Physics 103 Lab #5 — BALANCING AND EQUILIBRIUM

Name________________________________ **Section**_________

Lab Partner___________________________ **Date**_________

This experiment involves the balancing of torques about a central axis and the concept of center of gravity.

EQUIPMENT: Meter stick; fulcrum support; pan balance; one fulcrum clamp, three hanger clamps, three 50 g weight hangers, one 10 g slotted mass, one 20 g slotted mass, and one 50 g slotted mass

THEORY: If a force F acts on a rigid body at a distance d from an axis through the body, it may cause the body to rotate. A pivot point like the fulcrum of a lever, the axle of a wheel, the elbow joint of an arm, or the hinges on a door each provide an example of an axis through a rotating rigid body. The turning influence or "torque" causing the rotation equals the product of the force F times the perpendicular "lever arm" distance d from the axis to the line along which the force is exerted. So the formula for this torque would be:

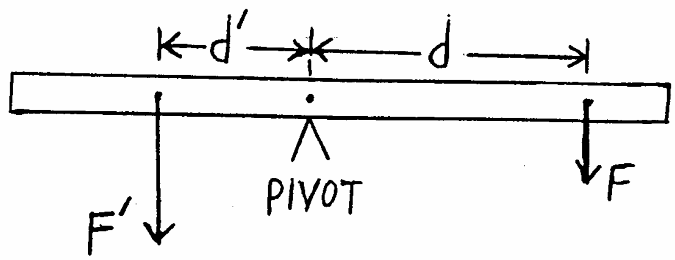
$$\text{torque} = Fd.$$

Center of Gravity (CG): The mass of a body is distributed throughout the whole body. However if the separate pulls of gravity on each part are added together, they form a single force, the "weight of the body", acting through a point called "the center of gravity." In other words gravity acts on a body as though all its mass was concentrated at that one point. For example, you must place your hand directly below the center of gravity of a very long, uniform stick so that it will balance, and therefore you feel its full weight on your hand.

If a body has an axis or is pivoted at its own center of gravity, and there are no other forces on it, then it will be in equilibrium, since its own weight will generate no torque to make it rotate. If it is pivoted at some other point (say if your hand were off center under the stick) then its own weight will generate a torque, equal to its weight times the distance between the pivot point and a vertical line through the center of gravity.

Equilibrium with multiple torques: Suppose we have a "rigid body," like a rectangular bar pivoted at its center of gravity, as shown on the next page, and a force F is applied to the bar at a distance d away from the pivot point. This torque may be balanced out by an equal torque acting in the opposite direction, for example, one due to a second force F' at a distance d' on the other side of the axis.

If d' is smaller than d, as shown, then F' will have to be larger than F for the torques to be equal. Mathematically, the condition for **equilibrium** will be F'd' = Fd.



<u>NOTES ON PROCEDURE:</u> In this experiment, the rigid body will be a meter stick and the forces will be the downward pull of gravity on the stick itself and some masses hung from the stick on sliding hangers. Don’t screw the clamps on too tight – the meter sticks get dented if you do. The knife-edges of the clamp’s "arms" must face *down* on the meter stick support clamp but they must face *up* on the weight-hanger clamps.
In taking the data, write the clamp <u>positions</u> you read from the meter stick in the little boxes above the diagram of the bar. From these, you can then figure out the lever arm distances d or d' by subtraction.

The mass of the clamps and weight hangers has to be included in the masses you record at each position. The clamps are supposed to be roughly 20 grams each, but you will have to weigh each clamp you use. You will not need to measure the mass of the pivot clamp in which the meter stick is held, since it is right at the pivot point and therefore contributes zero torque.

<u>PROCEDURE:</u>

1. Precisely measure and record the mass of the bare meter stick using the scale balance.

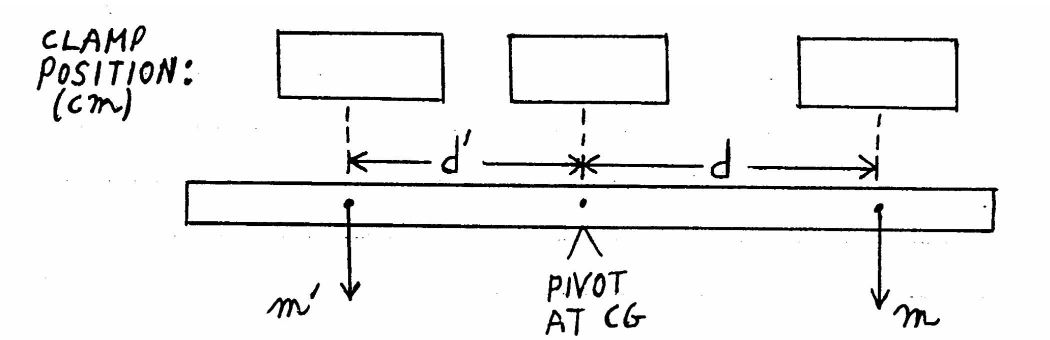
Meter stick mass = ______________ grams ________________kg

2. Locate the center of gravity of the meter stick by placing it in the support-clamp and adjusting it until it is in equilibrium. Record this **position**.

CG Position = _____________ cm _______________m

At this point, how far is the CG from axis of rotation? _____________

3. With the meter stick pivoted at its own center of gravity, place a mass m' of about 100 grams (including the clamp and hanger) at a distance of 30.00 cm to the left of the pivot point (this means d' = 30.00 cm; it does *not* mean the clamp lines up with the 30 cm mark on the meter stick). Experimentally determine by trial and error the lever arm distance d, i.e. where a mass m of about 80 grams (again including the clamp and hanger) must be placed to balance the stick. In recording your data, use the actual mass measured directly on the balance, which probably won't come out to be exactly 100 grams for m' or 80 grams for m.



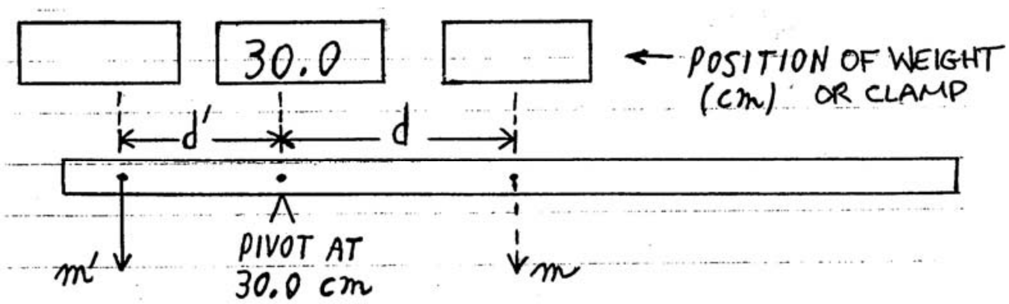
d' = 30.00 cm; m' = ____________ grams; m = ____________ grams; d = ____________ cm

Check your results by calculating where the 80 gram mass should be placed to balance the meter stick. You can get the answer by solving the equation m'd' = md for the unknown distance d. Remember to use d' = 30.00 cm and to use the measured masses for m' and m. NOTE: Since the forces F' and F are weights, F' = m'g and F = mg. The condition for balance:

Torque CCW =torque CW, so F''d' = Fd, which reduces to m'd' = md.

Compare the value of d just calculated to your experimental value of d by calculating %Diff.

4. Shift the meter stick support clamp away from the center of gravity to the 30.00 cm position on the stick. Balance the meter stick by placing a mass m' of about 150 grams to the left of the support as shown. Record the position of m' on the diagram. Calculate the mass m of the meter stick by equating the clockwise (CW) and counterclockwise (CCW) torques. HINT: The weight of the meter stick contributing to the CW torque acts at the stick's center of gravity.



m' = ________grams; d' = ____________ cm; m = ____________ grams; d = ____________ cm.

Compare the value of the mass m of the meter stick just found from torque principles to the direct measurement of its mass found on the pan balance by calculating the %Diff between the two values.

Give a detailed explanation of at least two possible reasons for any discrepancy. Be sure to support your claims.