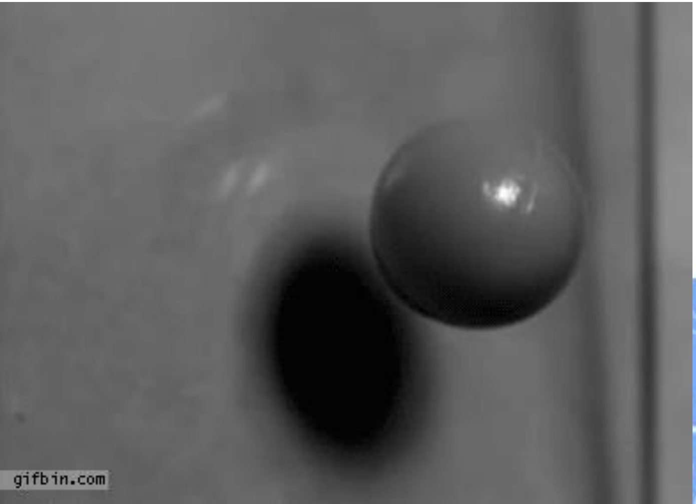
COM, MOMENTUM & COLLISION



Abhilash Sharma

B.Tech - NIT Calicut

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- 700+ selections in JEE Advanced
- 6000+ selections in JEE Mains

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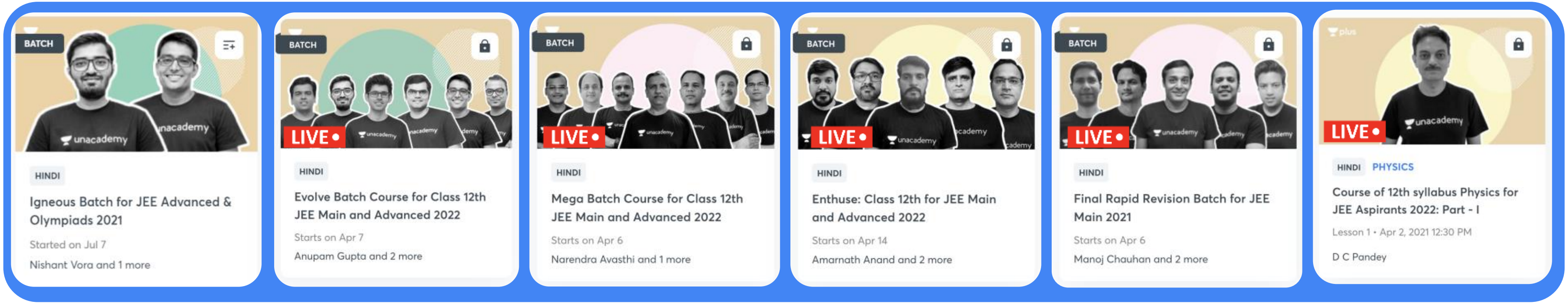

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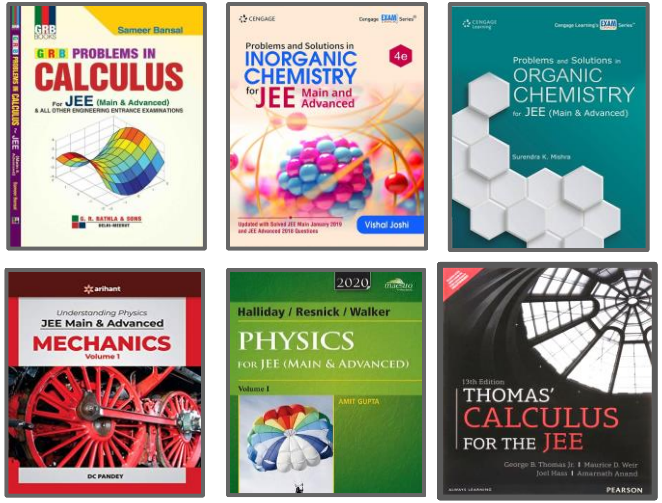

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for IIT JEE Main and Advanced 2024

Code: ABHILASH

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- Coverage of Class 11 JEE syllabus
- Enhance conceptual understanding of JEE Main & JEE Advanced subjects
- Systematically designed courses
- Strengthen JEE problem-solving ability

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Nishant Vora
Mathematics Maestro

Ajit Lulla
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Chemistry Maestro

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For more details, contact **8585858585**

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Mathematics Maestros

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Ajit Lulla
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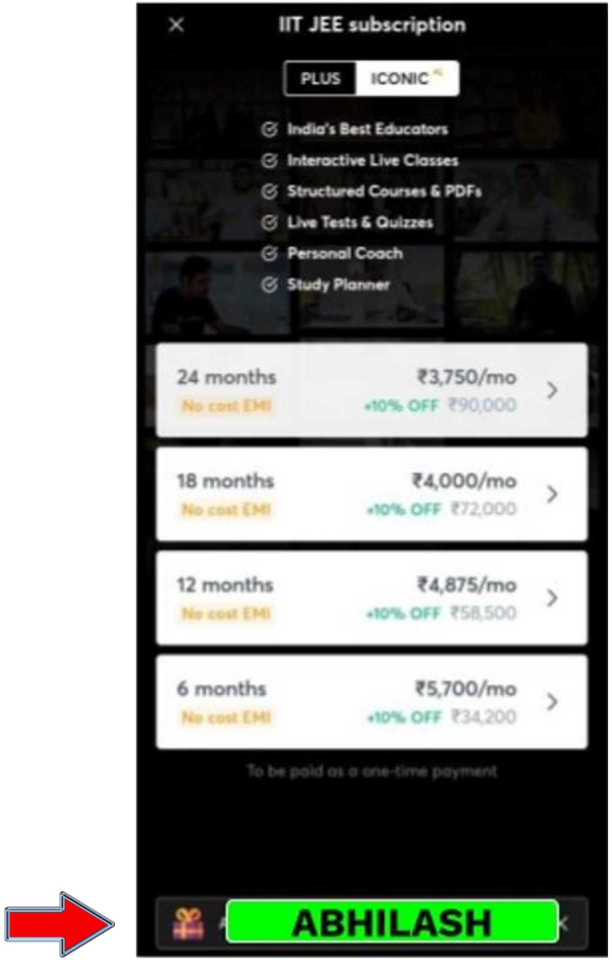
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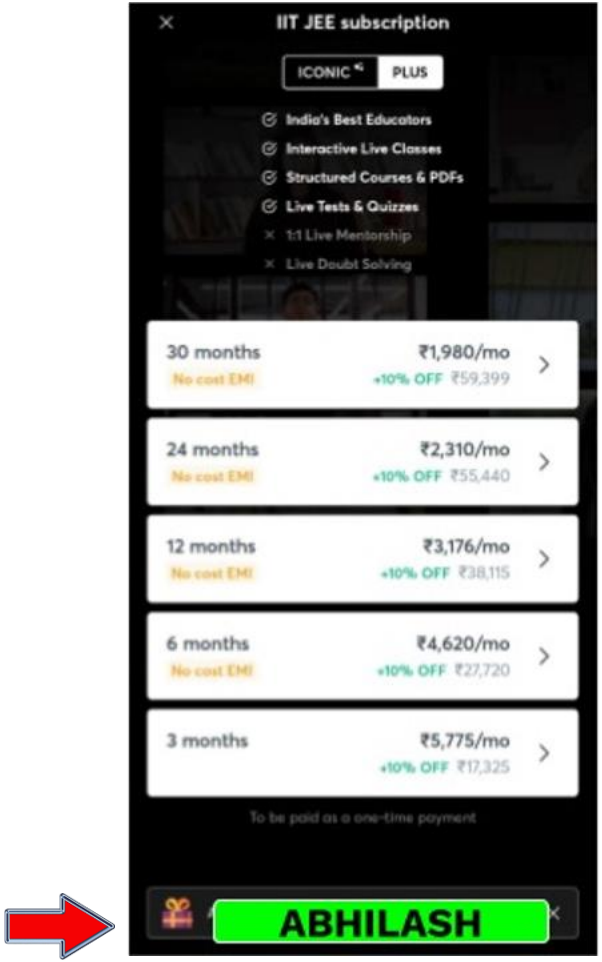
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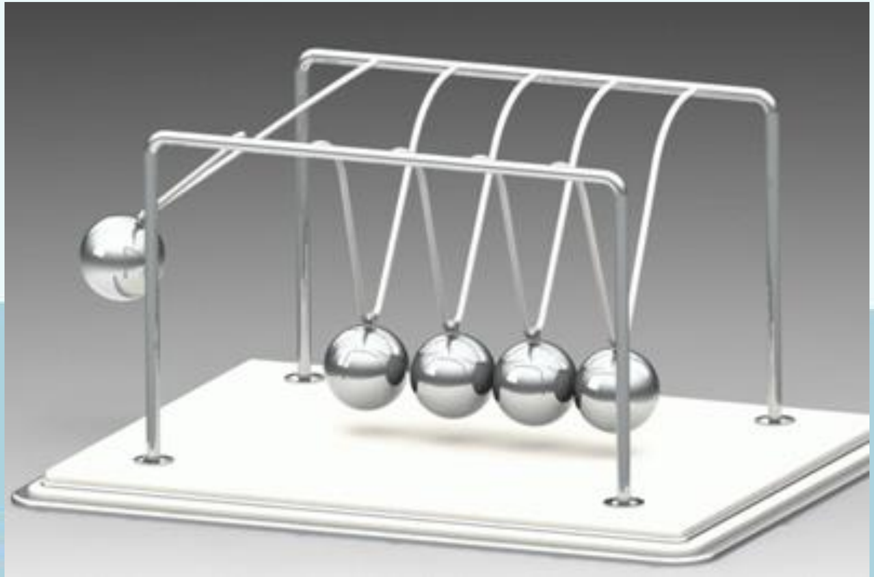
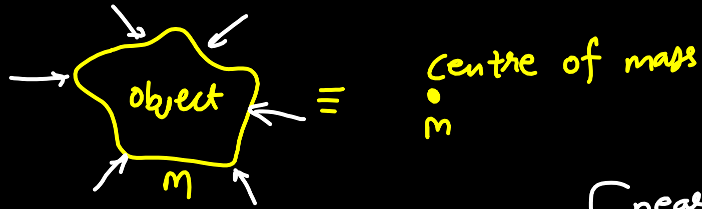
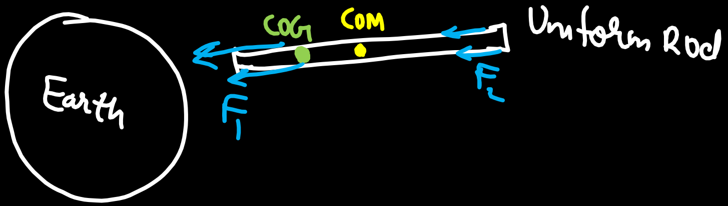


COM, Momentum & Collision

Centre of Mass



near earth surface COM is same as COG (Centre of Gravity)



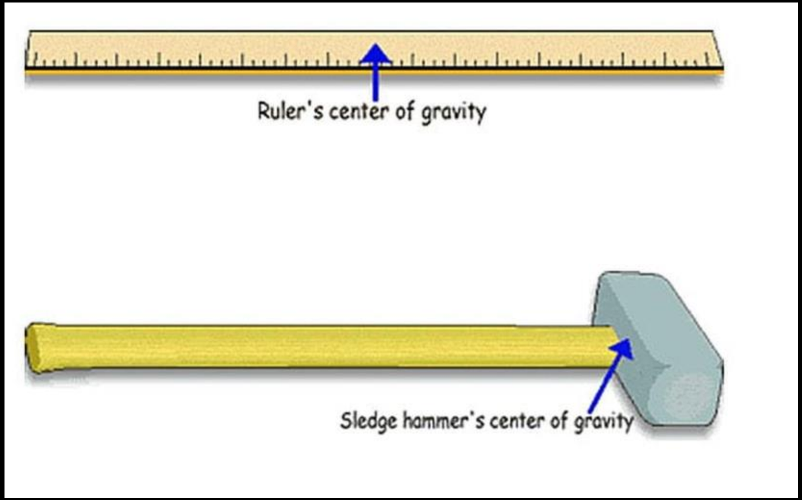
$F_1 > F_2$

Centre of Mass

1) COM
2) COG

} ⇒ Nearer to the heavier side

3) COB
4) COP



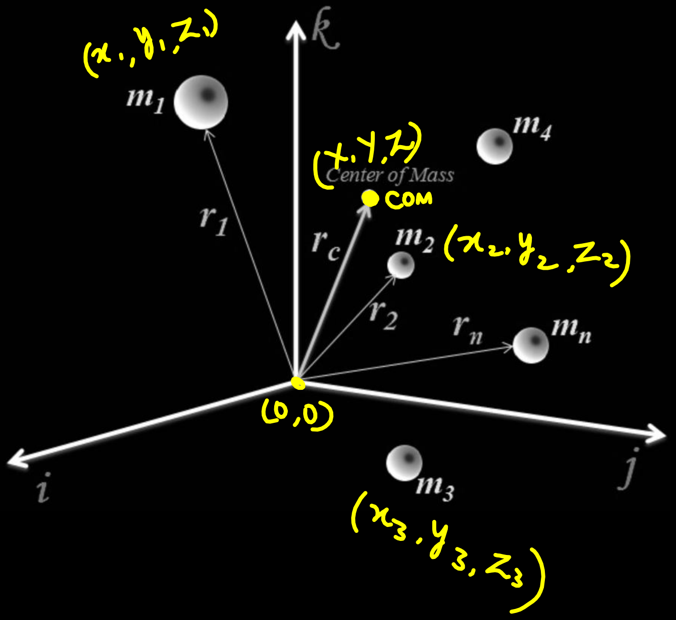
Centre of Mass

Discrete Mass System (Point masses)

$$X = \frac{m_1 x_1 + m_2 x_2 + \dots}{m_1 + m_2 + \dots}$$

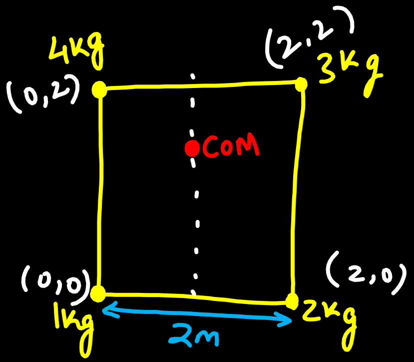
$$Y = \frac{m_1 y_1 + m_2 y_2 + \dots}{m_1 + m_2 + \dots}$$

$$Z = \frac{m_1 z_1 + m_2 z_2 + \dots}{m_1 + m_2 + \dots}$$



Centre of Mass

1) **Discrete Mass System**



$$X = \frac{1\times 0 + 2\times 2 + 3\times 2 + 4\times 0}{10}$$

$$\boxed{X = 1m}$$

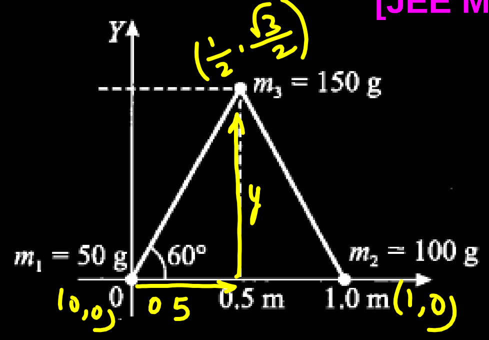
$$Y = \frac{1\times 0 + 2\times 0 + 3\times 2 + 4\times 2}{10}$$

$$\boxed{Y = 14m}$$

Q

Three particles of masses 50 g, 100 g and 150 g are placed at the vertices of an equilateral triangle of side 1 m (as shown in the figure). The (x, y) coordinates of the centre of mass will be

[JEE Main 2019]



(a) $\left(\frac{7}{12}\text{m}, \frac{\sqrt{3}}{8}\text{m}\right)$ (b) $\left(\frac{\sqrt{3}}{4}\text{m}, \frac{5}{12}\text{m}\right)$

(c) $\left(\frac{7}{12}\text{m}, \frac{\sqrt{3}}{4}\text{m}\right)$ (d) $\left(\frac{\sqrt{3}}{8}\text{m}, \frac{7}{12}\text{m}\right)$

+4

$$X = \frac{50\times0 + 100\times1 + 150\times\frac{1}{2}}{300}$$

$$X = \frac{175}{300} = \frac{35}{60} = \frac{7}{12}$$

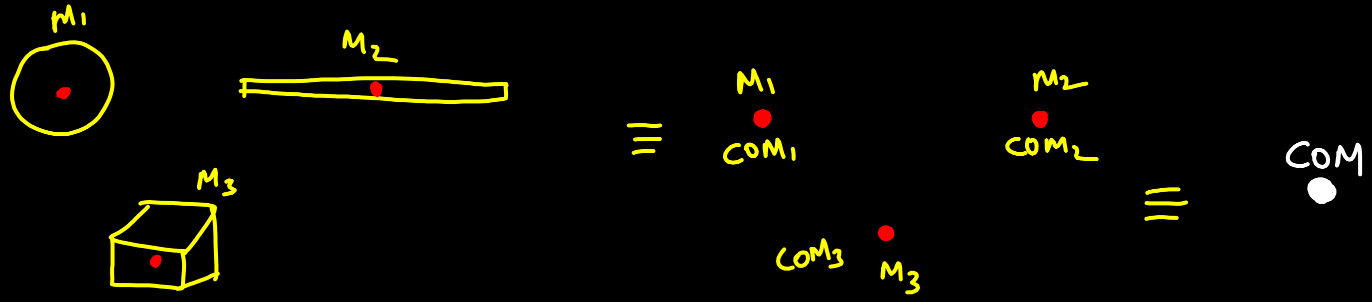
$$\tan 60° = \frac{y}{0.5}$$

$$y = \sqrt{3}/2 \text{ m}$$

$$Y = \frac{50\times0 + 100\times0 + 150\times\sqrt{3}/2}{300}$$

$$= \frac{150}{300}\frac{\sqrt{3}}{2} = \frac{\sqrt{3}}{4}\text{m}$$

3) System of objects



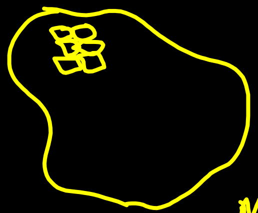
Centre of Mass

2) Continuous Body

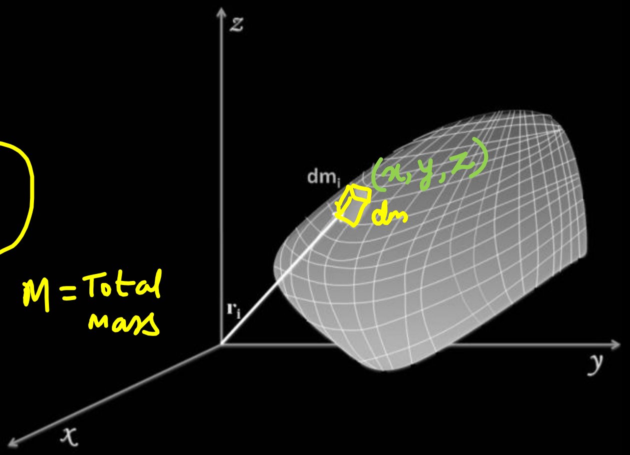
$$X = \frac{\int dm\, x}{\int dm} = \frac{1}{M}\int dm\, x$$

$$Y = \frac{1}{M}\int dm\, y$$

$$Z = \frac{1}{M}\int dm\, z$$



M = Total mass



Example

Rod Mass = M
Length = L

(x,0,0)

$$X = \frac{1}{M}\int dm\, x$$

$$= \frac{1}{M}\int \left(\frac{M}{L}dx\right) x$$

$$= \frac{1}{L}\int_0^L x\, dx$$

$$= \frac{1}{L}\left[\frac{x^2}{2}\right]_0^L = \frac{1}{L}\frac{L^2}{2}$$

$$\boxed{X = L/2}$$

Unitary Method

$L \rightarrow M$

$1 \rightarrow \frac{M}{L}$

$dm \Rightarrow \frac{M}{L} \times dx$

12 B ⇒ ₹36

1 B ⇒ ₹$\frac{36}{12}$ = ₹3

8B ⇒ ₹3 × 8 = ₹24

Q

A rod of length L has non-uniform linear mass density given by $\rho(x) = a + b\left(\frac{x}{L}\right)^2$, where a and b are constants and $0 \le x \le L$. The value of x for the centre of mass of the rod is at:

(a) $\frac{3}{2}\left(\frac{a+b}{2a+b}\right)L$

(b) $\frac{3}{4}\left(\frac{2a+b}{3a+b}\right)L$ ✓

(c) $\frac{4}{3}\left(\frac{a+b}{2a+3b}\right)L$

(d) $\frac{3}{2}\left(\frac{2a+b}{3a+b}\right)L$

[JEE Main 2019]

Mass per Unit length $= \rho(x) = a + b\frac{x^2}{L^2}$

$$dm = \rho\, dx$$

$$\int dm = \int \left(a + \frac{bx^2}{L^2}\right) dx$$

$$M = \int_0^L a\, dx + \frac{b}{L^2}\int_0^L x^2\, dx$$

$$M = aL + \frac{b}{L^2} \times \frac{L^3}{3} = aL + \frac{bL}{3}$$

$$\boxed{M = \left(a + \frac{b}{3}\right)L}$$

$$X = \frac{1}{M}\int dm \cdot x$$

$$X = \frac{1}{M}\int (\rho\, dx)\, x$$

$$= \frac{1}{M}\int \left(a + \frac{bx^2}{L^2}\right) x \, dx$$

$$= \frac{1}{M}\left[\int_0^L a\, x\, dx + \int_0^L \frac{b}{L^2} x^3\, dx\right]$$

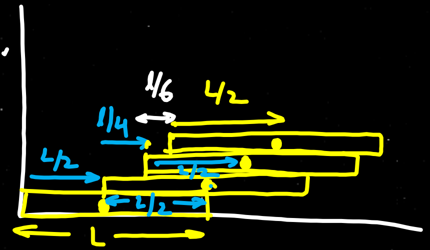
$$= \frac{1}{M}\left[\frac{aL^2}{2} + \frac{b}{L^2}\frac{L^4}{4}\right]$$

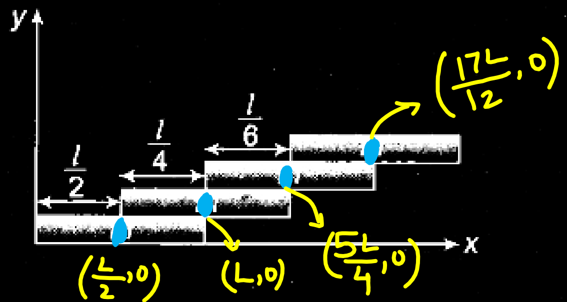
$$X = \frac{1}{\left(a + \frac{b}{3}\right)L}\left[\frac{aL^2}{2} + \frac{bL^2}{4}\right]$$

$$= \frac{(2a+b)L/4}{(3a+b)/3}$$

$$\boxed{X = \frac{3}{4}\frac{(2a+b)}{(3a+b)}L}$$

Find the x-coordinate of the centre of mass of the bricks shown in figure:





$\frac{L}{2}+\frac{L}{4}+\frac{L}{6}+\frac{L}{2}$

$L+\frac{(6+4)L}{24}$

$L+\frac{5}{12}L$

$\frac{17L}{12}$

(a) $\frac{24}{25}l$ (b) $\frac{25}{24}l$ (c) $\frac{15}{16}l$ (d) $\frac{16}{15}l$

$$X=\frac{mL/2+mL+m\left(\frac{5L}{4}\right)+m\left(\frac{17L}{12}\right)}{4m}=\frac{\frac{6+12+15+17}{12}}{4}L=\frac{50L}{4\times 12}$$

$$=\frac{25L}{24}$$

2	2, 4, 12
2	1, 2, 6
3	1, 1, 3

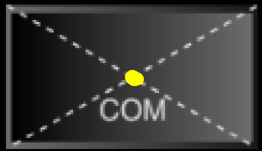
$25+18=43$

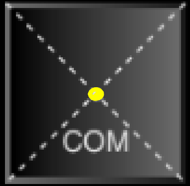
Centre of Mass

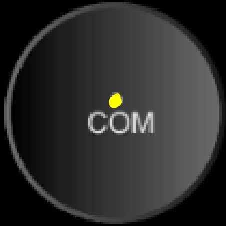
Uniform & symmetric Continuous Body

Uniform → mass distribution

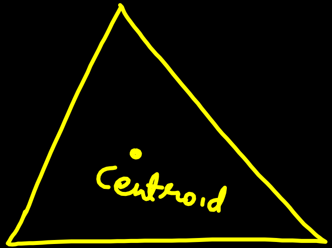
symmetric → shape







Geometrical Centre = COM



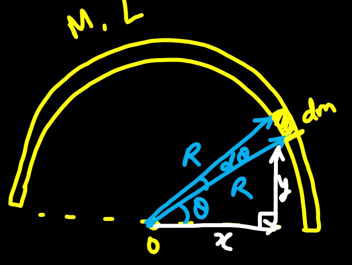
Centre of Mass

Uniform & Asymmetric Continuous Body

Semicircular Wire

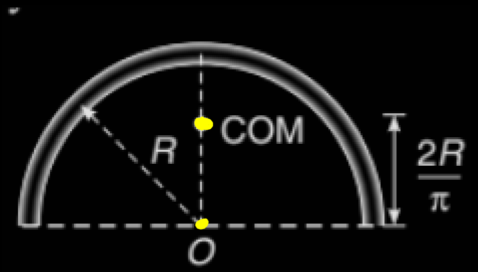
$$X = \frac{1}{M}\int dm\, x$$

$$Y = \frac{1}{M}\int dm\, y$$



$x = R\cos\theta$

$y = R\sin\theta$



element
Mass = dm
length = $dl = R\,d\theta$

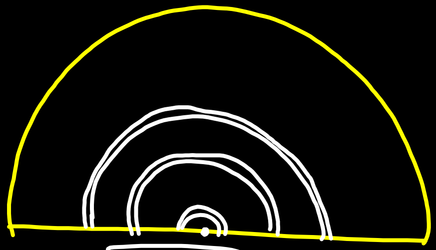
$$dm = \frac{M}{L} \times dl$$

$$Y = \frac{1}{M}\int \frac{M}{L}\,dl\,(R\sin\theta)$$

$$Y = \frac{2R}{\pi}$$

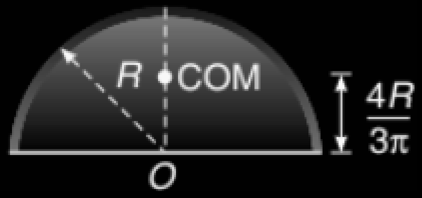
Centre of Mass

Semicircular Disc



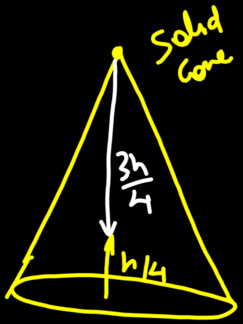
$x = 0$

$y = \frac{4R}{3\pi}$



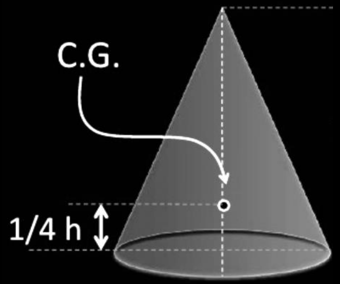
Centre of Mass

Cone



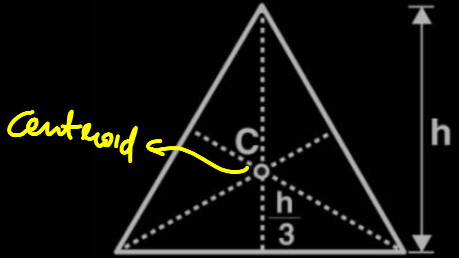
Hollow Cone

$x = 0,\ y = h/3$



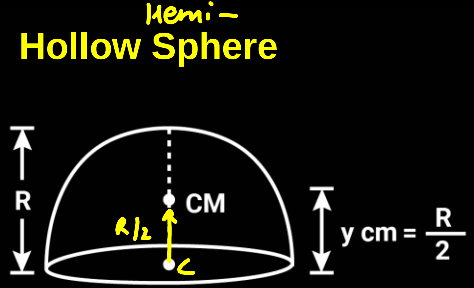
Solid cone

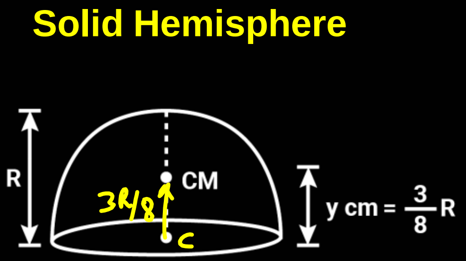
$x = 0,\ y = h/4$



Triangle

Centre of Mass

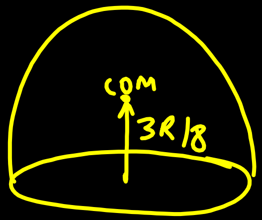




Q

The centre of mass of a solid hemisphere of radius 8 cm is x cm from the centre of the flat surface. Then value of x is ________. **[Main Sep. 06, 2020 (II)]**

$R = 8\text{ cm}$



$x = \frac{3R}{8} = 3\text{ cm}$

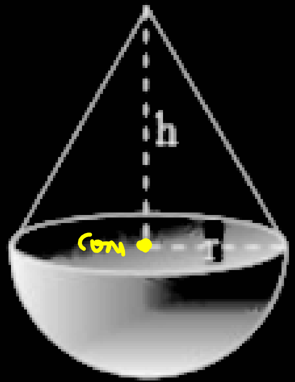
Q

HW Ans is comment

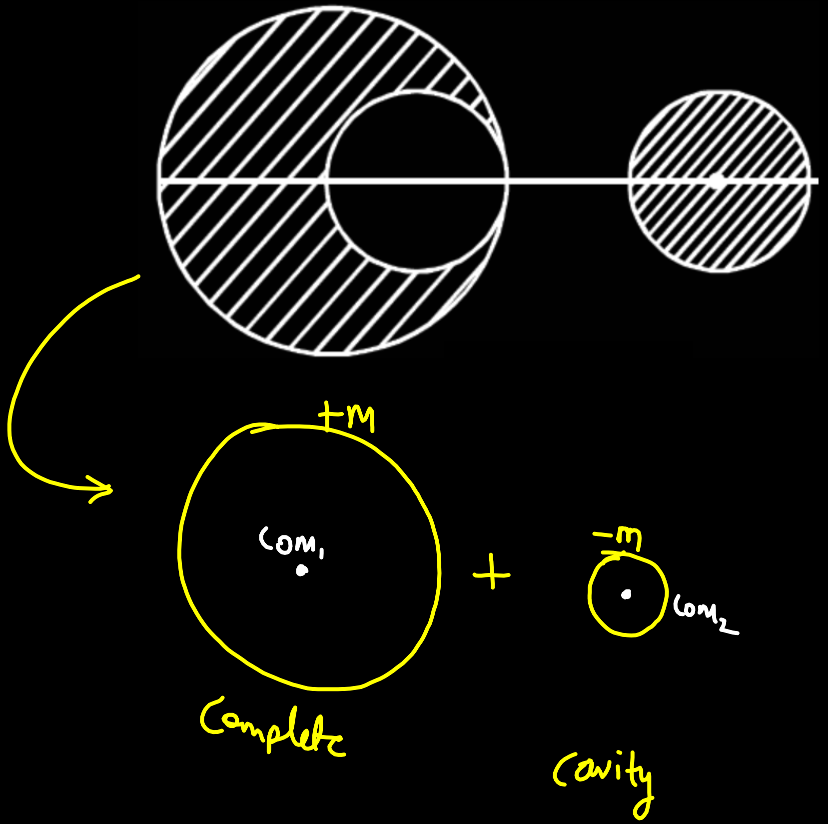
t me/abhilashsharmaiitjee

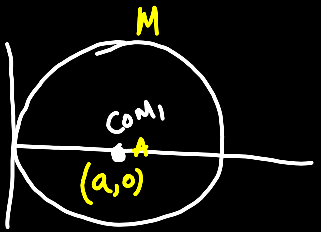
A uniform solid circular cone of base radius r is joined to a uniform solid hemisphere of radius r and of the same density, so as to have a common face. The centre of mass of the composite solid lies on the common face. The height of the cone is

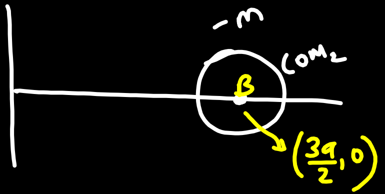
A. 2r
B. $\sqrt{3}r$
C. 3r
D. $\sqrt{6}r$



Centre of Mass of Objects with Cavity







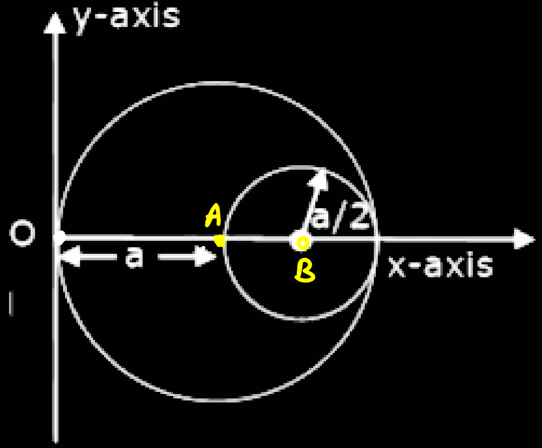
$$m = \frac{-M}{\pi a^2} \times \pi\left(\frac{a}{2}\right)^2$$

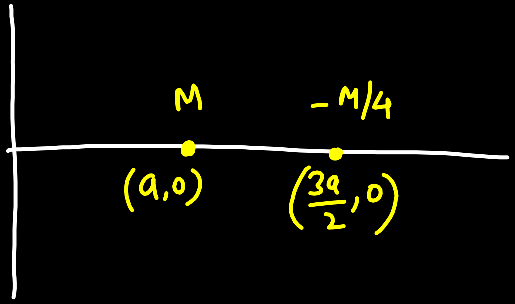
$$m = -\frac{M}{4}$$

A circular hole of radius a/2 is cut out of a circular disc of radius 'a' shown in figure. The centroid of the remaining circular portion with respect to point 'O' will be

[JEE Main 2021]

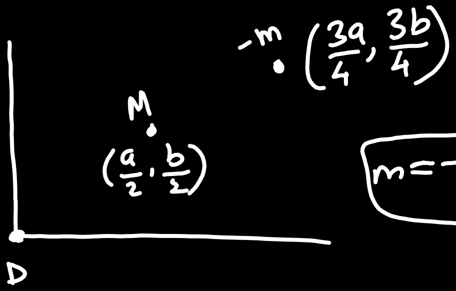
A. 10a/11
B. 2a/3
C. a/6
D. 5a/6 ✓





$$X = \frac{Ma + \left(-\frac{M}{4}\right)\left(\frac{3a}{2}\right)}{M + \left(-\frac{M}{4}\right)}$$

$$X = \frac{a - 3/8\,a}{3/4} = \frac{5a/8}{3/4} = \frac{5a}{6}$$



$$m = -\frac{M}{4}$$

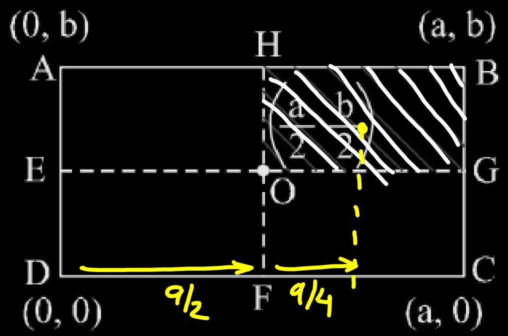
$$X = \frac{M\left(\frac{a}{2}\right) + \left(-\frac{M}{4}\right)\left(\frac{3a}{4}\right)}{M + \left(-\frac{M}{4}\right)} = \frac{\frac{a}{2} - \frac{3a}{16}}{3/4}$$

$$= \frac{\frac{5a}{16}}{3/4} = \frac{5a}{12}$$

Q

A uniform rectangular thin sheet ABCD of mass M has length a and breadth b, as shown in the figure. If the shaded portion HBGO is cut-off, the coordinates of the centre of mass of the remaining portion will be :

[JEE Main 2019]



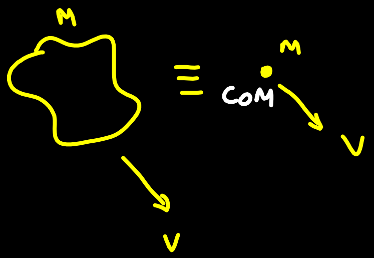
(a) $\left(\frac{3a}{4}, \frac{3b}{4}\right)$

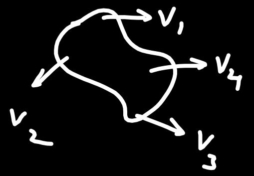
(b) $\left(\frac{5a}{3}, \frac{5b}{3}\right)$

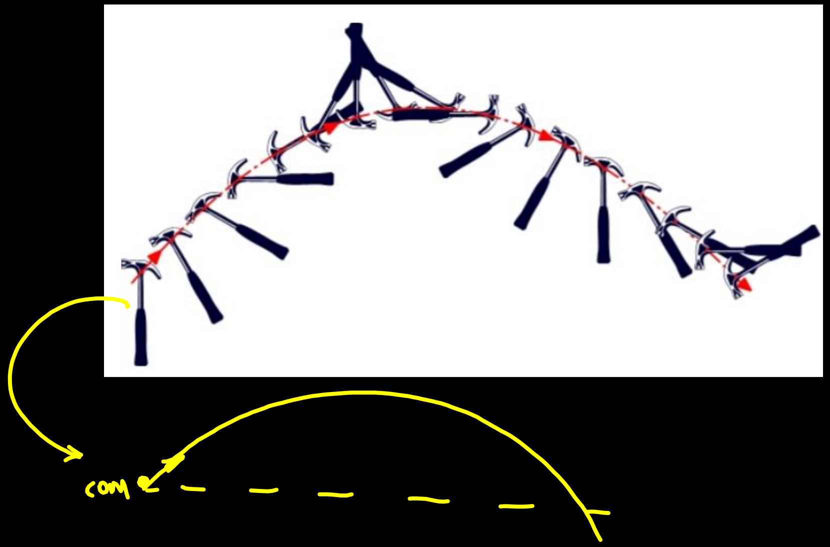
(c) $\left(\frac{2a}{3}, \frac{2b}{3}\right)$

(d) $\left(\frac{5a}{12}, \frac{5b}{12}\right)$ ✓

Motion of Centre of Mass







Motion of Centre of Mass

$$\vec{V}_{com} = \frac{d\vec{r}_{com}}{dt}$$

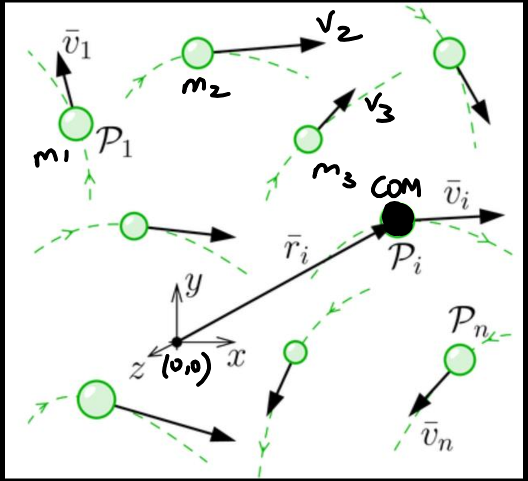
$$= \frac{d}{dt}\left[\frac{m_1\vec{r}_1 + m_2\vec{r}_2 + \ldots}{m_1 + m_2 + \ldots}\right]$$

$$\boxed{\vec{V}_{com} = \frac{1}{M}\left[m_1\vec{v}_1 + m_2\vec{v}_2 + \ldots\right]}$$

$$M\vec{V}_{com} = m_1\vec{v}_1 + m_2\vec{v}_2 + \ldots$$

$$M\vec{V}_{com} = \vec{P}_1 + \vec{P}_2 + \ldots$$

$$\boxed{M\vec{V}_{com} = \vec{P}_{system}}$$



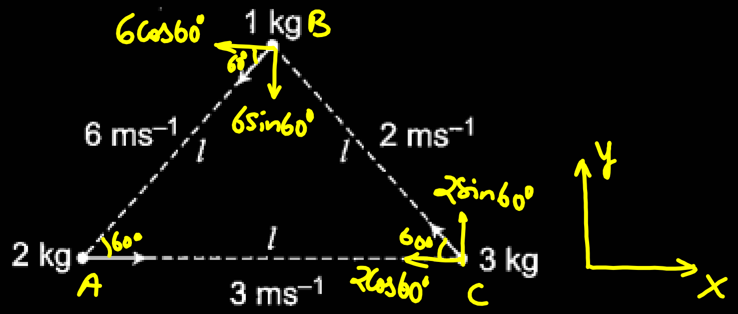
COM $\Rightarrow (X, Y, Z)$

$$\vec{r}_{com} = X\hat{i} + Y\hat{j} + Z\hat{k}$$

Unacademy Atoms

Q

Three particles of masses 1 kg, 2 kg and 3 kg are situated at the corners of an equilateral triangle move at speed 6 ms^{-1}, 3 ms^{-1} and 2 ms^{-1} respectively. Each particle maintains a direction towards the particle at the next corner symmetrically. Find velocity of CM of the system at this instant



(a) 3 ms^{-1} (b) 5 ms^{-1}

(c) 6 ms^{-1} (d) zero

$$V_{com} = \frac{m_1\vec{V_A} + m_2\vec{V_B} + m_3\vec{V_C}}{m_1 + m_2 + m_3}$$

$$\vec{V_A} = 3\hat{i}$$

$$\vec{V_B} = -3\hat{i} - 3\sqrt{3}\hat{j}$$

$$\vec{V_C} = -\hat{i} + \sqrt{3}\hat{j}$$

$$V_{com} = \frac{2(3\hat{i}) + 1(-3\hat{i} - 3\sqrt{3}\hat{j}) + 3(-\hat{i} + \sqrt{3}\hat{j})}{6}$$

$$= \frac{6\hat{i} - 3\hat{i} - 3\hat{i} - 3\sqrt{3}\hat{j} + 3\sqrt{3}\hat{j}}{6}$$

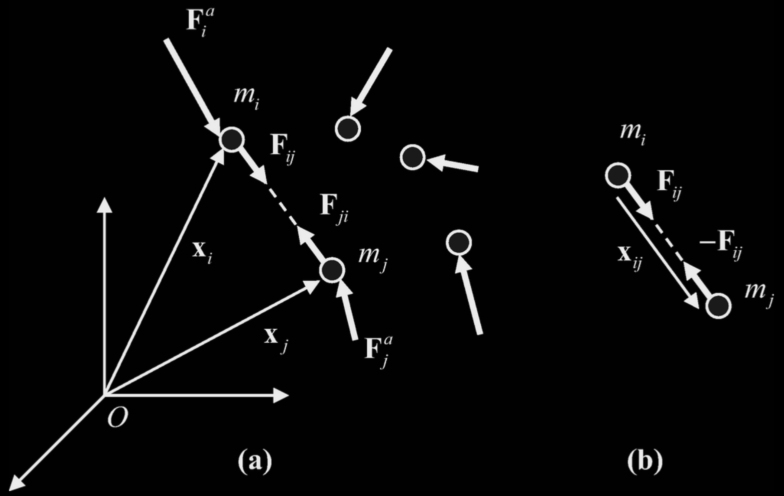
$$= 0$$

Acceleration of Centre of Mass

$$\vec{r}_{com} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + \ldots}{m_1 + m_2 + \ldots}$$

$$\vec{V}_{com} = \frac{m_1\vec{V}_1 + m_2\vec{V}_2 + \ldots}{m_1 + m_2 + \ldots}$$

$$\vec{a}_{com} = \frac{m_1\vec{a}_1 + m_2\vec{a}_2 + \ldots}{m_1 + m_2 + \ldots}$$

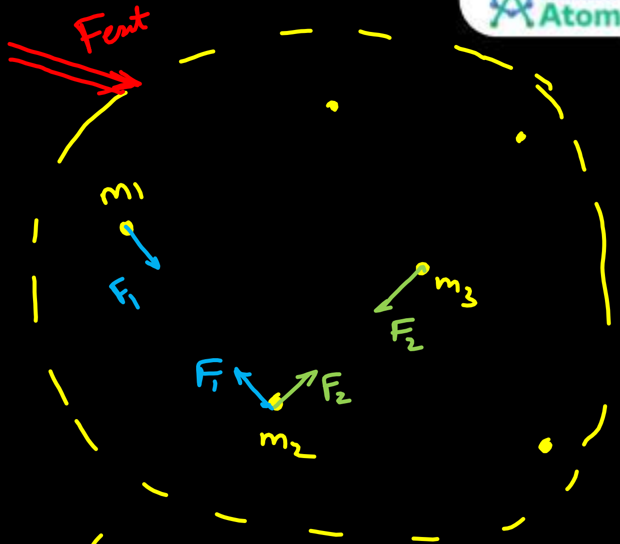


$$M\vec{a}_{cm} = m_1\vec{a}_1 + m_2\vec{a}_2 + \ldots\ldots$$

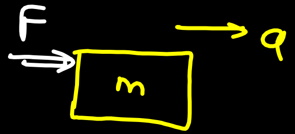
$$= (\vec{F}_1)_{net} + (\vec{F}_2)_{net} + \ldots\ldots$$

$$M\vec{a}_{cm} = (\vec{F}_{system})_{net}$$

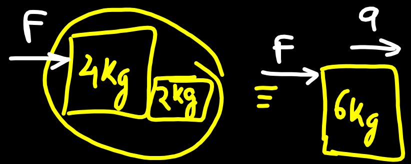
$$\boxed{M\vec{a}_{cm} = (\vec{F}_{net})_{external}}$$



$$(F_{system})_{net} = (F_{net})_{external}$$



$a = F/m$

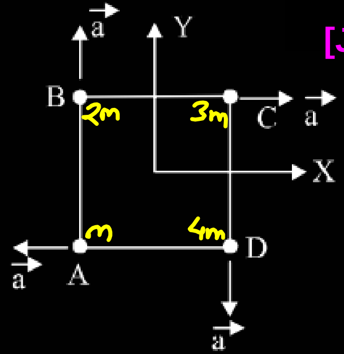


$a = F/6$

Q

Four particles A, B, C and D with masses $m_A = m$, $m_B = 2m$, $m_C = 3m$ and $m_D = 4m$ are at the corners of a square. They have accelerations of equal magnitude with directions as shown. The acceleration of the centre of mass of the particles is :

[JEE Main 2019]



(a) $\frac{a}{5}(\hat{i}-\hat{j})$ ✓

(b) a

(c) Zero

(d) $\frac{a}{5}(\hat{i}+\hat{j})$

$$\vec{a}_{com} = \frac{m(a_A)+2m(a_B)+3m(a_C)+4m(a_D)}{m+2m+3m+4m}$$

$$\vec{a}_{com} = \frac{m(-a\hat{i})+2m(a\hat{j})+3m(a\hat{i})+4m(-a\hat{j})}{10m}$$

$$= \frac{(-a+3a)\hat{i}+(2a-4a)\hat{j}}{10}$$

$$= \frac{2(a\hat{i}-a\hat{j})}{10}$$

$\vec{a}_A = -a\hat{i}$

$\vec{a}_B = +a\hat{j}$

$\vec{a}_C = a\hat{i}$

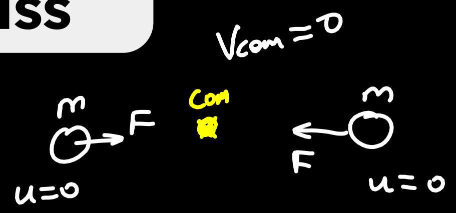
$\vec{a}_D = -a\hat{j}$

Acceleration of Centre of Mass

If $(\vec{F}_{net})_{external} = 0$

$\Rightarrow \vec{a}_{com} = 0$

$\Rightarrow \boxed{\vec{V}_{com} = \text{const}}$ $\Rightarrow$ If initially com was at rest, then it will remain at rest



$M\vec{V}_{com} = \vec{P}_{system}$

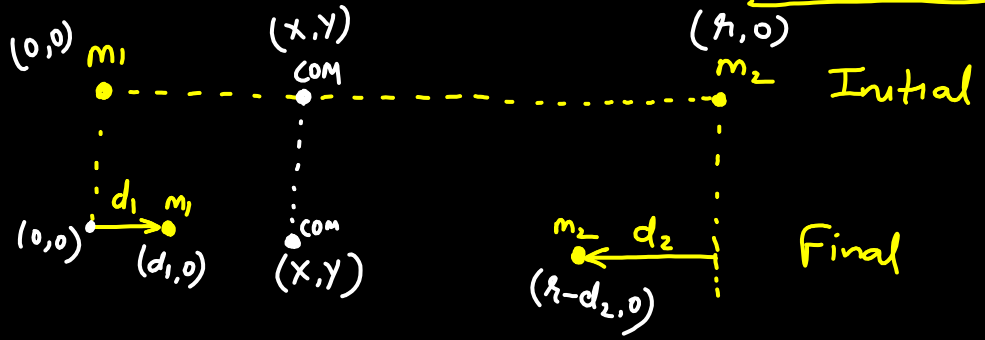
$\Rightarrow \boxed{\vec{P}_{system} = \text{Const}}$ $\Rightarrow$ Conservation of Linear Momentum of the system

Acceleration of Centre of Mass

Example

Very Important

Consider a two-particle system with the particles having masses m1 and m2 . If the first particle is pushed towards the centre of mass through a distance d, by what distance should the second particle be moved so as to keep the centre of mass at the same position ?



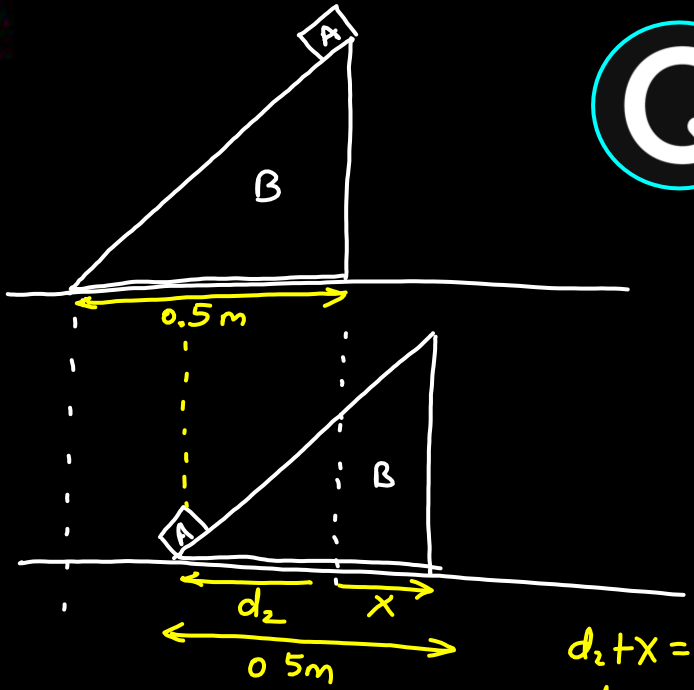
$$X = \frac{m_1 \times 0 + m_2 r}{m_1 + m_2}$$

$$X = \frac{m_1 d_1 + m_2 (r - d_2)}{m_1 + m_2}$$

$$\frac{m_2 r}{m_1 + m_2} = \frac{m_1 d_1 + m_2 (r - d_2)}{m_1 + m_2}$$

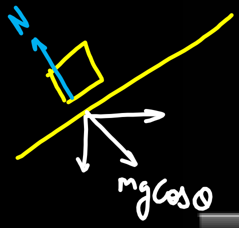
$$m_2 r = m_1 d_1 + m_2 r - m_2 d_2$$

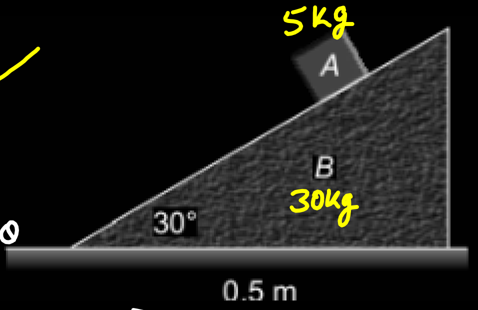
$$\boxed{m_1 d_1 = m_2 d_2} \star$$



Block A of mass 5 kg is placed on top of a smooth triangular block B having a mass of 30 kg. If the system is released from rest, determine the distance moved by B when A reaches the bottom. Neglect the size of block A.

A. 1/12
B. 1/14 ✓
C. 1/16
D. 1/20





$d_2 + x = 0.5$

$d_2 = 0.5 - x$

$m_2 = 5\,kg$

$d_1 = x$

$m_1 = 30\,kg$

$$\left[(F_{net})_{system}\right]_{Horizontal} = 0$$

Along Horizontal

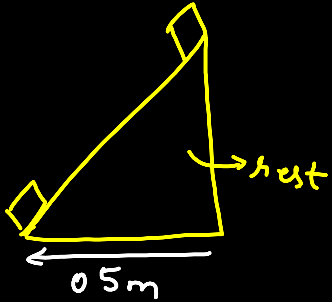
$$m_1 d_1 = m_2 d_2$$

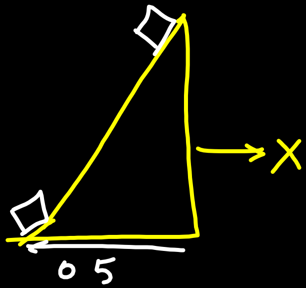
$$30x = 5(0.5 - x)$$

$$6x = 0.5 - x$$

$$7x = 0.5$$

$$\boxed{x = \frac{1}{14}\,m}$$

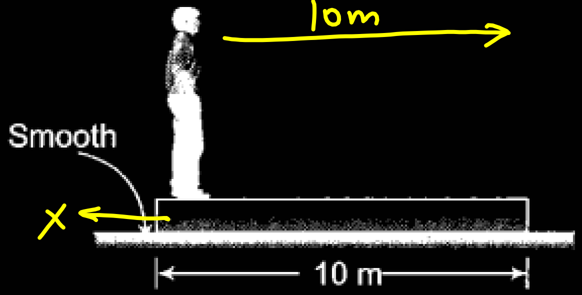




Net 0.5-x

Q

A wooden plank of mass 20 kg is resting on a smooth horizontal floor. A man of mass 60 kg starts moving from one end of the plank to the other end. The length of the plank is 10 m. Find the displacement of the plank over the floor when the man reaches the other end of the plank.



(a) 5 m
(b) 6.5 m
(c) 2.5 m
(d) 7.5 m ✓

Net motion of Man $= 10 - x$

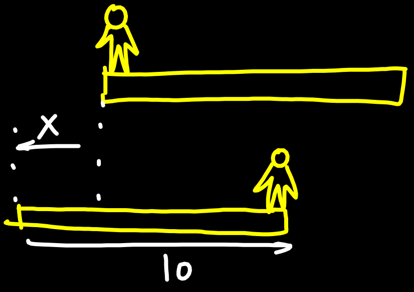
$M_1 d_1 = M_2 d_2$

$60(10 - x) = 20x$

$30 - 3x = x$

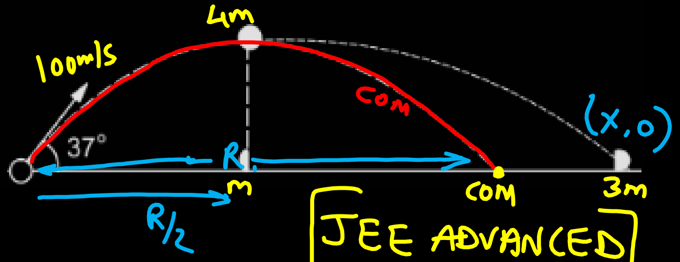
$x = 30/4$

$\boxed{x = 7.5\,m}$



A projectile is fired at a speed of 100 m/s at an angle of 37° above the horizontal. At the highest point, the projectile breaks into two parts of mass ratio 1:3, the smaller coming to rest. Find the distance from the launching point to the point where the heavier piece lands

A. 480 m
B. 960 m
C. 1120 m ✓
D. 2250 m



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$$(F_{net})_{horizontal} = 0$$

$$R = \frac{u^2 \sin 2\theta}{g} = \frac{(100)^2 \times 2 \times \frac{3}{5} \times \frac{4}{5}}{10}$$

$$\boxed{R = 960\ m}$$

(480, 0) m   (960, 0) COM   (x, 0) 3m

$$960 = \frac{m(480) + 3m(x)}{m + 3m}$$

$$960 \times 4 = 480 + 3x$$

$$x = 320 \times 4 - 160$$

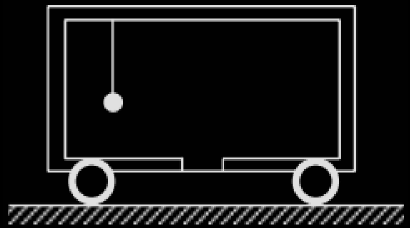
$$\boxed{x = 1120\,m}$$

HW

Ans in comment

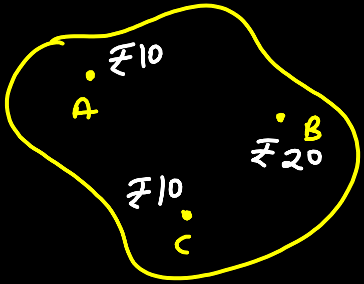
t.me/abhilashsharmaiitjee

A cart of mass 6kg is at rest on a frictionless horizontal surface and a pendulum bob of mass 2 kg hangs from the roof of the cart. The string breaks, the bob falls on the floor, makes several collisions on the floor and finally lands up in a small slot made in the floor. The horizontal distance between the string and the slot is 1 m. Find the displacement of the cart during this process

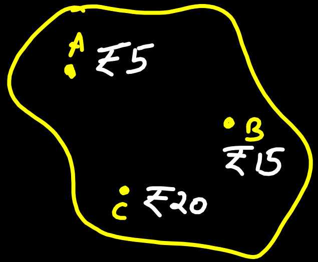


A. 10 cm
B. 25 cm
C. 50 cm
D. 75 cm

Linear Momentum Conservation



System: ₹ 40



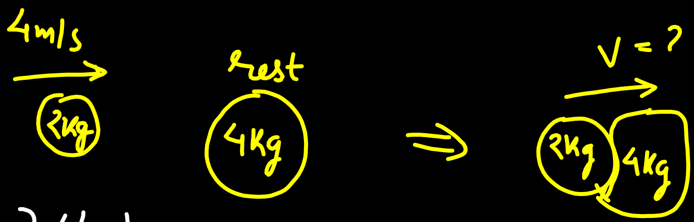
System = ₹40

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

Only if

$(\vec{F}_{net})_{external} = 0$

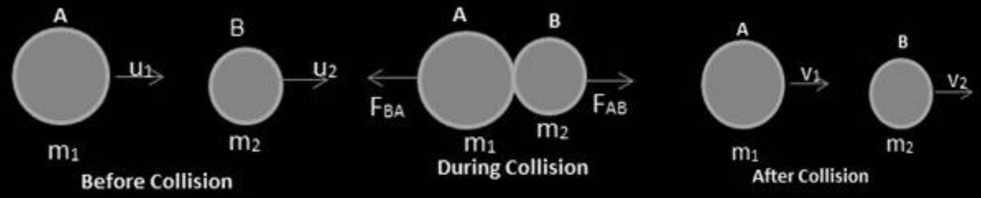
$\Rightarrow \vec{P}_{system} = \text{const}$



$2 \times 4 + 0 = 6v$

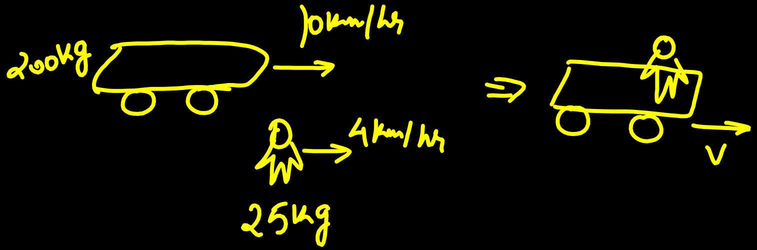
$v = 4/3 \text{ m/s}$

Linear Momentum Conservation



A bullock cart of mass 200 kg is moving at a speed of 10 km/h. As it overtakes a school boy walking at a speed of 4 km/h, the boy sits on the cart. If the mass of the boy is 25 kg, what will be the new velocity of the bullock cart ?

A. 16/3 km/h
B. 25/3 km/h
C. 28/3 km/h
D. 32/3 km/h



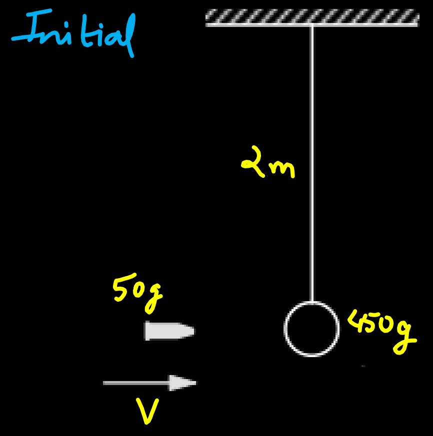
$$200 \times 10 + 25 \times 4 = 225 \times V$$

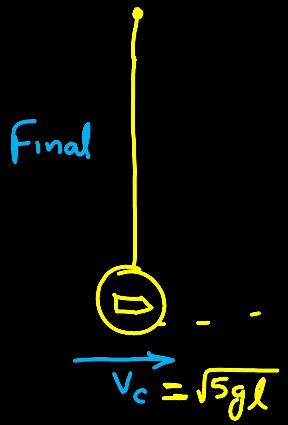
$$\frac{2100}{225} = V$$

$$\frac{420}{45} = \frac{84}{9} = \frac{28}{3} \frac{km}{hr}$$

A bullet of mass 50 g is fired horizontally into the bob of mass 450 g of a long simple pendulum with string length 2 m as shown in the figure. The bullet remains inside the bob and the bob just completes the vertical circular motion. Find the speed of the bullet

A. 10 m/s
B. 100 m/s
C. 500 m/s
D. 1000 m/s



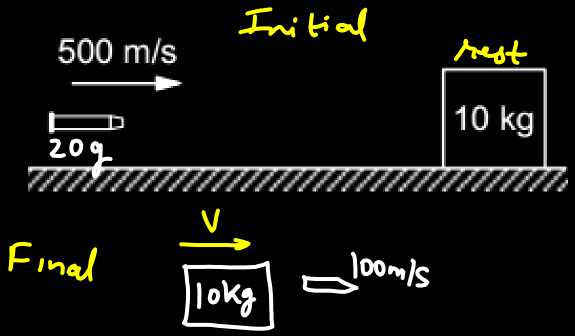


$$50v = (50+450)v_c$$
$$50v = (500)\sqrt{5gl}$$
$$v = 10\sqrt{5\times10\times2}$$
$$v = 100\text{ m/s}$$

Q

A bullet of mass 20 g travelling horizontally with a speed of 500 m/s passes through a wooden block of mass 10. 0 kg initially at rest on a level surface. The bullet emerges with a speed of 100 m/s and the block slides 20 cm on the surface before coming to rest. Find the friction coefficient between the block and the surface

A. 0.16
B. 0.32
C. 0.50
D. 0.72

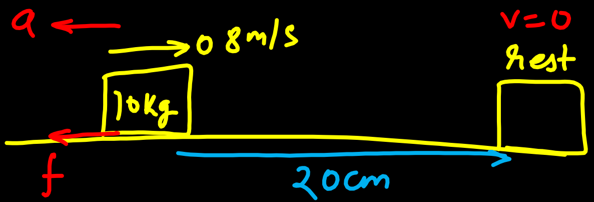


$$P_1 = P_2$$

$$500\times(20\times10^{-3}) = 10v + 100\times(20\times10^{-3})$$

$$10-2 = 10v$$

$$v = 0.8\ m/s$$



$$f = -ma$$

$$\mu(mg) = -ma$$

$$a = -\mu g$$

$u = 0.8\ m/s$, $v = 0$, $s = 0.2m$

$a = -\mu g$

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

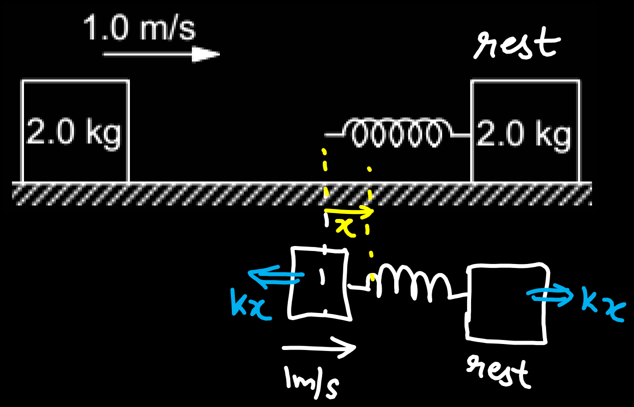
$0^2 = (0.8)^2 + 2(-\mu g)(0.2)$

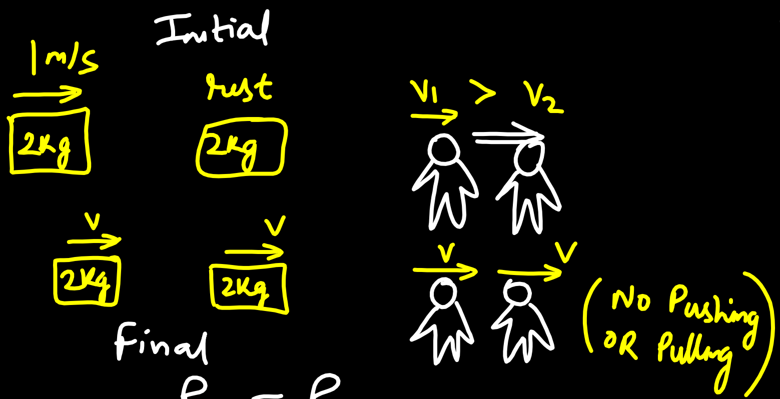
$4\mu = 0.64$

$\boxed{\mu = 0.16}$

A block of mass 2 kg is moving on a frictionless horizontal surface with a velocity of 1 m/s towards another block of equal mass kept at rest. The spring constant of the spring fixed at one end is 100 N/m. Find the maximum compression of the spring

A. 5 cm
B. 10 cm ✓
C. 15 cm
D. 20 cm





$$P_1 = P_2$$

$$2\times1 + 2\times0 = 2v + 2v$$

$$2 = 4v$$

$$\boxed{v = 0.5\,m/s}$$

$$E_1 = E_2$$

$$\frac{1}{2}\times 2\times(1)^2 = \left(\frac{1}{2}\times 2v^2\right)\times 2 + \frac{1}{2}kx^2$$

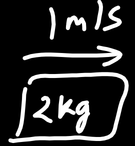
$$1 = 2v^2 + \frac{1}{2}\times 100x^2$$

$$1 - 2\times\left(\frac{1}{2}\right)^2 = 50x^2$$

$$\frac{1}{2} = 50x^2$$

$$x = \frac{1}{\sqrt{100}} = \frac{1}{10}\,m$$

$$\boxed{x = 10\,cm}$$

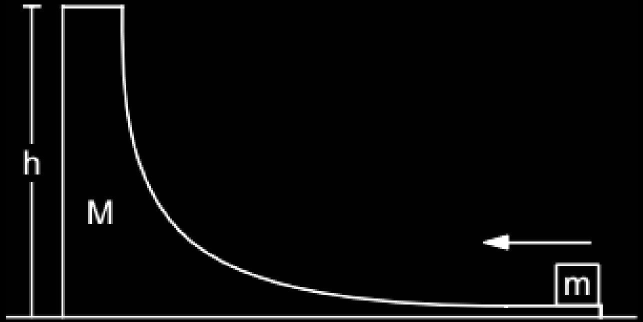


$$\frac{1}{2}\times 2\times v^2$$

HW As in comment

Figure shows a small body of mass 2 kg placed over a larger mass 8 kg whose surface is horizontal near the smaller mass and gradually curves to become vertical. The smaller mass is pushed on the longer one at a speed 10 m/s and the system is left to itself. Assume that all the surfaces are frictionless. Find the maximum height (from the ground) that the smaller mass ascends

A. 2 m
B. 4 m
C. 6 m
D. 8 m

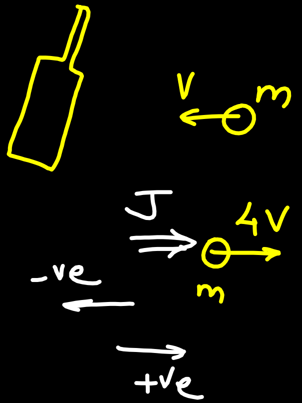


Impulse (J)

Impulse ⇒ A sudden momentum change.

$$\vec{J} = \vec{P_2} - \vec{P_1}$$

$kg \frac{m}{s}$



$$\vec{J} = \vec{P_2} - \vec{P_1}$$

$$J = m(4v) - [-mv]$$

$$J = 5mv$$

Impulse

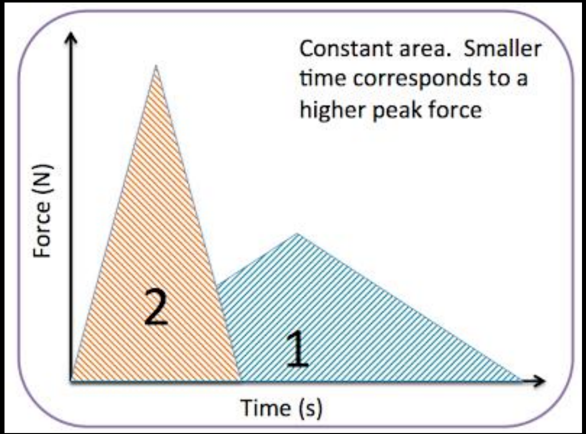
$$\vec{F} = \frac{d\vec{P}}{dt}$$

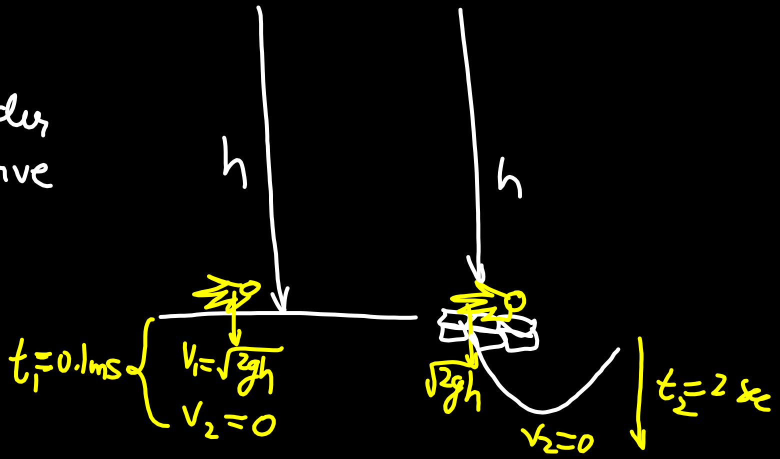
$$\int_{P_1}^{P_2} dp = \int_0^t F\,dt$$

$$P_2 - P_1 = \int F\,dt$$

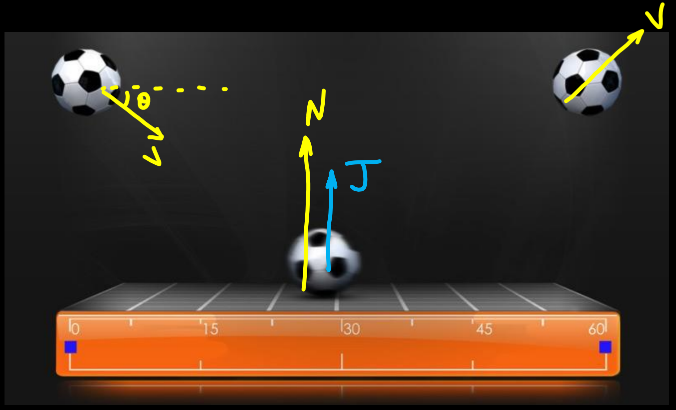
$$\boxed{J = \int F\,dt}$$ ⇒ Area under F-t curve

$$J = \int F\,dt$$



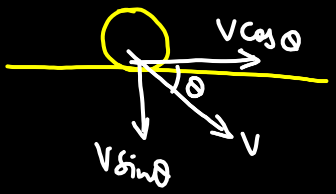


A ball of mass m moving with velocity v strikes the horizontal surface at an angle $\boldsymbol{\theta}$. Assuming no loss of energy, find the Impulse imparted to the ball

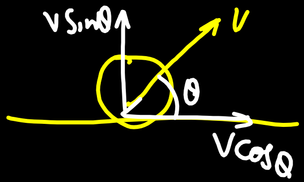


A. 2 mv
B. 2mv cos$\boldsymbol{\theta}$
C. 2mv sin$\boldsymbol{\theta}$
D. mv

Initial



Final



$$J_x = mv\cos\theta - mv\cos\theta = 0$$

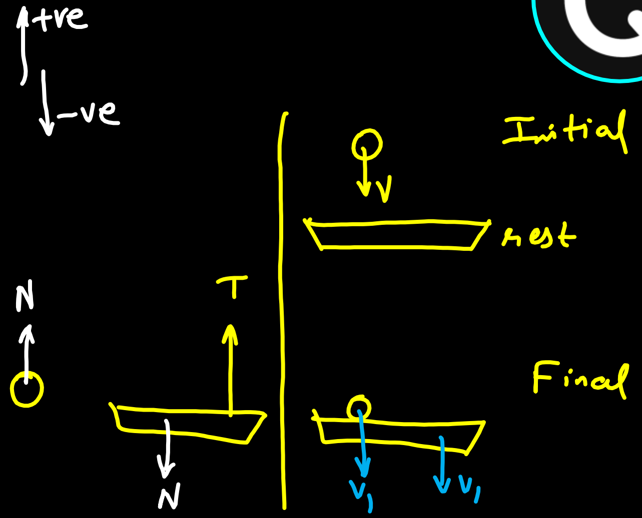
$$J_y = (+mv\sin\theta) - (-mv\sin\theta)$$

$$= 2mv\sin\theta$$

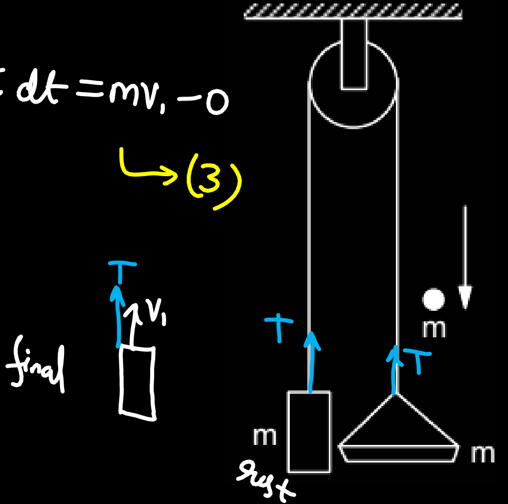
Q

A block of mass m and a pan of equal mass are connected by a string going over a smooth light pulley as shown in figure. Initially the system is at rest when a particle of mass m falls on the pan and sticks to it. If the particle strikes the pan with a speed v find the speed with which the system moves just after the collision.

A. v/2
B. 3v
C. v/3 ✓
D. 2v



Block ⇒ $\int T\,dt = mv_1 - 0$ → (3)



Ball ⇒ $\int N\,dt = m(-v_1) - m(-v)$ → (1)

Pan ⇒ $\int T\,dt - \int N\,dt = m(-v_1) - 0$ → (2)

Add (1) & (2)

$$\int T\,dt = +mV - 2mV_1$$

Using (3)

$$mV_1 = mV - 2mV_1$$

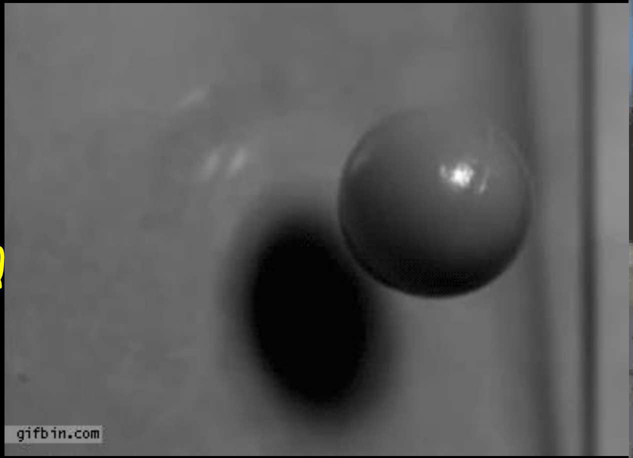
$$3mV_1 = mV$$

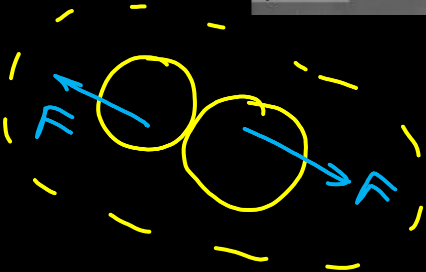
$$\boxed{V_1 = V/3}$$

Collision

⇒ Involves Impulsive Forces

⇒ They are internal





$(F_{net})_{external} = 0$

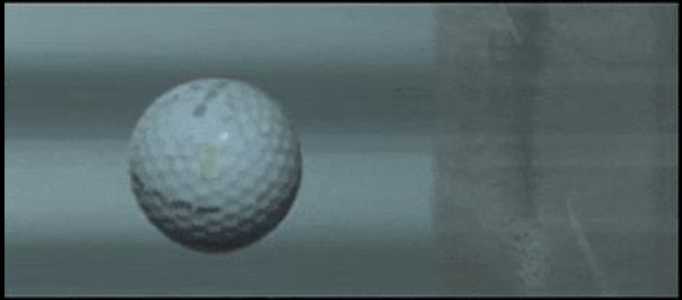
$\vec{P}_{system} = Const$ ⇒ For all Collisions

Collision

Tennis Ball ⇒ Elastic Collision

Plastic Ball ⇒ Inelastic Collision

Clay Ball ⇒ Completely Inelastic



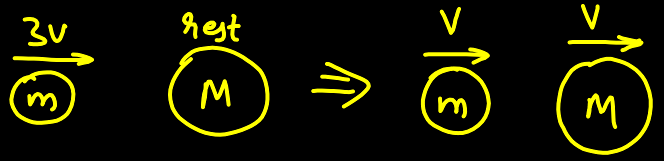
Types of Collision

Elastic	Inelastic	Completely Inelastic
Regains the shape	Deformation of shape	Loss of shape
⇒ No Energy Loss	⇒ Energy Loss	⇒ Huge Energy Loss
⇒ $P_1 = P_2$	⇒ $P_1 = P_2$	⇒ $P_1 = P_2$
⇒ $E_1 = E_2$	⇒ $E_1 > E_2$	⇒ $E_1 >> E_2$
⇒ $e = 1$	⇒ $0 < e < 1$	⇒ $e = 0$

Types of Collision

A ball of mass m moving with velocity 3v collides head on with a stationary ball of mass M. The velocity of both the balls become v after collision. The value of M/m

A. 1
B. 2
C. 3
D. 4



$$P_1 = P_2$$

$$3mv = (m+M)v$$

$$3m = m+M$$

$$2m = M$$

$$\boxed{\frac{M}{m} = 2}$$

Coefficient of Restitution (e)

$$e = \frac{\text{velocity of seperation}}{\text{velocity of Apprach}}$$

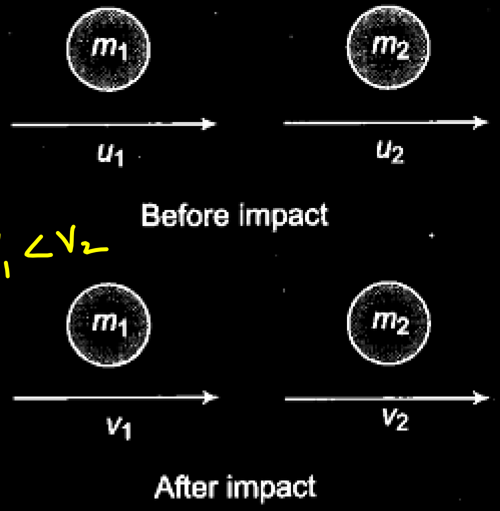
$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

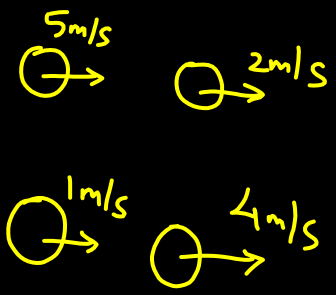
$e \Rightarrow +ve$

$0 \leq e \leq 1$

$u_1 > u_2$

$v_1 < v_2$



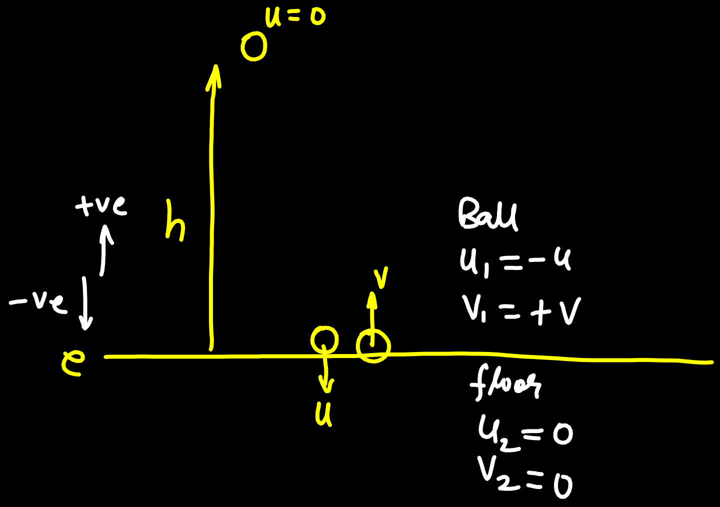


$$e = \frac{4-1}{5-2}$$

$e = 1$

Example

A ball dropped from height h collides with the floor and bounces up. If the coefficient of restitution between ball and floor is e, find the velocity with which the ball rises.

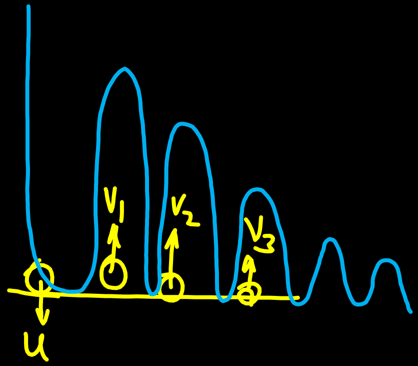


$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

$$e = \frac{0 - (v)}{-u - 0}$$

$$e = v/u$$

$$\boxed{v = eu}$$



$$v_1 = eu$$

$$v_2 = e^2 u$$

$$v_3 = e^3 u$$

$$v_n = e^n u$$

Completely Inelastic Collision

$\Rightarrow e = 0$

$$\frac{v_2 - v_1}{u_1 - u_2} = 0$$

$$\boxed{v_2 = v_1}$$

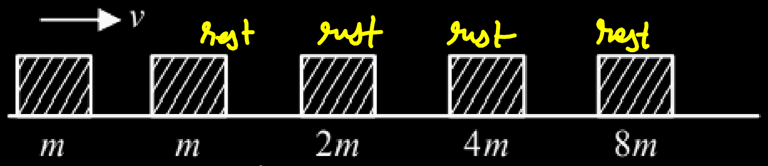
$\Rightarrow$ Objects stick together after the collision

Q

Blocks of masses m, $2m$, $4m$ and $8m$ are arranged in a line on a frictionless floor. Another block of mass m, moving with speed v along the same line (see figure) collides with mass m in perfectly inelastic manner. All the subsequent collisions are also perfectly inelastic. By the time the last block of mass $8m$ starts moving the total energy loss is p% of the original energy. Value of 'p' is close to :

[4 Sep. 2020 (I)]

Initial



(a) 77 (b) 94 (c) 37 (d) 87

$$P_1 = P_2$$

$$mv = (16m)\,v_1$$

$$v_1 = \frac{v}{16}$$

$$\%\text{ loss in KE} = \frac{KE_2 - KE_1}{KE_1} \times 100\,\%$$

$$= \left(\frac{KE_2}{KE_1} - 1\right)100\,\%$$

$$= \left(\frac{\frac{1}{2} \times 16m \times v_1^2}{\frac{1}{2} m v^2} - 1\right) \times 100\,\%$$

v_1

16m

$$\left(\frac{16\left(\frac{v}{16}\right)^2}{v^2} - 1\right) \times 100\%$$

$$= \left(\frac{1}{16} - 1\right) \times 100\%$$

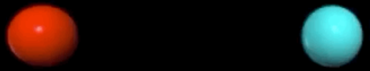
$$= \frac{-15}{16} \times 100\%$$

Inelastic Collision

$0 < e < 1$

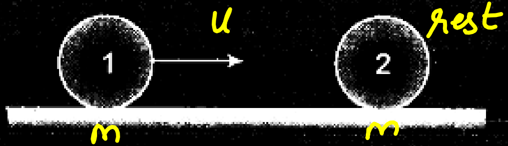
$\Rightarrow P_1 = P_2$

$\Rightarrow e = \dfrac{V_2 - V_1}{U_1 - U_2}$



Ball 1 collidies with an another identical ball 2 at rest as shown in figure.

Before ⇒



For what value of coefficient of restitution e, the velocity of second ball becomes two times that of 1 after collision

(a) 1/3 (b) 1/2 (c) 1/4 (d) 1/6

$P_1 = P_2$

After ⇒

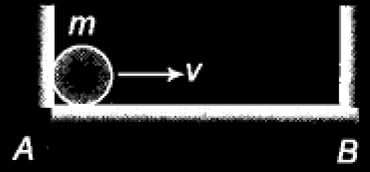
$mu = mv + m(2v)$

$u = 3v$

$e = \frac{v_2 - v_1}{u_1 - u_2} = \frac{2v - v}{u - 0} = \frac{v}{u} = \frac{1}{3}$

HW Ans in comment

A small ball moves towards right with a velocity v starting from A. It collides with the wall and returns back and continues to and fro motion. If the average speed for the first trip is $(2/3)v$, find the coefficient of restitution of impact (in 10^{-1}).



(a) 2 (b) 3 (c) 4 (d) 5

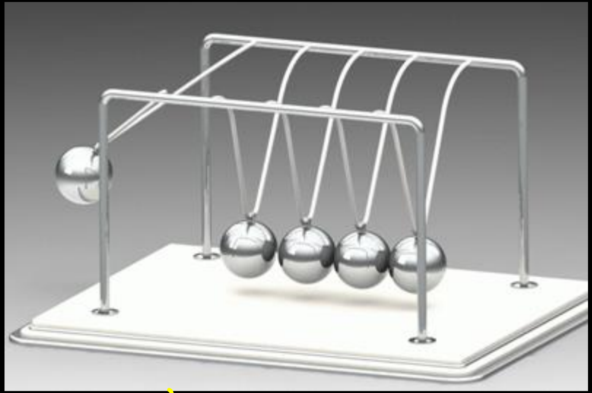
Elastic Collision

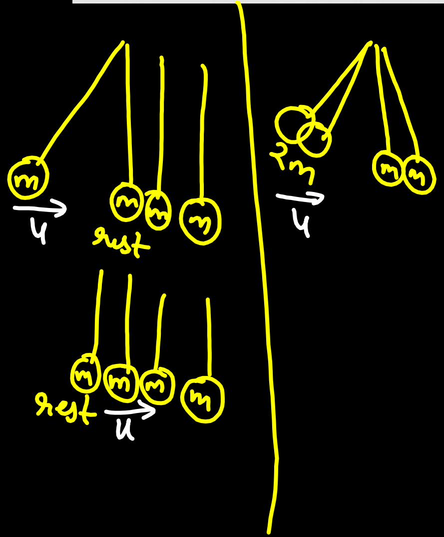
$$e = 1$$

$$\frac{v_2 - v_1}{u_1 - u_2} = 1$$

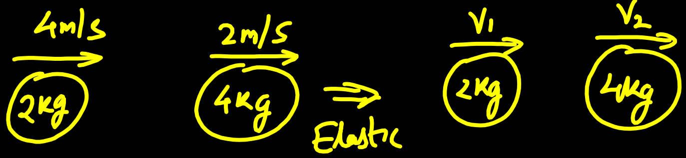
$$\Rightarrow v_2 - v_1 = u_1 - u_2$$

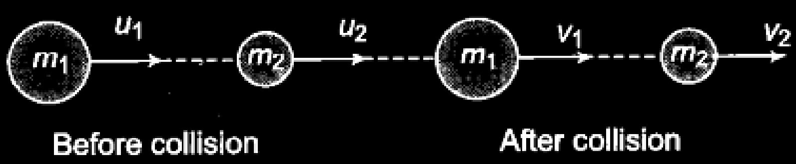
$$\Rightarrow P_1 = P_2$$





Elastic Collision





1) $v_2 - v_1 = 4 - 2$

$v_2 - v_1 = 2 \longrightarrow (1)$

2) $4 \times 2 + 2 \times 4 = 2v_1 + 4v_2$

$8 = v_1 + 2v_2 \longrightarrow (2)$

$v_2 = 10/3 \ m/s$

$v_1 = \frac{4}{3} \ m/s$

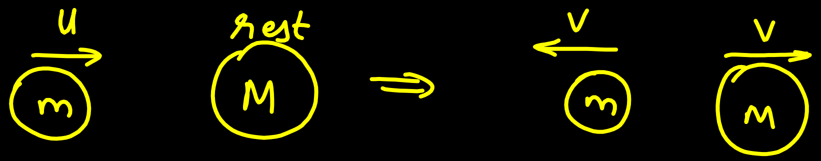
Not Needed

$$v_{1f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_{1i} + \left(\frac{2m_2}{m_1 + m_2}\right)u_{2i}$$

$$v_{2f} = \left(\frac{2m_1}{m_1 + m_2}\right)u_{1i} + \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_{2i}$$

An object of mass m collides elastically with another object of mass M which is at rest. After the collision the objects move with equal speeds in opposite direction. The ratio of the masses M/m is

(a) 3 (b) 2 (c) 1/2 (d) 1



1) $e = 1$

$v_2 - v_1 = u_1 - u_2$

$v - (-v) = u - 0$

$2v = u \rightarrow (1)$

2) $mu = -mv + Mv$

$m(2v) = (M - m)v$

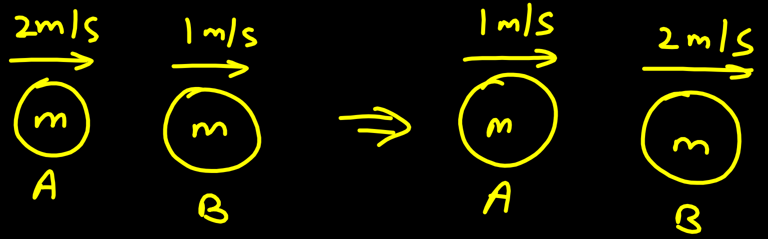
$2m = M - m$

$\frac{M}{m} = 3$

Elastic Collision

Special Cases

1) Equal Masses $m_1 = m_2$



Exchange of velocity

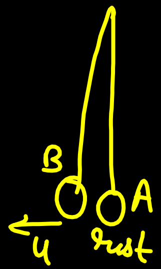
The bob A of a simple pendulum is released when the string makes an angle 45° with the vertical. At the bottom most point of its trajectory it hits another bob B of same material and same mass kept at rest on the table. Assuming no loss of energy

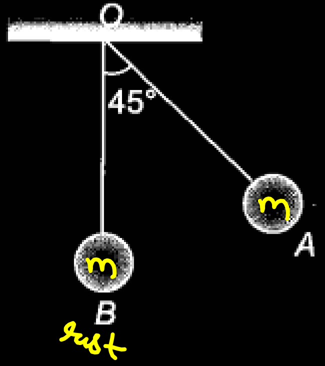
(a) Both A and B rise to the same height

(b) Both A and B come to rest at B

(c) Both A and B move with the same velocity of A

(d) A comes to rest and B moves with the velocity of A

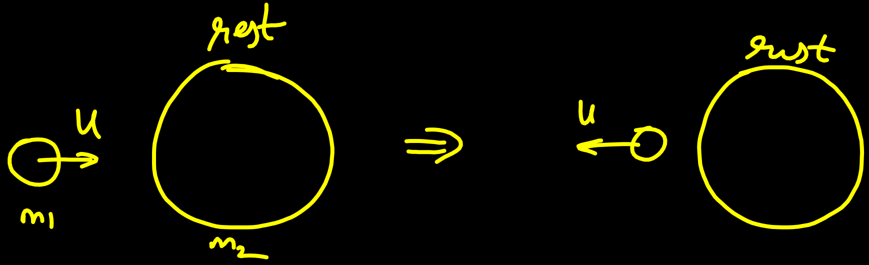




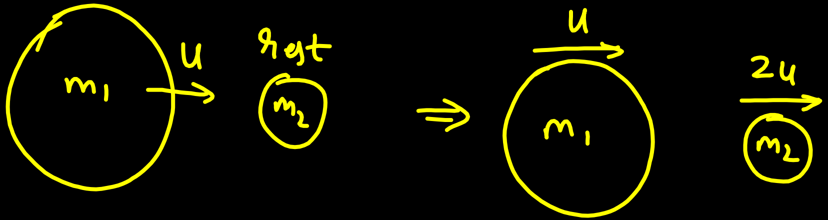
Elastic Collision

Special Cases

2) $m_1 << m_2$

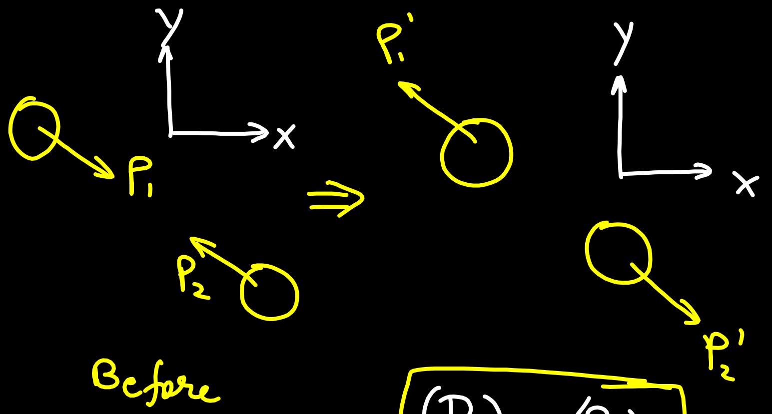


3) $m_1 >> m_2$



Collision in 2D

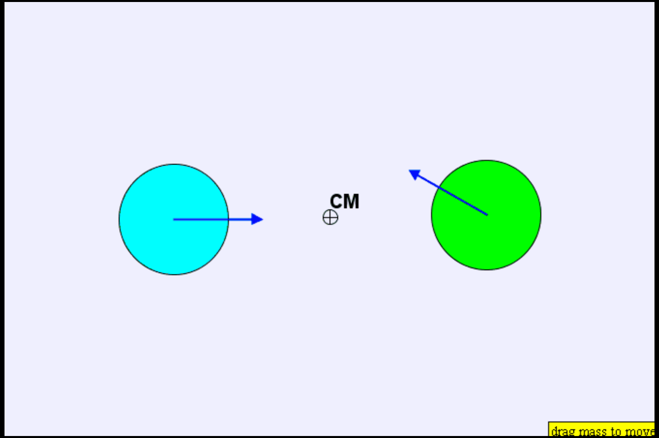
Tom OP



$$(P_1)_x = (P_2)_x$$
$$(P_1)_y = (P_2)_y$$

Collision in 2D

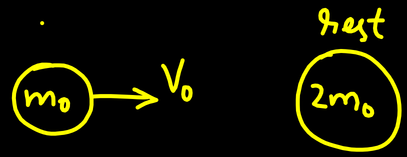
$$(F_{net})_{external} = 0$$

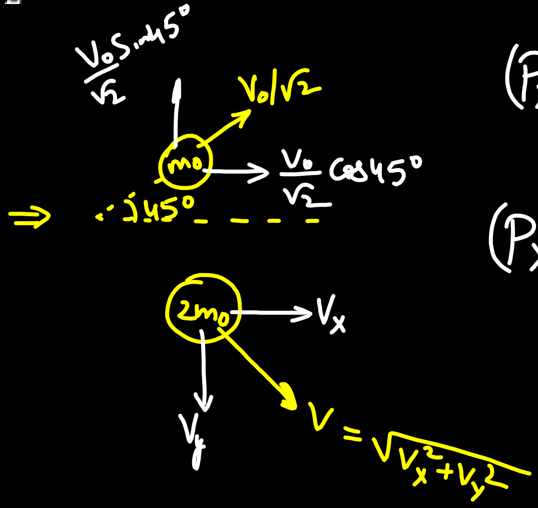


Q

A particle of mass m_0, travelling at speed v_0, strikes a stationary particle of mass $2m_0$. As a result the particle of mass m_0 is deflected through 45° and has a final speed of $\frac{v_0}{\sqrt{2}}$. Then the speed of the particle of mass $2m_0$ after this collision is

(a) $\frac{v_0}{2}$ (b) $\frac{v_0}{2\sqrt{2}}$ (c) $\sqrt{2}v_0$ (d) $\frac{v_0}{\sqrt{2}}$





$(P_x)_1 = m_0 V_0$, $(P_y)_1 = 0$

$(P_y)_2 = \left(m_0 \frac{V_0}{2}\right) - (2m_0 V_y)$

$(P_x)_2 = m_0 \frac{V_0}{2} + 2m_0 V_x$

y //

$$0 = \frac{m_0 V_0}{2} - 2m_0 V_y$$

$$\boxed{V_y = \frac{V_0}{4}}$$

x //

$$m_0 V_0 = \frac{m_0 V_0}{2} + 2m_0 V_x$$

$$\frac{m_0 V_0}{2} = 2m_0 V_x$$

$$\boxed{V_x = \frac{V_0}{4}}$$

$$V = \sqrt{\left(\frac{V_0}{4}\right)^2 + \left(\frac{V_0}{4}\right)^2}$$

$$V = \frac{\sqrt{2}V_0}{4} = \frac{V_0}{2\sqrt{2}}$$

Q

A particle of mass m with an initial velocity $u\hat{i}$ collides perfectly elastically with a mass 3 m at rest. It moves with a velocity $v\hat{j}$ after collision, then, v is given by :

[JEE Main 2020]

(a) $v = \sqrt{\frac{2}{3}}u$ (b) $v = \frac{u}{\sqrt{3}}$

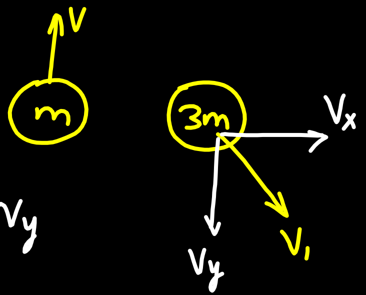
(c) $v = \frac{u}{\sqrt{2}}$ (d) $v = \frac{1}{\sqrt{6}}u$

Initial

$(P_x)_1 = mu$

$(P_y)_1 = 0$

Final



$(P_y)_2 = mV - 3mV_y$

$0 = mv - 3mV_y$

$\boxed{V_y = \frac{V}{3}}$

$(P_x)_2 = 0 + 3mV_x$

$mu = 3mV_x$

$\boxed{V_x = \frac{u}{3}}$

$$E_1 = E_2$$

$$\frac{1}{2}mu^2 = \frac{1}{2}mv^2 + \frac{1}{2}(3m)v_1^2$$

$$u^2 = v^2 + 3v_1^2$$

$$u^2 = v^2 + \left(\sqrt{v_x^2 + v_y^2}\right)^2 \times 3$$

$$u^2 = v^2 + \left(\frac{u^2}{9} + \frac{v^2}{9}\right) \times 3$$

$$u^2 = v^2 + \frac{u^2}{3} + \frac{v^2}{3}$$

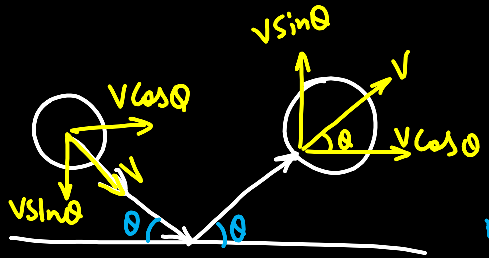
$$\frac{2}{3}u^2 = \frac{4v^2}{3}$$

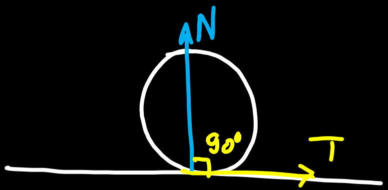
$$\boxed{u = \sqrt{2}\,v}$$

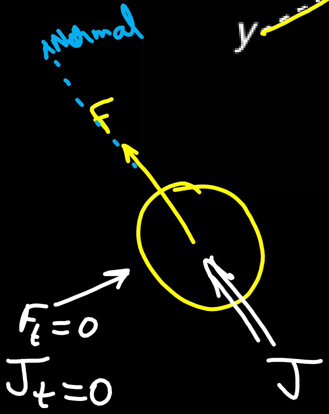
$$\boxed{v = \frac{u}{\sqrt{2}}}$$

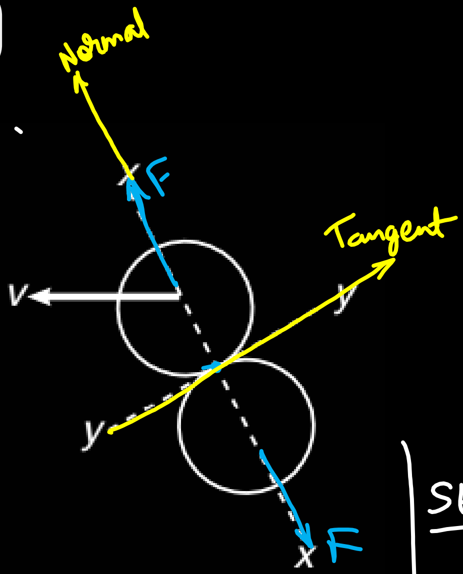
Oblique Collision

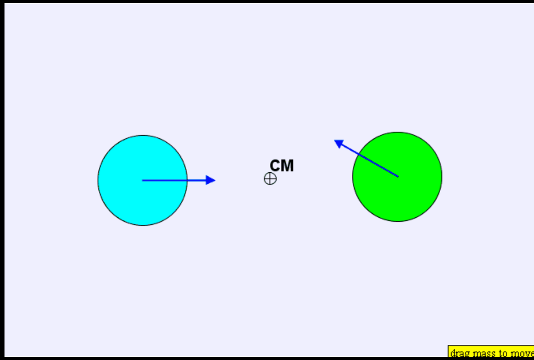
(2D OR 3D)











$J_{normal} \neq 0$

Step 1

Tangent $(J_t = 0)$

$V_{1t} = V_{2t}$

Step 2

Normal $(J_N \neq 0)$

$e =$

Example

A ball of mass 2 grams hits the floor with a speed 10 m/s making an angle of incidence 45° with the normal. The coefficient of restitution is 1/√3. The speed and the angle of reflection of the ball are

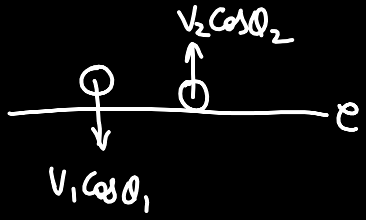
(a) 10 m/s, 45°
(b) 10√3/2 m/s, 60°
(c) 10√2 m/s, 30°
(d) 10√2/3 m/s, 60°

Along Tangent

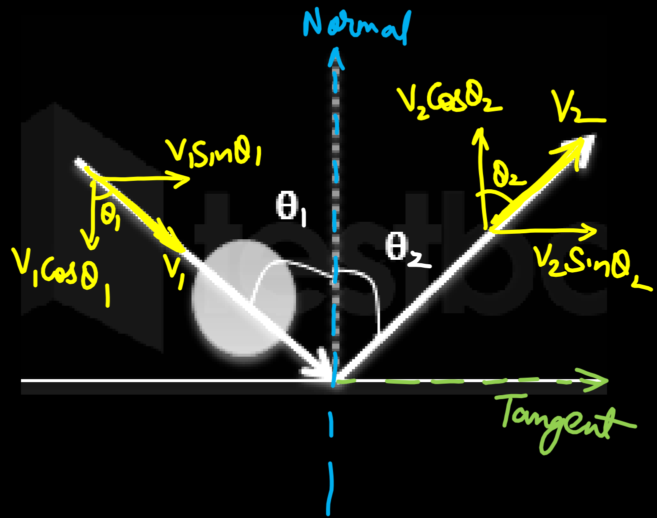
object's p = const.

$$v_1 \sin\theta_1 = v_2 \sin\theta_2 \quad \rightarrow (1)$$

Normal



$$V_2 \cos\theta_2 = e\, V_1 \cos\theta_1 \quad \rightarrow (2)$$



$$\frac{(1)}{(2)} \qquad \frac{v_1 \sin\theta_1}{e v_1 \cos\theta_1} = \frac{v_2 \sin\theta_2}{v_2 \cos\theta_2}$$

$$\frac{\tan\theta_1}{e} = \tan\theta_2$$

$$\frac{\tan 45^\circ}{1/\sqrt{3}} = \tan\theta_2$$

$$\boxed{\theta_2 = 60^\circ}$$

Using (1)

$$(10)\sin 45^\circ = v_2 \sin 60^\circ$$

$$\frac{10}{\sqrt{2}} = v_2 \frac{\sqrt{3}}{2}$$

$$\boxed{\frac{20}{\sqrt{6}} = v_2}$$

Q

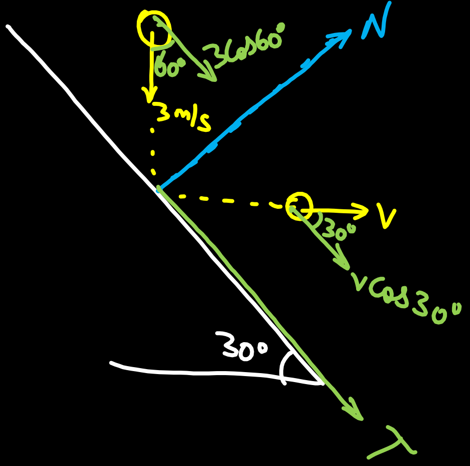
As shown in the figure a body of mass m moving with speed 3 m/s hits a smooth fixed incline plane and rebounds with a velocity v in the horizontal direction. If the angle of incline is 30°, then velocity v will be

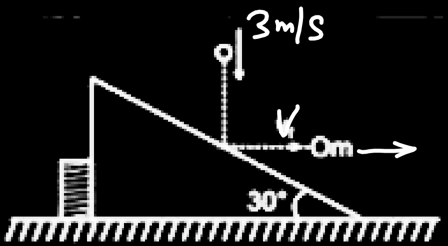
(a) 3 (b) √3 (c) 1/√3 (d) Not possible

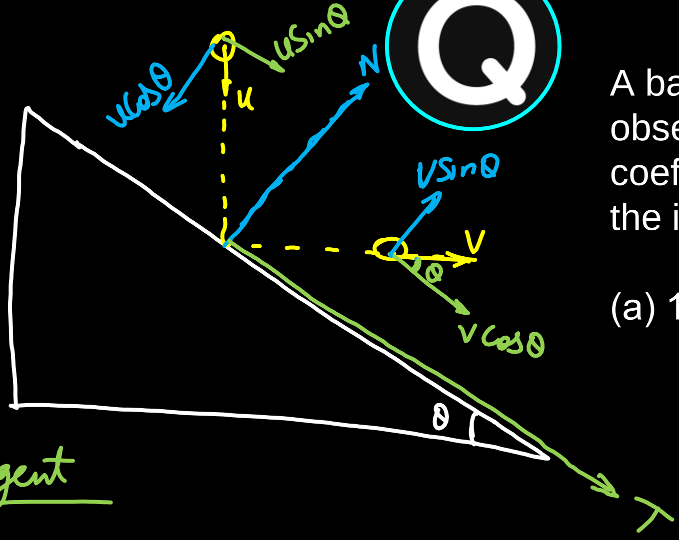
$$3\cos 60^\circ = v\cos 30^\circ$$

$$\frac{3}{2} = v\frac{\sqrt{3}}{2}$$

$$v = \sqrt{3}\ m/s$$







A ball is dropped on a smooth inclined plane and is observed to move horizontally after the impact. The coefficient of restitution between the plane and ball is e. If the inclination of the plane is θ, then the value of $\tan\theta$ is

(a) 1 (b) $\sqrt{e}$ (c) e/2 (d) e

Tangent

$$u\sin\theta = v\cos\theta$$

$$\tan\theta = \frac{v}{u} \rightarrow (1)$$

Normal

$$e(u\cos\theta) = v\sin\theta$$

$$e = \left(\frac{v}{u}\right)\tan\theta$$

$$e = \tan^2\theta$$

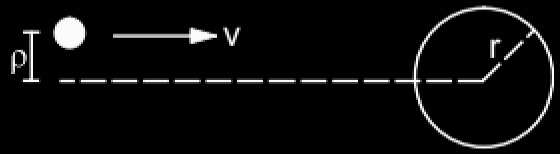
$$\tan\theta = \sqrt{e}$$

HW Ans in comment

Q

A small particle travelling with a velocity v=10 m/s collides elastically with a spherical body of equal mass and of radius r=5 m initially kept at rest. The centre of this spherical body is located a distance ρ=4m away from the direction of motion of the particle. Find the final velocity of the sphere.

(a) 10 m/s (b) 2m/s (c) 4m/s (d) 6m/s



HW Ans in comment

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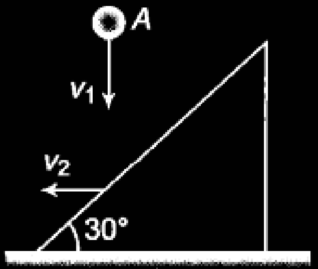
Q

A ball A is falling vertically downwards with velocity v_1. It strikes elastically with a wedge moving horizontally with velocity v_2 as shown in figure. What must be the ratio $\frac{v_1}{v_2}$ so that the ball bounces back in vertically upwards direction relative to wedge?

t.me/abhilashsharmaiitjee



(a) $\sqrt{3}$

(b) $\frac{1}{\sqrt{3}}$

(c) 2

(d) $\frac{1}{2}$

Variable Mass System

$F_{net} \Rightarrow$ accelerate

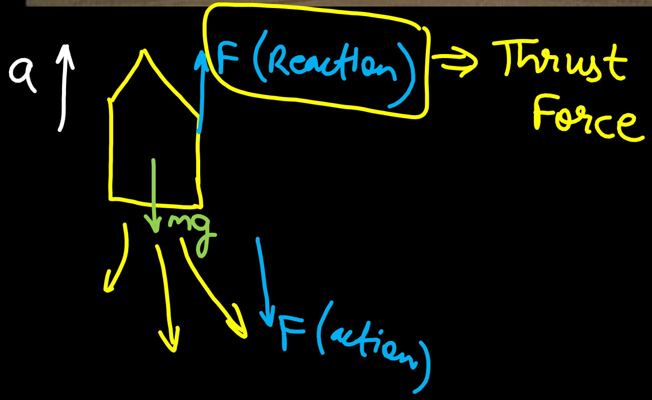
$$\vec{F}_{ext} = \frac{d\vec{P}}{dt} = \frac{d}{dt}(m\vec{v})$$

$$\vec{F}_{ext} = m\frac{d\vec{v}}{dt} + \vec{v}\frac{dm}{dt}$$

$$\vec{F}_{ext} = m\vec{a} + \vec{v}\frac{dm}{dt}$$

$$m\vec{a} = \vec{F}_{ext} - \vec{v}\frac{dm}{dt}$$

$\vec{v}\frac{dm}{dt} \rightarrow$ Thrust Force



Thrust Force

$$\vec{F}_t = \vec{v}\,\frac{dm}{dt}$$

$\mu = \frac{dm}{dt}$ = Rate of change of mass

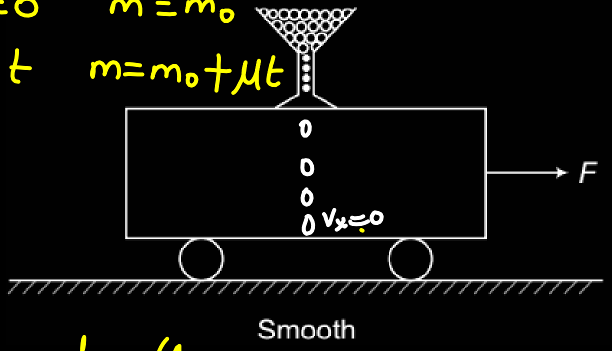
$$\boxed{F_t = \mu V}$$

Example

A constant force F is applied on a trolley of initial mass m_0 kept over a smooth surface at rest. Sand is poured gently over the trolley at a constant rate of μ kg/s. After time t, find the velocity of the trolley.

$t = 0 \quad m = m_0$

$t = t \quad m = m_0 + \mu t$

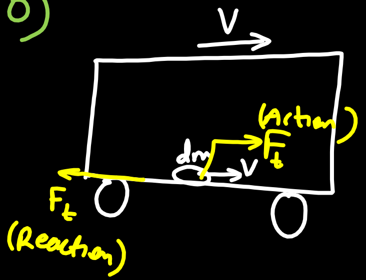


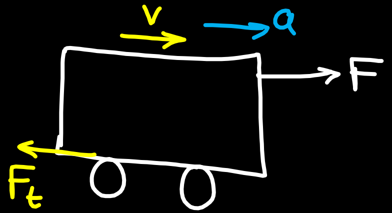
$dp = (dm)(v) - 0$

$f \cdot dt = (dm\, v - 0)$

$f = \frac{dm}{dt} v$

$f = \mu v$





$$F_{net} = ma$$

$$F - F_t = ma$$

$$F - \mu v = m\frac{dv}{dt}$$

$$\int_0^t \frac{dt}{m} = \int_0^v \frac{dv}{F - \mu v}$$

$$\int_0^t \frac{dt}{m_0 + \mu t} = \int_0^v \frac{dv}{F - \mu v}$$

$$\frac{1}{\mu}\ln(m_0 + \mu t)\Big|_0^t = \frac{1}{-\mu}\ln(F - \mu v)\Big|_0^v$$

$$\frac{m_0 + \mu t}{m_0} = \frac{F}{F - \mu v}$$

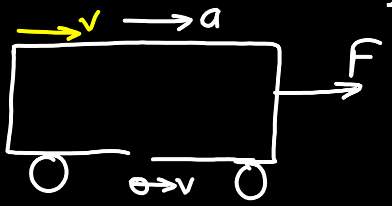
$$\frac{m_0}{m_0 + \mu t} = 1 - \frac{\mu v}{F}$$

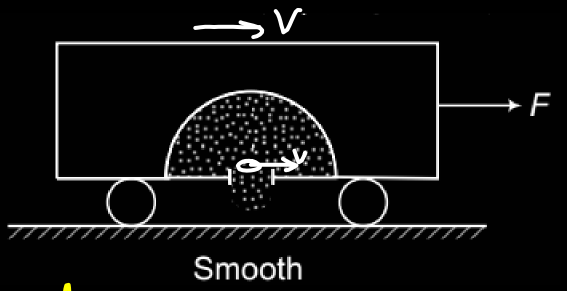
$$\frac{\mu v}{F} = \frac{\mu t}{m_0 + \mu t}$$

$$\boxed{v = \frac{Ft}{m_0 + \mu t}}$$

Example

A trolley of initial mass m0 is kept over a smooth surface as shown in figure. A constant force F is applied on it. Sand kept inside the trolley drains out from its floor at a constant rate of μ kg/s. After time t find the velocity of the trolley





$$F = ma$$

$$F = (m_0 - \mu t)\, a$$

$$F = (m_0 - \mu t) \frac{dv}{dt}$$

$$F \int_0^t \frac{dt}{m_0 - \mu t} = \int_0^v dv$$

$$\frac{F}{-\mu} \ln(m_0 - \mu t) \Big|_0^t = v$$

$$F_t = 0$$

$$dp = dm\, v - dm\, v$$

$$dp = 0$$

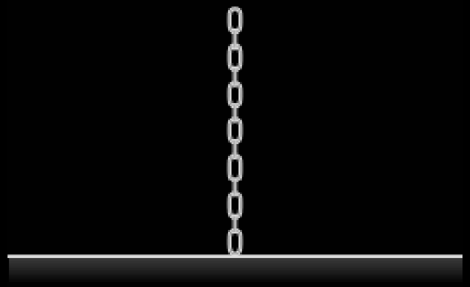
$$v = \frac{F}{\mu} \ln\left(\frac{m_0}{m_0 - \mu t}\right)$$

Q

HW

A uniform chain of mass m and length l hangs on a thread and just touches the surface of a weighing scale by its lower end. Find the reading of the scale when half of its length has fallen. The fallen part does not form heap.

(a) mg/2 (b) mg (c) 3mg/2 (d)



Variable Mass System

$$P_2 - P_1 = dP = \left[(m+dm)(v+dv)\right] - \left[dm\,u + mv\right]$$

$$dP = mv + m\,dv + dm\,v + dm\,dv - dm\,u - mv$$

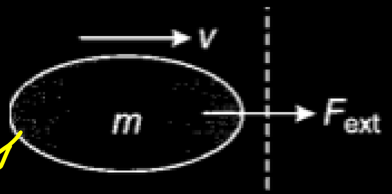
$$dP = m\,dv + dm(v-u)$$

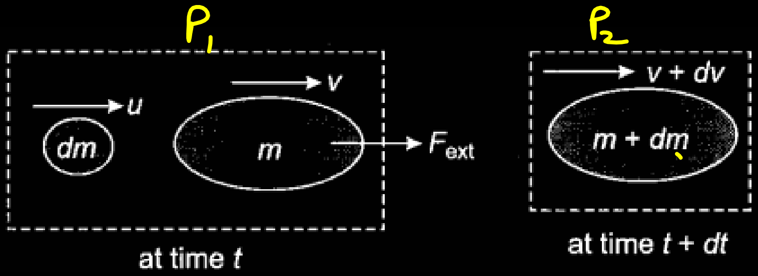
$$dP - dm(v-u) = m\,dv$$

$$dP + (u-v)\,dm = m\,dv$$

$$\frac{dP}{dt} + (u-v)\frac{dm}{dt} = m\frac{dv}{dt}$$

$$F_{ext} + (u-v)\frac{dm}{dt} = m\vec{a}$$





$$\vec{F}_{ext} + \vec{F}_{thrust} = \vec{F}_{net}$$

Variable Mass System

$$\vec{F}_{ext} + \vec{V}_r \frac{dm}{dt} = \vec{F}_{net}$$

$$F_t = V_r \frac{dm}{dt}$$

$$F_t = \mu V_r$$

Rocket Propulsion

$$F_{net} = F_t - mg$$

$$ma = \mu V_r - mg$$

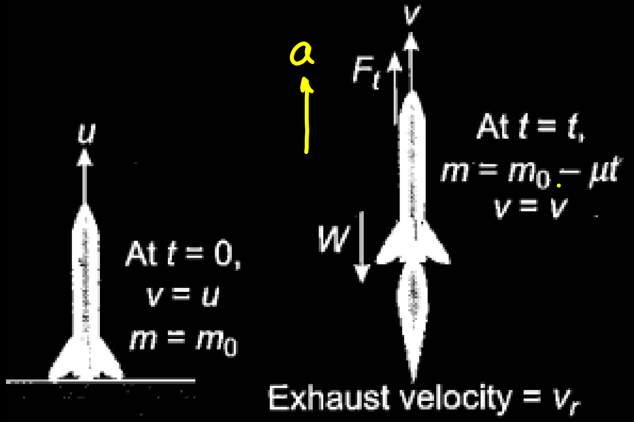
$$ma = \left(\frac{-dm}{dt}\right)V_r - mg$$

$$m\frac{dv}{dt} = -\frac{dm}{dt}V_r - mg$$

$$m\,dv = -dm\,V_r - mg\,dt$$

$$\int_u^v dv = -V_r\int_{m_0}^{m}\frac{dm}{m} - g\int_0^t dt$$

$$v - u = -V_r \ln\left(\frac{m}{m_0}\right) - gt$$



$$m = m_0 - \mu t$$

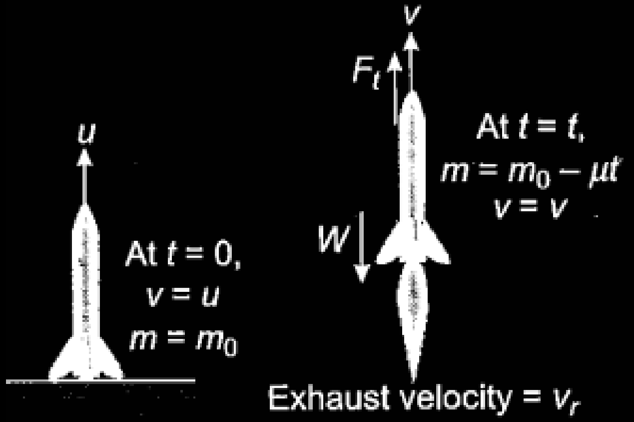
$$\frac{dm}{dt} = -\mu$$

$$-\frac{dm}{dt} = \mu$$

Rocket Propulsion

$$v = u + V_r \ln\left(\frac{m_0}{m}\right) - gt$$

$$v = u - gt + V_r \ln\left(\frac{m_0}{m_0 - \mu t}\right)$$



Generally

$u = 0$ & Ignoring Gravity

$$v = V_r \ln\left(\frac{m_0}{m_0 - \mu t}\right)$$

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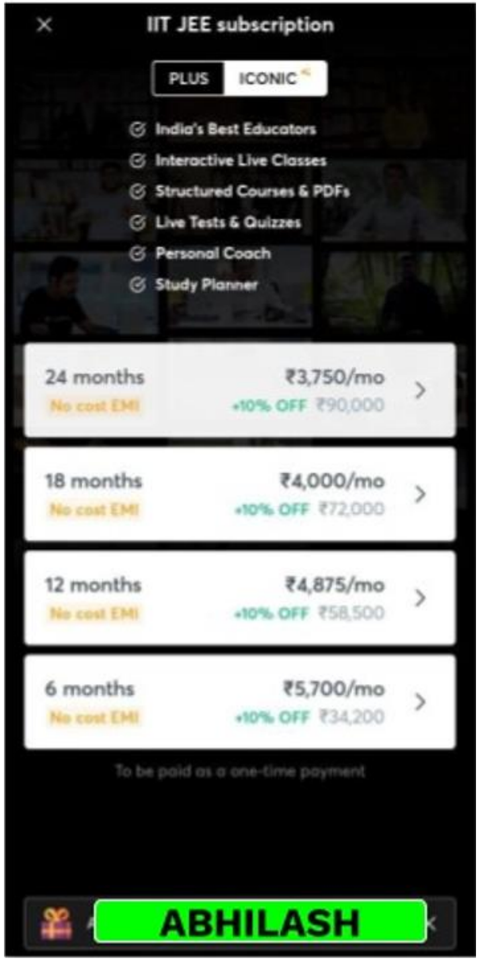
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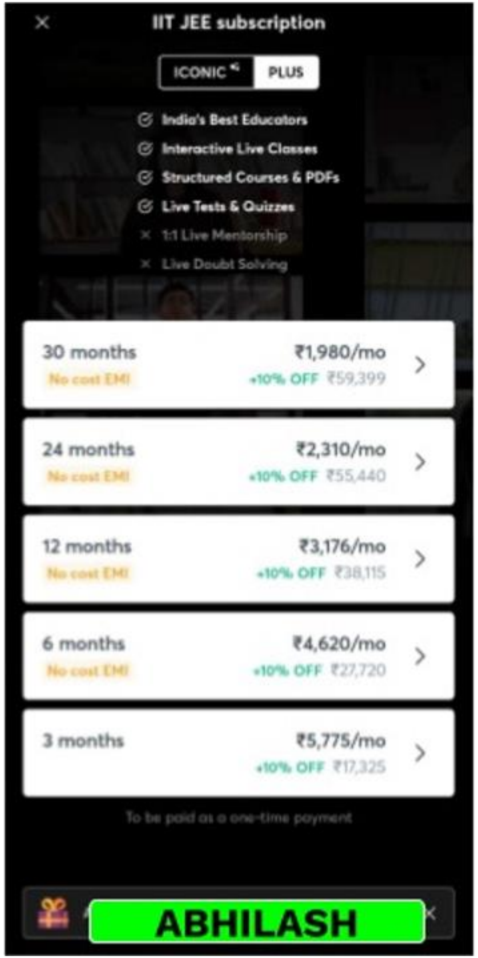
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