$ . If the coefficient of friction is  $0.2$ , find the time taken by the body to reach the bottom.



$$\left[ g = 9.8 \text{ m/s}^2; \sin 30^\circ = \frac{1}{2}; \cos 30^\circ = \frac{\sqrt{3}}{2} \right]$$

- ☒ A.  $2.3 \text{ s}$
- ☒ B.  $0.46 \text{ s}$
- ☒ C.  $1.3 \text{ s}$
- ☒ D.  $0.92 \text{ s}$





Net force along the inclined plane.

$$F = mg \sin \theta - qE \cos \theta - f$$

$$\Rightarrow F = mg \sin \theta - qE \cos \theta - \mu N$$

$$\Rightarrow F = mg \sin \theta - qE \cos \theta - \mu(qE \sin \theta + mg \cos \theta)$$

$$\Rightarrow F = 1 \times 9.8 \times \frac{1}{2} - 5 \times 10^{-3} \times 200 \times \frac{\sqrt{3}}{2} - 0.2 \left( 5 \times 10^{-3} \times 200 \times \frac{1}{2} + 1 \times 9.8 \times \frac{\sqrt{3}}{2} \right)$$

$$\Rightarrow F \approx 2.24 \text{ N}$$

$$\text{So, } a \approx F/m \approx 2.24 \text{ m/s}^2$$

Further,

$$\frac{h}{\sin \theta} = 0 + \frac{1}{2}at^2$$

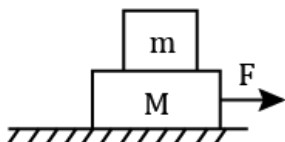
$$\Rightarrow \frac{1}{1/2} = \frac{1}{2} \times 2.24 \times t^2$$

$$\Rightarrow t \approx 1.3 \text{ s}$$

3. Two blocks ( $m = 0.5 \text{ kg}$  and  $M = 4.5 \text{ kg}$ ) are arranged on a horizontal frictionless table as shown in the figure. The coefficient of static friction between the two blocks is  $3/7$ . Then the maximum horizontal force that can be applied on the larger block so that blocks move together is \_\_\_\_\_ N.

(Round off to the nearest integer)

(Take  $g$  as  $9.8 \text{ ms}^{-2}$ )



Accepted Answers

21    21.0    21.00

Solution:

Maximum acceleration for both blocks to move together,

$$a_{max} = \mu g$$

$$\Rightarrow a_{max} = \frac{3}{7} \times 9.8$$

$$a_{max} = 4.2 \text{ m/s}^2$$

Now, considering both blocks are moving together with the acceleration of  $4.2 \text{ m/s}^2$ ,

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

$$\Rightarrow F_{max} = (4.5 + 0.5) \times 4.2 = 21 \text{ N}$$

4. A particle of mass  $M$  originally at rest is subjected to a force whose direction is constant but magnitude varies with time according to the relation  $F = F_0 \left[ 1 - \left( \frac{t-T}{T} \right)^2 \right]$

where  $F_0$  and  $T$  are constants. The force acts only for the time interval  $2T$ . The velocity  $v$  of the particle after time  $2T$  is :

- ☒ A.  $\frac{2F_0T}{M}$   
☒ B.  $\frac{F_0T}{2M}$   
☒ C.  $\frac{4F_0T}{3M}$   
☒ D.  $\frac{F_0T}{3M}$

From the given problem we can infer that

at  $t = 0, u = 0$

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

$$\text{or, } F = F_0 - \frac{F_0(t-T)^2}{T^2}$$

Therefore, we have

$$\text{acceleration, } a = \frac{F_0}{M} - \frac{F_0(t-T)^2}{MT^2} = \frac{dv}{dt}$$

$$\text{or, } \int_0^v dv = \int_{t=0}^{2T} \left( \frac{F_0}{M} - \frac{F_0(t-T)^2}{MT^2} \right) dt$$

$$\Rightarrow v = \left[ \frac{F_0}{M} t \right]_0^{2T} - \frac{F_0}{MT^2} \left[ \frac{t^3}{3} - t^2T + T^2t \right]_0^{2T}$$

$$\Rightarrow v = \frac{4F_0T}{3M}$$

The particle will have constant velocity, as force will not act after  $t = 2T$ , which will be equal to  $v$ .

Hence, option (c) is correct.

5. A particle is projected with velocity  $v_o$  along  $x$ -axis. A damping force is acting on the particle which is proportional to the square of the distance from the origin, i. e.  $ma = -\alpha x^2$ . The distance at which the particle stops :

☐ A.  $\left(\frac{2mv_o^2}{3\alpha}\right)^{\frac{1}{3}}$

☐ B.  $\left(\frac{3mv_o^2}{2\alpha}\right)^{\frac{1}{2}}$

☒ C.  $\left(\frac{3mv_o^2}{2\alpha}\right)^{\frac{1}{3}}$

☐ D.  $\left(\frac{2mv_o^2}{3\alpha}\right)^{\frac{1}{2}}$

For damping force, acceleration of the particle is,

$$a = \frac{-\alpha x^2}{m}$$

Here, acceleration of the particle is varying with distance.  
So that,

$$a = v \frac{dv}{dx} = \frac{-\alpha x^2}{m}$$

$$\Rightarrow v dv = \frac{-\alpha x^2}{m} dx$$

$$\Rightarrow \int_{v_i}^{v_f} v dv = \frac{-\alpha}{m} \int_{x_i}^{x_f} x^2 dx$$

$$\Rightarrow \left[ \frac{v_f^2 - v_i^2}{2} \right] = \frac{-\alpha}{m} \left[ \frac{x_f^3 - x_i^3}{3} \right]$$

Here,

$$v_f = 0, \quad v_i = v_0$$

$$x_f = x, \quad x_i = 0$$

$$\Rightarrow \left[ \frac{-v_0^2}{2} \right] = \frac{-\alpha}{m} \left[ \frac{x^3}{3} \right]$$

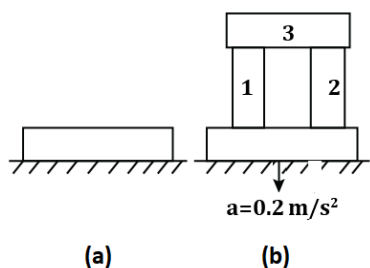
$$\Rightarrow \left[ \frac{v_0^2}{2} \right] = \frac{\alpha}{m} \left[ \frac{x^3}{3} \right]$$

$$\Rightarrow \left[ \frac{3mv_0^2}{2\alpha} \right] = x^3$$

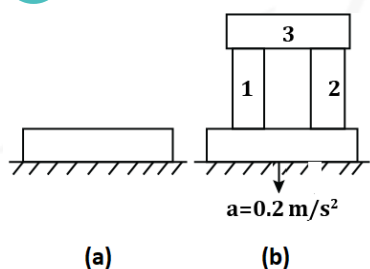
$$\Rightarrow x = \left( \frac{3mv_0^2}{2\alpha} \right)^{\frac{1}{3}}$$

Hence, (C) is the correct answer.

6. A steel block of mass 10 kg rests on a horizontal floor as shown in the figure (a). When three iron cylinders are placed on it as shown in the figure (b), the block and cylinders go down with an acceleration  $0.2 \text{ m/s}^2$ . The normal reaction  $R$  exerted by the floor, if masses of the iron cylinders are 20 kg each, is -



- ☒ A. 716 N
- ☒ B. 686 N
- ☒ C. 714 N
- ☒ D. 684 N



Assuming all four blocks are as a system.

Writing the force equation on the system in vertical direction,

$$Mg - R = Ma$$

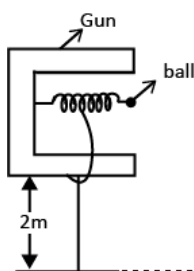
$$\Rightarrow (10 + (3 \times 20))10 - R = (10 + (3 \times 20)) \times 0.2$$

$$\Rightarrow R = 70(10 - 0.2) = 686 \text{ N}$$

Hence, option (B) is the correct answer.

7. In a spring gun having spring constant  $100 \text{ N/m}$ , a small ball  $B$  of mass  $100 \text{ g}$  is put in its barrel (as shown in the figure) by compressing the spring through  $0.05 \text{ m}$ . There should be a box placed at a distance  $d$  on the ground so that the ball falls in it. If the ball leaves the gun horizontally at a height of  $2 \text{ m}$  above the ground. The value of  $d$  in meter is \_\_\_\_\_.

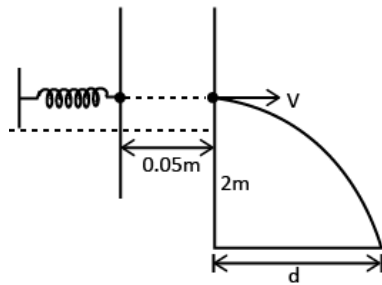
Take  $g = 10 \text{ m/s}^2$



Accepted Answers

1    1.0    1.00

Solution:



From energy conservation,

$$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$$

$$\Rightarrow v = x\sqrt{\frac{k}{m}} = 0.05\sqrt{\frac{100}{0.1}}$$

$$\Rightarrow v = \sqrt{2.5} \text{ m/s}$$

For vertical motion,

$$s_y = u_y t + \frac{1}{2}a_y t^2$$

$$\Rightarrow -2 = 0 \times t - \frac{1}{2} \times 10 \times t^2$$

$$\Rightarrow t = \sqrt{\frac{2}{5}} \text{ s}$$

For horizontal motion,

$$d = vt = \sqrt{2.5} \times \sqrt{\frac{2}{5}} = 1 \text{ m}$$



8. A body of mass  $m$  is launched up on a rough inclined plane making an angle of  $30^\circ$  with the horizontal. The coefficient of friction between the body and plane is  $\frac{\sqrt{x}}{5}$  if the time of ascent is half of the time of descent. The value of  $x$  is \_\_\_\_\_.

Accepted Answers

3

Solution:

Given:

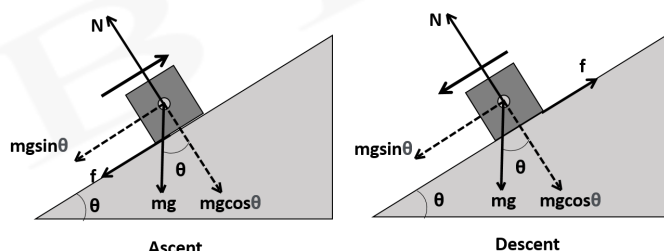
$$t_a = \frac{1}{2}t_d$$

Let's assume, the length of inclined plane is  $s$ .

$$s = \frac{1}{2}at^2 \Rightarrow t = \sqrt{\frac{2s}{a}}$$

So from given condition,

$$\sqrt{\frac{2s}{a_a}} = \frac{1}{2}\sqrt{\frac{2s}{a_d}} \dots\dots\dots (1)$$



Here, friction force,  $f = \mu mg \cos \theta$

$$a_a = g \sin \theta + \mu g \cos \theta$$

$$a_a = \frac{g}{2} + \frac{\sqrt{3}}{2}\mu g \quad (\because \theta = 30^\circ)$$

$$a_d = g \sin \theta - \mu g \cos \theta$$

$$a_d = \frac{g}{2} - \frac{\sqrt{3}}{2}\mu g$$

using the above values of  $a_a$  and  $a_d$ , and putting in equation (1), we will get

$$\mu = \frac{\sqrt{3}}{5}$$

$\therefore$  Correct answer : 3

9. Two bodies, a ring and a solid cylinder of same material are rolling down without slipping an inclined plane. The radii of the bodies are same. The ratio of velocity of the centre of mass at the bottom of the inclined plane of the ring to that of the cylinder is  $\frac{\sqrt{x}}{2}$ . Then, the value of  $x$  is \_\_\_\_\_.

Accepted Answers

3

Solution:

Suppose both the bodies start rolling from vertical height  $h$ .

Let,

$m_c$  = mass of cylinder,

$m_r$  = mass of ring,

$R$  = Radius of ring or cylinder,

Now, applying energy conservation between top & bottom of the inclined plane,

$$m_r gh = \frac{1}{2} I_r \omega_r^2 + \frac{1}{2} m_r v_r^2$$

Here,  $I_r = m_r R^2$  ;  $v_r = R \omega_r$

$$\Rightarrow m_r gh = \frac{1}{2} (m_r R^2) \left( \frac{v_r}{R} \right)^2 + \frac{1}{2} m_r v_r^2$$

$$\Rightarrow v_r = \sqrt{gh}$$

Similarly, for solid cylinder,

$$m_c gh = \frac{1}{2} I_c \omega_c^2 + \frac{1}{2} m_c v_c^2$$

Here,  $I_c = m_c R^2 / 2$  ;  $v_c = R \omega_c$

$$\Rightarrow m_c gh = \frac{1}{2} (m_c R^2 / 2) \left( \frac{v_c}{R} \right)^2 + \frac{1}{2} m_c v_c^2$$

$$\Rightarrow v_c = \sqrt{\frac{4gh}{3}}$$

$$\therefore \frac{v_r}{v_c} = \frac{\sqrt{3}}{2}$$

So, correct answer : 3

Alternate solution:

Let  $I_{poc}$  be the MOI about point of contact.

Now, applying energy conservation between top & bottom of the inclined plane,

$$m_r gh = \frac{1}{2} I_{r,poc} \omega_r^2$$

Here,  $I_{r,poc} = 2m_r R^2$  ;  $v_r = R\omega_r$

$$\Rightarrow m_r gh = \frac{1}{2} (2m_r R^2) \left( \frac{v_r}{R} \right)^2$$

$$\Rightarrow v_r = \sqrt{gh}$$

Similarly, for solid cylinder,

$$m_c gh = \frac{1}{2} I_{c,poc} \omega_c^2$$

Here,  $I_{c,poc} = 3m_c R^2 / 2$  ;  $v_c = R\omega_c$

$$\Rightarrow m_c gh = \frac{1}{2} (3m_c R^2 / 2) \left( \frac{v_c}{R} \right)^2$$

$$\Rightarrow v_c = \sqrt{\frac{4gh}{3}}$$

$$\therefore \frac{v_r}{v_c} = \frac{\sqrt{3}}{2}$$

10. A force  $\vec{F} = (40\hat{i} + 10\hat{j})$  N acts on a body of mass 5 kg. If the body starts from rest, its position vector  $\vec{r}$  at time  $t = 10$  s, will be :

☐ A.  $(100\hat{i} + 400\hat{j})$  m

☐ B.  $(100\hat{i} + 100\hat{j})$  m

☒ C.  $(400\hat{i} + 100\hat{j})$  m

☐ D.  $(400\hat{i} + 400\hat{j})$  m

Given that,

$$\vec{F} = (40\hat{i} + 10\hat{j}) \text{ N}$$

$$m = 5 \text{ kg}$$

As we know that,

$$\frac{\vec{r}}{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2} = \frac{\vec{F}}{m} = (8\hat{i} + 2\hat{j}) \text{ ms}^{-2}$$

Doing double integrating both side w.r.t.  $t$  from  $t = 0$  to  $t = t$  and we get

$$\Rightarrow \frac{d\vec{r}}{dt} = \vec{v} = (8t\hat{i} + 2t\hat{j}) \text{ ms}^{-1}$$

$$\Rightarrow \vec{r} = (8\hat{i} + 2\hat{j}) \frac{t^2}{2} \text{ m}$$

$\therefore$  At  $t = 10$  s

$$\vec{r} = (8\hat{i} + 2\hat{j}) 50 \text{ m}$$

$$\Rightarrow \vec{r} = (400\hat{i} + 100\hat{j}) \text{ m}$$

Hence, option (C) is correct.

11. The initial mass of a rocket is 1000 kg. Calculate at what rate the fuel should be burnt so that the rocket is given an acceleration of  $20 \text{ ms}^{-2}$ . the gases come out at a relative speed of  $500 \text{ ms}^{-1}$  with respect to the rocket : [use  $g = 10 \text{ ms}^{-2}$ ]

- ☒ A.  $60 \text{ kg s}^{-1}$
- ☐ B.  $6.0 \times 10^2 \text{ kg s}^{-1}$
- ☐ C.  $500 \text{ kg s}^{-1}$
- ☐ D.  $10 \text{ kg s}^{-1}$

From the question it is clear that we have to calculate the rate of change of mass with respect to time. The rocket thrust is equal to the burnt mass times relative velocity of the rocket.

$$\text{So, } F_{\text{thrust}} = \frac{dm}{dt} v_{\text{rel}}$$

The net force acting on the rocket is given by,

$$F_{\text{thrust}} - mg = ma$$

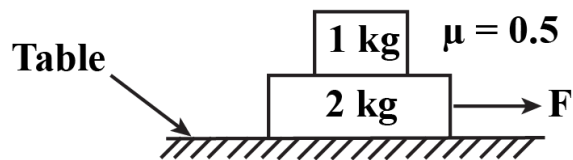
$$\text{i.e. } \frac{dm}{dt} v_{\text{rel}} - mg = ma$$

$$\frac{dm}{dt} \times 500 - 1000 \times 10 = 1000 \times 20$$

$$\text{Therefore, } \frac{dm}{dt} = 60 \text{ kg s}^{-1}$$

Hence, option (A) is correct.

12. The coefficient of static friction between the two blocks is 0.5 and the table is smooth. The maximum horizontal force that can be applied to move the blocks together is \_\_\_\_ N.  
(Take  $g = 10 \text{ ms}^{-2}$ )

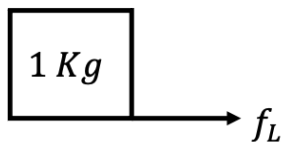


Accepted Answers

20                      20.0

Solution:

The free body diagram of block A is as shown below:



The maximum frictional force that can act on block A is given by,

$$f_L = \mu_s N = \mu_s mg = (0.5)(1 \times 10) = 5 \text{ N}$$

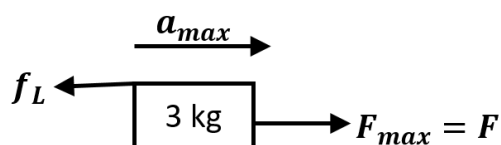
The maximum acceleration possible for the block A is given by,

$$a_{max} = \frac{f_L}{m} = \frac{5}{1} = 5 \text{ m/s}^2$$

Now, if the two blocks are to move together, the maximum possible acceleration of both the blocks should be  $5 \text{ m/s}^2$

Under this scenario, there is no slipping between the two blocks, and they should move as a single system with acceleration  $a = 5 \text{ m/s}^2$

The free body diagram of the system is shown below:

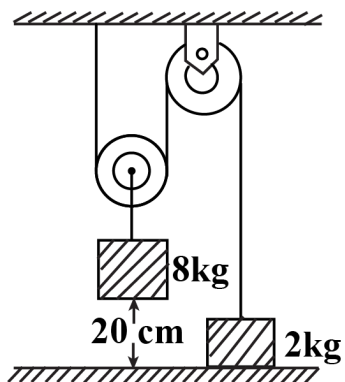


Using Newton's second law, we have:

$$F_{max} - f_L = ma_{max}$$

$$\therefore F = F_{max} = 5 + (3 \times 5) = 20 \text{ N}$$

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

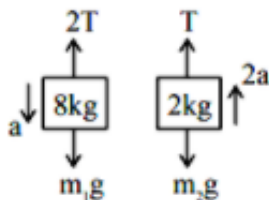


- ☐ A. 0.2 s
- ☐ B. 0.34 s
- ☐ C. 0.25 s
- ☒ D. 0.4 s

Let tension in the string attached to 2 kg mass be  $T$ ,  
Tension in the string attached to 8 kg mass is  $2T$

Using constraining equations,  
If acceleration of 8 kg mass is  $a$ , then acceleration of 2 kg mass is  $2a$

Free body diagram of masses can be drawn as,



From Newton's second law,

$$8g - 2T = 8a \dots (i)$$

$$T - 2g = 4a \dots (ii)$$

on substitution, we get,

$$8g - 2(2g + 4a) = 8a$$

$$4g = 16a$$

$$a = 2.5 \text{ ms}^{-2}$$

Now, from  $S = ut + \frac{1}{2}at^2$

$$0.2 = \frac{1}{2}(2.5)t^2$$

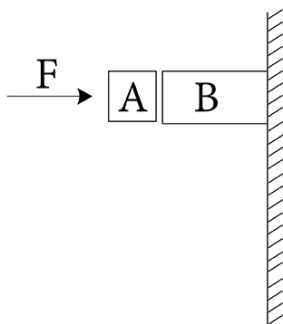
$$\frac{4}{25} = t^2$$

$$t = \frac{2}{5} = 0.4 \text{ s}$$

Hence, option (D) is correct.

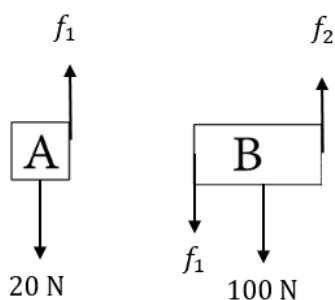


14. Given in the figure are two blocks A and B of weight  $20\text{ N}$  and  $100\text{ N}$ , respectively. These are being pressed against a wall by a force  $F$  as shown. If the coefficient of friction between the blocks is  $0.1$  and between block B and the wall is  $0.15$ , the frictional force applied by the wall on block B is



- ☒ A.  $100\text{ N}$
- ☒ B.  $80\text{ N}$
- ☒ C.  $120\text{ N}$
- ☒ D.  $150\text{ N}$

As both the masses are in equilibrium, static friction will be acting on the blocks which can be found from balancing the forces in vertical direction.



Writing force balance in vertical direction for block A,

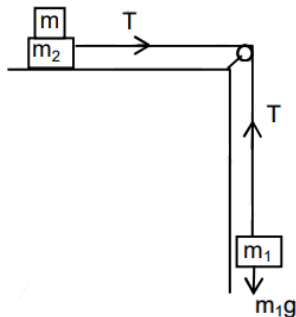
$$f_1 = \text{weight of the block A} = 20\text{ N}$$

Writing force balance in vertical direction for block B,

$$f_2 - f_1 = \text{weight of the block B} = 100\text{ N}$$

From these equations, we get the value of  $f_2$  (frictional force between the wall and block B) as  $120\text{ N}$

15. Two masses  $m_1 = 5 \text{ kg}$  and  $m_2 = 10 \text{ kg}$  connected by an inextensible string over a frictionless pulley are moving as shown in the figure. The coefficient of friction of horizontal surface is 0.15. The minimum weight  $m$  that should be put on top of  $m_2$  to stop the motion is



- ☐ A. 43.3 kg
- ☐ B. 10.3 kg
- ☐ C. 18.3 kg
- ☒ D. 23.3 kg

$$\mu(m + m_2) = m_1$$

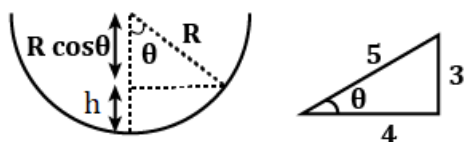
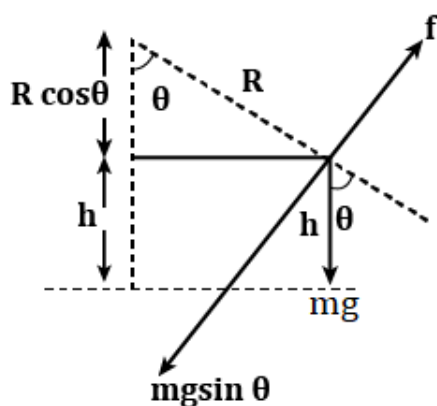
$$m + m_2 = \frac{m_1}{\mu} \Rightarrow m = \frac{m_1}{\mu} - m_2$$

$$m = \frac{5}{0.15} - 10 = 23.33 \text{ kg}$$

16. An insect is at the bottom of a hemispherical ditch of radius 1 m. It crawls up the ditch but start slipping after it is at height  $h$  from the bottom. If the coefficient of friction between the ground and the insect is 0.75, then  $h$  is : ( $g = 10 \text{ ms}^{-2}$ )

- ☒ A. 0.20 m  
☐ B. 0.45 m  
☐ C. 0.60 m  
☐ D. 0.80 m

FBD of the insect can be shown as below



From FBD, for balancing,

$$mg \sin \theta = f = \mu mg \cos \theta$$

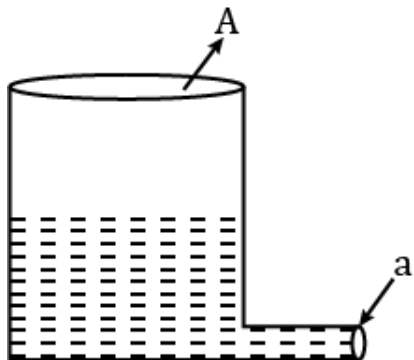
$$\Rightarrow \tan \theta = \mu = 0.75 = \frac{3}{4}$$

From the shown geometry we have,

$$h = R - R \cos \theta = R - R \left( \frac{4}{5} \right) = \frac{R}{5}$$

$$\therefore h = \frac{R}{5} = 0.2 \text{ m} \quad [\because \text{radius, } R = 1 \text{ m}]$$

17. A light cylindrical vessel is kept on a horizontal surface. Area of base is  $A$ . A hole of cross-sectional area ' $a$ ' is made just at its bottom side. The minimum coefficient of friction necessary to prevent sliding the vessel due to the impact force of the emerging liquid is ( $a \ll A$ ) :



- ☒ A.  $\frac{A}{2a}$
- ☒ B. None of these
- ☒ C.  $\frac{2a}{A}$
- ☒ D.  $\frac{a}{A}$

Exit speed of liquid is given by

$$v^2 = 2gh$$

Where  $h$  is the height of liquid

So, impact force of emerging liquid,

$$F = \rho av^2 = 2\rho agh$$

For no sliding condition,

$$f \geq F$$

Where,  $f$  is the force of friction.

$$f = \mu mg = \mu(\rho Ah)g$$

$$\Rightarrow \mu \rho Ahg \geq 2\rho agh$$

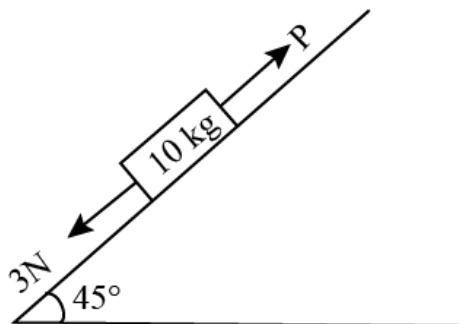
$$\Rightarrow \mu \geq \frac{2a}{A}$$

So the minimum coefficient of friction for the vessel is,

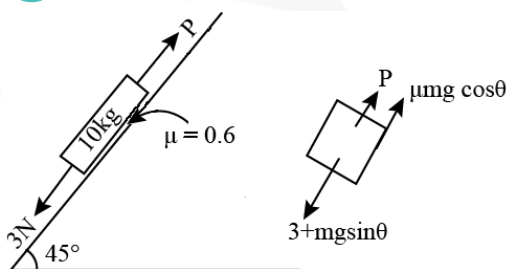
$$\therefore \mu = \frac{2a}{A}$$

Hence, option (C) is correct.

18. A block of mass 10 kg is kept on a rough inclined plane as shown in the figure. A force of 3 N is applied on the block. The coefficient of static friction between the plane and the block is 0.6. What should be the minimum value of force  $P$ , such that the block does not move downward? (take  $g = 10 \text{ ms}^{-2}$ )



- ☒ A. 32 N  
☐ B. 18 N  
☐ C. 23 N  
☐ D. 25 N



When minimum force  $P$  is applied to stop the downward motion of the block,

$$3 + mg \sin \theta = P + \mu mg \cos \theta$$

$$3 + \frac{100}{\sqrt{2}} = P + 0.6 \times 100 \times \frac{1}{\sqrt{2}}$$

$$3 + 50\sqrt{2} = P + 30\sqrt{2}$$

$$\therefore P = 31.28 \approx 32 \text{ N}$$

Hence, option (A) is correct.

19. Statement I: It is easier to pull a heavy object than to push it on a level ground.

Statement II: The magnitude of frictional force depends on the nature of the two surfaces in contact.

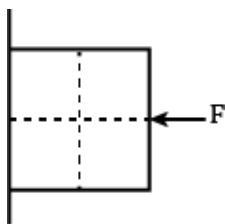
- ☐ A. Both Statements are true and Statement II is the correct explanation for Statement I.
- ☒ B. Both Statements are true and Statement II is not the correct explanation for Statement I.
- ☐ C. Statement I is true and Statement II is false.
- ☐ D. Statement I is false and Statement II is true.

There is an increase in normal reaction ( $N$ ) when the object is pushed and there is a decrease in normal reaction when the object is pulled (but strictly not horizontally).

And we know that,  
Frictional force,  $f = \mu N$

Therefore, Both Statements are true but Statement II does not explain correctly Statement I.

20. A block of mass  $m$  is at rest under the action of force  $F$  against a wall as shown in figure. Which of the following statement is incorrect ?



- ☒ A.  $f = mg$  (where  $f$  is the frictional force)
- ☒ B.  $F = N$  (where  $N$  is the normal force)
- ☒ C.  $F$  will not produce torque
- ☒ D.  $N$  will not produce torque

This is the equilibrium of coplanar forces. Hence,  
 $\sum F_x = 0$  ;  $\sum F_y = 0$  ;  $\sum \tau_c = 0$

$$\sum F_x = 0$$

$$\therefore F = N$$

$$\sum F_y = 0$$

$$f = mg$$

$$\sum \tau_c = 0$$

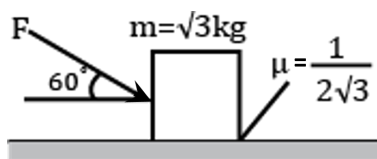
$$\therefore \tau_N + \tau_f = 0$$

Since,  $\tau_f \neq 0$

$$\therefore \tau_N \neq 0$$

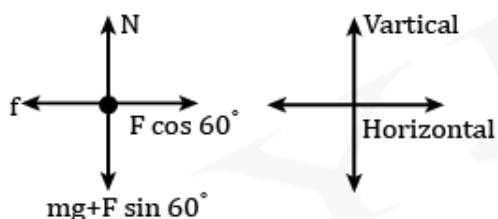
Hence, option (D) is correct.

21. What is the maximum value of the force  $F$  such that the block shown in the arrangement, does not move?



- ☒ A. 20 N
- ☐ B. 10 N
- ☐ C. 12 N
- ☐ D. 15 N

Free body diagram (FBD) of the block (shown by a dot) is shown in the figure.



For vertical equilibrium of the block,

$$N = mg + F \sin 60^\circ$$

$$N = \sqrt{3}g + F \frac{\sqrt{3}}{2} \dots\dots\dots (1)$$

For no motion, force of friction,

$$f \geq F \cos 60^\circ \Rightarrow \mu N \geq F \cos 60^\circ$$

$$\frac{1}{2\sqrt{3}} \left( \sqrt{3}g + \frac{\sqrt{3}F}{2} \right) \geq \frac{F}{2}$$

$$\Rightarrow g \geq \frac{F}{2}$$

$$F \leq 2g = 20 \text{ N}$$

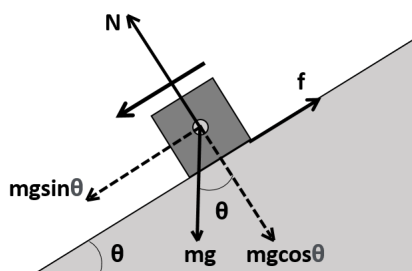
Therefore, the maximum value of  $F$  is 20 N.

Hence, option (A) is correct.



22. A block of mass 2 kg rests on a rough inclined plane making an angle of  $30^\circ$  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.  $0.7 \times 9.8$  N



Since, block is in rest so applied force will be less than the limiting friction.

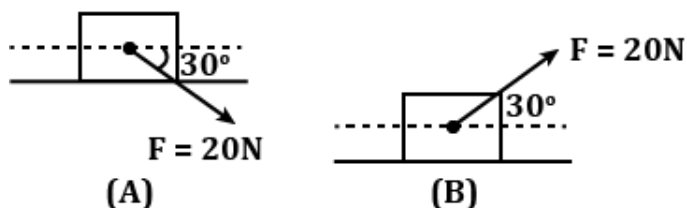
$$\therefore \mu mg \cos \theta > mg \sin \theta$$

$$\therefore \text{Force of friction is } f = mg \sin \theta$$

$$f = 2 \times 9.8 \times \frac{1}{2} = 9.8 \text{ N}$$

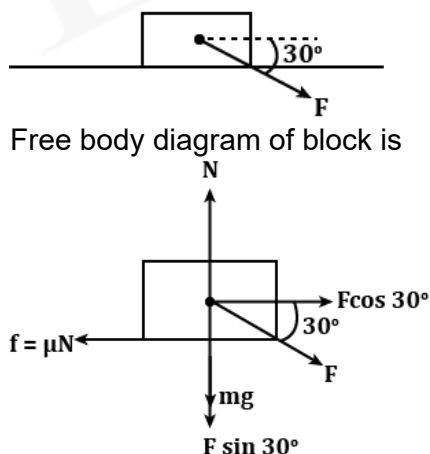
Hence, option (A) is correct.

23. A block of mass 5 kg is (i) pushed in case (A) and (ii) pulled in case (B), by a force  $F = 20$  N, making an angle of  $30^\circ$  with the horizontal, as shown in the figures. The coefficient of friction between the block and the floor is  $\mu = 0.2$ . The difference between the accelerations of the block, in case (B) and case (A) will be (Take,  $g = 10 \text{ ms}^{-2}$ )



- ☒ A.  $0.4 \text{ ms}^{-2}$   
☒ B.  $3.2 \text{ ms}^{-2}$   
☒ C.  $0.8 \text{ ms}^{-2}$   
☒ D.  $0 \text{ ms}^{-2}$

Case I : Block is pushed over surface



Free body diagram of block is

In this case, normal reaction,

$$N = mg + F \sin 30^\circ = (5 \times 10) + (20 \times \frac{1}{2}) = 60 \text{ N}$$

[Given,  $m = 5 \text{ kg}$ ,  $F = 20 \text{ N}$ ]

Force of friction,  $f = \mu N = 0.2 \times 60 = 12 \text{ N}$  [ $\because \mu = 0.2$ ]

So, net force causing acceleration ( $a_1$ ) is

$$F_{\text{net}} = ma_1 = F \cos 30^\circ - f$$

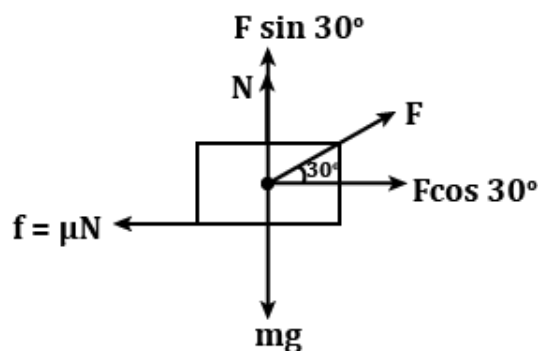
$$\Rightarrow ma_1 = 20 \times \frac{\sqrt{3}}{2} - 12$$

$$\therefore a_1 = \frac{10\sqrt{3} - 12}{5} = 1 \text{ ms}^{-2}$$

Case II : Block is pulled over the surface



Free body diagram of block is,



Net force causing acceleration is

$$F_{\text{net}} = F \cos 30^\circ - f = F \cos 30^\circ - \mu N$$

$$\Rightarrow F_{\text{net}} = F \cos 30^\circ - \mu(mg - F \sin 30^\circ)$$

If acceleration is now  $a_2$ , then

$$a_2 = \frac{F_{\text{net}}}{m} = \frac{F \cos 30^\circ - \mu(mg - F \sin 30^\circ)}{m}$$

$$= \frac{20 \times \frac{\sqrt{3}}{2} - 0.2 \left( 5 \times 10 - 20 \times \frac{1}{2} \right)}{5} = \frac{10\sqrt{3} - 8}{5}$$

$$\Rightarrow a_2 = 1.8 \text{ ms}^{-2}$$

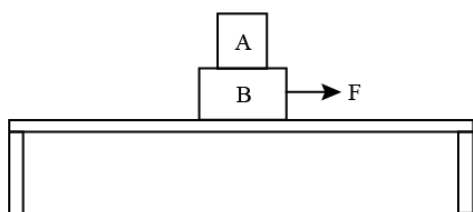
So, difference between  $a_1$  &  $a_2$  is,

$$\Delta a = a_2 - a_1 = 1.8 - 1 = 0.8 \text{ ms}^{-2}$$

Hence, option (C) is correct.

24. Two blocks A and B of masses  $m_A = 1 \text{ kg}$  and  $m_B = 3 \text{ kg}$  are kept on the table as shown in figure. The coefficient of friction between A and B is 0.2 and between B and the surface of the table is also 0.2. The maximum force  $F$  that can be applied on B horizontally, so that the block A does not slide over the block B is

[Take,  $g = 10 \text{ m/s}^2$ ]



- ☐ A. 12 N
- ☒ B. 16 N
- ☐ C. 8 N
- ☐ D. 40 N

Acceleration  $a$  of system of blocks A and B is,

$$a = \frac{\text{Net force}}{\text{Total masses}} = \frac{F - f_1}{m_A + m_B}$$

Where,  $f_1$  = friction between B and the surface =  $\mu(m_A + m_B)g$

So,

$$a = \frac{F - \mu(m_A + m_B)g}{(m_A + m_B)} \dots\dots\dots (1)$$

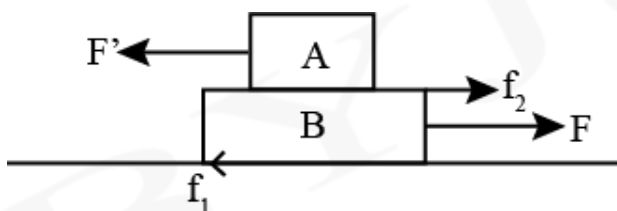
Here,  $\mu = 0.2$ ,  $m_A = 1$  kg,  $m_B = 3$  kg,  $g = 10 \text{ ms}^{-2}$

Substituting the above values in Eq. (1), we have

$$a = \frac{F - 0.2(1 + 3) \times 10}{1 + 3}$$

$$a = \frac{F - 8}{4} \dots\dots\dots (2)$$

Due to acceleration of block B, a pseudo force  $F'$  acts on A.



This force  $F'$  is given by  $F' = m_A a$

Where,  $a$  is acceleration of A and B caused by net force acting on B.

For A to slide over B; pseudo force on A, i.e.  $F'$  must be greater than friction between A and B.

$$\Rightarrow m_A a \geq f_2$$

We consider limiting case,

$$\begin{aligned} m_A a &= f_2 \\ \Rightarrow m_A a &= \mu(m_A)g \\ \Rightarrow a &= \mu g = 0.2 \times 10 = 2 \text{ ms}^{-2} \dots\dots\dots (3) \end{aligned}$$

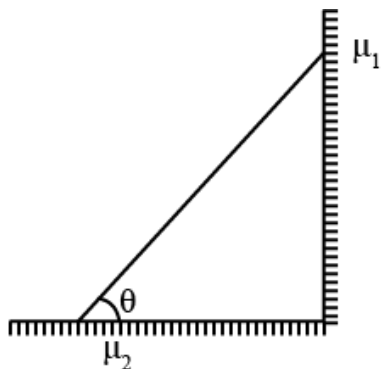
Putting the value of  $a$  from Eq. (3) into Eq. (2) we get

$$\frac{F - 8}{4} = 2$$

$$\therefore F = 16 \text{ N}$$

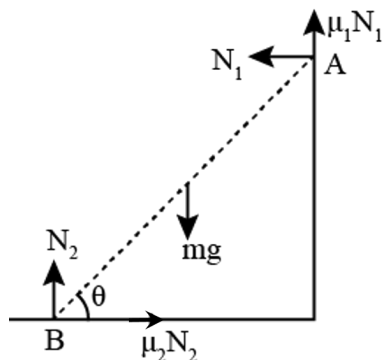
Hence, option (B) is correct.

25. In the figure, a ladder of mass  $m$  is shown leaning against a wall. It is static equilibrium making an angle  $\theta$  with the horizontal floor. The coefficient of friction between the wall and the ladder is  $\mu_1$  and that between the floor and the ladder is  $\mu_2$ . The normal reaction of the wall on the ladder is  $N_1$  and that of the floor is  $N_2$ . If the ladder is about to slip, then



- ☒ A.  $\mu_1 = 0, \mu_2 \neq 0$  and  $N_2 \tan \theta = \frac{mg}{2}$
- ☒ B.  $\mu_1 \neq 0, \mu_2 = 0$  and  $N_1 \tan \theta = \frac{mg}{2}$
- ☒ C.  $\mu_1 \neq 0, \mu_2 \neq 0$  and  $N_2 = \frac{mg}{1 + \mu_1 \mu_2}$
- ☒ D.  $\mu_1 = 0, \mu_2 \neq 0$  and  $N_1 \tan \theta = \frac{mg}{2}$

$\mu_2$  can never be zero for equilibrium.



When  $\mu_1 = 0$ , we have

$$N_1 = \mu_2 N_2 ; N_2 = mg$$

$$\tau_B = 0$$

$$\Rightarrow mg \frac{L}{2} \cos \theta = N_1 L \sin \theta$$

$$\Rightarrow N_1 = \frac{mg \cot \theta}{2} \Rightarrow N_1 \tan \theta = \frac{mg}{2}$$

When,  $\mu_1 \neq 0$  we have

$$\mu_1 N_1 + N_2 = mg$$

$$\mu_2 N_2 = N_1$$

$$\Rightarrow N_2 = \frac{mg}{1 + \mu_1 \mu_2}$$

Hence, option (C) is correct.