

The center of mass of an object is not necessarily a physical location on the object. The center of mass of an object is the mass-weighted average position of all of the mass within an object; therefore, the center of mass of an object can be physically outside the object. Some possible examples: banana, horseshoe, golf club, donut, etc.



Finding the center of mass of the Earth and Moon system:

Knowns:  $R_{(\text{Earth to Moon})_{\text{average}}} = 3.844 \times 10^8 \text{m}$ ;  $M_E = 5.972 \times 10^{24} \text{kg}$ ;  $M_M = 7.348 \times 10^{22} \text{kg}$ ;  $x_{CM} = ?$



$$x_{CM} = \frac{M_E x_E + M_M x_M}{M_E + M_M} = \frac{(5.972 \times 10^{24})(0) + (7.348 \times 10^{22})(3.844 \times 10^8)}{5.972 \times 10^{24} + 7.348 \times 10^{22}}$$

$$\Rightarrow x_{CM} = 4,672,203 \text{m} \ \& \ R_{\text{Earth}} 6.378 \times 10^6 \text{m}$$

$$\Rightarrow 6,378,000 - 4,672,203 = 1,705,797 \text{m} \left( \frac{1000 \text{m}}{1 \text{km}} \right) \approx 1,700 \text{km} \ (x_{cm} \text{ below Earth's surface})$$



$x = 0$  (Relative diameters between Earth and Moon are correct, however, distance between Earth and Moon as shown is way too small.)

Some questions which address net force stumbling blocks:

- Can an object moving at a constant velocity have more than one force acting on it?
  - Yes, however, those forces must balance out to cause zero net force on the object. That will make the acceleration of the object zero and mean the object is moving at a constant velocity.

$$\cdot \sum \vec{F} = m\vec{a} = \vec{0} \Rightarrow \vec{a} = \vec{0} \Rightarrow \vec{v} = \text{constant}$$

- This is called Translational Equilibrium.

- Can an object move at a constant velocity and have zero forces acting on it?
  - Yes, this will also cause a net force of zero on the object.
- Can an object move at a constant velocity and have only one force acting on it?
  - No, it is impossible for one force to have a net force of zero, so the object will be accelerating and the velocity of the object will not be constant.

$$\cdot \sum \vec{F} = m\vec{a} \neq \vec{0} \Rightarrow \vec{a} \neq \vec{0} \Rightarrow \vec{v} \neq \text{constant}$$

- Does a moving object have to have a force acting on it in the same direction as its velocity?
  - No, there are plenty of examples of this. Here is one: A hockey puck which is sliding and slowing down has a force of kinetic friction from the surface opposite its velocity direction, an upward force normal, and a downward

force of gravity. None of those forces are in the same direction as the direction of the velocity of the hockey puck.

- *Are the force normal and force of gravity acting on an object always equal in magnitude?*
  - No, this is true when the upward force normal and the downward force of gravity are the only forces acting on the object in the y-direction and the object is not accelerating in the y-direction.
    - $\sum F_y = F_N - F_g = ma_y = m(0) = 0 \Rightarrow F_N = F_g$
    - There are other specific examples where the force normal and force of gravity could have the same magnitude.
      - An object on a ceiling being pushed upward with an applied force which has twice the magnitude as the force of gravity.
      - An object on a 60° incline with a force applied down and normal to the incline which has a magnitude which equals half the magnitude of the force of gravity.

*Weight and mass are not the same.* If you have any questions about this, I have an entire [video](#) for you!!

*The force of gravity parallel is always, ALWAYS, directed down the incline.*

*Please never, ever write  $F = ma$ .* You are not some riffraff member of the regular populace; you are a Flipping Physics student!

$$\bullet \sum \vec{F} = m\vec{a}$$

*Free Body Diagrams:*

- I am sorry, however, I have too much to say about free body diagrams. They will have to have their own video which is in my [Ultimate Exam Slayer](#).<sup>1</sup>

*Newton's Third Law:*  $\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$

- Both objects exert the same magnitude force on the other object.
  - The more massive object does not apply a larger force on the less massive object.
- Both objects do not have the same acceleration.
  - The object with the larger mass will have a smaller acceleration. (see Newton's Second Law)
    - This assumes the net force is the same in both instances.

---

<sup>1</sup> Note to self: I want to make this a free portion of my UES, however, I need to make sure I will have enough not free videos in my "Exam Tips" section first.



- Newton's Third Law force pairs act on different objects.
  - They are not both in the free-body diagram for a single object.
- Both forces act at the same time. This is not an action/reaction event.

*There is only one force acting on an object in free-fall.* That force is the force of gravity and it is always directed straight toward the center of the planet which is, by definition, always down.

- When the object is moving upward in free-fall, the force of gravity is still down. The force of gravity accelerates the object downward; this slows the speed of the object down as it moves upward.
- The object still has a force of gravity acting downward on it when it is at the top of its path and momentarily has zero velocity. That force of gravity is still accelerating the object downward; this switches the velocity from being upward to downward at the top of the path.
- $\sum F_y = -F_g = ma_y \Rightarrow -mg = ma_y \Rightarrow a_y = -g$