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Engr 101 Section: ______ **Date/Time Completed** 9/13/18

LEARNING OBJECTIVES

After finishing this laboratory, you will be able to

- Use a digital scale and balance system
- Describe the concept of a Moment (aka Torque)
- Calculate the moments due to various weights on a beam
- Calculate lever arms to achieve equilibrium of a beam
- Calculate and describe mechanical advantage

DELIVERABLE (Submit by end of lab to your instructor.)

Work in groups of 3-4 and answer the questions in this handout. One handout per group – but individually submitted.

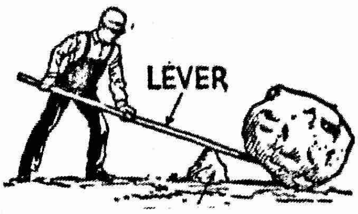
Each person needs to submit a completed handout electronically on Blackboard. Ensure that you submit a single, easily readable pdf file.

MATERIALS

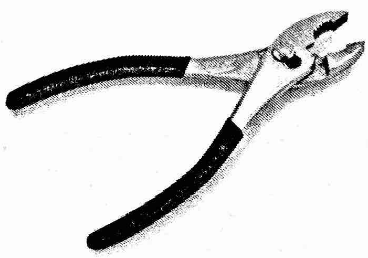
- Yardstick (beam)
- Binder clip
- 2 triangular wood supports/pivots
- 1 wood spacer block
- 9 large washers
- DigiWeigh 600g/21oz scale – *this is a precision instrument – use care and avoid overloading it.*
- Calculator – *use a cell phone ...*

INTRODUCTION

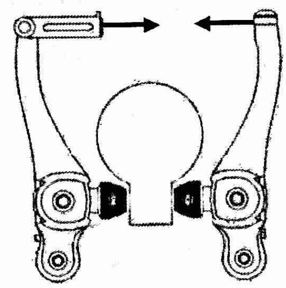
In the ancient world, 6 simple machines were invented that were essential to the advancement of civilization: *the lever, the wheel & axle, the pulley, the inclined plane, the wedge, and the screw.* These machines enabled such advances as the construction of buildings, productive agriculture, safe drinking water, and transportation. Most machines today are still based on these 6 machines and their underlying principles. Here are three examples that use levers:



The Lever
www.cool-science-projects.com



Pliers
www.howstuffworks.com



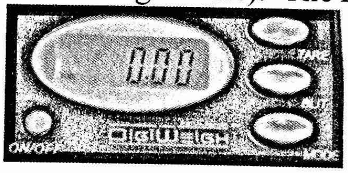
Cantilever Bicycle Brakes
www.triz-journal.com

This lab will examine one of these simple machines: *the lever* and its underlying principles. We will explore the concepts of moments and mechanical advantage. Archimedes said: "Give me a lever long enough and a fulcrum on which to place it, and I shall move the world." This lab will examine what he meant.

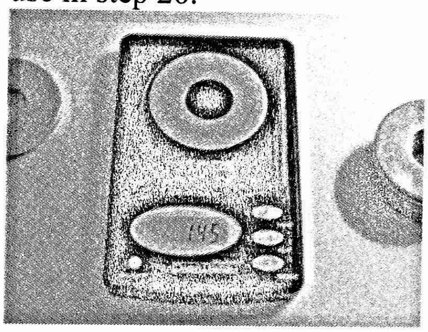
PROCEDURE

1. Obtain the group materials –*the number of groups is limited by the number of sets available.*

2. Turn on the DigiWeigh scale and press the *MODE* button until "OZ" (ounces) appears at the right of the display. Press the *TARE* button to zero the display ("tare" is the traditional term for zeroing a scale). The *BLIT* button toggles the backlight.



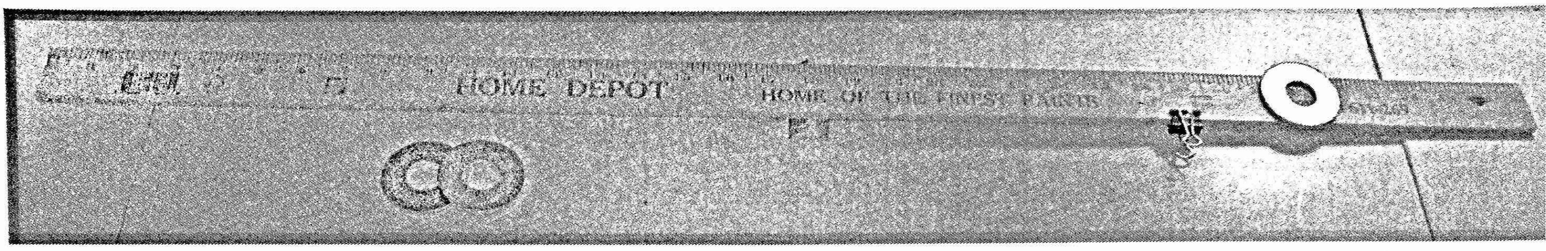
3. Weigh each of the washers to find 9 that are within +/- 0.05 oz of each other (tip: sort them from heaviest to lightest). Use these 9 for this lab. Record this average weight, for use in step 7: 1.64 oz. Mark *one* washer that is closest to the average weight, for use in step 26.



Inches and Feet
Inches are abbreviated with double quotes.
Feet are abbreviated with single quotes.
5" means 5 inches
2' means 2 feet
2' 5" means 2 feet and 5 inches

4. Find the notch under the 18.0" mark on the yardstick, and sit that notch over the wood pivot.
   - Place the yardstick so the 1" mark is on your left, for easier reading.
   - Clip the binder clip on either side to balance the yardstick reasonably well. Place the clip just on the edge of the yardstick. Keep this clip on for the whole lab.

5. Place 1 washer centered at 12.0" to the right of the pivot (at the yardstick's 30.0" mark). **Place 2 washers together to the left such that they balance the beam.** Record the distances *from the pivot to the washers*:
   - 1 washer at 12 " to the right of the pivot (yardstick's 30.0 mark)
   - 2 washers at 5 3/4 " to the left of the pivot (yardstick's 12 1/4 mark)



6. Terminology and Theory
   - The distances from the washers to the pivot are called **"Lever Arms"** or **"Moment Arms"**.
   - When a force acts perpendicular to a lever, as it does with the washer's weight and the beam, we call the product a moment or torque.

     (Force) * (Lever Arm) = **"Moment"** (aka "Torque"), or

     $$F * D = M \qquad \text{(Eq. 1)}$$
   - In English units, as in this lab, moments have units of ft-lb, in-lb, or in-oz.
   - Moments may try to rotate the object either clockwise (**cw**) or counterclockwise (**ccw**).
   - If the body is in rotational **equilibrium**, the body will not accelerate either cw or ccw. In that case, the *counterclockwise moments* are *equal* to the *clockwise moments*, and the body is in *equilibrium* – i.e., it is balanced and does not accelerate. This is true of the sum of what could be few or many moments acting on the one body. Mathematically, we can write this as:

     $$\sum M_{ccw} = \sum M_{cw} \qquad \text{(Eq. 2)}$$

For example, we can use equations (1) and (2) to solve for an unknown lever arm when the beam is in equilibrium (balanced). For the setup in step 5:

Single washer moment: $M_1 = (1.45\text{ oz}) * (12.0\text{ in})$ in the *clockwise* direction

Double washer moment: $M_2 = 2 * (1.45\text{ oz}) * (D_2)$ in the *counterclockwise* direction

Equation (2): $\sum M_{ccw} = \sum M_{cw}$

$M_2 = M_1$ (there is only 1 moment on both sides)

$2 * (1.45\text{ oz}) * (D_2) = (1.45\text{ oz}) * (12.0\text{ in})$

Cancel the washer weights: $2 * D_2 = 12.0$ in

Solving, $D_2 = 6.0$ in, which is what we found experimentally in Step 5.

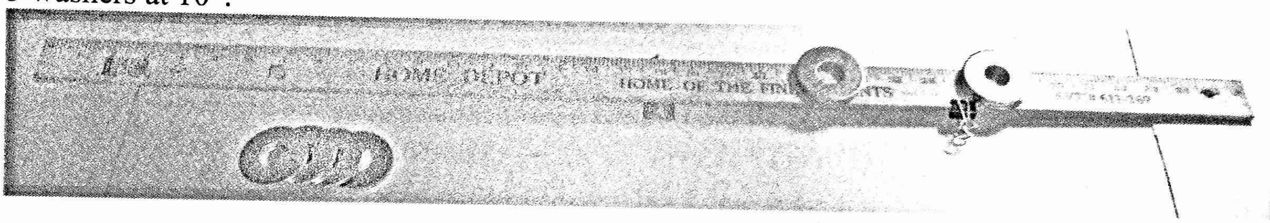
7. Now let's *calculate* a different combination. Assume 2 washers are 15" to the right of the pivot (at 33.0" on the yardstick). Use equation (2) to predict where 3 washers should go to achieve equilibrium. Hint: use "W" instead of the actual washer weight since it will cancel out. Start with equation 2: $\sum M_{ccw} = \sum M_{cw}$

avg weight x2 avg weight x3
(15)(3.28) = (D)(4.92)

Prediction of at equilibrium location for 3 washers: 10 " (to the left of the pivot)

8. Test your prediction: place the washers such that they balance the beam. Record the distances from the pivot to the washers:
   - 2 washer at 15 " to the right of the pivot
   - 3 washers at 9 7/8 " to the left of the pivot
   - How accurate was your prediction? About 1/8" off, very close

9. Congratulations – you just calculated and demonstrated the rotational version of Newton's First Law! Now assume 2 sets of washers are to the right of the pivot: 2 washers at 5", and 3 washers at 10".



Use equation (2) to predict where 4 washers should go to achieve equilibrium:

$$\sum M_{ccw} = \sum M_{cw}$$

(5)(3.28) + (10)(4.92) = (D)(6.56)

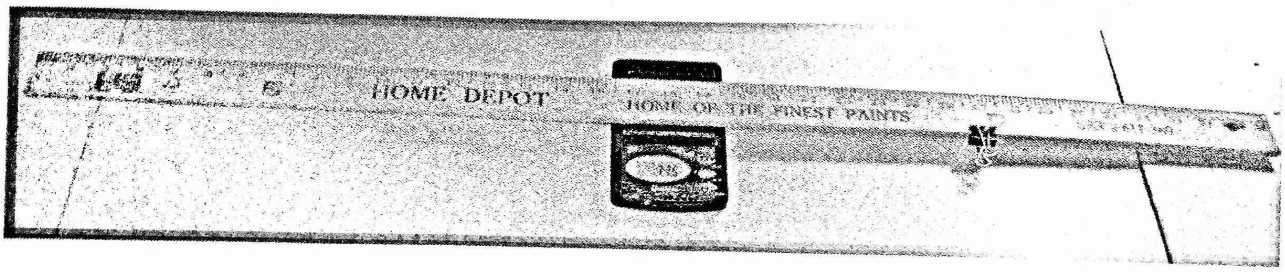
Prediction of at equilibrium location for 4 washers: 10 " (to the left of the pivot) 16.4+49.2 = 65.6

D = 10

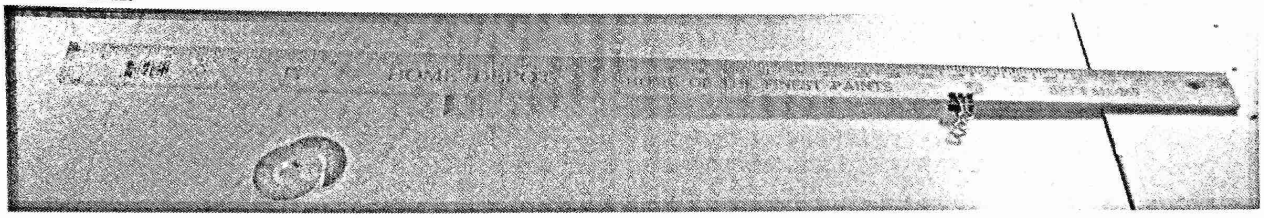
10. Test your prediction: place the washers such that they balance the beam. Record the distances from the pivot to the washers:
   - 2 washer at 5.0 " to the right
   - 3 washer at 10.0 " to the right
   - 4 washers at 9.9 " to the left
   - How accurate was your prediction? Very accurate about ≈ .1" off

11. In practice, engineers usually have to account for moments due to the weight of the beam itself. (*We haven't had to worry about this yet because the weight of the ruler has been right at the axis of rotation.*)

Weigh the yardstick (keep the binder clip on): 4.16 oz



12. Now offset the beam so the pivot is at 12.0", resting in the other notch under the yardstick's 12" mark.



13. The weight of a beam is distributed along its length, but *we can think of its entire weight as if it is concentrated at its center of gravity (CG). The CG is the same as the balance point* of the object (the yardstick's 18.0" mark).

    Since the CG of the beam is no longer directly over the pivot, the beam weight now has a clockwise moment around the new pivot. For example,

    M = F * D = (Beam weight in oz) * (18.0 in - 12.0 in)
    = (*3.75* oz) * (6.0 in) *(your beam may be a different weight)*
    = *22.5* oz-in *(your result may be different)*

14. <u>Calculate where 2 washers should go to balance this offset beam.</u> Use ounces for the weight of *your* washers and *your* beam. Start with equation 2:

    18-12

    (D) (3.28) = 6(4.16)

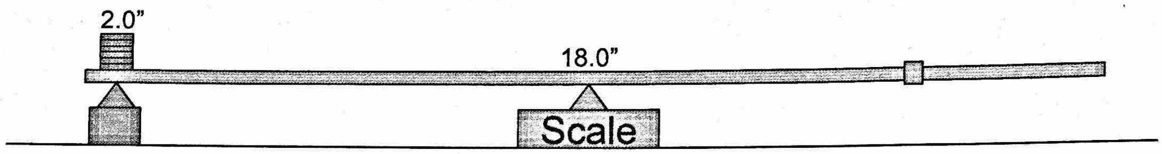
    D = 7.6 in to the left

15. <u>Test and evaluate your prediction:</u>

    Our prediction was accurate

16. So far the beam has had only one support/pivot. Now let's look at forces and moments for a beam with *two supports*. First, setup one support by placing the triangular wood support (pivot) on the scale and tare (zero) that load.

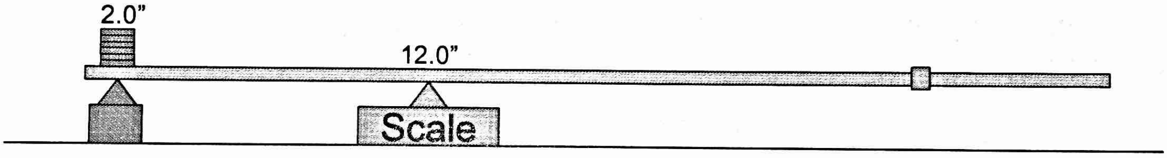
17. Set the yardstick + clip on the triangular support on top of the scale, at the yardstick's 18.0" mark. Place the other support + wood spacer under the beam at the yardstick's 2.0" mark, and stack 5-6 washers directly on top.



18. What does the scale read? 4.15 oz It should be very similar to step 12. Why is the scale reading the same despite the new support and stack of washers?

The weight of washers is being supported by the wood block supports

19. Now move the scale & triangular support to the yardstick's 12" mark (10" to the right of the left support). What does the scale read now? 6.60 oz



We will consider the new left support as our "pivot" for moment calculations: ***all lever arms will be measured from the left support for the rest of this lab.***

20. Let's look at why the scale reads approx 6.0 oz . Assume the pivot is at the *left support.* Equation (2) now has 2 terms, and each has its own lever arm relative to the left support:
    i. The weight of the beam which acts at its CG, pushing the beam *down* (gravity).
        a. Its lever arm is (18.0 – 2.0) in = *16.0 in.*
        b. The moment is (16.0 * (Beam weight)), trying to rotate the beam *clockwise* about the left support.
    ii. The force that the right wood support (on the scale) exerts *upward* on the beam, keeping the beam from falling. We'll pretend this is unknown and solve for it.
        a. Its lever arm is (12.0 – 2.0) in = 10.0 in.
        b. The moment is (F_{scale} * 10.0 in), trying to rotate the beam *counterclockwise* about the left support.

21. Using Equation (2), calculate F_{scale} for your beam, and compare. Start by writing Equation (2):

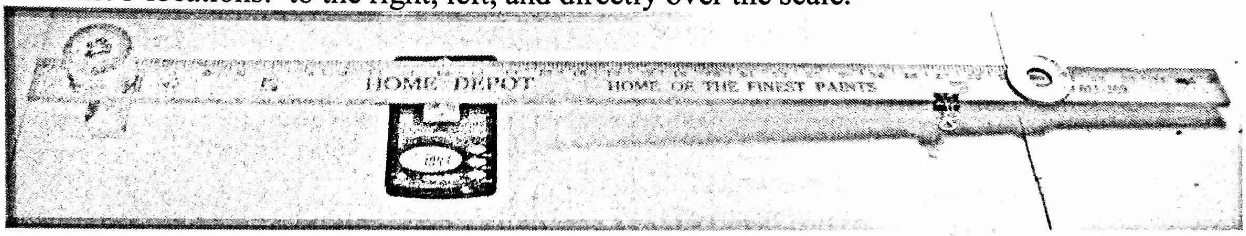
$$\Sigma M_{ccw} = \Sigma M_{cw}$$

$$M_2 = M_1$$

$$F_{scale}(10) = (16)(4.16)$$

$$F_{scale} = 6.66$$

22. Next, we'll look at the incremental effect of placing a single washer on the beam.
- *Before* placing the single washer, tare the load on the scale.
- Use the marked washer from Step 3 for best accuracy. Weight = 1.64 oz
- Try out different single washer placements and observe the scale reading. Try at least 3 locations: to the right, left, and directly over the scale.

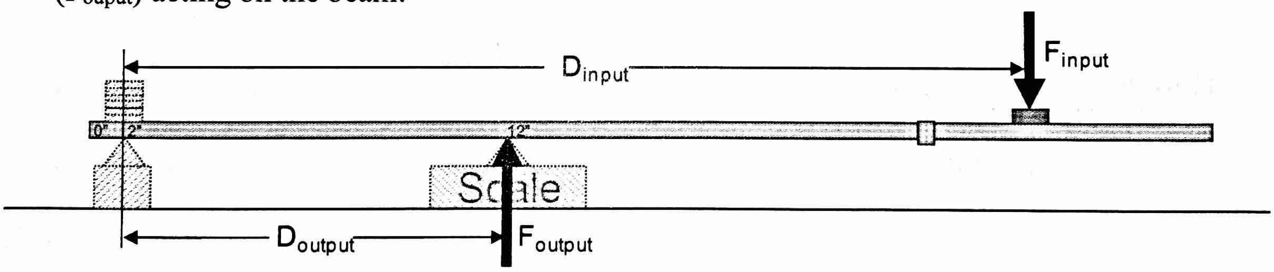


- Describe in words the general trends that you observe.

left - .82
over scale - 1.64
right - 2.94
all the way on the right end - 5.12

Heavier it is the further to the right it is

23. We can think of the *washer* as the *input* force (weight), and the *scale* reading as the *output* force. Each has a lever arm relative to the left support (see figure below). Earlier, you varied D_{input}, and observed F_{output}. This schematic shows the washer weight (F_{input}) and scale reading (F_{ouput}) acting on the beam:



- For this case, equation (2) simplifies to just 2 terms:

$$M_{input} = M_{output}$$

$$F_{input} * D_{input} = F_{output} * D_{output} \qquad \text{(Equation 3)}$$

Mechanical Advantage (MA)

- Rearranging equation 3 as ratios, we get the *Mechanical Advantage (MA)* of the washer in this lever system. Mechanical Advantage predicts the *force multiplication* of a machine. *Rewrite* equation 3 *in terms of F_{output} and F_{input}:*

$$\frac{D_{input}}{D_{output}} = \frac{F_{output}}{F_{input}} = MA$$

- Rewrite equation 3 again, solving for F_{output} in terms of MA and F_{input} (leave as variables):

$$F_{output} = MA \cdot F_{input} \, , \, \frac{D_{input}}{D_{output}}$$

24. Now we'll place the washer at specific yardstick locations and see how well Mechanical Advantage can be predicted.

- Fill out all but the last 2 columns of the table below, based on Step 25.
- Run the experiment: place the single washer on the yardstick at the locations indicated, and observe the scale readings (F_{output}, Recorded). Then calculate how well the $F_{outputs}$ agree.

Yardstick mark (in)	**D_{input}** Lever arm of washer relative to left support (Yardstick mark – 2") (in)	**MA** From D_{input}/D_{output}	**F_{output}** *Calculated* from step 25c (oz)	**F_{output}** *Recorded* from scale reading (oz)	**Ratio** of calculated / recorded F_{ouptut}
2.0	0	0	0	0	(undefined)
7.0	5	$\frac{1}{2}$	.82	0.82	1
12.0	10	1	1.64	1.62	1.01
22.0	20	2	3.28	3.26	1.01
32.0	30	3	4.92	4.90	1.00

$F_{output} = MA\ F_{input}$

How well do the $F_{outputs}$ agree (examine the ratios)?

They agree well, the ratios are close together

When the washer is to the right of the scale support, it affects the scale force more than its actual weight. This means it has high "mechanical advantage" or "leverage". Mechanical advantage is very useful to engineers, just as it was to Archimedes and the ancient world: *it allows us to amplify or reduce forces to whatever amount we want.* And you can calculate it in the design stage.