Lab #7 Static Equilibrium

Purpose: To investigate the two conditions of static equilibrium.

Equipment: Force table, weight hangers and weight set
Protractor
Rectangular graph paper (2 sheets)
Moment of Force Apparatus

Discussion Part 1:

The First Condition of Static Equilibrium: $\Sigma F = 0$

Static equilibrium results when the net force (first condition) and the net torque (second condition) on a body are separately zero. The force table is a convenient device for applying forces of varying magnitude and direction on a point object. It is designed so that when the center ring is in equilibrium at the center of the table, then angles of force can be read directly off the table itself. The angles are inscribed, in degrees, around the circumference of the table, with two scales, one running clockwise, the other counter-clockwise.

There are two other methods for analyzing the forces, which are applied to the center ring:

I. The method of components. An x-y coordinate system is superimposed on the force table, origin at the center. The applied forces are decomposed trigonometrically into components along the x and y axes, and the components are summed separately. If the vector forces sum to zero, then so do the individual horizontal and vertical components.

II. The method of vector diagrams. Vector sums are represented graphically by drawing each vector, complete with magnitude and direction, successively, the tail of each connected to the head of the precious vector in the sum. The vector sum is that vector which is drawn from the tail of the first summed vector to the head of the last summed vector.

Procedure:

1. Apply two forces to the ring by hanging a mass of 100 g at 30° and a mass of 200 g at 150°, respectively. Find experimentally the third force necessary to keep the ring in static equilibrium at the center of the table. Tap the table repeatedly to allow the system to overcome any residual friction and thus permit the ring to find its true equilibrium position. Sight horizontally along each of the strings (and shift their positions on the ring slightly if necessary) to be sure they point directly to the hole in the center of the metal ring. Otherwise the strings will form angles slightly different than the angles read from the table's scale.
   Also, analyze this equilibrium by each of the other two methods described above.

2. Use the force table to answer experimentally the following question:

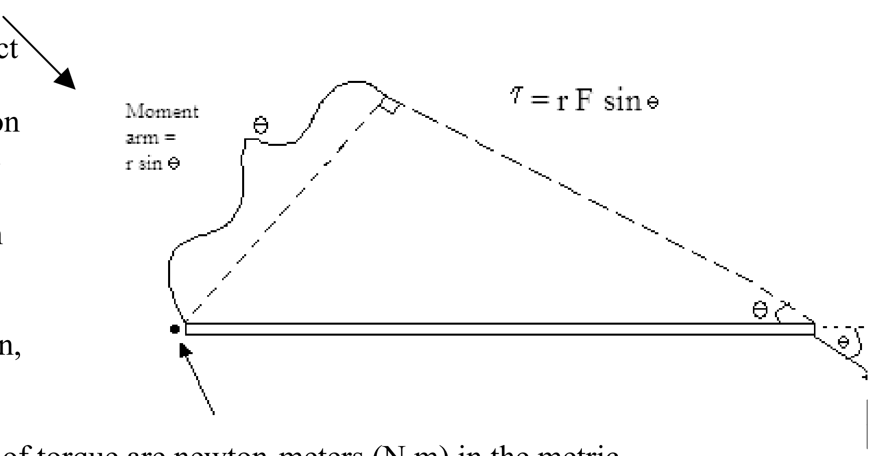
> A force equal to the weight of a 50 g mass is applied to a point mass, which is prevented from accelerating by two restraining strings, each forming an angle of 95° with the applied force, so that the restraining strings have an angle of 170° between them. What tension is necessary in the restraining strings to prevent the mass from accelerating?

Analyze this equilibrium experimentally with the force table and by each of the other two methods described above.

Part 2:

The Second Condition of Static Equilibrium: $\Sigma\tau = 0$

Torque is a quantity that measures how effectively a force causes rotation. A rotating object familiar to all of us is a hinged door. We can cause rotation of the door in several ways, but the most effective way is to push or pull (force) in a direction at right angles to the face of the door at a point farthest from the hinged side of the door. As can be seen from this drawing, torque is equal to the product of force, lever arm (or moment arm), and the sine of the angle of application of the force. Maximum torque occurs when θ is a right angle (when r and F in the figure are perpendicular). Then torque is simply forces times the moment arm distance. Note also that when r and F are in the same direction, θ is zero and there IS no torque, because the force doesn't have any tendency to cause rotation. The units of torque are newton-meters (N.m) in the metric system and foot-pounds (ft-lb) in the British system. So the units for torque are the same as those for work and energy, although torque and work represent very different physical quantities. Torque is a vector quantity. (Recall that work is a scalar.)



The first condition for static equilibrium requires that the sum of the forces on an object equals zero, while the second condition for static equilibrium requires that the sum of the torques must equal zero. The moment of force apparatus provides a fairly simple means of studying the way various forces that act on a single object (in this case, a meter stick) can cause rotational tendencies that offset, or "balance", each other in one way or another.

Most text adopt the convention that torques producing counterclockwise motion are positive, while those producing clockwise motion are negative, so that:

However, this convention is not needed when one simply considers absolute values and writes the equation in a different way:

$$\Sigma \tau_{ccw} = \Sigma \tau_{cw}$$

The instructor will demonstrate the use of the moment of force apparatus in solving a practice problem both mathematically and experimentally.

Procedure:

The moment for force apparatus consists of a meter stick, metal support stand, and several levels clamps, which can be used either as weight hangers or as a knife-edge to rest in the fulcrum "V" of the support stand. Attach one lever clamp with the knife-edge down at the 50-cm point and verify that the meter stick is visually horizontal when placed on the fulcrum. It may be necessary to shift the level clamp slightly one way or the other to achieve this balance. Your instructor will explain how to compensate for this. Place the meter stick so that the zero-cm mark is on your left and the 100-cm mark is on your right. The fulcrum is now at the center of mass of the meter stick, so the meter stick's own mass will not be a factor as we study rotational tendencies of forces due to additional suspended masses.

A. Next, while your partner holds the meter stick still, place a lever clamp with 10 g suspended at the 10-cm point and one with 20 g suspended at the 25-cm point. Then hang one with 30 g from the other side (the 50- to 100-cm side) of the fulcrum, and move it until you locate the placement that achieves a (visually) horizontally balanced meter stick. Record this location.

   Then do the same on the 50- to 100-cm side of the meter stick with a lever clamp suspending 40 g of mass, and record the location of the placement that achieves horizontal balance.

   The lever clamps' masses cannot be ignored: they each average 17.75 grams. Nor can we neglect the mass of the paper clips, which attach the masses to the lever clamps: They average 0.50 grams. Finally, compare your experiment placement distances to the mathematically correct values. What are some possible REASONS for any difference? (Discuss in your conclusions.)

B. Move the fulcrum to the 40-cm point of the meter stick. (Now you'll have to find the mass of the meter stick and consider its contribution to the overall torque equation.) The instructor will provide you with an object of unknown mass. Suspend the string loop from the 65-cm point. Determine the mass of the unknown object by finding ANY mass & lever clamp placement combination on the other side of the fulcrum (there are an infinite number of them) that causes the meter stick to balance.

Report this result to the instructor. He or she will provide you with the actual mass of the unknown object. Use this information to compute the percent of error. Again, in your calculations, don't neglect the masses of the lever and paper clips as torque-producers.

Questions:

Part 1:

1. Which of the 3 methods describe is most accurate?

2. Why are the other two methods less accurate? (Error sources)

Part 2:

1. Why might the meter stick alone not balance exactly at the 50-cm point?

2. What are other error sources in this procedure?