Madeline, 8th grade
If one cone with a diameter of 10 cm and one of 20cm both fall from 2 meters, why will the 20cm one fall slower (focusing on air resistance and surface area)?

One thing you learn very quickly when you do science, Madeline, is that scientists need to be very particular about the questions they ask and how they ask them. Questions must be **precise** (asking only one specific thing) and **accurate** (asking exactly the thing you want to ask).

What does this have to do with air resistance?

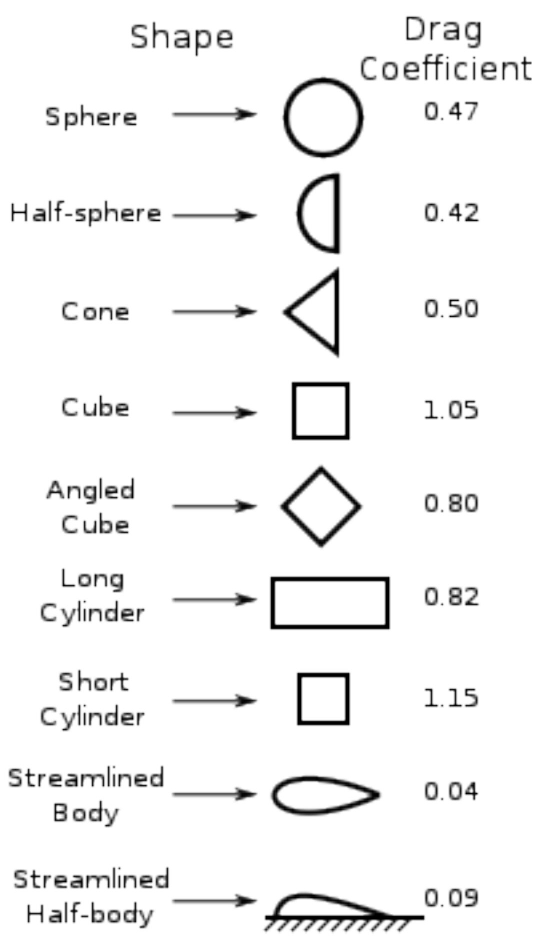
Well, depending on how one interprets your question, the answer could range from "the 20cm cone falls slower" to "the 10cm one falls slower" to "they both fall the same" to even "neither, they both fly away into the sky!"

Let's take a look at why:

When objects fall through the atmosphere, there can be many different **forces** acting on them. As you may have learned in a physics class, a force is anything that accelerates an object. (Note that scientists use the word "accelerate" to mean "to change the speed of an object" or "to change the direction an object is moving"). Among these forces, the most important are the **gravitational** force, **drag** (also called air resistance or fluid resistance), and the **buoyant** force.

The **gravitational force** is one you should be very familiar with. Massive objects (like the earth) exert a force on other objects with mass (like you!) toward their center. The way gravity works, the force on an object is **proportional to** its mass (so if your friend weighs twice as much as you do, the earth pulls twice as hard). Physicists still aren't quite sure why gravity exists or why the gravitational force only seems to care about how much mass things have, but the important takeaway for this question is that because of how gravity's force scales with mass, **all objects in the absence of wind resistance will fall at the same rate.** (You can show this using Newton's second law: **F=ma**. If **F**orce always doubles when **m**ass doubles, then **a**cceleration is always the same!) Here's a sweet video from the 1971 Apollo mission to the moon where Commander Astronaut David Scott drops a feather and a hammer at the same time on the moon to see if they fall at the same rate in a vacuum: http://youtu.be/5C5_dOEyAfk This means that **if you dropped both of your cones on the moon, they would land at the same time!**

Drag force is kind of like friction, which is the force that resists the motion of solid surfaces on solid surfaces. Friction is the reason car tires can stop, it's why gears wear out and need oil, and it's why your hands get warm when you rub them together really fast. Drag is the friction caused when a fluid (like air) rubs against the surface of an object when it's moving. However unlike regular friction (which only depends on what the surfaces are made of and the forces between them) drag depends on surface area, velocity, and shape. Very generally, as an object's velocity increases, its drag increases. That's why it's easy to accelerate from 0 to 5 miles per hour on your bike, but very hard to accelerate from 10 to 15 miles per hour on a bike. The biggest difference is that the faster you go, the harder air drags. Additionally, the more surface area something has, the more drag there is. In this case, surface area doesn't mean total surface area but rather the surface area facing the direction of motion. If you stick your hand out of a moving car's window with your palm facing down toward the ground you feel a little force from the wind, but when you turn your palm toward the direction of the wind you feel a much greater force! The surface area of the skin on your hand doesn't change, but the surface area facing the wind does. Finally, shape can affect air drag too, but those effects are more subtle and complicated to explain. Here's a chart that gives **drag coefficients** for different shapes. A drag coefficient is a relative number that tells you how an object's shape affects drag, all other factors being equal. Higher numbers mean more drag; lower numbers mean less drag. Notice how the shapes that look like airplane wings have almost no drag!

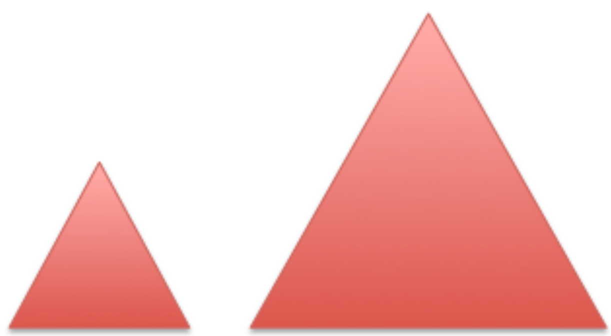


Measured Drag Coefficients

In your case, if your two cones had the same mass and merely had a different shape, the 20cm diameter one falls slower because it has more surface area facing the wind, just like your hand gets pushed harder by the wind out a car window when you point your palm toward the wind! This is the case in the blue diagram.

However, if your cones had different mass, your story would be very different. What if instead of changing the *shape* of your cone, you just change the *size* so that they two cones look the same? This is the case in the red diagram.

Change shape, change diameter, but constant mass



Change diameter, change mass but same shape

In this case, the mass and surface area increase. This means that drag increases, but the gravitational force also increases because gravity pulls harder on things with more mass. Which force wins? Does drag increase faster or does gravitational force increase faster?

The answer lies in scaling. Surface area, and therefore drag, increases with the diameter squared. You may have seen the equation for the area of a circle: $A=\pi r^2$. That r-squared term means that every time you double the radius, you increase the area by a factor of $2^2=4$. Volume, which is related to mass and therefore the gravitational force, is related to the diameter *cubed* (to the 3rd power). If you look up the volume of a cone, you'll find that it has an r^3 term in it. This means that if you double the radius, the mass increases by a factor of $2^3=8$! Therefore the gravitational force from mass increases faster than the drag force from surface area, so **if your cones are similar, meaning they look like the same shape, then your 20cm cone will actually fall faster than the smaller cone!** This is the same reason that sand falls faster than dust and why big bubbles in soda rise faster than small bubbles in soda (you can think of bubbles as "falling up" in your glass.)

The **buoyant force** is related to the **density** of the fluid an object is in. (It sounds weird, but air is technically a fluid) When you float in a pool, you float because the water pushes against gravity with a force equal to the weight of water you displace. A brick one gallon in volume sinks because it weighs more than a gallon of water. Put another way, bricks sink because they are denser than water. However, bricks fall slower in water than in air primarily because of the buoyant force on them. Air is much less dense than water, bricks, or whatever you normally happen to be talking about so under most circumstances people ignore the buoyant force when discussing air. However, if your cones are similar in density or lighter than air, the buoyant force becomes important. Imagine your cones are hollow and are filled with helium gas (the same gas in balloons). **If your cones are less dense than air, when you drop them from 2 meters, neither falls slower than the other because they will both float into the air!**

So, the important takeaway here should be as follows: the difference between the answer to the question that you think you're asking and the question someone else thinks you're asking can be exact opposites if neither of you ask for clarification. This is true in science, but it's also true in life. If two people are arguing and seem not to understand or listen to each other at all, maybe it's best to start at square one and make sure that no one is talking about cone-shaped balloons. ☺