STATIC EQUILIBRIUM

Purpose

a. To understand torque by experimentally measuring and manipulating them.

b. To determine static equilibrium conditions by different torques that operate on a system.

Theory

When an object with mass m is treated as a point particle without structure, its mechanical equilibrium can be achieved when the net external force on it is zero, i.e.,

$$\sum F_i = 0. \qquad (1)$$

When the object has a finite size, its mechanical equilibrium must satisfy another condition: the sum of all torques to a given reference point is equal to zero:

$$\sum \tau_i = 0, \qquad (2)$$

Torque (τ) gives rotational effect. Torque due to a force about a point is defined as the product of the force and the perpendicular distance from the point to the line of action of the force. The torque can be considered positive or as clockwise or counter clockwise.

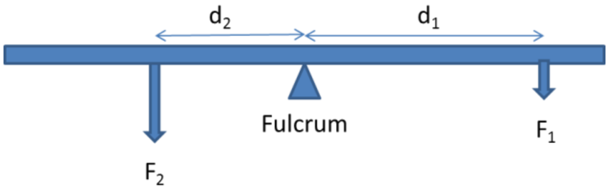

Figure 1.

In this experiment you will use several parallel forces. Figure 1 shows a uniform beam that has a fulcrum at the center O. $\mathbf{F_1}$ and $\mathbf{F_2}$ are two parallel forces acting on the beam at distances d_1 and d_2 from the center respectively. The torque due to the force $\mathbf{F_1}$ is equal to F_1d_1 clockwise and that due to the force $\mathbf{F_2}$ is F_2d_2 counter clockwise. If the system is in static equilibrium, $F_2d_2 - F_1d_1 = 0$. Note that the torque due to a force can be varied by changing the distance. Thus a balance can be achieved even with different forces. For example, Figure 2 shows a seesaw that can rock back and forth easily. As shown, the lighter child weighs 50 lbs. and sits 9ft from the fulcrum. Its torque will be (50 lbs.)x(9ft) = 450 lbs.ft. Similarly, the heavier child (or a parent) sits at 1ft from the fulcrum, so its torque will be 200 lbs.ft and the seesaw will tend to rotate (if not blocked by the ground) counter clockwise. If we want the seesaw to be balanced we will have to move the smaller child to sit 4ft from the fulcrum so the two torques will be equal.

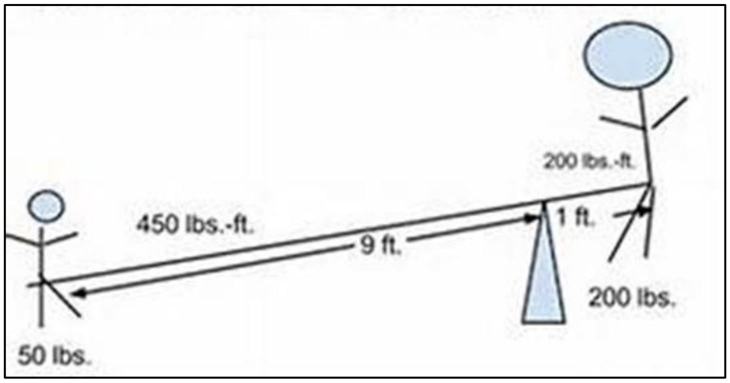

Figure 2. Illustration of a lever with plenty of torque to lift a load. Ref: http://study.com/academy/lesson/levers-definition-classes-examples.html

Apparatus

A triple beam scale, a spring scale, a meter bar with a knife edge clamps and its supporting holder, suspension clamps with their stirrups and hooked weights of 50 and 100 grams.

Description of apparatus

Figure below shows the apparatus you will use in this experiment.

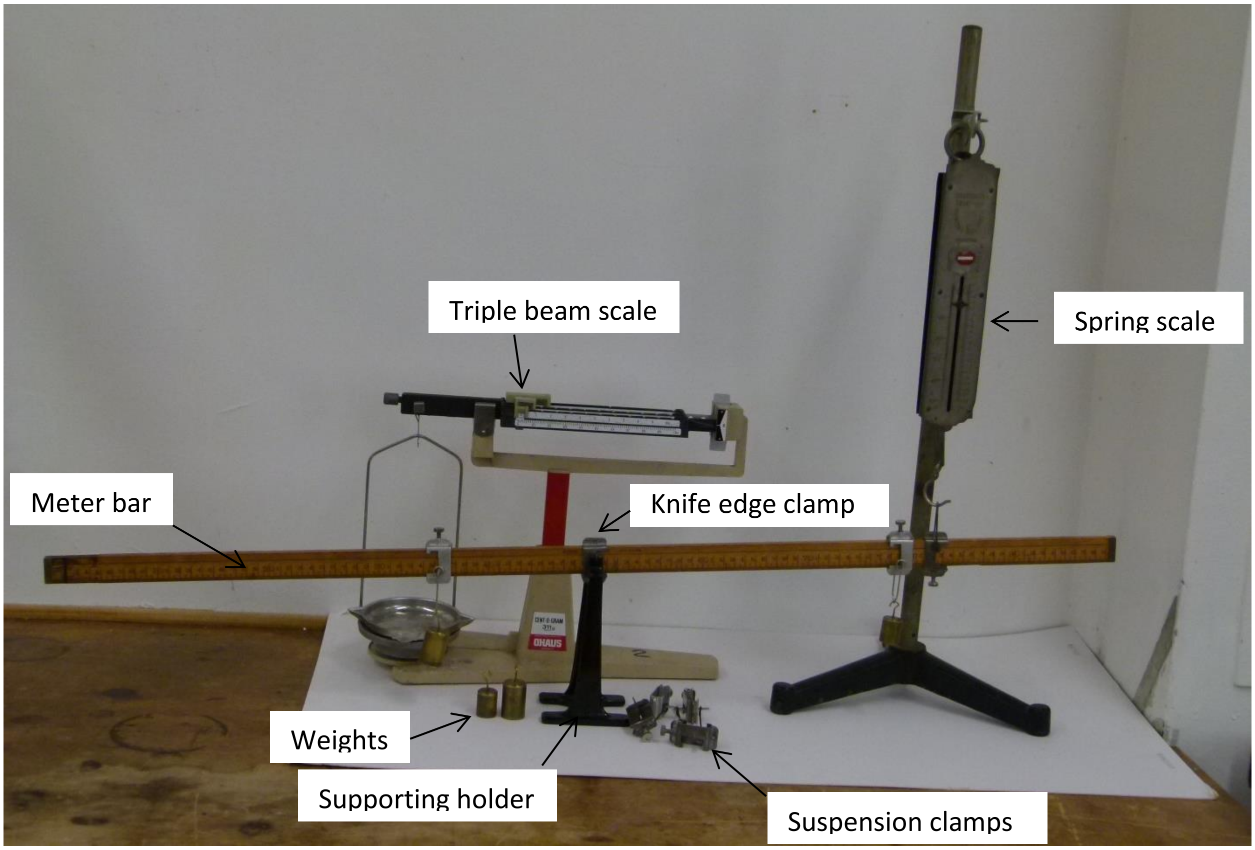

Figure 3. Experimental setup

You will use two different scales to measure mass in this experiment, as shown in Fig. 3.

A Triple Beam scale to measure masses that is a mechanical balance with a beam supported by a fulcrum. On one side of the fulcrum is a pan on which the object is placed. On the other side, the beam is split into three parallel beams. This apparatus actually uses the principle of static equilibrium you are going to learn in this lab. The beam remains balanced when net torques on both sides are equal. In measuring the mass of an object weight blocks on triple beams are adjusted to balance the beam. Remember the torque due to a same force (weight) can be increased by increasing the distance from the fulcrum. The far beam reads only in 100 g increments. The middle beam reads only in 10 g increments. The weight blocks in these two beams must always sit in a "notch". They cannot be placed at arbitrary points on the beam. The weight on the front beam can be placed to read continuously from 0 to 10 grams. The balance should be placed on a leveled surface to use it. Before measuring you should check if the balance is properly zeroed. *When all the weight blocks on triple beam are at zero gram position, the mark at the end of the triple beam must stay at Zero*. You can adjust a knob at the other end of the beam to bring the mark to zero position.

You will also use a spring scale to measure masses. It measures the mass based on the gravity and spring force. The spring is elongated when a load is attached to the hook at the lower end. The elongation is calibrated to measure the mass of the load attached.

Procedure

Part I: Experimental preparation

1. Check the triple beam balance scale and make sure when all four weights are moved to the left and nothing on the pan, the balance scale should indicate zero grams.
2. Check the spring scale if the needle indicates zero grams when nothing hanging. We are going to measure weight in the unit of grams in this lab.
3. Obtain average weight for the 6 clamps by weighing them together on the balance scale, and record the value as the average weight (W_{clamp}). Repeat the measurement by using spring scale and see it measures same.
4. Measure the weight of meter bar without the clamp using both scales and record it as the weight of bar (W_{bar}).
5. Now, insert a knife edge clamp on the meter bar and practice how to balance the meter bar on the supporting holder, find and record the position of the center of gravity (read knife-edge position on meter bar with accuracy to millimeter).

For each of the following experiments, record your data in the form of a diagram, i.e., draw a horizontal line to represent the meter bar with the meter scale on top as shown in the data sheet page and record on the line the position of each force with its magnitude and direction including the weight of the bar.

Part II: Determining the weight of meter bar by balancing torque

1. Shift the clamp so that the knife-edge is at the 35 cm mark and insert a suspension clamp with a 100 gram weight. Now slide the clamp which supports a 100 gram weight until equilibrium is obtained, and record the clamp position on the meter bar as X_1 in Table 1 on the data sheet.
2. Repeat above procedure with the 150 gram weight (using 100 and 50 gram weights) and record position as $X_{2.}$
3. Repeat again with the 50 gram and record position as X_3.

You should complete the calculation in Table 1 before proceeding to the following parts of the experiment.

From the data in the table 1, calculate the weight of the meter bar for each case using the knowledge of balancing torque. Then, find the average value.

Part III: Experimental confirmation of the conditions for mechanical equilibrium

In this part of the experiment, you will verify

a. the first condition for equilibrium by comparing total downward and upward forces.
b. the second condition for equilibrium by comparing the sum of the clockwise and counterclockwise torques.

1. Suspend three weights from the bar at any positions and note down the positions on your diagram.
2. Slide the bar in the supporting clamp until the system balances. Note down the balance position on your diagram.
3. Now remove the whole system from the supporting holder and measure the force at the supporting clamp with the spring scale. This gives you the total upward force.

Computation:

Calculate total downward forces by adding all the forces including the weight of the bar and compare with the reading on the spring scale.

From the all forces acting on the bar and their positions, calculate the sum of the clockwise and counterclockwise torques. In computing torques, take the reference point at the knife edge and do not forget that the weight of the bar must be considered.

Part IV: Additional manipulation of torques

1. Arrange six clamps on the bar so that one is at 10 cm mark, one at the 90 cm mark and four others distributed between them. Support the bar at the 10 cm mark by means of the stand and at the 90 cm mark by means of the spring balance. Hang weights on the four remaining clamps. Make sure the bar remains horizontal when balanced.
2. Read the spring scale.
3. Interchange the spring scale with the stand. Do not hook the balance on a stand. This time you have to hold the spring balance to make the bar horizontal and read the spring scale.

Computation:

1. Compute the first spring balance reading by taking torques with reference point at the 10 cm mark. Check your result against the actual spring balance reading.
2. Check the sum of the two spring balance readings against the total downward force to verify the first condition for equilibrium.

In your report make a separate tabulated summary for each part, showing how observed values compare with the computed values.

Questions

1. Describe what the motion of the rigid system will be if:
    a. The first condition for equilibrium is not satisfied.
    b. The second condition for equilibrium is not satisfied.
    c. Neither condition for equilibrium is satisfied.
2. If equal numbers of suspension clamps are on each side of the support, can their weights be omitted from the calculations? Explain.
3. When the center of gravity of the meter bar was determined in Part I, was the bar supported at a point above, or coinciding with the center of gravity? Would any difficulty have been encountered in trying to balance the bar if the clamp were inverted? Explain.
4. In Part IV, how would the reading of the spring balance be affected if it remained in a vertical position but held the meter bar inclined at 30^o above the horizontal? Draw a diagram to explain.
5. If the triple beam balance scale and spring scale were taken to the top of Mt. Everest, do you think they measure same as in NYC?

Data Sheet

Date of experiment performed:

Name of the group members:

Weight of all clamps using triple beam scale =

Average weight of the clamp (W_{clamp}) =

Weight of all clamps using spring scale =

Average weight of the clamp (W_{clamp}) =

Weight of meter bar using triple bean scale (W_{bar}) =

Weight of meter bar using spring scale (W_{bar}) =

Position of the center of gravity of the meter bar =

Table 1. **Determining the weight of meter bas by balancing torque**

Clamp Position (mm)		W_{bar} (gram) Calculated by balancing torque	W_{bar} (gram) Measured by spring scale	Deviation (%)
X_1				
X_2				
X_3