EPFL

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General Physics: Mechanics

PHYS-101(en)

Lecture 6b: Momentum, impulse, and center of mass

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Conceptual question

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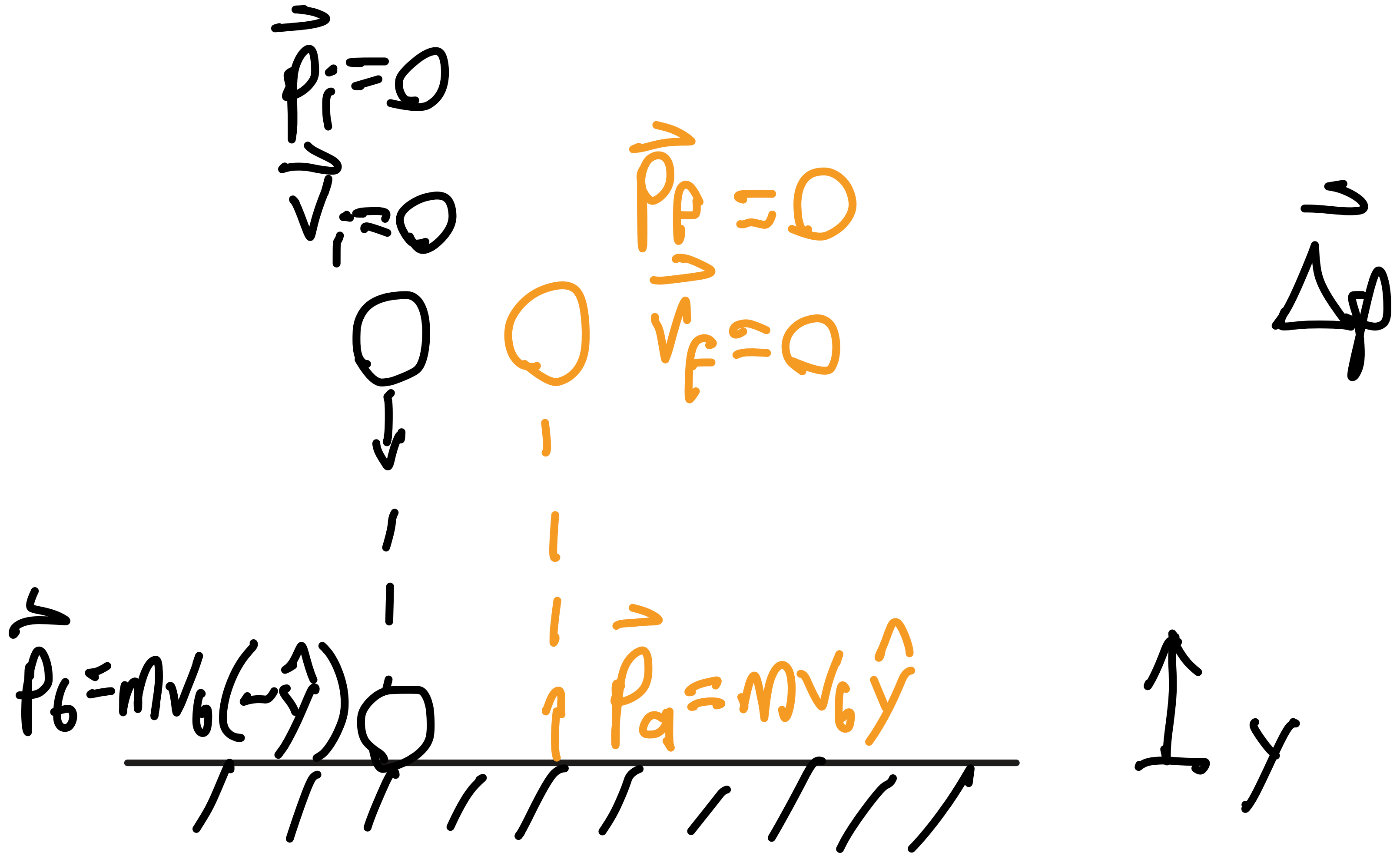
Session ID: epflphys101en

You drop a ball that bounces off the ground in a perfectly elastic manner. Is the ball's momentum conserved?

A. Yes

[✓ B. No]



$$\Delta\vec{p} = \vec{p}_a - \vec{p}_b = m v_b \hat{y} - (-m v_b \hat{y})$$
$$= 2 m v_b \hat{y}$$

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If you drop an egg on the floor, it will break, but if you drop it (from the same height) on a mattress, it won't. Why?

$\Delta t_{floor} < \Delta t_{matt}$

A. The change in momentum decreases…

[✓ B.] The average force decreases…

This may be true as well → C. The maximum force decreases…

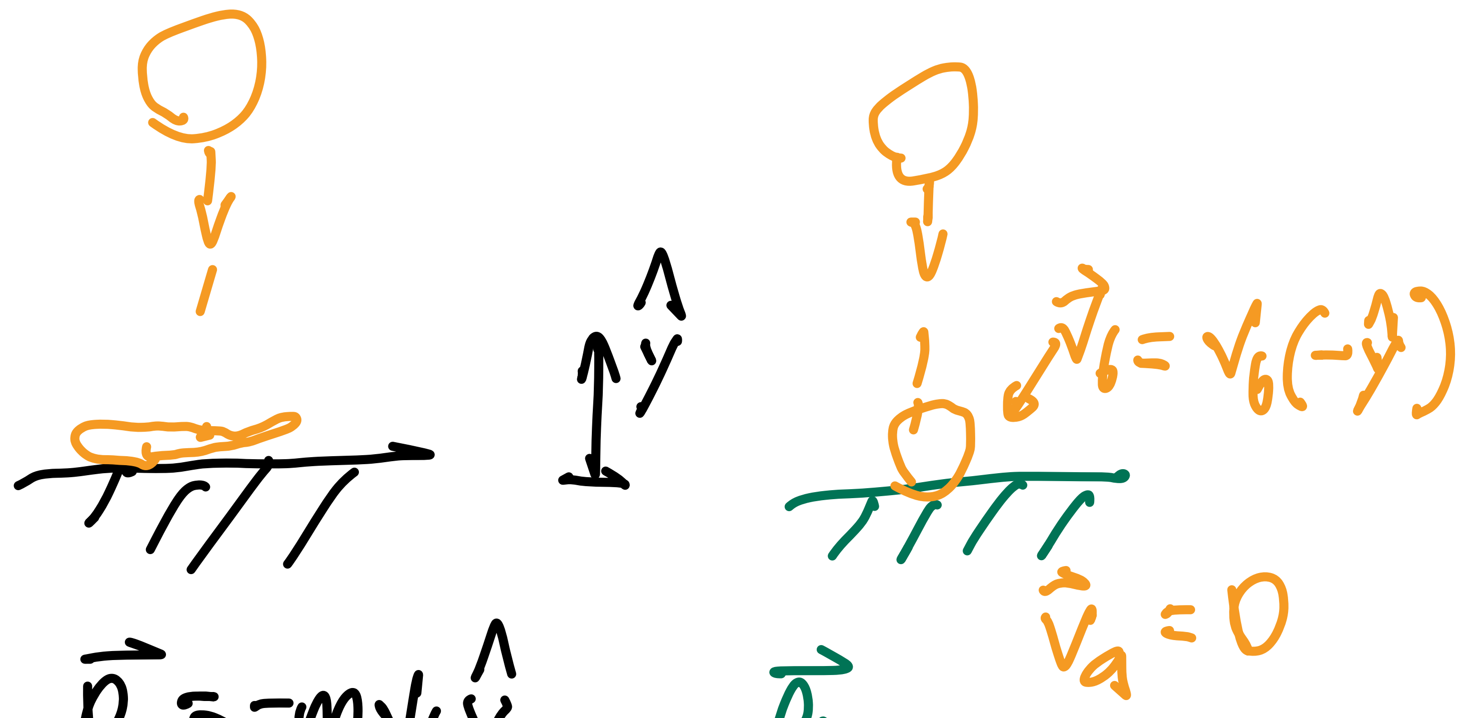
D. The impulse decreases…

E. None of the above.

when using the mattress.

$$\vec{I} = \vec{F}_{avg} \cdot \Delta t$$

$$\Rightarrow \vec{F}_{avg} = \frac{1}{\Delta t} \vec{I}$$



$$\vec{p}_b = -m v_b \hat{y} = \vec{p}_b$$

$$\vec{p}_a = 0 = \vec{p}_a$$

$$\vec{I} = \Delta \vec{p} = \vec{p}_a - \vec{p}_b = m v_b \hat{y} = \vec{I}$$

$$\vec{F}^{floor}_{avg} = \frac{1}{\Delta t_{floor}} \vec{I} > \vec{F}^{matt}_{avg} = \frac{1}{\Delta t_{matt}} \vec{I}$$

Conceptual question

When Javier Sotomayor broke the high jump world record (going over a 2.45 m high bar), did his center of mass also go over this height?

A. Yes, necessarily.

B. Not necessarily.

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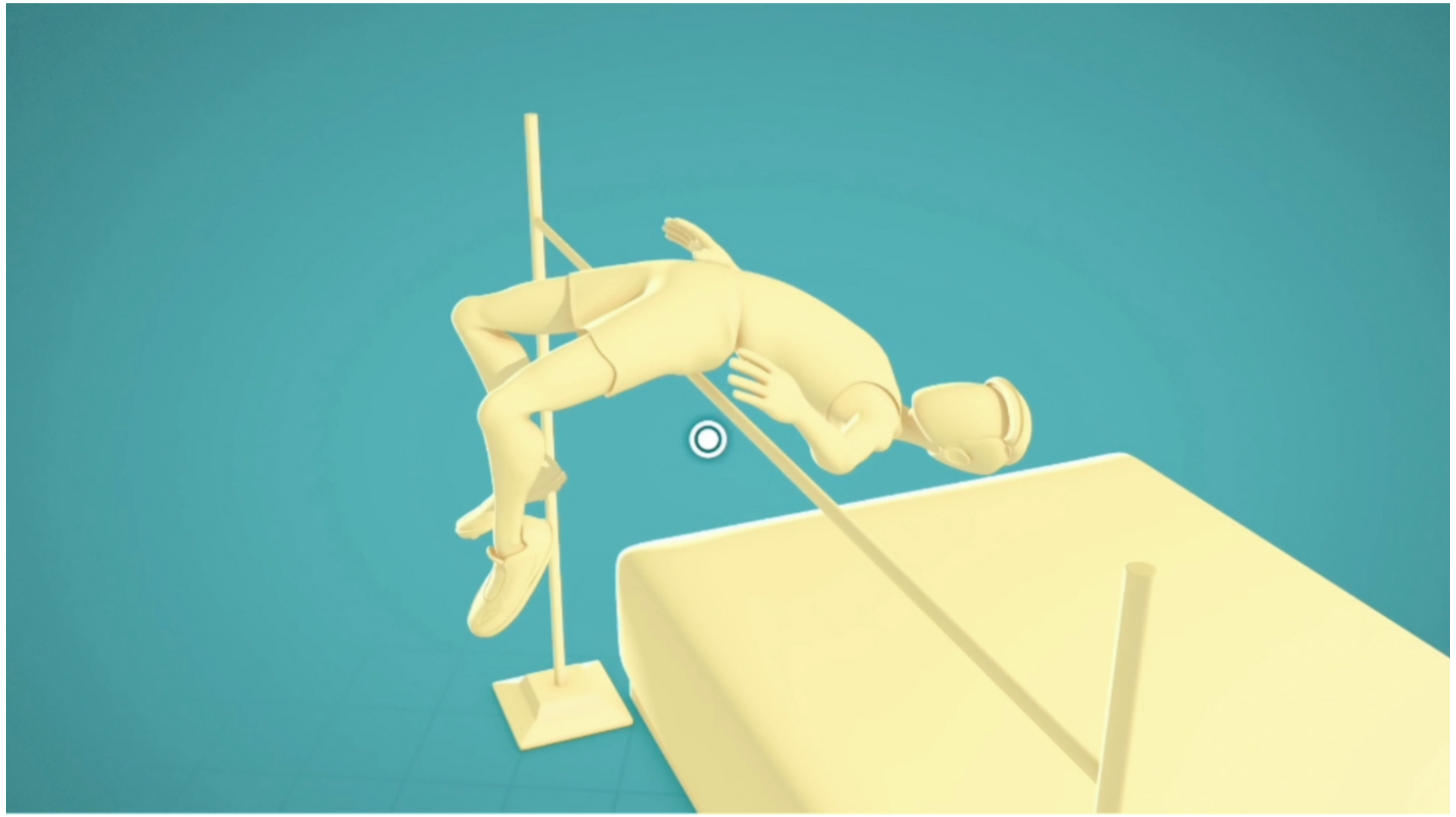
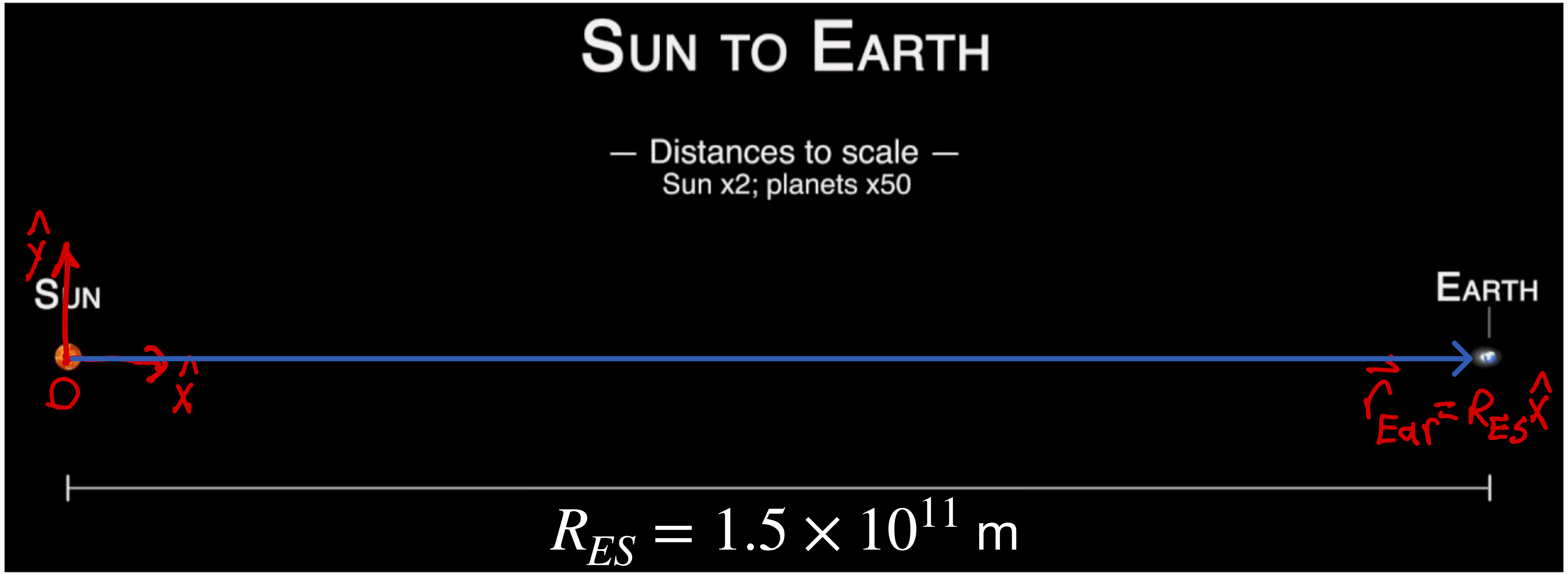
[✓ B.] Not necessarily.



Example: Center of mass Sun-Earth

The mean distance from the Earth to the Sun is $R_{ES} = 1.5 \times 10^{11}$ m. The mass of the Earth is $m_E = 6.0 \times 10^{24}$ kg and the mass of the Sun is $m_S = 2.0 \times 10^{30}$ kg. The mean radius of the Earth is $r_E = 6.4 \times 10^6$ m. The mean radius of the Sun is $r_S = 6.4 \times 10^8$ m. Where is the location of the center of mass of the Earth-Sun system?



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$$\vec{R}_{CM} = \frac{m_S \overset{0}{\cancel{\vec{r}_S}} + m_E \overset{R_{ES}\hat{x}}{\vec{r}_{\underline{Ear}}}}{m_S + m_E} = \frac{m_E}{m_S + m_E} R_{ES}\hat{x} \approx \frac{m_E}{m_S} R_{ES}\hat{x} = \frac{6 \cdot 10^{24}\,\cancel{\text{kg}}}{2 \cdot 10^{30}\,\cancel{\text{kg}}} \cdot 1.5 \cdot 10^{11}\,\text{m}\,\hat{x}$$

$$= 3 \cdot 10^{-6} \cdot 1.5 \cdot 10^{11}\,\text{m}\,\hat{x}$$

$$= 4.5 \cdot 10^{5}\,\text{m}\,\hat{x}$$

$$= \underline{450\,\text{km}\,\hat{x}}$$

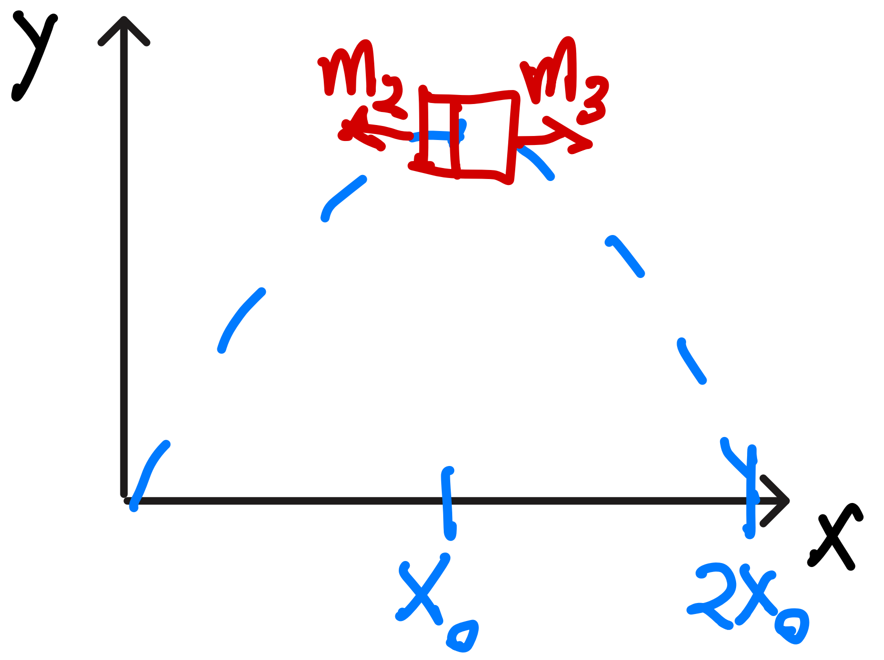
$$< r_E << r_S$$

Example: Exploding projectile

An instrument-carrying projectile of mass m_1 accidentally explodes at the top of its trajectory. The horizontal distance between launch point and the explosion is x_0. The projectile breaks into two pieces that fly apart horizontally. The larger piece, m_3, has three times the mass of the smaller piece, m_2. To the surprise of the scientist in charge, the smaller piece returns to earth at the launching station. Neglect air resistance and effects due to the earth's curvature.

$m_3 = 3m_2$

How far away, x_3^f, from the original launching position does the larger piece land?



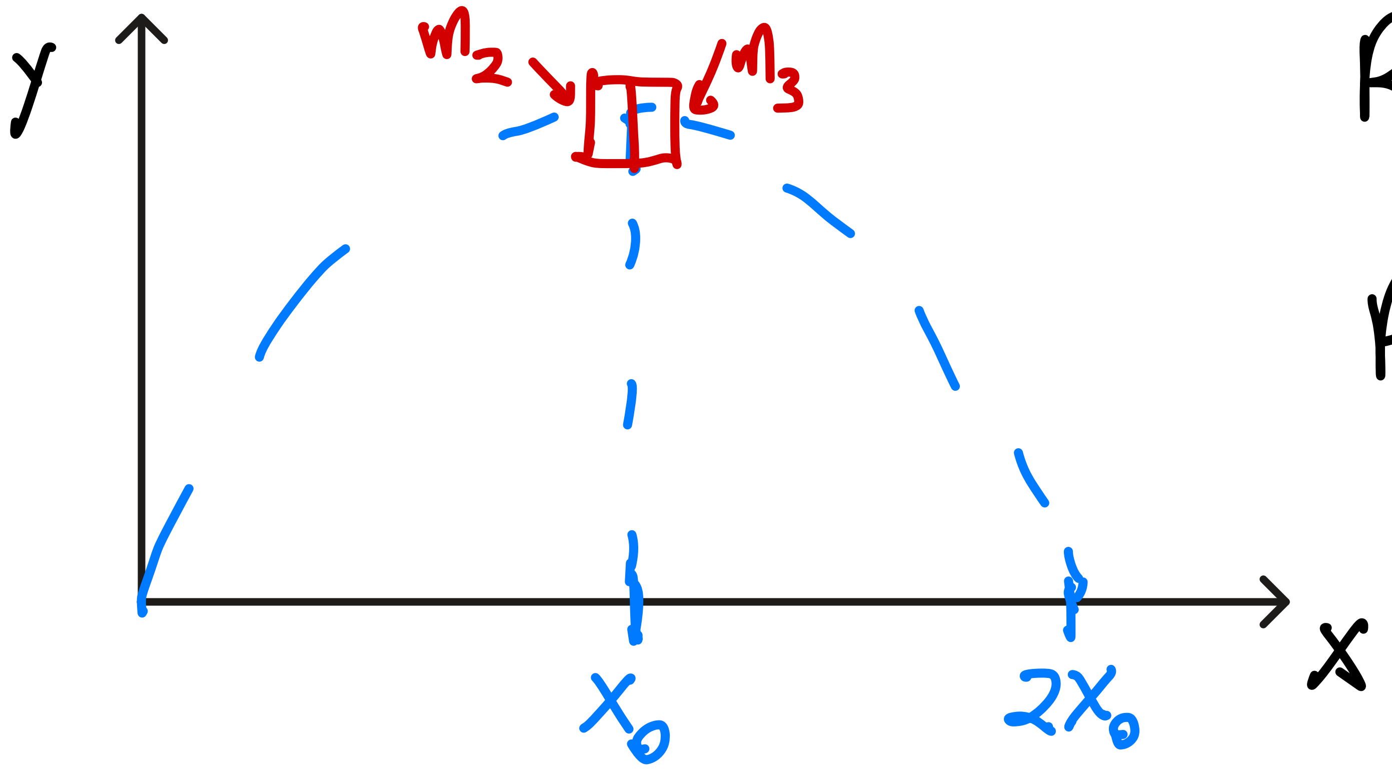
$$\vec{R}_{CM} = \frac{m_2\vec{r}_2 + m_3\vec{r}_3}{m_2+m_3} \Rightarrow X_{CM} = \frac{m_2X_2+m_3X_3}{m_2+m_3}$$

$$\underline{X_{CM}^f} = \frac{m_2\overset{0}{\cancel{X_2^f}} + m_3X_3^f}{m_2+m_3} = \frac{m_3}{m_2+m_3}X_3^f \Rightarrow m_3X_3^f = (m_2+m_3)\cdot 2x_0$$

$$= 2X_0$$

$$\Rightarrow x_3^f = 2x_0\left(\overbrace{\frac{m_2}{m_3}}^{=\frac{1}{3}} + \underbrace{\frac{m_3}{m_3}}_{=1}\right) = 2x_0\cdot\frac{4}{3} = \boxed{\frac{8}{3}x_0}$$

Example: Exploding projectile



If $x_0 = v_1 T \Rightarrow T = \frac{x_0}{v_1}$

$m_3 = 3m_2$

$m_1 = m_2 + m_3 = m_2 + 3m_2 = 4m_2$

$$\Rightarrow \frac{m_1+m_2}{m_3} = \frac{4m_2+m_2}{3m_2} = \underline{\frac{5}{3}}$$

Velocity of m_1 along x: $v_1\hat{x}$

Right before explosion: $\vec{p}_b = m_1 v_1 \hat{x}$

Right after explosion: $\vec{p}_a = m_2 \underbrace{v_2}_{-v_1}\hat{x} + m_3 v_3 \hat{x} = -m_2 v_1 \hat{x} + m_3 v_3 \hat{x}$

$$\vec{p}_b = \vec{p}_a \Rightarrow m_1 v_1 = -m_2 v_1 + m_3 v_3 \Rightarrow (m_1+m_2) v_1 = m_3 v_3$$

$$\Rightarrow v_3 = \frac{m_1+m_2}{m_3} v_1 = \frac{5}{3} v_3$$

$$\Rightarrow \underbrace{v_3 T}_{x_3^f - x_0} = \frac{5}{3} v_1 T = \frac{5}{3} x_0$$

$$\Rightarrow x_3^f - x_0 = \frac{5}{3} x_0 \Rightarrow \boxed{x_3^f = \frac{8}{3} x_0}$$