Water Bottle Torque

Directions and Suggestions for Teacher

Purpose:

This lab is designed to give students a hands-on experience with the ideas of torque and rotational equilibrium. In this lab students will be examining the connection between the mass of an object and the distance the object must be placed from the equilibrium point in order to balance a system.

Virtual Part:

(https://www.thephysicsaviary.com/Physics/Programs/Labs/TorqueWithWaterBottle/)

The virtual part of this lab could be done before students do a live version of the lab or if you have limited lab space you can have half the students working on the virtual part of the lab while the other half work on the live part of the lab.

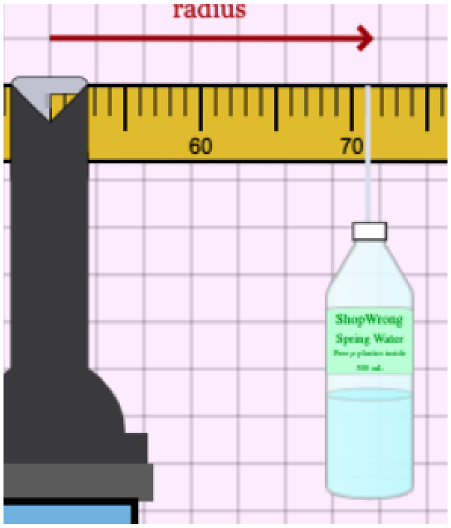
Balancing the System:

Some students might get water bottles with water levels that are too low to balance the system. Just tell the students to change the water level until they are able to balance the system.

Students should slide the water bottle until they get the meter stick as level as possible. There is a grid behind the system to help them get the meter stick to be level. If they click on the water bottle, it will become locked in place. This will be helpful to do when they have balanced the system. If they need to unlock the water bottle, they should click on it a second time.

Measuring Radius:

When the system is balanced, the students should carefully look at the location of the string from which the bottle is hanging. This location will help them determine the radius that they will be recording. In the virtual program all the meter sticks will balance at exactly the 50 cm mark. So, to get the radius, they will be subtracting 50 from the location of the string when the system is balanced. In the picture below, the radius would be 21 cm.



Measuring Mass:

Students will click on “Measuring Mass” when they are ready to get the mass of the water bottle. When students are using the triple beam balance, they will benefit by clicking on the zoom option to see a larger version of the third beam of the balance. Students should estimate the mass to the nearest 0.01 gram.

If students are having trouble with their triple-beam balance skills you can have them use the program found here (https://www.thephysicsaviary.com/Physics/Programs/Games/ReadtheTripleBeamHard/)

Although there are twenty different levels on the virtual program, students need not do all levels. I would not suggest less than 5 levels as it is a good practice to collect more data to have greater confidence in your results. The program will randomize the mass and location of the object on the left side of the meter stick, so all students will get different results. Students should not refresh the website while working or it will generate new values for candy and container mass and thus make all the old data irrelevant.

Below is a sample of what potential data might look like.

Data:

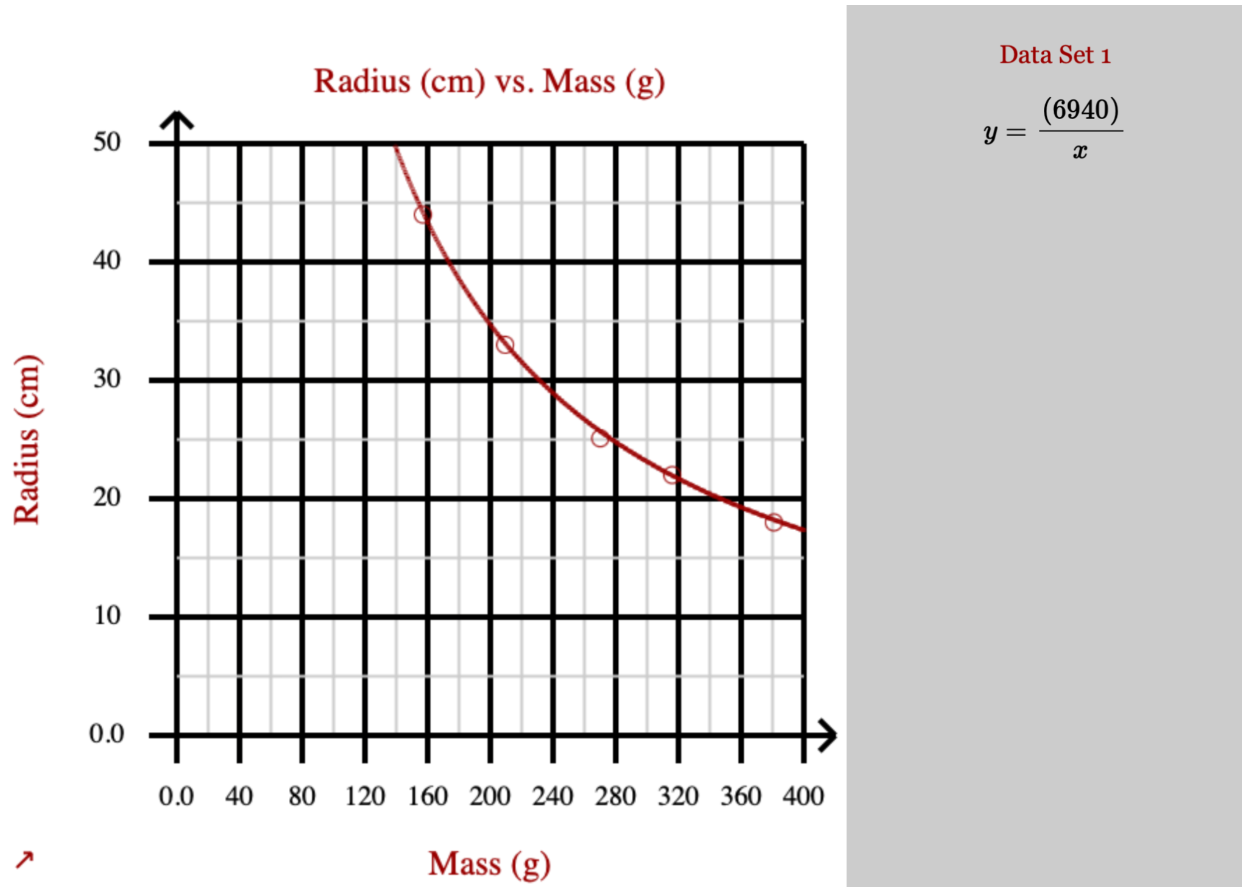
Level #	Mass (g)	Radius (cm)
6	157.00	94.0
10	209.42	83.0
13	270.10	75.1
16	316.02	72.0
20	380.89	68.0

Graphing Data:

(https://www.thephysicsaviary.com/Physics/Programs/Tools/Graphing/)

Once students have finished collecting data, they should graph it and find a relationship between the variables. The mass of the bottle in grams is the independent variable and should be placed on the x-axis and the radius in cm should be on the y-axis.

I prefer always having the students transfer their graph onto their lab sheet by hand.



Equation:

For this graph students get an inverse relationship between the variables. This indicates to them that a larger mass will require the bottle to be placed at a smaller radius..

The equation for an inverse relationship is given below.

y = (graph constant)/x

We want to continue to emphasize to them the idea that each of these letters has real physical significance. Looking at the axes, they should see that the y is the radius in cm and the x is the mass in g. So the equation becomes:

radius = (graph constant)/(mass)

We then want students to think about the significance of the graph constant. We should have them understand that all students got a different graph constant and that the graph constant should be the mass of the object on the left side of the meterstick times the radius for the object on the left side of the meter stick. This will not be obvious to most students, so you will probably need to show them that this equation comes from the idea that the torque clockwise is equal to the torque counter-clockwise.

So long as we work in the same units, we can keep things in grams and cm. When calculating torque, we would normally have to convert masses to forces by multiplying by the gravitational field of the planet. Since we would have to do this for both sides of the torque = torque equation, we can skip this step and just write.

(mass on left)(radius for left) = (mass of bottle)/(radius of bottle)

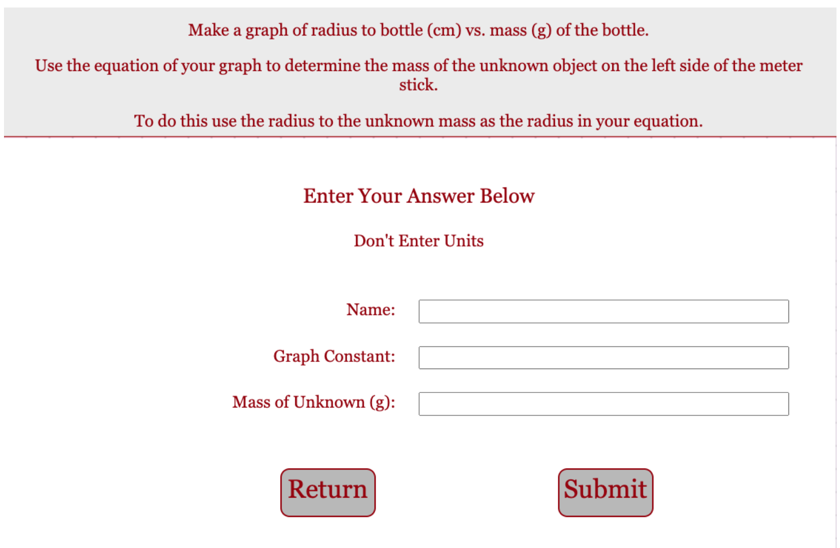
Solving this for the radius of the bottle we get a formula just like the one we found when graphing where the graph constant is

graph constant = (mass on left)(radius for left)

Checking their work:

Once the students have reached the point where they have graphed and created an equation, they will then be able to check their work. They should simply hit “Finished” on the program to be brought to a form they can fill out to see if they did everything correctly. Remind students that they all will be getting different answers and that they shouldn’t worry if their answers differ from those of their classmates.

Make sure to stress that they should have graphed mass in grams and the radius in cm. They will be entering their graph constant that made the curve best fit their data. They will then measure the radius to the mass on the left side of their meter stick to allow them to calculate the mass of the unknown object on the left side of the meter stick. They can hit the “Return” button to go back to the screen with the meter stick.



I would normally offer a small amount of extra credit added to the lab grade if they get all their answers correct. I would have them show me their completion certificate so I could record that they earned the extra credit. If a student doesn’t get everything correct, you can have them redo the lab by refreshing their page if time permits.

Live Part:

I always suggest a live lab counterpart to any virtual lab that you do with your students. There are so many balancing types of labs that you can do with your students in a live setting, so I will restrict myself to explaining how you could reproduce a lab similar to the virtual one they have just done.

1. **Cross Beam:**
    a. The equipment depicted in this virtual program is very common to have in a typical physics lab. So the best option would be to use a meter stick and torque supports similar to the depiction in the lab.
    b. If you don't have this equipment, a PVC pipe could be used as the cross-beam. You could predrill a hole in the PVC pipe right at the center and then use a wooden dowel through the hole as the pivot. Students would have to measure the radii using a ruler, meter stick or measuring tape.
2. **Water Bottle**
    a. Giving each group a new water bottle filled with cold water might be a nice option for them. They could drink a bit of water between trials to change the water level. Don't share water bottles during a pandemic!!
    b. If you have old water bottles, just have the students use sand to change the mass of the bottle.
3. **Unknown Mass**
    a. Feel free to use anything as the unknown mass, but be mindful that if you make the unknown too light or too heavy, students might have trouble balancing the water bottle for the different trials.
    b. I have used toys hanging from strings to make the lab a bit more interesting. After they collect all their data and graph you can see how accurately they worked by comparing their calculated mass to the real mass of the toy.

Conclusion:

I personally like to have students write out a conclusion by hand after they are done the entire lab (live part and virtual part). Some things you can have students include in the conclusion.

1. **Restatement of the purpose.**
    a. This is a great way to open the conclusion
    b. It helps to reinforce the reason we were doing the lab.
2. **Brief Summary of the steps**
    a. I don't want too much here but I do want students to transition from the purpose to the results with a sentence or two summary of the steps.
    b. This part of the conclusion should paint with a very broad brush what type of data we were collecting and what remained constant when collecting data.
3. **Results**
    a. I want students to clearly state what type of relationship existed between the two variables we were examining.
    b. I want them to clearly explain what this means in simple to understand terms.
    c. Basically, they will be making sense of the equation they have discovered in the lab.
4. **Error**
    a. They should talk about their percentage of error from the lab (you can have them do this for the live part or the virtual part or both).
    b. They should brainstorm at least one possible source of that error and how it can be minimized if they redid the lab.
5. **Limitations to the model**
    a. Whenever possible I want them to think about when the mathematical model for the lab would break down and no longer apply.
    b. For instance, with this lab, if the water bottle is too light they will not have enough meter stick on the right side to balance the system. If the water bottle is too heavy, they might not be able to move it close enough to the balancing point to get the system into rotational equilibrium.

Going Further

If you have the time, you could challenge the students with the following types of things.

1. Show the students mechanical balances (equal arm or triple-beam) and show them how they are balancing torques to determine mass.

2. Have the students graph how things would have been different for their graphs if they had used a heavier mass on the left side of the meter stick.