## Static Equilibrium Lab: Activities, Data and Analysis Section

Student Name_____   Lab Instructor's Initials_____

Activity 1: Getting a feel for torque

1. You are given a meter-stick and various masses on rubber bands.
    Hold the meter-stick so that the 100cm end points away from your body and the 0cm end is pointing towards your body. **Grip the meter so that the edge of your hand is at the 10cm mark.**
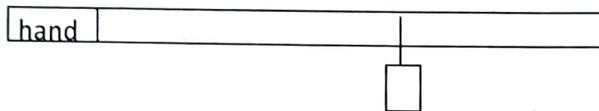
Rate the "difficulty" of holding the meter-stick **<u>HORIZONTAL</u>** while your lab partner puts various masses at various locations on the meter-stick. If the situations are equally difficult, rate them with the same value.

<u>Predict the difficulty for all the situations first then perform the experiment.</u>

| Situation The meter-stick is horizontal	Rate the Difficulty Easiest (1), Medium (2), Most Difficult (3)	
	Prediction	Actual
with a **200 g mass at the 90cm mark**		
with a **400 g mass at the 90cm mark**		
with a **200 g mass at the 50cm mark**		
with a **400 g mass at the 50cm mark**		

1. What happens in the situations described above?
    The hanging mass exerts a force on the meter-stick due to its weight. If the hand doesn't hold the meter-stick tight, the meter-stick will turn (rotate). Torque characterizes the ability of an applied force to cause rotation. In these situations, the force exerted on the meter-stick by the hanging weight produces a torque. In holding the meter-stick tight, the force exerted by the hand produces a counter torque so that the meter-stick doesn't rotate.

2. From your results, qualitatively summarize on what factors a torque depends and how.

In this set of experiments, you will **only vary the angle at which you hold the meter-stick**, not the hanging mass, nor its position on the meter-stick. Rate the difficulty of each situation.

Predict the difficulty for all the situations first then perform the experiment.

Situation with the **100g mass at 90cm mark.**	Rate the Difficulty Easiest (1), Medium (2), Most Difficult (3)	
	Prediction	Actual
The meter-stick is **horizontal**		
The meter-stick is roughly **30° above horizontal**		
The meter-stick is roughly **60° above horizontal**		
The meter-stick is roughly **30° below horizontal**		
The meter-stick is roughly **60° below horizontal**		

3. How does the direction of an applied force affect the torque?
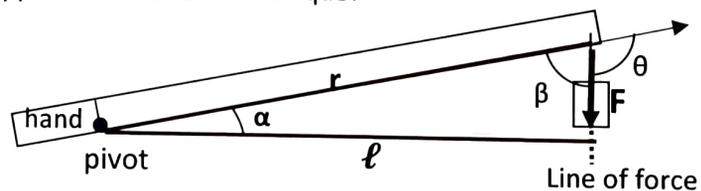
(a) In this figure, when the angle α changes, does **r**, the distance from the pivot point (the edge of the hand) to the point where the force is applied, change?

(b) When the angle α changes, does ℓ, the **perpendicular** distance from the pivot point to the line of force, change?

4. Combining the above two sets of experiment, the magnitude of the torque depends on:

- The magnitude of the applied force F
- The **perpendicular** distance from the pivot point to the line of force ℓ (named **lever arm**)

> Magnitude of torque
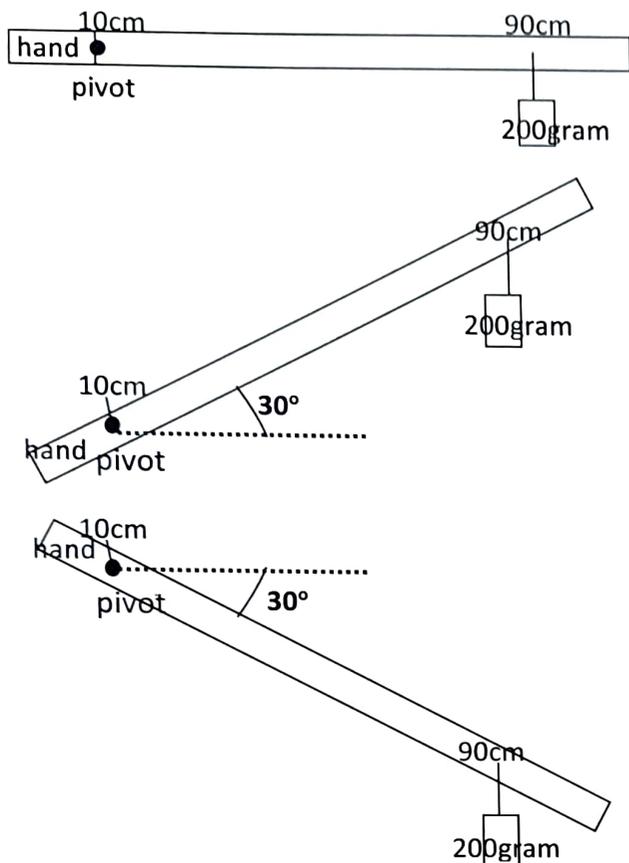> = force × lever arm
> = $F\ell$

Alternatively, the magnitude of the torque depends on:

- The magnitude of the applied force F
- The distance r
- The angle θ (pay attention to which angle in the drawing is θ)

> Magnitude of torque
> = $Fr \sin\theta$

Since $\sin\theta = \sin\beta$, then $r\sin\theta = r\sin\beta = \ell$, therefore $F\ell = Fr\sin\theta$

5. In each of the following situations, <u>**draw, label and calculate the lever arm**</u>, and <u>**calculate the torque**</u>

10cm
hand ●
pivot
90cm
200gram

90cm
200gram
10cm
hand pivot
30°

10cm
hand
pivot
30°
90cm
200gram

6. Calculate the torque in each of the following situations and fill in the table: (Don't change your predictions or experimental results on last page.)

Situation The meter-stick is horizontal	Rate the Difficulty Easiest (1), Medium (2), Most Difficult (3)	
	Calculated torque	rank
with a **200 g mass at the 50cm mark**		
with a **200 g mass at the 90cm mark**		
with a **400 g mass at the 90cm mark**		
Situation with the **200g mass at 90cm mark.**	Rate the Difficulty Easiest (1), Medium (2), Most Difficult (3)	
	Calculated torque	Rank
The meter-stick is **horizontal**		
The meter-stick is roughly **30° above horizontal**		
The meter-stick is roughly **60° above horizontal**		
The meter-stick is roughly **30° below horizontal**		

Activity 2: The Seesaw

Here we'll look at a simple model of a favorite piece of playground equipment.

Boy and girl on a playground seesaw	Experimental Model
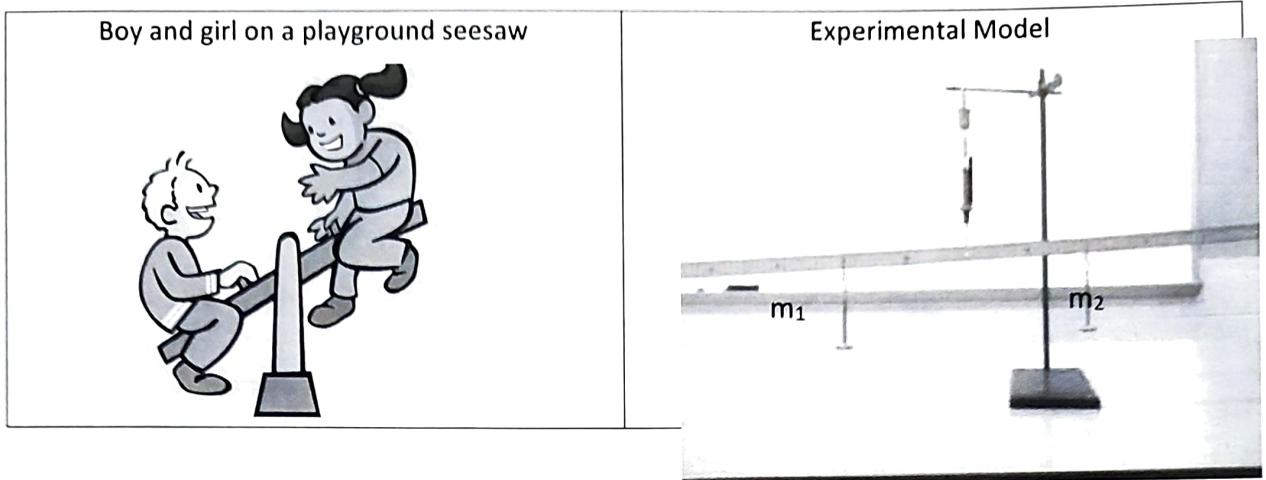
Directions:

1. On the picture of the experimental set-up (right, above), label which item represents the "boy", which represents the "girl", and which represents the pivot point.

2. Zero your force meter: Hold the spring scale force meter vertically, without hanging anything from it. Turn the plastic screw at the top until the plunger aligns with 0 N.

3. Suspend your force meter from the metal stand by looping the metal ring over the metal rod. Then suspend the meter-stick from the force meter by inserting the hook through the center hole of the meter-stick.

4. Your meter-stick should be balanced, since there are no masses hanging from it.

Part A: Modeling two kids of equal mass on a Seesaw

Take two empty mass hangers (they are 50 g each). Slide a metal clip over the meter stick and place it at the 30 cm mark, hang one mass hanger under the clip.

5. Where should you put the other metal clip + mass hanger so that the meter stick remains in balance?

   Hang the other metal clip + mass hanger at the location you predicted. If your prediction is wrong, adjust the location of the other metal clip + mass hanger till the meter stick is in balance. Read the force meter.

   Reading of the force meter with a correct unit =

6. For this set up,
   a. Draw a force diagram of all the forces
      (Hint: 4 forces) exerted on the meter-stick.
      Label each force. (Hint: the weight of the meter
      -stick is distributed over the stick, but it can be
      regarded as concentrated at the "center of mass".)

   a. Write the equations for static equilibrium using Newton's 2nd Law.

   b. Now solve for the mass of the meter-stick.

   c. Using a scale, experimentally measure the mass of the meter-stick. What is the % difference
   between the calculated and experimental values? Here the experimental value is more accurate.

   $$percent\ difference = \frac{|calculated\ value - experimental\ value|}{experimental\ value} \times 100$$

   Measured mass of the meter-stick with an appropriate unite =

   % difference =

7. In Activity 1, we focused on the magnitude of a torque. Torque also has a direction.
   - If a torque tends to rotate the object in the counterclockwise (**CCW**) direction, it is "**+**".
   - If a torque tends to rotate the object in the clockwise (**CW**) direction, it is "**-**".

   For this set up, look at your force diagram in 6.a.
   a. With respect to the pivot point, calculate the torque of each force. Indicate the direction of
   each torque by a "+" (CCW) or "–" (CW).

   b. Write out the sum of all torques in **7.a.** This sum of torques is called the <u>net torque</u>.

   Your result (if correct) in 7. b. is the second condition for static equilibrium. (What is the first
   condition? Hint: 6.b.)

   c. Why does the mass of the meter-stick not matter in the calculation in 7.a.?

Part B: Modeling Unequal Masses on a Seesaw

7. Now consider a situation where a parent and a child want to ride on the seesaw together. If the pivot point remains at the center of the seesaw, where should each person sit? (*Answer qualitatively here, using terms such as "near the pivot" or "far from the pivot"*).

8. Draw a force diagram for the situation where a parent and child ride on a seesaw together.
    a. Label all the forces; use "m_1" and "m_2" for the masses of the parent and child, respectively.
    b. Label the distance from the pivot for each force; use "L_1" and "L_2" for the parent and child, respectively.
    c. Label the direction for the torques; use "*CW*" and "*CCW*" for clockwise and counter-clockwise, respectively. Also, indicate if they will be positive "+" or negative "-" torques.
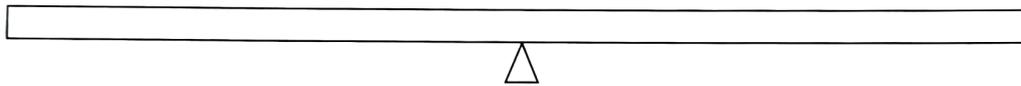
9. Determine the value of the unknown quantity in this table. Calculate first (show your calculations) then determine the value experimentally.

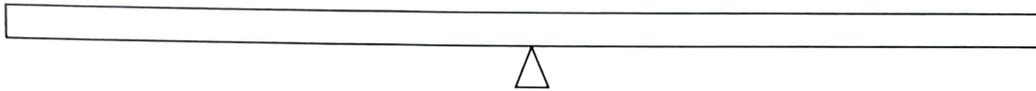|	Mass	Distance From Pivot		% Difference
		Prediction/Calculation	Experimental	
Parent	m_1 = 210g	L_1=	L_1=	
Child	m_2 = 80g	L_2= 0.40m	L_2= 0.40m	N/A

Show your calculations:

Calculate the magnitude of the force from the spring force meter (which simulates the pivot of the seesaw). What is the reading from the spring force meter? Here the calculated value is more accurate.

$$percent\ difference = \frac{|calculated\ value - experimental\ value|}{calculated\ value} \times 100.$$ Calculate the % difference.

Part C: Modeling Two kids and One Adult on a Seesaw

11. Now consider a situation where another child wants to ride on a seesaw as well. The second child sits down between the first child and the pivot. Draw a free-body diagram for this situation where two children and a parent ride on a seesaw together.

    a. Label all the forces; use "m_1", "m_2", and "m_3" for the masses of the parent, first child, and second child, respectively.

    a. Label the distance from the pivot for each force; use "L_1", "L_2", and "L_3" for the parent, first child, and second child, respectively.

    b. Label the direction for the torques; use "**CW**" and "**CCW**" for clockwise and counter-clockwise, respectively.

12. Determine the value of the unknown quantity. Calculate first then determine experimentally.

|	Mass	Distance From Pivot		% Difference
		Prediction/Calculation	Experimental	
Parent	$m_1 = 210g$	$L_1 = 0.30m$	$L_1 = 0.30m$	N/A
Child 1	$m_2 = 80g$	$L_2 = 0.40m$	$L_2 = 0.40m$	N/A
Child 2	$m_3 = 110g$	$L_3 =$	$L_3 =$	

Show your calculations:

Calculate the magnitude of the force from the spring force meter. What is the reading from the spring force meter? Here the calculated value is more accurate. $percent\ difference = \frac{|calculated\ value - experimental\ value|}{calculated\ value} \times 100$. Calculate the % difference.

Part D: Now it is your turn to design the experiment (only calculation is needed).

	Distance From Pivot	Mass calculation	
Parent	*Choose your own L₁* $L_1 =$ _____	To represent the parent, choose your own m_1 $m_1 =$	
Child	*Choose your own L₂* $L_2 =$ _____	What should be the mass of the child? Show your calculation in step c. $m_2 =$	

a. Choose your own values of L_1 and L_2.

b. Choose your own value of the mass of the parent, m_1.

c. Draw a force diagram for the situation where a parent and child ride on a seesaw together.
Label all the forces; use "**m_1**" and "**m_2**" for the masses of the parent and child, respectively.
Label the distance from the pivot for each force; use "**L_1**" and "**L_2**" for the parent and child, respectively.
Label the direction for the torques; use "**CW**" and "**CCW**" for clockwise and counter-clockwise, respectively. Also, indicate if they will be positive "**+**" or negative "**-**" torques.
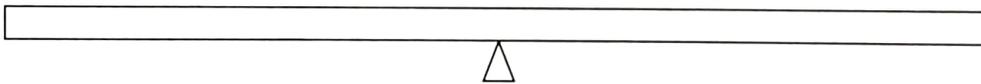
d. Show how the second condition for static equilibrium (sum of all torques (net torque) equals zero) can be used to determine the mass of the child m_2.

e. Apply the first condition of static equilibrium (Net force equals zero) to calculate the magnitude of the force from the spring force meter.

ARCHIMEDES' PRINCIPLE AND BUOYANCY LAB

Objective:
Determine the density of various objects using Archimedes' principle.

Available Equipment:
Activity 1: Eggs, beakers, and salt.
Activity 2: Wood blocks with a ruler on the side and a tub of liquid
Activity 3: Balance, prince's pendant, beaker of water, 25 ml graduated cylinder, and
   an assortment of metal rods
Activity 4: Balance, graduated cylinder, a spring, and cylinders made from wood and
   aluminum

Theory: Archimedes' Principle
   When an object is submerged or partially submerged in a fluid, the volume taken up by the object displaces an equal volume of the fluid. The difference in pressure (between the top and bottom of the object) applied by the fluid onto the object results in an upward force on the object; this phenomenon is known as buoyancy. This upward force can be calculated from Archimedes' principle:

Any object completely or partially submerged in a fluid experiences an upward force, called buoyant force F_B, equal to the weight of the fluid displaced by the object.

$$\left. \begin{array}{l} F_B = W_{fluid} \\ W_{fluid} = m_{fluid}\, g \\ m_{fluid} = \rho_{fluid} V_{fluid} \end{array} \right\} \Rightarrow F_B = \rho_{fluid} V_{fluid}\, g \quad (1)$$

where ρ_{fluid} represents the density of the fluid, V the volume of fluid displaced by the object and g is the gravitational acceleration. It is interesting to note that the buoyant force does not depend on the density of the object, but on the density of the fluid and how much volume of the fluid is displaced.

Activities

Activity 1: Egg in salt water (Demonstration)

Activity 2: Finding the density of a floating object

Activity 3: Finding the density of a fully submerged object

Activity 4: Finding the elastic constant for a spring using Archimedes' principle.

Go to the Activities, Data and Analysis Section and follow directions.