Lab 3: Torque and Rotational Equilibrium **by R.E. Tremblay**

Purpose: To investigate torque, center of gravity and rotational equilibrium.

Equipment: Meter stick, support, masses, clamps, weight hangers, platform balance.

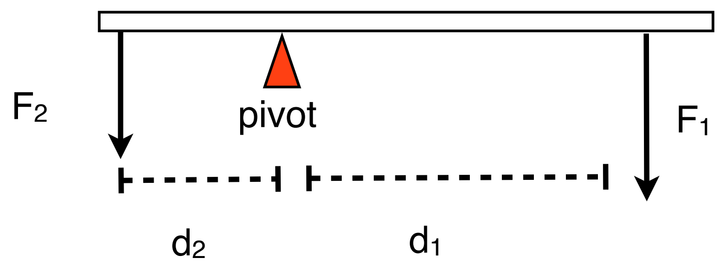
Discussion: Torque is the turning effect of a force. You cannot turn a doorknob, a screwdriver or anything else without applying a torque.

Angular acceleration is the rate at which a system's angular velocity changes. If an object's rate of rotation doesn't change, then its angular acceleration is zero and it is said to be in rotational equilibrium. Rotational equilibrium is only possible when the clockwise torque on an object equals the counterclockwise torque on the object.

Definition of torque: $\text{Torque} \equiv F_{\perp} d$

Torque can be calculated by multiplying the perpendicular component of an applied force $F_{\perp}$ ', by its distance 'd' from the pivot. For example, in the diagram below, the clockwise torque is determined by multiplying F_1 by d_1. The counterclockwise torque is determined by multiplying F_2 by d_2.

Fig. 1



If the angular velocity of a system remains constant, the clockwise torque must equal the counterclockwise torque.

Equation 1: Clockwise torque = Counterclockwise torque

$$F_1 \bullet d_1 = F_2 \bullet d_2$$

Center of Gravity (C.O.G.)

The center of gravity of a system is the point about which there is no net torque when the system is supported at only that place. You can balance an object by putting a support beneath its center of gravity (c.o.g.). Gravity acts on a body as if all its mass was concentrated at its center of gravity.
Before you continue, please view the [torque lecture.]

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Lab Preparation sheet Name ________________________

Hand in <u>before</u> the lab begins.

1. Draw and label a diagram exactly like Fig. 1

2. Write the definition of torque.

3. Solve the following equation for F_2:

$$F_1 d_1 = F_2 d_2$$

4. Solve the following equation for d_2.

$$F_1 d_1 = F_2 d_2$$

Procedure: Part 1-Center of Gravity

1a. Slide a meter stick clamp on the meter stick and locate the center of gravity(c.o.g.) of the meter stick by placing it in the support-stand and adjusting its position until the meter stick is balanced.

2a. Draw ***figure 1*** on your worksheet and label the position of the center of gravity of your meter stick on the data sheet. The position of the support is called the pivot point and in this case it is below the c.o.g of the meter stick.

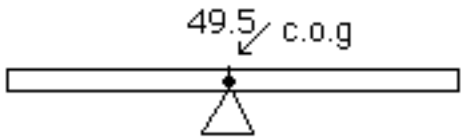

Figure 1

Part 2-Practice using the torque formula.

2a. d_2 experimental: Draw ***figure 2*** on your worksheet and label all of the known values as we go. Place a total mass of approximately 100 grams(F_1) at a distance of 30 cm(d_1)to the left of the pivot point. Y**ou don't need exactly 100 grams, you just need to know how much mass you have**.

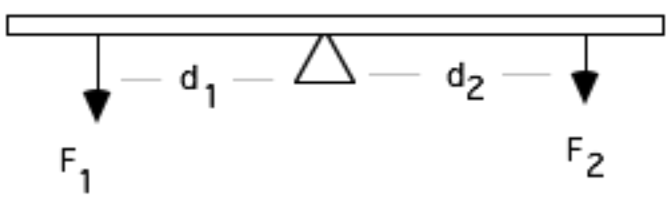

Figure 2

Note that d_1 is given as 30 cm. Place approximately 80 grams of mass(F_2) to the right of the pivot point and position it so that the system does not rotate. **Don't forget to make a diagram of your set-up and label your exact masses.** Observe and record the distance between the pivot and the 80 gm mass as **d_2 experimental**.

2b. d_2 mathematical: Solve equation 1 for d_2 -- as shown below.

Equation 1: Clockwise torque = Counterclockwise torque

$$F_1 \bullet d_1 = F_2 \bullet d_2$$

Therefore, $d_2 =$

Substitute your values for F_1,d_1, and F_2 and then calculate the value of d_2. Record this position as **d_2 mathematical**.

If d_2 experimental and d_2 mathematical are in close agreement, then you are doing 'OK' and may proceed. If they don't agree, try to determine what went wrong. If after five minutes you are still having trouble, ask your lab. instructor for assistance.

Part 3. **More torque practice: Remove all masses that were used in part 2.**

3a. Determine d_3 experimentally. Place approximately 90 grams of mass 45 cm to the left of the pivot point; place about 100 grams of mass 20 cm to the left of the pivot and finally place approximately 200 grams of mass to the right of the pivot and position it so the system does not rotate. Draw Fig. 3 and write the exact values of your masses in your diagram. Record the distance between the 200 gm mass and the pivot as **'d_3 experimental' on your data sheet**.

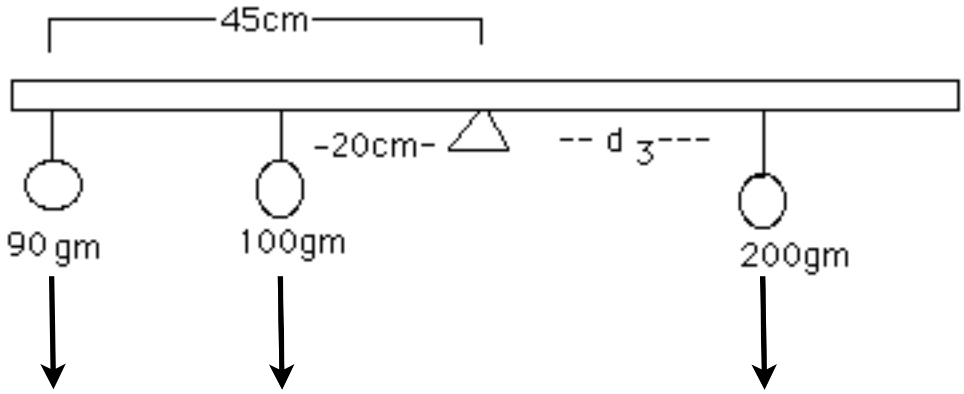

Figure 3

3b. Mathematically calculate the value of d_3. Using the concept that the total clockwise torque must equal the total counterclockwise torque when a system is in equilibrium, solve for **d_3**. Enter its value as **d_3 mathematical** under part 3 of your data sheet. See the example below.

clockwise torque = counter clockwise torque

200 gm (d_3) = 90 gm(45 cm) + 100 gm(20 cm)

Solving for d_3,

$$d_3 = \frac{90g \cdot 45cm + 100g \cdot 20cm}{200g}$$

<u>Your actual mass values will differ slightly from the ones used in the above example.</u>

Part 4: Determining the mass of the meter stick. We will use the concept that clockwise torque equals counterclockwise torque when a system is at rotational equilibrium to determine the mass of a meter stick.

4a, Remove all weights and hangers. Place the meter stick support 30 cm to the left of the center of gravity(c.o.g.) of the meter stick.

4b. Balance the system by placing approximately 250 grams of mass to the left of the support. Record the mass that you used.

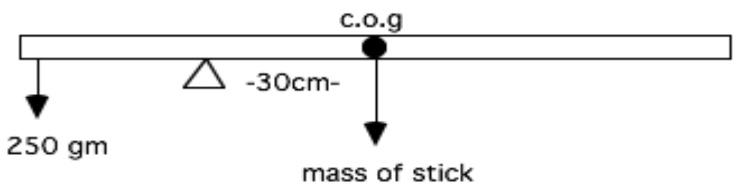

Figure 4

4c. Draw and label Fig. 4. Indicate the exact mass that you used. **<u>Don't forget to draw in the 'mass of stick vector'</u>**.

4d. Just as you did for part B, write Clockwise torque = counter clockwise torque and calculate the mass of the meter stick, M_s. Remember that the entire mass of the meter stick acts as if it hangs from the center of gravity. Enter the value as **experimental mass of meter stick** in part 4 of your data sheet.

6. Use the platform balance to determine the actual mass of the meter stick and enter the value as the **measured mass of meter stick**, on part 4 of the data sheet.

7. The calculated mass and the measured mass of the meter stick should agree to within 2% error. If not, find out what where you went wrong.

Part 5: Making your own balance and determining the mass of an unknown object.

5a. <u>Return your platform balance to the cabinet before proceeding</u>. Do not proceed until the platform balance is put away. Ask your instructor for an unknown mass.

5b. Construct a balance with your meter stick and use it to determine the mass of the unknown object given to you by the lab instructor. **You cannot use equal distances for d_1 and d_2.** Draw a diagram of the set-up on your data sheet.

5c. After you have written the object's mass on your data sheet <u>in ink</u>, take the mass and your data sheet to the instructor. The instructor will put your mass on a platform balance and determine its actual mass. You need to be within 2% of the actual mass to receive full credit.

5d. Determine the percent error and enter its value on the data sheet.

Name________________Section___

<u>Calculations and diagrams</u>: Attach more paper if needed.

Part 1: Determining the center of gravity of the meter stick

Part 2: Use the torque formula and clockwise torque equals counterclockwise torque to determine d_2.

2a. d_2 experimental ______________________

2b. d_2 mathematical __________________________

Name________________Section___

<u>Calculations and diagrams</u>: Attach more paper if needed.

Part 3:

3a. Determine d_3 experimentally.

3b. Mathematically calculate the value of d_3.

Part 4: Determining the mass of the meter stick. **Use the torque formula and the clockwise torque equals counterclockwise torque statement to determine the mass of the meter stick**

Part 5: Determine the mass of an unknown object: **Use the torque formula and the clockwise torque equals counterclockwise torque statement to determine mass of the unknown object given to you by your lab instructor.**

Data Sheet:

Name____________________

Summary of Data and Results:

Part 1: **Determining the center of gravity of the meter stick**

1. Center of gravity ________

Part 2: **Experimentally and mathematically (torque formula) determine d_2 and d_3.**

2a. d_2 experimental ________

2b. d_2 mathematical ________

Part 3: **3a. d_3 experimental ________**

3b. d_3 mathematical ________

Part 4: **Calculating and measuring the mass of the meter stick**

4a. Calculated mass of the meter stick _____________

4b. Measured mass of the meter stick ____________

3. percent error _______________

Part 5: **Your predicted mass of the unknown object given to you by your lab instructor in ink________**

Actual mass as determined by your lab instructor__________

Percent error____________

$$\% \text{ error} = \frac{\text{difference between your answer and the correct answer}}{\text{correct answer}} \cdot 100\%$$