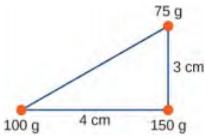
# 4.E: Systems and the Center of Mass Exercises

## Conceptual Questions

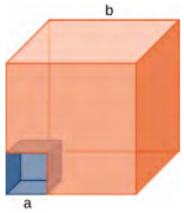
1. Suppose a fireworks shell explodes, breaking into three large pieces for which air resistance is negligible. How does the explosion affect the motion of the center of mass? How would it be affected if the pieces experienced significantly more air resistance than the intact shell?
2. It is possible for the velocity of a rocket to be greater than the exhaust velocity of the gases it ejects. When that is the case, the gas velocity and gas momentum are in the same direction as that of the rocket. How is the rocket still able to obtain thrust by ejecting the gases?

## Problems

3. Three point masses are placed at the corners of a triangle as shown in the figure below. Find the center of mass of the three-mass system.




4. Two particles of masses $m_1$ and $m_2$ separated by a horizontal distance D are released from the same height h at the same time. Find the vertical position of the center of mass of these two particles at a time before the two particles strike the ground. Assume no air resistance.
5. Two particles of masses $m_1$ and $m_2$ separated by a horizontal distance D are let go from the same height h at different times. Particle 1 starts at t = 0 , and particle 2 is let go at t = T. Find the vertical position of the center of mass at a time before the first particle strikes the ground. Assume no air resistance.
6. A cube of side a is cut out of another cube of side b as shown in the figure below. Find the location of the center of mass of the structure. (**Hint**: Think of the missing part as a negative mass overlapping a positive mass.)




7. A 5.00-kg squid initially at rest ejects 0.250 kg of fluid with a velocity of 10.0 m/s. (a) What is the recoil velocity of the squid if the ejection is done in 0.100 s and there is a 5.00-N frictional force opposing the squid's movement? (b) How much energy is lost to work done against friction?
8. A rocket takes off from Earth and reaches a speed of 100 m/s in 10.0 s. If the exhaust speed is 1500 m/s and the mass of fuel burned is 100 kg, what was the initial mass of the rocket?
9. Repeat the preceding problem but for a rocket that takes off from a space station, where there is no gravity other than the negligible gravity due to the space station. 8
10. How much fuel would be needed for a 1000-kg rocket (this is its mass with no fuel) to take off from Earth and reach 1000 m/s in 30 s? The exhaust speed is 1000 m/s.
11. What exhaust speed is required to accelerate a rocket in deep space from 800 m/s to 1000 m/s in 5.0 s if the total rocket mass is 1200 kg and the rocket only has 50 kg of fuel left?
12. **Unreasonable Results** Squids have been reported to jump from the ocean and travel 30.0 m (measured horizontally) before re-entering the water. (a) Calculate the initial speed of the squid if it leaves the water at an angle of 20.0°, assuming negligible lift from the air and negligible air resistance. (b) The squid propels itself by squirting water. What fraction of its mass would it have to eject in order to achieve the speed found in the previous part? The water is ejected at 12.0 m/s; gravitational force and friction are neglected. (c) What is unreasonable about the results? (d) Which premise is unreasonable, or which premises are inconsistent?

## Additional Problems

13. If the entire population of Earth were transferred to the Moon, how far would the center of mass of the Earth-Moon-population system move? Assume the population is 7 billion, the average human has a mass of 65 kg, and that the population is evenly distributed over both the Earth and the Moon. The mass of the Earth is $5.97 \times 10^{24}$ kg and that of the Moon is $7.34 \times 10^{22}$ kg. The radius of the Moon's orbit is about $3.84 \times 10^{5}$ m.
14. Two friends are in small boats. The mass of the first boat plus the person is 300 kg; the mass fo the second boat plus the person is 400 kg. They have a rope between the two boats that is 30 feet long. If both friends pull slowly on the rope, how far will the lighter person move?
15. You friend wonders how a rocket continues to climb into the sky once it is sufficiently high above the surface of Earth so that its expelled gasses no longer push on the surface. How do you respond?
16. To increase the acceleration of a rocket, should you throw rocks out of the front window of the rocket or out of the back window?

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