

Title

Still; include keywords

Timothy J. O'Mara, Physics Department, State University of New York - Buffalo State College 1300 Elmwood Avenue, Buffalo, New York 14222

<timomara@frontier.com>

**Abstract:** I will describe the construction of a Cavendish Balance made from ~~cheap~~ <sup>readily - Found and inexpensive</sup> materials, for demonstration in high school physics class.

**Acknowledgements:** This paper addresses requirements for PHY690: Masters' project at SUNY-Buffalo State College under the guidance of Dr. Dan MacIsaac.

**Introduction:**

The device that we will be constructing ~~is called~~ <sup>is</sup> a torsion balance. The torsion balance was first developed to measure the force of gravity by John Mitchell before 1783 (Clotfelter, 1987). Mitchell borrowed ideas from Coulomb's experiments to measure the force between two charged spheres (McCormach & Jungnickel, 1996). Mitchell died (1793) before completing his work and Henry Cavendish finished his work and reported his findings in 1798 (Cavendish). The Mitchell/Cavendish experiments were originally designed to measure the Earth's density. Their results were later used to determine the universal constant of gravity (G). (Clotfelter, 1987)

The balance consists of a ~~rigged~~ <sup>Newton's</sup> beam suspended from a fiber attached at the center; at either end of the beam are two equal masses. The masses are composed of a material much denser than the beam. Since gravity acts on both the masses equally the effect of gravity downwards is canceled by the upward force of the beam leveling the balance. The balance is then allowed to come to equilibrium so no torsion force is present in the fiber. Large masses are then placed on opposite sides of the masses hung from the balance. The force of gravity between the large and suspended masses is opposed by the torque from twisting the fiber. When the balance reaches a new equilibrium with the large masses in place the angle of deflection of the beam can be measured. By measuring the amount the balance twists to cancel the force of gravity the magnitude of the gravitational attraction can be measured. (diagram 1)

The force of gravity is extremely weak and this fact leads to several major difficulties in doing this experiment. The balance must be very sensitive to be able to measure the force; because of this you must isolate the device from outside influences as much as possible. Air currents will cause the balance to swing back and forth and mask any effect of gravity. Other forces such as electro static and magnetic forces can also overcome the effect of gravity. Finally any large masses around the device may skew the results. In the directions for construction I will address all of these concerns.

The design that I ~~will describe~~ <sup>used was</sup> is intended to be a demonstration of Newton's law of Universal Gravitation. Newton's law states that all objects with mass attract all other objects

Colons

Can you cite Cavendish or Coulomb directly?

Id

lower case

Write in past tense as much as possible

past tense

you did this; it

was done already.

(comment on rough size? absent)

P#

— sample calc for this apparatus.

with mass. This is often difficult for students to visualize because the only mass that they have encountered that is large enough to create a noticeable force is the Earth. Most people think that only the Earth causes gravity and no other objects. Some students will accept that large objects like the Sun and Moon will cause gravity, but few will accept that the force is truly universal. This demonstration is intended to show them that even small objects exert a force of gravity on each other.

It is very important that the students start thinking about the forces of gravity between ordinary objects. Camp and Clement, in their book "Preconceptions in Mechanics", developed two units on gravitational forces. In the lessons they suggest that a video of a working Cavendish balance be shown (Camp & Clement, 2008). The authors also suggest that the instructor build a mock-up balance to show their students (Camp & Clement, 2008), with the device that is described in this paper a teacher can construct a working balance with virtually no budget. The introduction of a video will cause some of the students to doubt the universality of gravity, but if they see the device in action they are more likely to bridge the gap between large massive objects generating gravity to the idea that all objects with mass generating a gravitational field.

The main focus of this design was to produce a usable device as cheaply as possible. All of the materials are readily accessible and affordable. Time should be taken to set up the apparatus and some modifications may be necessary.

### Construction of Balance;

#### List of Materials

- Meter Stick
- 30 pound test (or stronger) fishing line
- 2 1Kg masses (preferably made from brass or iron)
- 2 small mirrors, or flexible plastic mirrors that can be cut into small pieces
- Aluminum Can
- Bowl
- Electrical tape
- Aluminum foil
- 1 eye hook (to attach line to ceiling) other methods are possible
- Two buckets filled with water/dirt/sand
- Laser pointer and stand to hold it.

#### Tools you may need

Clamps, hot glue gun/ glue sticks, drill, utility Knife, electronic scale (for advanced projects), knife balance (optional), level

#### Steps for construction

nic

practical calc  
in a  
working  
classroom?

Can you  
make + edit  
a video on  
your own  
or provide  
us with  
video to edit?

PH

## Setting up balance

*really!*

The first step is that you need to find the balance point of the meter stick. Due to inconsistencies in the material (mine are made from wood) you cannot assume that the balance point is at the 50cm mark on your meter stick. I did this by placing the meter stick on a knife balance and adjusting it till the meter stick was level (photo 1). I then marked the ruler at this point (photo 2). On the meter stick that I used the balance point was at the 48.5cm mark. This point is important for when you hang the balance. It will be used to help leveling the balance and to determine the turning point of the balance.

Hanging the balance from one point requires that the exact balance point be found (the knife balance will be close, but there will be some error) and attaching the line to that point. It will create a balance that will be very difficult to balance and will be subject to oscillations in the vertical direction. Instead of this we will use a two point contact on the balance and a line that will form a triangle with the pivot line attached to the vertex of the triangle (diagram 2). I will call this setup the A frame setup from now on. To construct the A frame you first mark two points the same distance from the balance point of the meter stick. I marked mine 20cm from the balance point in either direction. My points were at 28.5cm and 68.5cm (photo 3). You want to mark the points towards the top of the meter stick, I chose to hang the meter stick so that the numbers were upright (arbitrary, but it helps to keep the top and the bottom easy to distinguish). We will be drilling a hole slightly larger than the fishing line you want to put the hole as close to the edge without splitting the wood. Drill the holes in the meter stick (photo 4).

*These photos are absent.*

We will hang the masses from the bottom of the meter stick; both of these steps are to ensure that the balance will not rotate so the wide side is perpendicular to the vertical. We want the meter stick to remain with the narrow side (edge) perpendicular to the vertical. The main reason for this is because a wooden stick is much more ridged when oriented this way. The natural tendency is for the stick to rotate at which point it will bend. The meter stick is much more likely to break in this orientation. This will also affect the horizontal distance between the masses and make the moment of inertia more difficult to calculate. The moment of inertia will be needed for the more advanced uses of this device. The mirrors are also much easier to attach to the wide sides of the ruler, the mirror need to be perpendicular to the floor to bounce the laser off of.

*rigid ≠ ridged*

Once the holes are drilled, you should cut a piece of fishing line that is approximately twice the distance between the two holes. Put end of the line through the hole and tie off both ends. (Photo 5) The next step is to mark off two points the same distance from the ends of the balance. These points should be located as close to the ends and as close to the bottom as is practical, again we will be drilling holes at these points and we do not want the wood to split. I chose a point that was .5cm from the ends and near the bottom. (Photo 6) Cut two lengths of fishing line the same length, approximately 20cm long. Tie a loop in one end to hang the masses from and tie the other end through the hole. (Photo 7) Tie them so that the two masses hang the

*in density why so far from 50cm? cannot.*

*cf. bifilar*

*missing photos*

same distance below the meter stick. We do this so that the masses will be at the same height so that when we use the balance the forces will all be as close to parallel as possible.

For the small masses I used 1Kg <sup>BRASS</sup> lab masses. I did this for two reasons\*first lab masses are very accurate so there is no need to weigh them and second they generally are made from brass or iron. ~~Metallic masses will not accumulate any static charges~~ <sup>if grounded</sup> on them. My masses were made of brass. Brass is preferable to iron because the iron masses may be affected by the Earth's <sup>-js</sup> magnetic field. If this occurs you will have constructed a compass and not a Cavendish balance. <sup>i</sup> If no lab masses are available you can use liter bottles filled with water or sand. If you use bottles you will have to find there mass if you want to do experiments with the apparatus, and you <sup>must</sup> ~~should~~ cover them with aluminum foil to prevent static build up. Larger masses can be used but keep in mind the strength of the fishing line. Find the weight of the balance plus weights and then add 40% to that to see if the fishing line will hold. The 40% is added to take into account loss of strength due to the knots in the line and as a safety margin (citation 8). The strongest fishing line that I found was 30lb test, stronger line is certainly available but cost may become an issue. <sup>Any spinning probs with fishing line?</sup>

their masses

I then hung the balance from a hook in the ceiling to see that it was balanced and that the knots held. (Photo 8)

Once the balance is tested attach the mirrors and water brake. We will use the mirrors to bounce a laser off of to measure the rotation of the balance. The water brake is used to try to minimize the effects of air currents that would otherwise disrupt the balance. First the mirrors are cut to size. They should be about 5cm across by the width of the meter stick. I used thin flexible plastic mirrors, because they are much easier to cut to size. The plastic mirrors do not resolve as clear an image as a glass mirror, but I feel that this short coming is far out weighted by not having to cut a glass mirror. (Photo 9) Once the mirrors are cut to size I used a hot glue gun and some clamps to attach them to the balance. Be sure to place the mirrors over the line you drew at the center of balance, I undercut the mirrors top to bottom so that I could still see where the center line was. When the laser lever is set up you will want the laser to fall as close to the axis of rotation as possible. If the balance is set up so that it is level the axis of rotation will be at the center line. Use a glue stick or hot glue gun to attach the mirrors to either side of the balance. I clamped the mirrors while the glue dried to ensure that they were flat against the balance (Photo 10). I placed paper between the clamp and the mirrors to prevent the mirrors from being scratched. This step is more important for the plastic mirrors than glass mirrors. I attached mirrors to each side so I had more options for where to put the laser.

part in write have

The water brake is made of a strip cut from an aluminum can and attached to the bottom of the meter stick. The water will be held in a soup bowl. First I cut a strip from the can with a utility knife. (Photo 11) Be careful not to cut yourself and be aware the edges of the strip will probably be jagged, you will clean up the edges with a scissors at the end. Be sure to cut a strip larger than you plan to make the water brake. The water brake can be any size, with the

Small photos on closey @pops please

PH

direct  
grad  
instructions

understanding that the larger that you make the brake the less it will be affected by air currents, but the slower it will rotate. Through some trial and error (the pictures are of a smaller water brake than I actually used) I found that a brake about 5.5 cm wide and about 6cm tall works well. It gave a rotation time of around 10-20 minutes and was not greatly affected by small air currents in the room. (Photo 12) The 6cm tall takes into account that a section of the height is folded over for an attachment surface to the bottom of the meter stick. I measured the thickness of the ruler's edge and marked that distance on the brake. I then put the brake in a vice and folded it over to form an L shape (Photo 13+ 14). To attach the brake to the balance I used glue again and clamped, try to center the brake on the center line. I added electric tape later to help hold both the water break and the knots in the line that passed through the holes (Photo 15).

You will need to find a room that is free as possible from air currents. Find a location that is far from windows and the door. If the experiment will be done in the winter, turn off heating system if practical. I used a small store room that had only one small window that I sealed off (Photo 16). To attach the pivot line to the ceiling using an eye hook that you can screw into the ceiling. If this is not possible find a suitable attachment point that can support the balance. Cut a length of line that will extend from the ceiling to a point about 0.5m off the floor. This allows the line to stretch once the balance is attached, with room for the balance to swing freely. Tie one end of the line to the eye hook (Photo 17) and the other to the A frame line on the balance. Do this without the masses attached to prevent the masses from falling. Tie the pivot line to the A frame with a knot that can be slid along the A frame line (Photo 18). Hang the masses at the same time, you may require a second set of hands for this, or support one end of the balance while you hang the first mass. The line will stretch quite a bit when the masses are hung. (Photo 19)

So  
not  
practical  
for working  
classroom.

Rotation + spinning while steady.

Place a level on the balance and slide the knot of the pivot line back and forth till the balance is level. At this point the knot should be directly over the center line and the level will pivot around the center line (Photo 20).

OK

Allow the balance to hang freely for a one to two days to allow any twist that the line had from being wrapped around spool to unwind. Once the balance has reached an equilibrium point mark the position of the two masses on the floor. I placed Styrofoam blocks on either side of one of the masses to prevent it from swinging wide while I set up the water brake and the laser. If you bump the balance or just the air currents that you create while walking around are enough to set the balance oscillating for over an hour. Once the blocks are in place, use a small stand (toolbox in my case) and several shims to raise the water bowl up to the balance. It is important that you get as much of the brake into the water as possible but you need to leave room for the balance to swing freely without hitting the top of the bowl. Once you have the bowl in place, fill the bowl with water. This water should damp out any swinging from small air currents. (Photo 21)

Jared Case