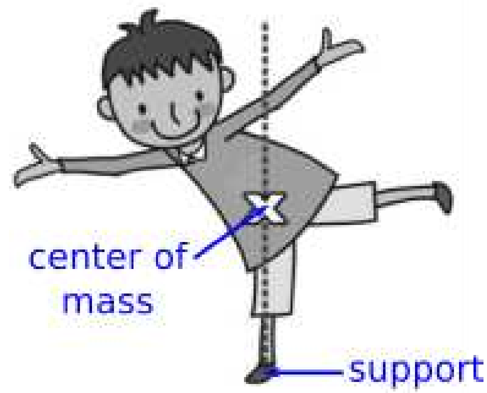
Center of Mass and Balance

- **Gravity** pulls down an object as if it were pulling on a special point called the "**center of mass**".
- To stay balanced, an the center of mass has to be over (or below) he support of the object
- The center of mass depends on the object shape and where the heaviest parts are.
- To be in **stable equilibrium** (righting itself when pushed) the center of mass of an object should be as low as possible.



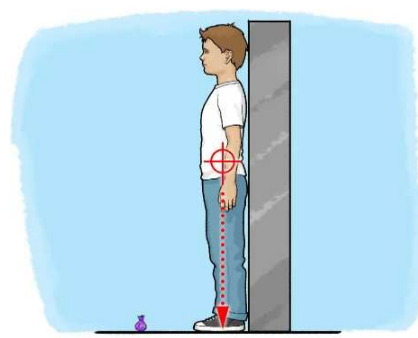
Part 1: Bet You Can't!

The following challenges may seem simple – but the Laws of Physics will be working against you. And they are not to be defied.

1. Bet you can't balance on one leg!
Stand sideways with your shoulder against a wall (or door). You right foot should be sideways up against the wall. Try lifting up your left foot to balance on one leg.

Could you do it? ______________________________

2. Bet you can't pick up a coin!
Stand with your back and heels against the wall. Have a helper place a coin a couple inches front of your toes. Without moving your feet, try leaning over to pick up the coin.



Could you do it? ______________________________

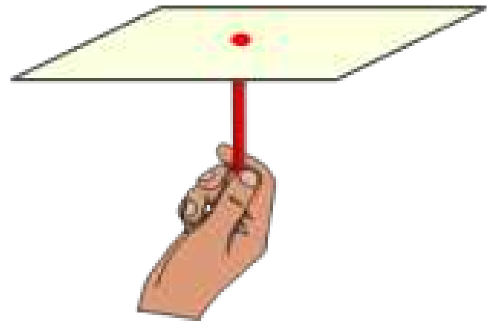
In order to stay balanced, the **center of mass** of an object has to be over its base of support. Otherwise the object topples over. When we're standing up, we adjust the shape of our bodies so that our center of mass is over our feet – you learn to do this as a baby learning to walk. When leaning forward, you need to shift your rear end backward to stay balanced. If there is a wall behind you preventing this, the center of mass moves forward beyond your feet as you lean, and you topple forward.

Part 2: Finding the Center of Mass

Let's try our hand at finding the center of mass of an object. Finding the center of mass of a symmetric object is easy – it will be right in the center.

1. Measure and cut an 8" by 6" rectangle of cardboard

2. Measure and mark a point exactly in the middle of your rectangle (4" from the side and 3" from the top).



3. Put the eraser end of a pencil underneath the central point and try to make the rectangle balance.

Can you make it balance if the eraser is on the center dot?

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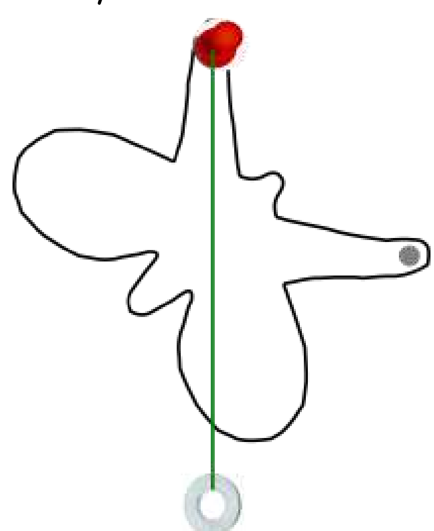
4. Now put the pencil underneath another point of the rectangle (not the center).

Could the rectangle balance if the pencil was away from the dot? _______________

For the object to balance, its center of mass (dot) has to be over its support (pencil).

Now let's find the center of mass for an object that's not symmetric.

5. Cut out the paper butterfly at the end of this worksheet. Trace the butterfly shape onto your cardboard rectangle and cut that out as well.



Try putting your pencil eraser under the original dot you drew on the rectangle.

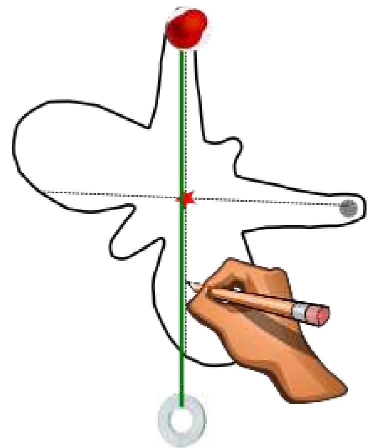
Will it balance now? _________________________

6. Hole-punch two holes at the very tips of the narrow butterfly wings.

7. Hang your washer or key from a short string (about 8"). Make a loop on the other end of the string and hang it off a pushpin. Put the pushpin through one of your holes in the butterfly wings and hold the pin against the wall. The string and the cutout should be able to swing freely on the pin.

8. Draw a line on your cutout along the path of the string.

9. Repeat, putting the pushpin through the 2nd hole, letting the cutout and string swing freely, and drawing another line.



The place where the two lines cross should be the center of mass!

10. Try balancing your cutout on the back end of a pencil.

Did you find the center of mass point approximately correctly?

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Did the center of mass move closer to the front of the butterfly (wide wings) or closer to the back (narrow wings) compared to where it was for the rectangle?

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Why do you think the center of mass no longer exactly half-way between the front wing tip and the back wing tip? _____________________

When gravity pulls down an object, it acts as if it was pulling on the center of mass. When you let your cutout swing freely, the center of mass will hang vertically, as low as it can go below the pin The washer on a string also hangs vertically, so the line of the string should always pass through the center of mass!

Can we change the center of mass without cutting a new shape?

11. Tape a quarter at the tip of each wide wing of the butterfly. The quarters should be as far forward as possible.

Make a prediction: which way do you think the center of mass will shift?

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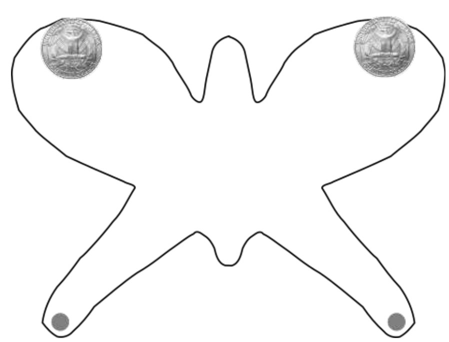

12. Repeat the trick with the pushpin and string to get the new center of mass. Put the pushpin through each hole, let the shape swing freely, and trace along the string

13. Try balancing your butterfly with the pencil eraser under the center of mass you found–- watch it appear to magically float!

Part 3: Stable Equilibrium

When the support is narrow, having your center of mass over the support is not enough to be stably balanced. Stable equilibrium means that when an object is pushed a little bit, it will respond by returning to where it was. A tiny push is not enough to make it fall.

1. Set your popsicle stick sticking out off the edge of a table, with a heavy book on the other end to keep it from falling.

2. Try balancing a pencil vertically on top of it. If you can get it to balance, try pushing the pencil the tiniest bit.

Could you get the pencil to achieve stable equilibrium?

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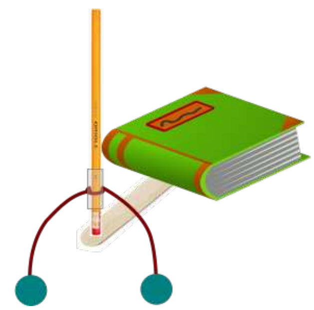
Your pencil has a center of mass that is high above the popsicle stick. A tiny push will move that center of mass sideways off the stick and the pencil will fall. It is not stable.

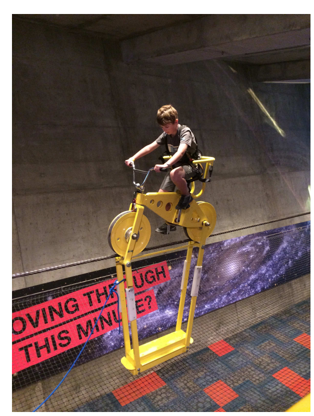


3. Twist 3 pipe-cleaners together to make a thicker wire.

4. Wrap the triple pipe-cleaner around the bottom section of your pencil. Use a piece of tape to keep it from sliding.

4. Make 2 identical balls of modeling clay, each about ½" to 1" an inch across. Attach these balls to the tips of the pipe-cleaners.

5. Try making the pencil balance on the popsicle stick, with the clay balls hanging down below the stick. Adjust the pipe-cleaners and add or remove clay from the balls as need.



6. Try pushing the pencil a tiny bit with your finger.

Were you able to achieve stable equilibrium? ________________

Where do you think is the center of mass of your pencil + clay "tightrope walker"?

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To be in stable equilibrium over a very narrow support, the center of mass has to be below the support. Then tilting the object slightly raises this center, and mass pulls the center back down, bringing the object back to its equilibrium position. Stunt-men and science museums use this idea to ride bicycles on tight-wires!