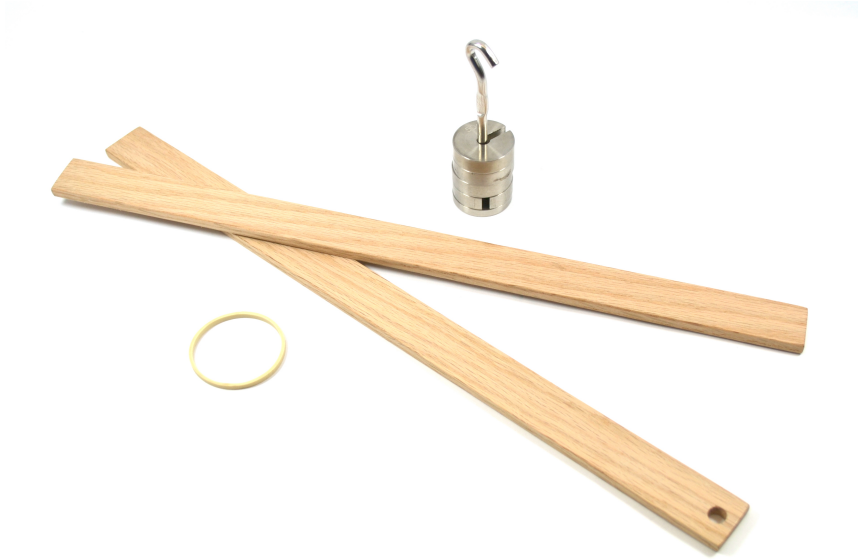
GARAGE PHYSICS by eisco



Center of Mass Kit

GP00003

Center of Mass or *center of gravity* is the unique point on any solid body about which the weight is balanced in all directions. It is also the point where if a force is applied, the motion of the object is in the same direction as the force. If the force is applied away from the center of mass, it must additionally rotate. You already take into account your own center of mass everyday. If you were to ever lean over too far, your center of mass would topple you over. **Try it!**

With this kit, we will explore the center of mass of a two body system, to discover how we can extend our weights over the edge of a table.

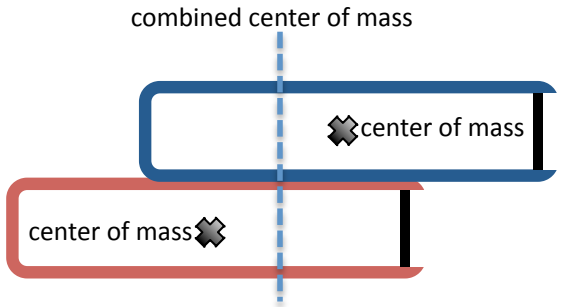
Next Generation Science Standards (NGSS):

PS2 Motion and Stability: Forces and Interactions

To try: Take a bunch of hardcover books, all of about the same size. We are going to see how far you can stack them over the side of a table.

Place the first book so it is almost entirely over the table, and just a little hanging over. Place the second book so it is on top of the first book, but hanging over in the same direction as the first. Continue placing books on top a little further over the edge… until they topple!

The point where they topple over is when the combined center of mass of all the books extends past the table edge.



Try again with a different order of books, see if you can get them to hang further out with the heavier books on the bottom. Think of how this affects the center of mass.

To try: Can you bend over and touch your toes while standing up? Go ahead and try it now. If you are flexible enough, you should be able to do so easily.

There is one place in the room where no one can touch their toes though! Stand with your heels and your back all the way against a wall. Now try to bend over and touch your toes. Can't do it, can you? Don't feel bad, it is almost impossible for all humans.

To find out why, go ahead and try in the middle of the room again. As you bend over, notice where your body goes. You should notice that your back side actually moves further back to keep you in balance as the top of your body moves forwards. This keeps your center of mass over your feet and prevents you from tipping over. With your back against a wall, your body can't compensate!

Try this too: Can you stand on the tips of your toes? Ballerinas spend most of a performance on their tip toes, see if you can as well.

Try to stand on the tips of your toes when you are facing a wall. Place your toes all the way against the wall, and lean forward so your nose touches the wall as well. Go ahead and try to stand on your tippy toes again… and you can't!

Can you come up with a reason why this is not possible? Think about it in terms of the same reason you weren't able to bend over with your back against the wall.

Find the center of mass:

Take the stick without the hole in it. Find the point lengthwise that you can balance it on your finger without it tipping over. This is the stick's center of mass. It should be the very middle of the stick, since if the wood is of even density, there is an equal amount of mass on either side of the stick. Check this with a ruler; the stick is 15.5 inches long so the middle point is 7.75 inches to either side of the stick.

Now take the ruler and mark in half inches along one side of the stick from the center of mass to the end of the stick. Make a mark every half inch until the end.

Testing the center of mass:

Put the stick flat on a table with the short side of the stick along the edge of the table. Then slowly push the stick over the edge. At what point does the stick topple over the side of the table? It should be when the center of mass passes over the edge of the table.

What if we want to hang the stick further off the table?

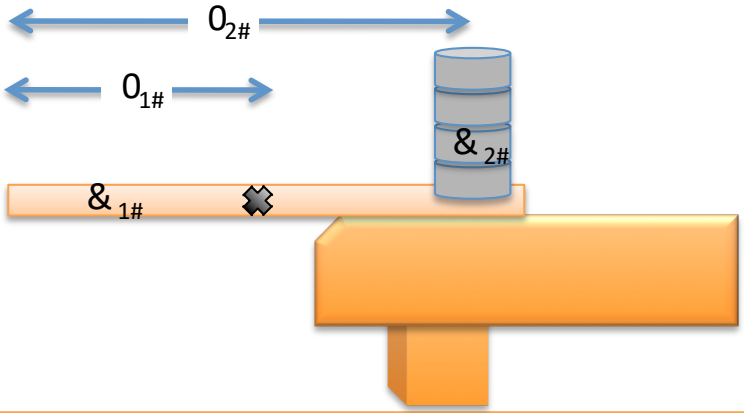
Can you think of a way to keep the stick from falling over? One way is to place something heavy on the stick. You may think that you are keeping it on the table because you are weighing it down, but really you have modified the center of mass of the system (the stick plus the weight) so now the center of mass is over the table.

Center of mass of two objects:

It is simple to calculate the center of mass of two objects. To do so, we first add the positions of the center of mass of each object, multiply by their own mass, and then divide by the total mass of the system or:

$$X_{cm} = m_1x_1 + m_2x_2 / (m_1 + m_2)$$

To try: Place the stick on top of a table again. Take the four 50 gram masses from the hanger and place them one on top of another at the end of the stick.



Since we have a light weight (the stick) with its center of mass in the middle of the stick, and a much heavier weight on the end of the stick, think about where the center of mass of the whole system is now. Is it near the center of the stick, or has it moved more towards the end of the stick?

You can calculate the new center of mass with the equation on the left.

To try: Now slide the stick with masses toward the edge of the table. Can you move the stick so the old center of mass is over the edge of the table? At what point does the stick topple over?

Now set up the stick and masses again and slide over the edge of the table so that the stick is just before it is about to fall over. What would happen if you remove one of the weights now? Test your hypothesis!

Balancing Trick:

There is a second way that we can extend the first stick past its center of mass. Instead of placing a mass on top of it, we can counter balance it underneath the table. To do so, we will need the second stick, rubber band, and the masses on the hanger. Place the two sticks on top of each other and thread a rubber band around the middle of the sticks, then hook the mass through the hole in the second stick and hang on the edge of a table so it resembles the figure below.

Why does it not tip? At first glance it may look like the system should tip over, but now we know better! Of course the system's center of mass is located before the edge of the table.

To try: Place the upper stick so it barely rests on the edge of the table. Carefully remove one weight at a time. What do you think will happen when you remove too much weight? Where is the center of mass when it finally tips over?#

Advanced Calculation:#

To calculate the center of mass of the three bodies (the two sticks and the hanging mass) we can use the following equation.

$$X_{cm} = m_1x_1 + m_2x_2 + m_3x_3 / (m_1 + m_2 + m_3)$$

You can use the marks you made on top to estimate the projected distance from the end of the upper stick horizontal to the table. Or if you are familiar with trigonometry, use the included protractor to measure the angle between the two sticks. Take the cosine of the angle and multiply by the length along the bottom stick to determine the distances labeled x1 and x2.