Center of Mass and Collision

Question1

A body of mass 2 kg is moving towards north with a velocity of $20 \mathrm{~ms}^{-1}$ and another body of mass 3 kg is moving towards east with a velocity of $10 \mathrm{~ms}^{-1}$. The magnitude of the velocity of the centre of mass of the system of the two bodies is

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Options:

A.

$20 \mathrm{~ms}^{-1}$

B.

$10 \mathrm{~ms}^{-1}$

C.

$15 \mathrm{~ms}^{-1}$

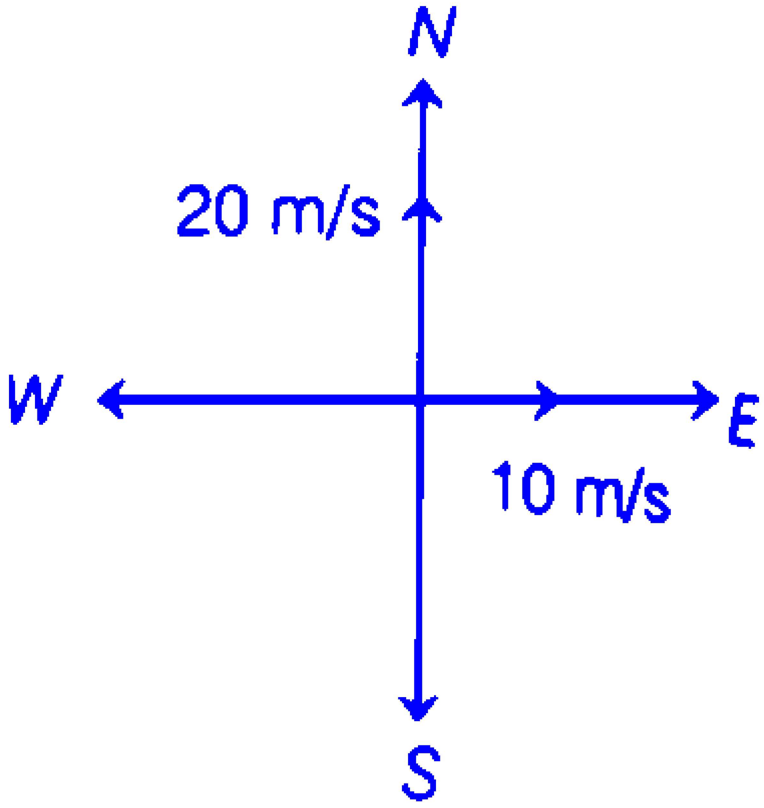
D.

$2 \sqrt{5} \mathrm{~ms}^{-1}$

Answer: B

Solution:

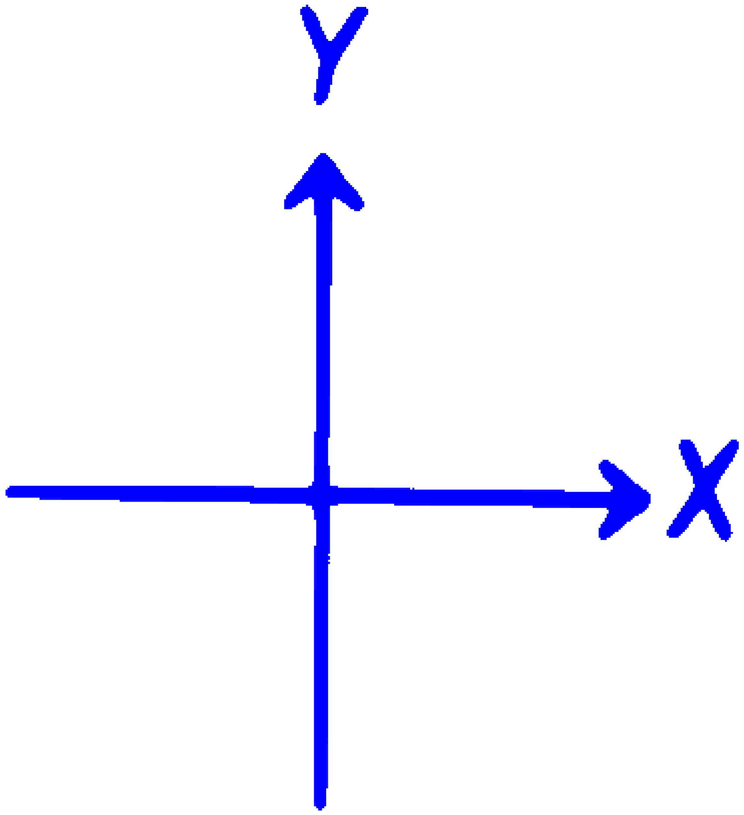
Velocity of mass 2 kg is $20 \mathrm{~m} / \mathrm{s}$ North.



So, $v_1 = 20\hat{\mathbf{j}}$

and velocity of mass 3 kg is 10 m/s east

So, $v_2 = 10\hat{\mathbf{i}}$



Now, velocity of centre of mass

$$v_{\mathrm{CM}}=\frac{m_1 v_1+m_2 v_2}{(m_1+m_2)}$$

$$v_{\mathrm{CM}}=\frac{2\times 20\hat{\mathbf{j}}+3\times 10\hat{\mathbf{i}}}{(2+3)}$$

$$v_{\mathrm{CM}}=8\hat{\mathbf{j}}+6\hat{\mathbf{i}}$$

So, magnitude of velocity

$$|v_{\mathrm{CM}}|=\sqrt{8^2+6^2}=10\ \mathrm{m/s}$$

Question2

A body of mass ' m ' moving along a straight line collides with a stationary body of mass ' $2m'$. After collision if the two bodies move together with the same velocity, then the fraction of kinetic energy lost in the process is

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Options:

A.

$\frac{1}{2}$

B.

$\frac{2}{3}$

C.

$\frac{3}{4}$

D.

$\frac{1}{3}$

Answer: B

Solution:

According to conservation of momentum

$mv_i + 2m \times 0 = (m + 2m)v_f$

$\Rightarrow \quad v_f = \frac{v_i}{3}$

$\therefore$ Loss in kinetic energy

$$\begin{aligned} \triangle \mathrm{KE} &= \frac{1}{2}mv_i^2 - \frac{1}{2}(3m)v_f^2 \\ &= \frac{1}{2}mv_i^2 - \frac{3}{2}m\left(\frac{v_i}{3}\right)^2 \\ &= \frac{1}{2}mv_i^2 - \frac{1}{6}mv_i^2 = \frac{1}{3}mv_i^2 \end{aligned}$$

$\therefore$ Fraction of kinetic energy lost

$= \frac{\Delta \mathrm{KE}}{K_i} = \frac{\frac{1}{3}mv_i^2}{\frac{1}{2}mv_i^2} = \frac{2}{3}$

Question3

A disc of mass 0.2 kg is kept floating in air without falling by vertically firing bullets each of mass 0.05 kg on the disc at the rate of 10 bullets per every second. If the bullets rebound with the same speed, then the speed of each bullet is

(Acceleration due to gravity $= 10 \mathrm{~ms}^{-2}$)

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Options:

A.

$2 \mathrm{~ms}^{-1}$

B.

$10 \mathrm{~m} \mathrm{~s}^{-1}$

C.

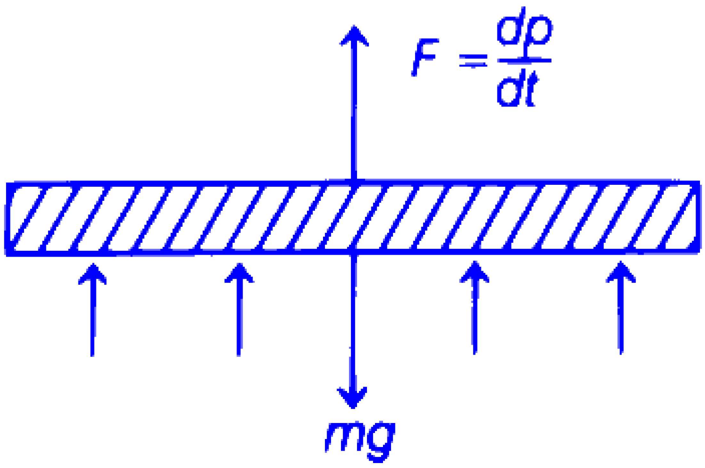
$20 \mathrm{~ms}^{-1}$

D.

$1 \mathrm{~ms}^{-1}$

Answer: A

Solution:



As disc is floating in air without falling, force by bullets balances gravitational force.

$\Rightarrow \quad\left(\frac{N \Delta p}{\Delta t}\right)=m_d g$

Here, $N=$ number of bullets fired $\frac{\Delta p}{\Delta t}=$ Rate of change of one bullet $m_d=$ mass of disc

Hence, bullets rebound with same speed, momentum change for each bullet $=m(v-(-v))=2 m v$

$\therefore \quad \frac{N}{t} \cdot 2 m_b v=m_d g$

Substituting given values,

$$10 \times 2 \times 0.05 \times v=0.2 \times 10$$
$$\therefore \quad v=\frac{0.2 \times 10}{10 \times 2 \times 0.05}=2 \mathrm{~m} / \mathrm{s}$$

Question4

A body moving along a straight line collides another body of same mass moving in the same direction with half of the velocity of the first body. If the coefficient of restitution between the two bodies is 0.5 , then the ratio of the velocities of the two bodies after collision is (Treat the collision as one dimensional)

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Options:

A.

2 : 5

B.

5 : 7

C.

2 : 3

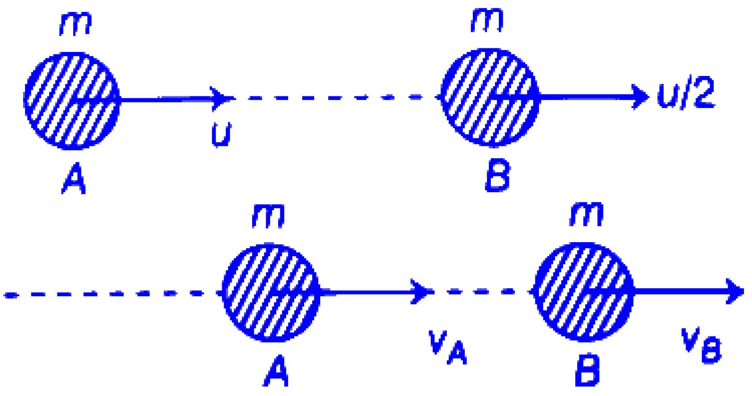
D.

3 : 7

Answer: B

Solution:

Before collision



Let initial velocities are u and $\frac{u}{2}$ and final velocities are v_A and v_B. Then, momentum is conserved,

$mu + \frac{mu}{2} = mv_A + mv_B$

or

$v_A + v_B = \frac{3u}{2} \qquad \ldots(i)$

Coefficient of restitution is 0.5 ,

$$\Rightarrow \quad e = \frac{v_B - v_A}{u_A - u_B} = \frac{v_B - v_A}{u - \left(\frac{u}{2}\right)}$$

$$\Rightarrow \quad v_B - v_A = \frac{u}{4} \qquad \ldots(ii)$$

From (i) and (ii)

$v_B = \frac{7}{8} \cdot u \qquad \ldots(iii)$

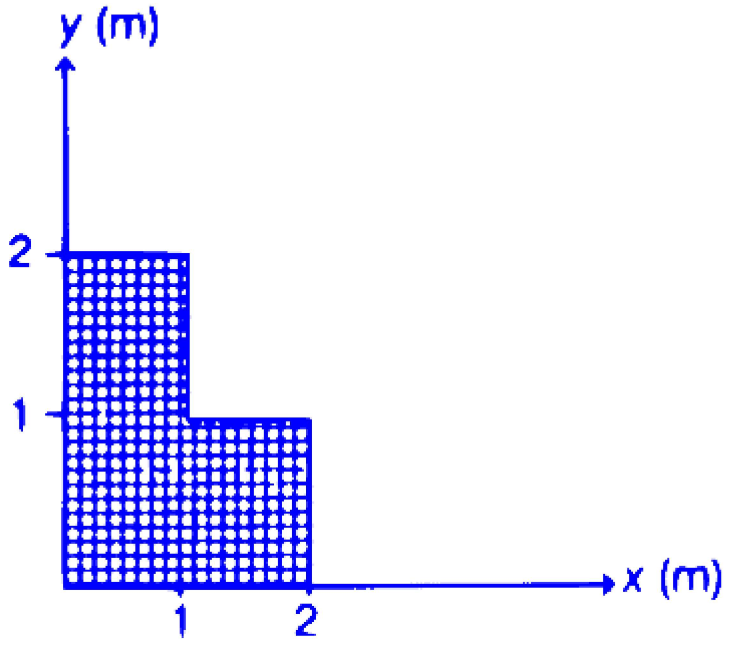
And from (i) and (iii)

$v_A = \frac{5}{8} u \qquad \ldots (iv)$

Hence, ratio $\frac{v_A}{v_B} = \frac{\frac{5}{8}}{\frac{7}{8}} = \frac{5}{7}$

Question5

The co-ordinates of the centre of mass of a uniform L shaped plate of mass 3 kg shown in the figure is



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Options:

A.

$\left(\frac{5}{6} m, \frac{5}{6} m\right)$

B.

$\left(\frac{3}{2} m, \frac{3}{2} m\right)$

C.

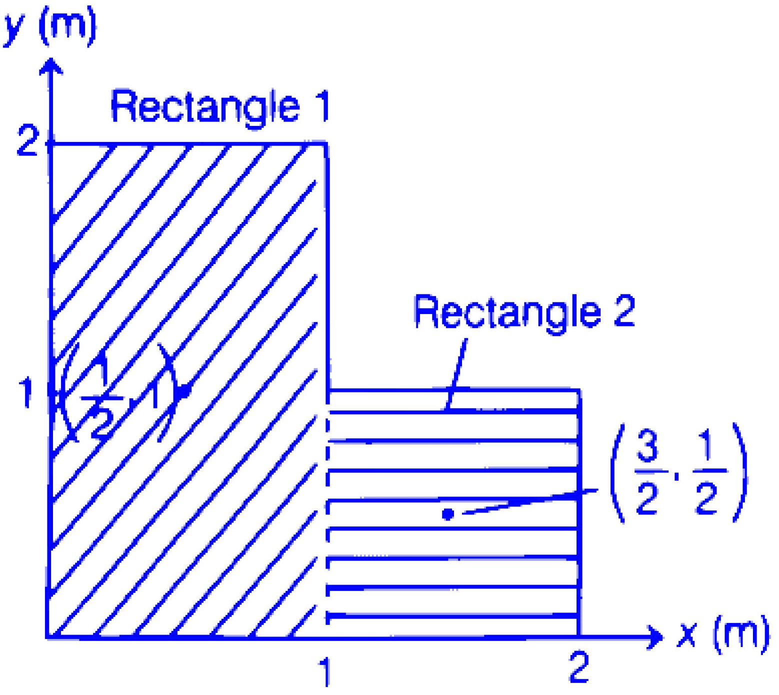
$\left(\frac{1}{2} m, \frac{1}{2} m\right)$

D.

$\left(\frac{6}{5}m, \frac{6}{5}m\right)$

Answer: A

Solution:



If σ be the mass per unit area, Then,

$$\sigma = \frac{3}{2 \times 1 + 1 \times 1}$$
$$= 1 \text{ kg/m}^2$$

$\therefore$ mass of rectangle-1,

$m_1 = \sigma A_1 = 1 \times 2 \times 1 = 2 \text{ kg}$

mass of rectangle-2,

$m_2 = \sigma A_2 = 1 \times 1 \times 1 = 1 \text{ kg}$

$$\therefore X_{\text{CM}} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$
$$= \frac{2 \times \frac{1}{2} + 1 \times \frac{3}{2}}{2 + 1} = \frac{5}{6} \text{ m}$$

and $Y_{\text{CM}} = \frac{m_1 y_1 + m_2 y_2}{m_1 + m_2}$

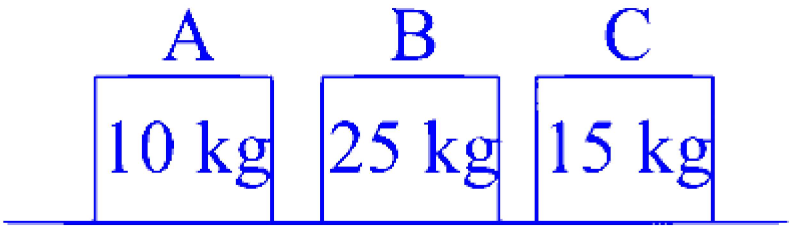
$= \frac{2 \times 1 + 1 \times \frac{1}{2}}{2+1} = \frac{5}{6} \text{ m}$

$\therefore$ Centre of mass

$= (X_{\text{CM}}, Y_{\text{CM}}) = \left(\frac{5}{6} \text{ m}, \frac{5}{6} \text{ m}\right)$

Question6

Three blocks A, B and C are arranged as shown in the figure such that the distance between two successive blocks is 10 m . Block A is displaced towards block B by 2 m and block C is displaced towards block B by 3 m . The distance through which the block B should be moved, so that the centre of mass of the system does not change is



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Options:

A.

1.4 m , towards block C

B.

1.5 m , towards block A

C.

2 m , towards block A

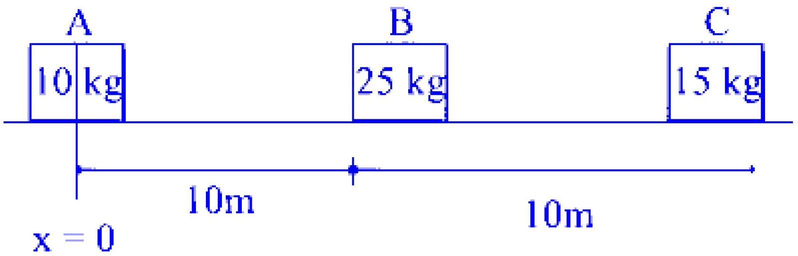
D.

1 m , towards block C

Answer: D

Solution:

First we calculate centre of mass of system let block A is at origin ($x=0$)



$$x_{CM} = \frac{10(0) + 25(10) + 15(20)}{10 + 25 + 15}$$

$$x_{CM} = \frac{550}{50} = 11 \text{ m}$$

Now, new position of block A with respect to origin is $x = 2$ m and new position of block $C, x = 20 - 3 = 17$ m.

Let new position of block B with respect to origin is Y, so that centre of mass remains at same position

$$\begin{aligned} Then, \; x_{\text{CM}} = 11 &= \frac{10(2) + 25(y) + 15(17)}{50} \\ 550 &= 20 + 25y + 255 \\ 25y &= 550 - 275 = 275 \\ y &= \frac{275}{25} = 11 \text{ m} \end{aligned}$$

So, block B should move $11 - 10 = 1$ metre towards block C.

Question7

Two balls each of mass 250 g moving in opposite directions each with a speed 16 ms^{-1} collide and rebound with the same speeds. The impulse imparted to one ball due to the other is

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Options:

A.

4 kg ms^{-1}

B.

16 kg ms^{-1}

C.

8 kg ms^{-1}

D.

2 kg ms^{-1}

Answer: C

Solution:

Impulse on ball = Change in momentum

$$\begin{aligned} &= m(v-u) \\ &= 0.25[16-(-16)] \\ &= 8 \text{ kg m/s} \end{aligned}$$

Question8

A block of mass 10 kg moving with a speed of $5\hat{\mathrm{i}} \mathrm{ms}^{-1}$ on a frictionless horizontal surface suddenly explodes into two pieces. If one piece with mass 4 kg moves with a speed of $10\hat{\mathbf{i}} \text{ ms}^{-1}$, then the velocity of the second piece is

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Options:

A.

7.67 ms^{-1}

B.

1.67 ms^{-1}

C.

6.67 s ms^{-1}

D.

2.67 ms^{-1}

Answer: B

Solution:

According to conservation of momentum.

$$mu = m_1v_1 + m_2v_2$$
$$10 \times 5\hat{\mathbf{i}} = 4 \times 10\hat{\mathbf{i}} + 6 \times v_2$$
$$\Rightarrow \quad v_2 = \frac{5}{3}\hat{\mathbf{i}} = 1.67\hat{\mathbf{i}} \text{ ms}^{-1}$$

Question9

A steel sphere of radius 1.2 cm collides a second steel sphere at rest. If the collision is elastic and after the collision the first sphere continues to move in its initial direction with a velocity of $\frac{7}{9}$ times its initial velocity, then the radius of the second sphere is

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Options:

A.

1.8 cm

B.

2.4 cm

C.

1.2 cm

D.

0.6 cm

Answer: D

Solution:

Given:

The final velocity of the first sphere, $v_1 = \frac{7}{9}u_1$

$u_2 = 0$ (the second sphere is at rest)

The mass of a sphere is proportional to the cube of its radius: $m \propto R^3$

Let m_1 and m_2 be the masses, and R_1 and R_2 be the radii of the first and second spheres.

Step 1: Use the formula for an elastic collision

After the collision, the velocity of the first sphere is:

$v_1 = \frac{(m_1 - m_2)u_1 + 2m_2u_2}{m_1 + m_2}$

Step 2: Substitute $u_2 = 0$

$v_1 = \frac{(m_1 - m_2)u_1}{m_1 + m_2}$

We know $v_1 = \frac{7}{9}u_1$:

$\frac{7}{9}u_1 = \frac{(m_1 - m_2)u_1}{m_1 + m_2}$

Divide both sides by u_1 (since $u_1 \neq 0$):

$\frac{7}{9} = \frac{m_1 - m_2}{m_1 + m_2}$

Step 3: Solve for m_1 in terms of m_2

Multiply both sides by $(m_1 + m_2)$:

$7(m_1 + m_2) = 9(m_1 - m_2)$

$7m_1 + 7m_2 = 9m_1 - 9m_2$

$7m_2 + 9m_2 = 9m_1 - 7m_1$

$16m_2 = 2m_1$

$m_1 = 8m_2$

Step 4: Relate masses to radii

Since mass of a sphere, $m \propto R^3$:

$\frac{m_1}{m_2} = \left(\frac{R_1}{R_2}\right)^3$

$8 = \left(\frac{R_1}{R_2}\right)^3$

Step 5: Solve for R_2

Take the cube root of both sides:

$\frac{R_1}{R_2} = 2$

$R_1 = 2R_2$

$R_2 = \frac{R_1}{2}$

Plug in $R_1 = 1.2$ cm:

$R_2 = \frac{1.2}{2} = 0.6$ cm

Question10

If two bodies of masses 2 kg and 3 kg are moving at right angles with velocities 20 ms^{-1} and 10 ms^{-1} respectively, then the velocity of the centre of mass of the system of the two bodies is

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Options:

A.

5 ms^{-1}

B.

30 ms^{-1}

C.

10 ms^{-1}

D.

14 ms^{-1}

Answer: C

Solution:

$$\begin{aligned} v_{\text{CM}} &= \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \\ &= \frac{2 \times 20\hat{\mathbf{i}} + 3 \times 10\hat{\mathbf{j}}}{2+3} = \frac{40\hat{\mathbf{i}} + 30\hat{\mathbf{j}}}{5} \\ v_{\text{CM}} &= 8\hat{\mathbf{i}} + 6\hat{\mathbf{j}} \\ \therefore |v_{\text{CM}}| &= \sqrt{8^2 + 6^2} = \sqrt{100} = 10 \text{ m/s} \end{aligned}$$

Question11

A particle of mass 8μ g in motion collides with another stationary particle of mass 4μ g. If the collision is perfectly elastic and one dimensional, the ratio of their de-Broglie wavelengths after collision is

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Options:

A.

4 : 1

B.

3 : 1

C.

1 : 1

D.

2 : 1

Answer: D

Solution:

Step 1: Find the final velocities after the collision

The first particle has mass 8 μg and moves with speed u_1. The second particle has mass 4 μg and is at rest, so $u_2 = 0$.

The formula for the final speed of the first particle after an elastic, one-dimensional collision is: $v_1 = \frac{(m_1-m_2)u_1+2m_2u_2}{m_1+m_2}$ Plug in the numbers:

$$v_1 = \frac{(8-4)u_1+2\times4\times0}{8+4} = \frac{4u_1}{12} = \frac{u_1}{3}$$

The formula for the final speed of the second particle is: $v_2 = \frac{2m_1u_1+(m_2-m_1)u_2}{m_1+m_2}$ Plug in the numbers:

$$v_2 = \frac{2\times8u_1+(4-8)\times0}{8+4} = \frac{16u_1}{12} = \frac{4}{3}u_1$$

Step 2: Find the de-Broglie wavelength for each particle

The de-Broglie wavelength formula is: $\lambda = \frac{h}{mv}$ where h is Planck's constant, m is mass, and v is velocity.

To compare their wavelengths, find the ratio: $\frac{\lambda_2}{\lambda_1} = \frac{m_1 v_1}{m_2 v_2}$

Plug in the values found earlier: $\frac{\lambda_2}{\lambda_1} = \frac{8\times\frac{u_1}{3}}{4\times\frac{4}{3}u_1}$

Simplify the expression: $= \frac{8\times\frac{u_1}{3}}{4\times\frac{4u_1}{3}} = \frac{8u_1/3}{16u_1/3} = \frac{8u_1}{16u_1} = \frac{1}{2}$

So, $\frac{\lambda_1}{\lambda_2} = 2$ which means the ratio of their wavelengths after the collision is $2:1$.

Question12

A soccer ball of mass 250 g is moving horizontally to the left with a speed $22\ \mathrm{ms}^{-1}$. This ball is kicked towards right with a velocity $30\ \mathrm{ms}^{-1}$ at an angle 53° with the horizontal in upward direction. Assuming that it took 0.01 s for the collision to take place, the average force acting is $\left(\cos 53^\circ = \frac{3}{5}, \sin 53^\circ = \frac{4}{5}\right)$

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Options:

A. 1000 N

B. 986 N

C. 1166 N

D. 2000 N

Answer: C

Solution:

The mass of the soccer ball is given as:

$m = 250\ \mathrm{g} = 0.25\ \mathrm{kg}$

Initially, the ball is moving horizontally to the left with a speed of:

$22\ \mathrm{m/s}$

After being kicked, the ball is moving to the right with a velocity of:

$30\ \mathrm{m/s}$

at an angle of 53° with the horizontal, in the upward direction. The collision lasts for:

$t = 0.01\,\text{s}$

To solve for the average force, we need to find the horizontal and vertical components of the final velocity:

$v_{f_x} = 30 \times \frac{3}{5} = 18\,\text{m/s}$

$v_{f_y} = 30 \times \frac{4}{5} = 24\,\text{m/s}$

The change in momentum (Δp) is calculated as:

For the horizontal component:

$\Delta p_x = m(v_{f_x} - v_i) = 0.25[18 - (-22)]$

$\Delta p_x = 0.25 \times 40 = 10\,\text{kg m/s}$

For the vertical component:

$\Delta p_y = m(v_{f_y} - 0) = 0.25 \times 24$

$\Delta p_y = 6\,\text{kg m/s}$

The total change in momentum is:

$\Delta p = \sqrt{\Delta p_x^2 + \Delta p_y^2} = \sqrt{(10)^2 + (6)^2}$

$\Delta p = \sqrt{136}\,\text{kg m/s}$

Finally, the average force acting on the ball is:

$F_{\text{avg}} = \frac{\Delta p}{\Delta t} = \frac{\sqrt{136}}{0.01}$

$F_{\text{avg}} = 1166\,\text{N}$

Question13

A body of mass 30 kg moving with a velocity $20\ \text{ms}^{-1}$ undergoes one-dimensional elastic collision with another ball of same mass moving in the opposite direction with a velocity of $30\ \text{ms}^{-1}$. After collision the velocity of first and second bodies respectively are

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Options:

A. $25 \mathrm{~ms}^{-1}, 30 \mathrm{~ms}^{-1}$

B. $30 \mathrm{~ms}^{-1}, 30 \mathrm{~ms}^{-1}$

C. $30 \mathrm{~ms}^{-1}, 20 \mathrm{~ms}^{-1}$

D. $40 \mathrm{~ms}^{-1}, 15 \mathrm{~ms}^{-1}$

Answer: C

Solution:

Given:

Mass of first body, $m_1 = 30 \mathrm{~kg}$

Initial velocity of the first body, $u_1 = 20 \mathrm{~m/s}$

Mass of the second body, $m_2 = 30 \mathrm{~kg}$

Initial velocity of the second body, $u_2 = -30 \mathrm{~m/s}$ (since it is moving in the opposite direction)

Since the collision is elastic, and the masses are equal, the principle of conservation of momentum and kinetic energy indicates that the velocities after the collision will be exchanged. Therefore:

Final velocity of the first body, $v_1 = u_2 = -30 \mathrm{~m/s}$

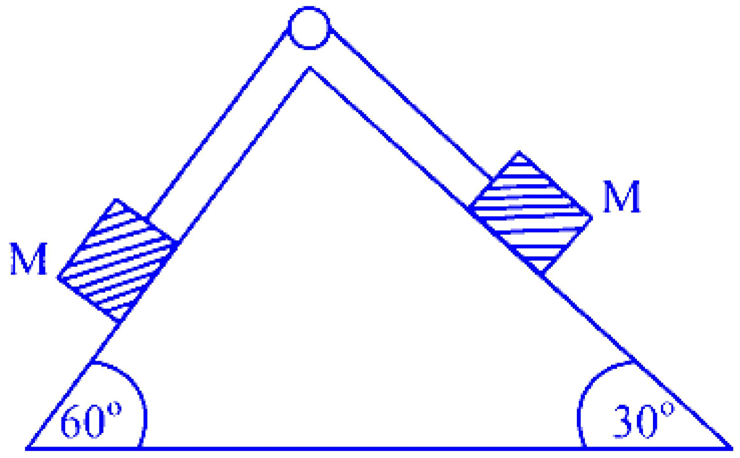
The negative sign indicates that the first body moves in the opposite direction compared to its initial direction.

Final velocity of the second body, $v_2 = u_1 = 20 \mathrm{~m/s}$

Similarly, this means the second body also moves in the opposite direction to its initial motion.

Question14

Two blocks of equal masses are tied with a light string passing over a massless pulley (assuming frictionless surfaces) acceleration of centre of mass of the two blocks is $\left(g = 10 \mathrm{~ms}^{-2}\right)$



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Options:

A. $\frac{5(\sqrt{3}-1)}{2}$

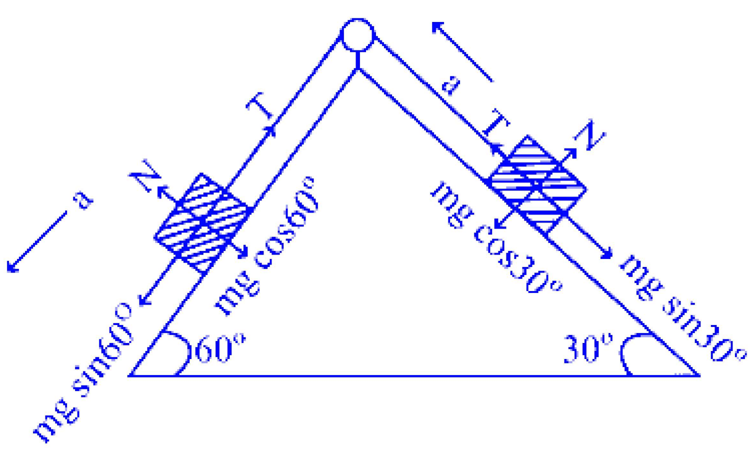
B. $\frac{5(\sqrt{3}-1)}{2\sqrt{2}}$

C. $\frac{5(\sqrt{3}+1)}{2\sqrt{2}}$

D. $\frac{5(\sqrt{3}-1)}{\sqrt{2}}$

Answer: B

Solution:



From the figure,

$mg\sin 60^\circ - T = ma$ ...(i)

$T - mg\sin 30^\circ = ma$ ...(ii)

Adding both Eq. (i) and Eq. (ii), we get

$mg(\sin 60^\circ - \sin 30^\circ) = 2ma$

$$a = \frac{g}{2}\left(\frac{\sqrt{3}}{2} - \frac{1}{2}\right)$$

$$a = \frac{g}{4}(\sqrt{3} - 1) \quad \ldots(iii)$$

Given, $m_1 = m_2 = m$ ...(iv)

$$\mathbf{a}_1 = -a\cos 60^\circ \hat{\mathbf{i}} - a\sin 60\hat{\mathbf{j}} = \frac{a}{2}(-\hat{\mathbf{i}} - \sqrt{3\mathbf{j}})$$

$$\mathbf{a}_2 = -a\cos 30^\circ \hat{\mathbf{i}} + a\sin 30\hat{\mathbf{j}}$$

$$= \frac{a}{2}(-\sqrt{3\hat{\mathbf{i}}} + 1\hat{\mathbf{j}})$$

Acceleration of the centre of mass

$$\mathbf{a}_{\text{com}} = \frac{m_1\mathbf{a}_1 + m_2\mathbf{a}_2}{m_1 + m_2}$$

From Eq. (iv), $\mathbf{a}_{\text{com}} = \frac{\mathbf{a}_1 + \mathbf{a}_2}{2}$

$$\mathbf{a}_{\text{com}} = \frac{\frac{a}{2}(-\hat{\mathbf{i}} - 3\sqrt{3\hat{\mathbf{j}}}) + \frac{a}{2}(-\sqrt{3\hat{\mathbf{i}}} + \hat{\mathbf{j}})}{2}$$

$$|\mathbf{a}_{\text{com}}| = \left| \frac{a}{4}[(-1 - \sqrt{3})\hat{\mathbf{i}} + (1 - \sqrt{3\hat{\mathbf{j}}})] \right|$$

$$\left[\because |a\hat{\mathbf{i}} + b\hat{\mathbf{j}}| = \sqrt{a^2 + b^2}\right]$$

$$|\mathbf{a}_{\text{com}}| = \frac{a}{4}\left[\sqrt{(-1 - \sqrt{3})^2 + (1 - \sqrt{3})^2}\right]$$

$$= \frac{a}{4}[\sqrt{1 + 3 + 2\sqrt{3} + 1 + 3 - 2\sqrt{3}}]$$

$$= \frac{a}{4}2\sqrt{2}$$

Putting value of a from Eq. (iii),

$$= \frac{g}{4 \cdot 4} \cdot 2\sqrt{2}(\sqrt{3} - 1)$$

$$= \frac{10 \times 2\sqrt{2} \times (\sqrt{3} - 1)}{4 \times \sqrt{2} \times 2\sqrt{2}}$$

$$= \frac{10}{4\sqrt{2}}(\sqrt{3} - 1)$$

$$|a_{\text{com}}| = \frac{5(\sqrt{3} - 1)}{2\sqrt{2}} \text{ m/s}^2$$

Question15

A ball falls freely from rest from a height of 6.25 m on a hard horizontal surface. If the ball reaches a heightd 81 cm after second bounce from the surface, the coefficient of restitution is

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Options:

A. 0.3

B. 0.45

C. 0.75

D. 0.6

Answer: D

Solution:

Given:

Initial height, $h_i = 6.25\,\text{m}$

Height after second bounce, $h_2 = 81\text{ cm} = 0.81\,\text{m}$

The formula for the coefficient of restitution e is:

$e = \sqrt{\frac{h_{\text{after}}}{h_{\text{before}}}}$

Let h_1 be the height reached after the first bounce. According to the formula, we have:

$h_1 = e^2 \cdot h_i$

After the second bounce, the height h_2 is given by:

$h_2 = e^2 \cdot h_1$

Substituting the expression for h_1, we get:

$h_2 = e^2 \cdot (e^2 \cdot h_i) = e^4 \cdot h_i$

Rearranging the equation, we find:

$e^4 = \frac{h_2}{h_i}$

Substituting the given values:

$e^4 = \frac{0.81}{6.25}$

Simplifying further:

$e^4 = \frac{81}{625}$

Taking the fourth root, we calculate e:

$e = \frac{3}{5} \Rightarrow e = 0.6$

Question16

A body of mass 2 kg collides head on with another body of mass 4 kg . If the relative velocities of the bodies before and after collision are $10 \mathrm{~ms}^{-1}$ and $4 \mathrm{~ms}^{-1}$ respectively. The loss of kinetic energy of the system due to the collision is

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Options:

A. 28 J

B. 56 J

C. 84 J

D. 42 J

Answer: B

Solution:

Given:

Mass of the first body, $m_1 = 2 \mathrm{~kg}$

Mass of the second body, $m_2 = 4 \mathrm{~kg}$

Initial relative velocity, $u_{\text{rel}} = 10 \mathrm{~ms}^{-1}$

Final relative velocity, $v_{\text{rel}} = 4 \mathrm{~ms}^{-1}$

First, calculate the coefficient of restitution (e):

$e = \frac{v_{\text{rel}}}{u_{\text{rel}}} = \frac{4}{10} = \frac{2}{5}$

The loss of kinetic energy ($\Delta \mathrm{KE}$) in the system due to the collision is given by:

$\Delta \mathrm{KE} = \frac{1}{2} \cdot \frac{m_1 m_2}{m_1 + m_2} \cdot \left(1 - e^2\right) \cdot \left(u_{\text{rel}}\right)^2$

Substituting the given values:

$\Delta KE = \frac{1}{2} \cdot \frac{2\times4}{(2+4)} \cdot \left[1 - \left(\frac{2}{5}\right)^2\right] \cdot (10^2)$

$= \frac{4}{6} \cdot \left(1 - \frac{4}{25}\right) \cdot 100$

$= \frac{4}{6} \cdot \frac{21}{25} \cdot 100$

$= \frac{336}{6} = 56\,\text{J}$

Thus, the loss of kinetic energy of the system due to the collision is 56 J.

Question17

A wooden plank of mass 90 kg and length 3.3 m is floating on still water. A girl of mass 20 kg walks from one end to the other end of the plank. The distance through which the plank moves is

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Options:

A. 30 cm

B. 40 cm

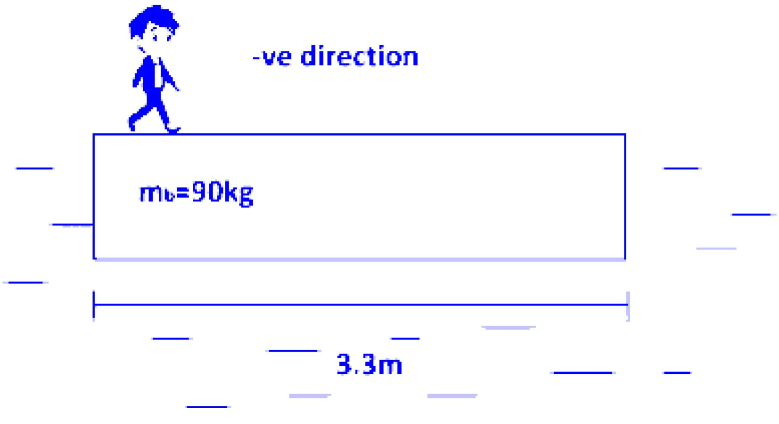
C. 80 cm

D. 60 cm

Answer: D

Solution:

$m_q = 20$ kg



In the above problem, centre of mass of the system (plank + girl) remains at rest as no external force acts on the system. We have,

$\Delta X_{\mathrm{cm}}=\frac{m_g \Delta X_1+m_b \Delta X_2}{m_g+m_b}$

Since, $\Delta X_{\mathrm{cm}}=0$ (COM remains at rest, i.e., $v_{\mathrm{cm}}=0$)

Let the forward direction of movement of girl is negative and the direction of opposite to it is positive.

Suppose the plank moves n cm, when girl walks from one end to the other end of the plank, then,

$$
\begin{aligned}
& m_g[-(3.3-x)]+m_b x=0 \\
& m_b x=m_g(3.3-x) \\
& 90 x=20 \times 3.3-20 x \\
& 110 x=20 \times 3.3 \\
& x=\frac{20 \times 3.3}{110}=0.6 \mathrm{~m} \\
& x=60 \mathrm{~cm}
\end{aligned}
$$

Question18

A ball falls freely from rest on to a hard horizontal floor and repeatedly bounces. If the velocity of the ball just before the first bounce is $7 \mathrm{~ms}^{-1}$ and the coefficient of restitution is 0.75 , the total distance travelled by the ball before it comes to rest is (acceleration due to gravity $=10 \mathrm{~ms}^{-2}$)

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Options:

A. 10.75 m

B. 9.75 m

C. 8.75 m

D. 11.75 m

Answer: C

Solution:

To find the total distance a ball travels before coming to rest after repeatedly bouncing, we use the following approach:

Initial setup: The ball falls freely from rest, with a velocity just before the first bounce of $7\,\text{ms}^{-1}$, and the coefficient of restitution $e = 0.75$. The acceleration due to gravity is $10\,\text{ms}^{-2}$.

Distance traveled: The ball falls a height h before the first bounce. After each bounce, it reaches successively lower heights $h_1, h_2, \ldots$, where:

$h_1 = e^2 h$

$h_2 = e^4 h$

And so on.

Total distance formula: The total distance d covered by the ball is:

$d = h + 2h_1 + 2h_2 + \ldots$

This can be rewritten using geometric series:

$d = h + 2e^2 h(1 + e^2 + e^4 + \ldots)$

Using the sum of an infinite geometric series $S = \frac{1}{1-e^2}$, we have:

$d = h + 2e^2 h\left(\frac{1}{1-e^2}\right)$

Simplifying, we get:

$d = h\left(\frac{1+e^2}{1-e^2}\right)$

Plugging in the values: Given $e = \frac{3}{4}$, the distance d becomes:

$d = h\left(\frac{1+\left(\frac{3}{4}\right)^2}{1-\left(\frac{3}{4}\right)^2}\right) = \frac{25}{7} \times h$

Calculating h:

Using the kinematic equation:

$v^2 = u^2 + 2gh \quad \Rightarrow \quad (7)^2 = 0 + 2 \times 10 \times h$

Solving for h, we find:

$\frac{49}{20} = h$

Finding total distance d:

Using the relation obtained:

$d = \frac{25}{7} \times \frac{49}{20} = 8.75\,\text{m}$

Therefore, the total distance traveled by the ball before it comes to rest is $8.75\,\text{m}$.

Question19

Two blocks of masses m and $2m$ are connected by a massless string which passes over a fixed frictionless pulley. If the system of blocks is released from rest, the speed of the centre of mass of the system of two blocks after a time of 5.4 s is (acceleration due to gravity $= 10 \mathrm{~ms}^{-2}$)

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Options:

A. $18 \mathrm{~ms}^{-1}$

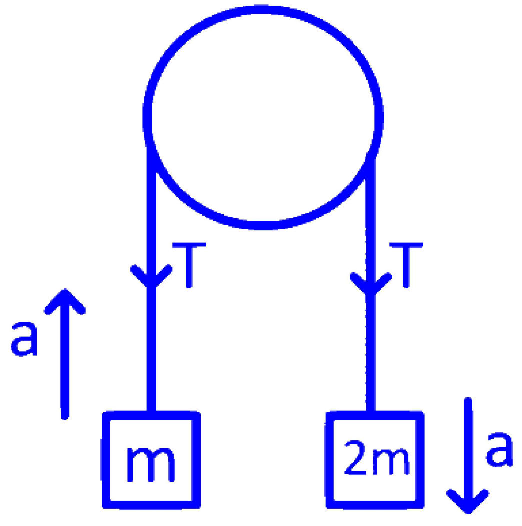
B. $8 \mathrm{~ms}^{-1}$

C. $4 \mathrm{~ms}^{-1}$

D. $12 \mathrm{~ms}^{-1}$

Answer: A

Solution:



For mass $2m$,

$2ma = 2mg - T \ldots (i)$

For mass m,

$ma = T - mg \ldots (ii)$

On solving Eqs. (i) and (ii), we get

$\therefore \quad a=\frac{g}{3}$

$\because \quad v=u+a t$

$\Rightarrow \quad v=0+\frac{g}{3} \times 5.4(\because u=0)$

$\Rightarrow \quad v=\frac{10}{3} \times 5.4=18 \mathrm{~m} / \mathrm{s}$

Question20

In an inclastic collision, after collision the kinetic energy

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Options:

A. increases by 2 times

B. is less than before collision

C. is more than before collision

D. remains same

Answer: B

Solution:

In an inelastic collision, although the momentum is conserved, kinetic energy is not. Some of the initial kinetic energy is converted into other forms of energy, such as heat, sound, or energy used in deforming the colliding bodies. This means that the kinetic energy after the collision is less than before the collision.

So, the correct answer is:

Option B: is less than before collision

To summarize:

In an inelastic collision, momentum is conserved.

Kinetic energy decreases because some energy is lost to other forms (like heat or sound).

Therefore, the kinetic energy after collision is less than the kinetic energy before the collision.

Question21

Ball A of mass 1 kg moving along a straight line with a velocity of $4 \mathrm{~ms}^{-1}$ hits another ball B of mass 3 kg which is at rest. After collision, they stick together and move with the same velocity along the same straight line. If the time of impact of the collision is 0.1 s then the force exerted on B is

AP EAPCET 2022 - 5th July Morning Shift

Options:

A. 30 N

B. 24 N

C. 36 N

D. 27 N

Answer: A

Solution:

For ball A,

$m_A = 1 \mathrm{~kg}, v_A = 4 \mathrm{~ms}^{-1}$
for ball $B, m_B = 3 \mathrm{~kg}, v_B = 0$

$\therefore$ Total momentum before collision,

$$\begin{aligned} p_i &= m_A v_A + m_B v_B \\ &= 1 \times 4 + 3 \times 0 = 4 \mathrm{~kg} - \mathrm{ms}^{-1} \end{aligned}$$

Since, after collision, both body stick together, therefore, it is the case of perfectly enelastic collision. Let v be the common velocity, then total momentum after collision,

$$\begin{aligned} p_f &= (m_A + m_B) v \\ &= (1+3) v = 4v \end{aligned}$$

According to law of conservation of linear momentum,

$$\begin{aligned} p_i &= p_f \\ \Rightarrow 4 &= 4v \Rightarrow v = 1 \mathrm{~ms}^{-1} \end{aligned}$$

Time of impact, $\Delta t = 0.1 \mathrm{~s}$

Force exerted on the body B,

$$F_B = \frac{\Delta p_B}{\Delta t} = \frac{m_B(v_B - u_B)}{\Delta t} = \frac{3(v-0)}{0.1}$$

$$\Rightarrow \quad F_B = \frac{3(1-0)}{0.1} = \frac{3}{0.1} = 30 \text{ N}$$

Question22

Two balls A and B, of masses M and $2M$ respectively collide each other. If the ball A moves with a speed of 150 ms^{-1} and collides with ball B, moving with speed v in the opposite direction. After collision if ball A comes to rest and the coefficient of restitution is 1 (one), then the speed of the ball B before it collides with ball A is

AP EAPCET 2022 - 4th July Evening Shift

Options:

A. 37.5 ms^{-1}

B. 12.5 ms^{-1}

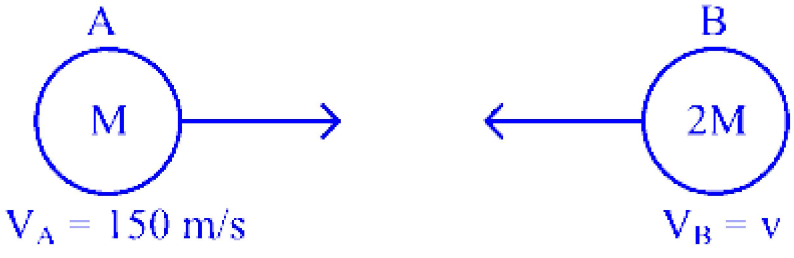
C. 75 ms^{-1}

D. 25 ms^{-1}

Answer: A

Solution:

According to first situation



Total momentum before collision,

$$p_i = mv_A + 2mv_B$$
$$= m \times 150 + 2m \times v = 150m + 2mv$$

Since, coefficient of restitution, $e=1$

Hence, after collision, body A transfer its complete velocity to body B. hence, after collision velocity of body $B, v'=150-v$.

Total momentum after collision,

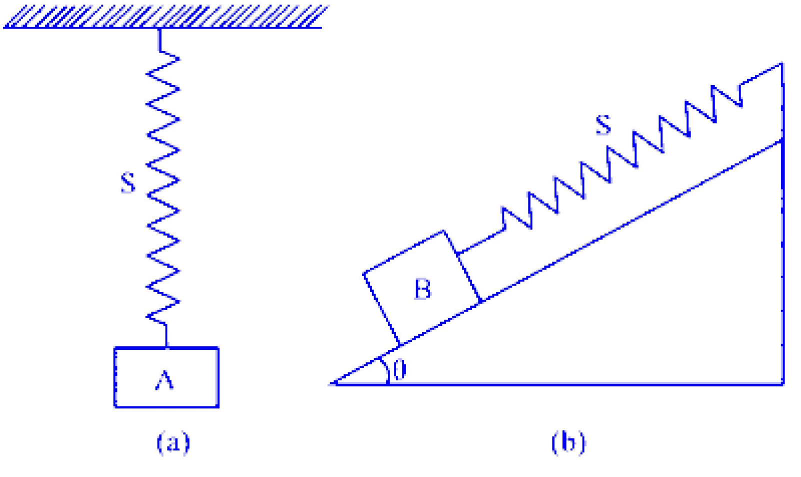
$$\begin{aligned} p_f & =2 m v'+m \times 0 \\ & =2 m v' \\ & =2 m(150-v) \end{aligned}$$

According to law of conservation of momentum,

$$\begin{aligned} p_i & =p_f \\ 150 m+2 m v & =2 m(150-v) \\ 150+2 v & =300-2 v \Rightarrow 4 v=150 \\ \Rightarrow \quad v & =37.5 \mathrm{~m} / \mathrm{s} \end{aligned}$$

Question23

As shown in the figure, an iron block A of volume $0.25 \mathrm{~m}^3$ is attached to a spring S of unstretched length 1.0 m and hanging to the ceiling of a roof. The spring gets stretched by 0.2 m . This block is removed and another block B of iron of volume $0.75 \mathrm{~m}^3$ is now attached to the same spring and kept on a frictionless incline plane of 30° inclination. The distance of the block from the top along the incline at equilibrium is



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Options:

A. 1.1 m

B. 1.3 m

C. 1.6 m

D. 1.9 m

Answer: B

Solution:

Given, volume of block $A = 0.25\ \text{m}^3$

Let the density of iron be $\rho \text{kg/m}^3$.

Thus, mass of iron block, $A = 0.25\rho$ kg

When block A is attached to the spring elongation produced $(x) = 0.2$ m.

Thus, force on spring of spring constant k is

$F = -kx$

($-$ve sign denotes force is in opposite direction of elongation)

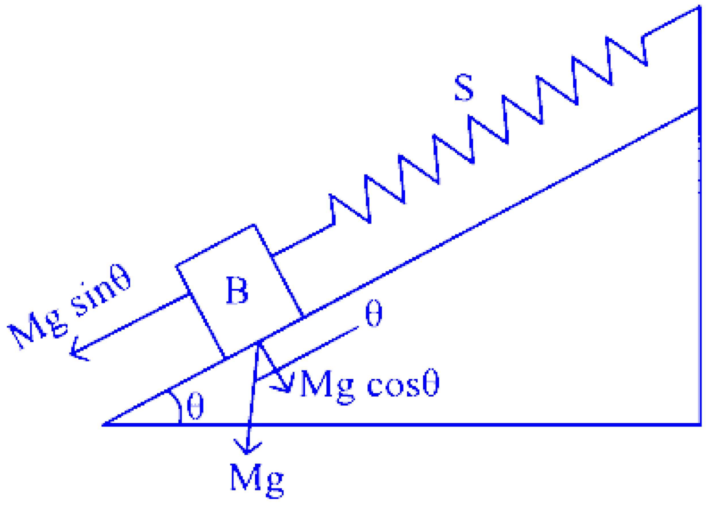
$$mg = -k(0.2)$$
$$0.25\rho g = -0.2k \Rightarrow k = 1.25\rho g\ \text{N/m}$$

Now, the same spring is attached to another block B.

Volume of block $B = 0.75\ \text{m}^3$

Mass of block $B = 0.75\rho$ kg

FBD of the spring system on inclined surface is given as



Force on block $B, F = -(kx)$
$Mg\sin\theta = -kx$
$0.75\rho g\sin 30^\circ = -(-1.25\rho g)x$
$\frac{0.75}{1.25}\sin 30^\circ = x \Rightarrow \frac{0.75}{1.25} \times \frac{1}{2} = x$
$\Rightarrow \quad x = 0.3 \text{ m}$

Thus, the distance of block from the top = original length of spring + elongation = 1 m + 0.3 m = 1.3 m

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Question24

A ball of mass 0.5 kg moving horizontally at 10 ms^{-1} strikes a vertical wall and rebounds with speed v. The magnitude of the change in linear momentum is found to be $8.0 \text{ kg} - \text{ ms}^{-1}$. The magnitude of v is

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Options:

A. 6.0 ms^{-1}

B. 9.0 ms^{-1}

C. 26.0 ms^{-1}

D. 13.0 ms^{-1}

Answer: A

Solution:

Given, mass of ball $m = 0.5 \text{ kg}$

Initial velocity, $u = 10 \text{ ms}^{-1}$

Change in momentum, $\Delta p = 8 \text{ kg} - \text{ms}^{-1}$

According to given situation change in momentum of ball

$$\Delta p = p_f - p_i$$
$$\Rightarrow \quad 8 = mv - m(-u)$$
$$\Rightarrow \quad 8 = m(v + u)$$
$$\Rightarrow \quad 8 = 0.5(v + 10)$$
$$\Rightarrow \quad 16 = v + 10$$
$$\Rightarrow \quad v = 6 \text{ ms}^{-1}$$

Question25

Masses $m\left(\frac{1}{3}\right)^N \frac{1}{N}$ are placed at $x = N$, when $N = 2, 3, 4 \ldots \infty$. If the total mass of the system is M, then the centre of mass is

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Options:

A. $\frac{1}{6} \frac{m}{M}$

B. $\frac{1}{5} \frac{m}{M}$

C. $\frac{1}{3} \frac{m}{M}$

D. $\frac{1}{2} \frac{m}{M}$

Answer: A

Solution:

distribution of masses is given as $m\left(\frac{1}{3}\right)^N \frac{1}{N}$

Which are placed at $x = N$

when, $N = 2, 3, 4 \ldots \ldots \ldots \infty$

Centre of mass of this discrete system is given as

$X = \frac{\Sigma m_i x_i}{\Sigma m_i}$

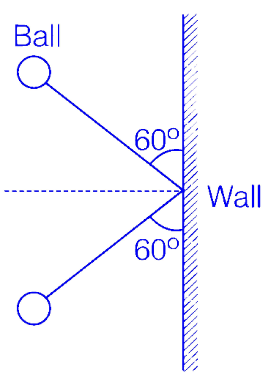
where, Σm_i is the total mass, which is given as M.

Thus,

$$X=\frac{\sum m_i x_i}{M}$$
$$=\frac{1}{M}\sum_{n=2}^{\infty} m\left(\frac{1}{3}\right)^N \frac{1}{N}\times N$$
$$=\frac{m}{M}\sum_{n=2}^{\infty}\left(\frac{1}{3}\right)^N$$
$$=\frac{m}{M}\left(\frac{1}{3^2}+\frac{1}{3^3}+\frac{1}{3^4}\cdots\cdots\frac{1}{3^\infty}\right)$$
$$=\frac{m}{M}\times\frac{1}{9}\left(1+\frac{1}{3}+\frac{1}{3^2}+\frac{1}{3^3}\cdots\cdots\right)$$
$$=\frac{m}{M}\times\frac{1}{9}\left(\frac{1}{1-\frac{1}{3}}\right)$$
$(\because S_n=\frac{a}{1-r}$ when $r<1$ in G.P series)
$$=\frac{m}{M}\times\frac{1}{9}\times\frac{3}{2}=\frac{m}{6M}$$

Question26

A ball of mass 3 kg, moving with a speed of100 ms^{-1}, strikes a wall at an angle 60°(as shown in figure). The ball rebounds atthe same speed and remains in contact withthe wall for 0.2 s, the force exerted by theball on the wall is



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Options:

A. $1500\sqrt{3}$ N

B. 1500 N

C. $300\sqrt{3}$ N

D. 300 N

Answer: A

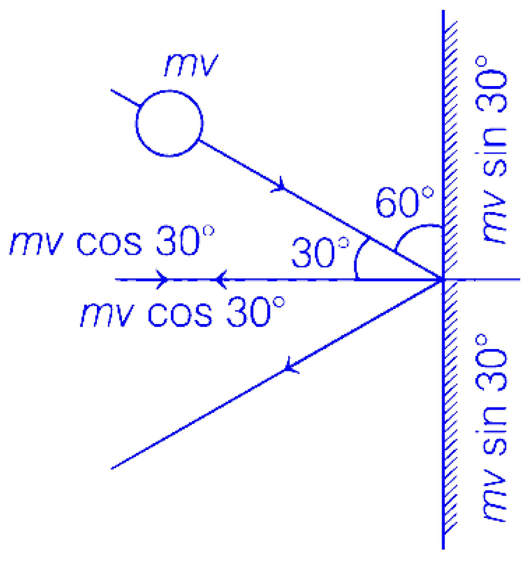
Solution:

According to given diagram,

Mass of ball, m = 3 kg

Speed of ball, v = 100 ms^{-1}

Time of contact, t = 0.2 s



As we know that,

$F = \frac{\Delta p}{\Delta t}$

where, F = force

Δp = change in momentum

Δt = change in time

$\therefore \quad F = \frac{2mv\cos 30^{\circ}}{0.2}$

$= \frac{2\times3\times100\times\frac{\sqrt{3}}{2}}{0.2} = 1500\sqrt{3}\,\mathrm{N}$

Question27

A metal ball of mass 2 kg moving with avelocity of 36 km/h has a head on collisionwith a stationary ball of mass 3 kg. After thecollision, if both balls move together, thenthe loss in kinetic energy due to collision is

Options:

A. 40 J

B. 60 J

C. 100 J

D. 140 J

Answer: B

Solution:

Given, mass of ball 1, $m_1 = 2$ kg,

Mass of ball 2, $m_2 = 3$ kg

$$u_1 = 36 \text{ km/h} = 36 \times \frac{5}{18} \text{ m/s} = 10 \text{ m/s}$$
$$u_2 = 0$$

After collision, the two balls will stick together and their combined velocity be v.

Now, by using law of conservation of momentum,

$$m_1 u_1 + m_2 u_2 = (m_1 + m_2) v$$
$$\Rightarrow \quad v = \frac{2 \times 10 + 3 \times 0}{5} = 4 \text{ ms}^{-1}$$

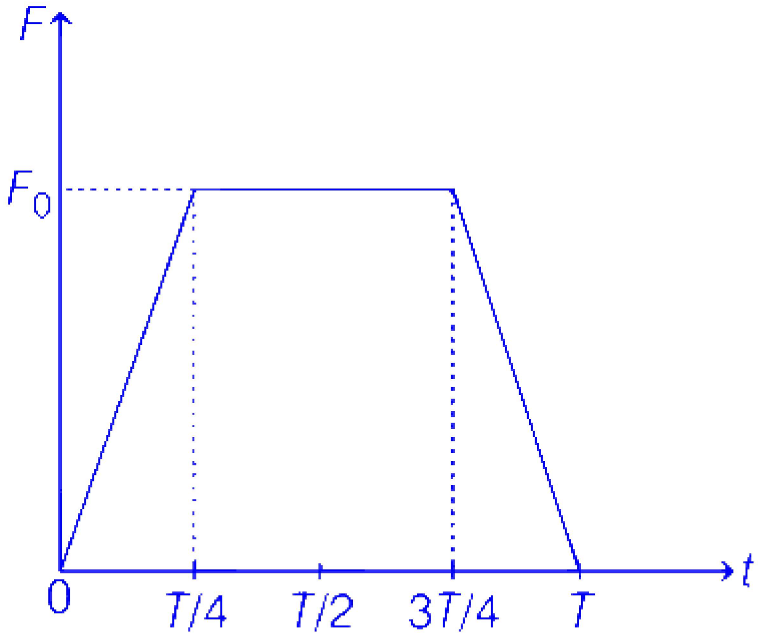
$\therefore$ Energy loss $=$ Energy before collision $(E_2)-$ Energy after collision (E_1)

$$= \left(\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2\right) - \frac{1}{2}(m_1 + m_2) v^2$$
$$= \left(\frac{1}{2} \times 2 \times 10^2 + \frac{1}{2} \times 3 \times 0^2\right) - \frac{1}{2}(2+3) 4^2$$
$$= \frac{1}{2} \times 2 \times 100 - \frac{1}{2} \times 5 \times 16$$
$$= 100 - 40 = 60 \text{ J}$$

Question28

A particle of mass m, moving with a velocityv makes an elastic collision in one dimensionwith a stationary particle of mass m. Duringthe collision, they remain in contact witheach other for an

extremely small time T.Their force of contact, with time is shown inthe figure. Then, F_0



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Options:

A. $\frac{2mv}{T}$

B. $\frac{4mv}{3T}$

C. $\frac{mv}{T}$

D. $\frac{3mv}{T}$

Answer: B

Solution:

According to graph

Since, $F =$ rate of change of momentum $= dp/dt$

$$\Rightarrow \int_{p_1}^{p_2} dp = \int_0^T F dt = \text{ Area under graph}$$
$$= \frac{1}{2} \times \frac{T}{4} \times F_0 + \frac{2T}{4} \times F_0 + \frac{1}{2} \times \frac{T}{4} \times F_0$$
$$= \frac{F_0 T}{8} + \frac{2F_0 T}{4} + \frac{F_0 T}{8} = \frac{6F_0 T}{8}$$
$$\Rightarrow p_2 - p_1 = \frac{3F_0 T}{4} \Rightarrow mv - 0 = \frac{3F_0 T}{4}$$
$$\Rightarrow F_0 = \frac{4mv}{3T}$$

Question29

The sum of moments of all the particles in asystem about its centre of mass is always

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Options:

A. minimum

B. zero

C. maximum

D. infinite

Answer: B

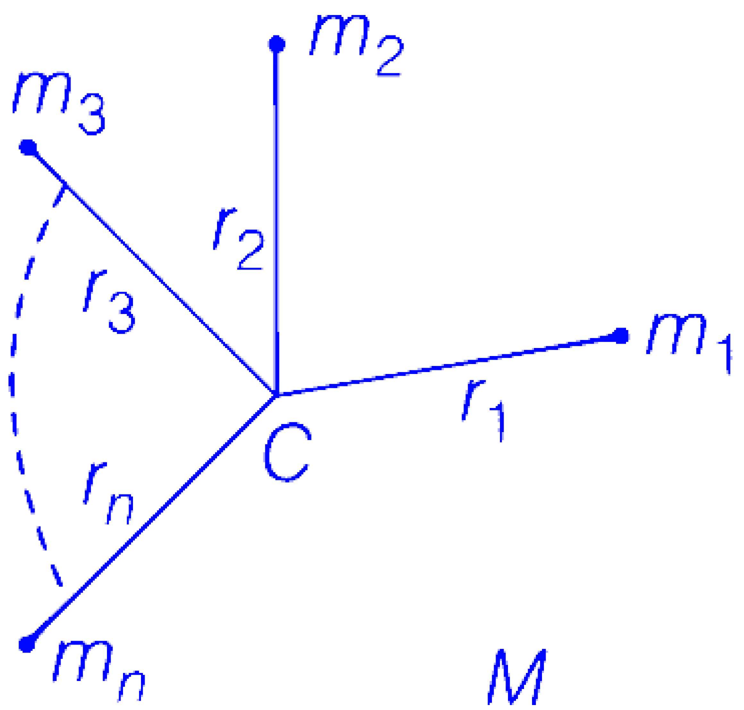
Solution:

We know that,

$\mathbf{r} = \frac{m_1\mathbf{r}_1 + m_2\mathbf{r}_2 + m_3\mathbf{r}_3 + \ldots + m_n\mathbf{r}_n}{M}$ ...... (i)

Let origin be the centre of mass of the body which is represented by C.

i.e. $r = 0$



Let origin be the centre of mass of the body which is represented by C.

i.e. $\mathbf{r}=0$

$\therefore$ From Eq. (i), we get

$m_1\mathbf{r}_1+m_2\mathbf{r}_2+m_3\mathbf{r}_3+\ldots m_n\mathbf{r}_n=0$ .... (ii)

Net moment of all particles in the system about centre of mass C.

$$\begin{aligned}\boldsymbol{\tau}_C &= m_1g\mathbf{r}_1+m_2g\mathbf{r}_2+m_3g\mathbf{r}_3+\ldots m_ng\mathbf{r}_n \\ &= g\left[m_1\mathbf{r}_1+m_2\mathbf{r}_2+m_3\mathbf{r}_3+\ldots+m_n\mathbf{r}_n\right] \\ &= g\times 0 \quad \text{[from Eq. (ii)]} \\ &= 0\end{aligned}$$

Hence, sum of moments of all the particles in a system about its centre of mass is always zero.
