LAB 09: TORQUE AND STATIC EQUILIBRIUM

The Objectives

There are four basic components to a lever system:

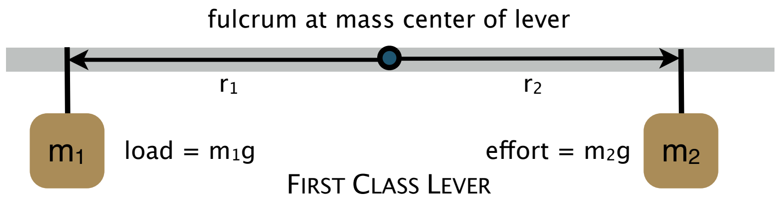
1. a rigid structure (the *lever*)
2. a pivot point (*fulcrum*) for that rigid structure to rotate about
3. a mechanical force (called a *load* or resistance) acting on the rigid structure that attempts to cause it to rotate and
4. another mechanical force (called an *effort*) acting on the rigid structure that attempts to prevent it from rotating.

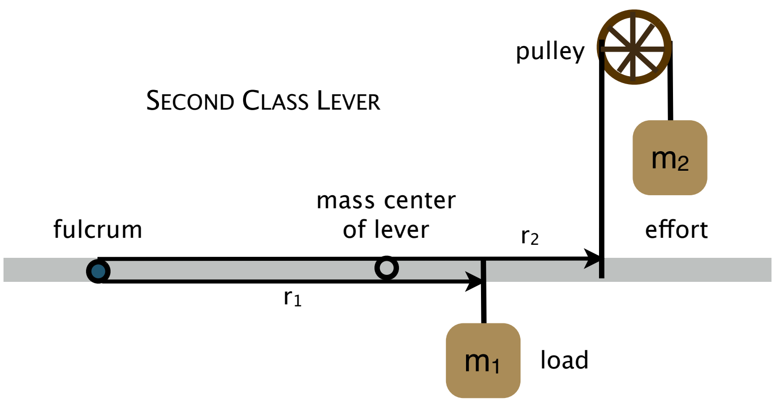
Using a meterstick for a lever, one can position a fulcrum anywhere along its length. Similarly, one can apply a load anywhere, then determine the required effort to prevent rotation. The three classes of levers are defined by the positions of the load and effort relative to the fulcrum.

The *mechanical advantage* of a lever is simply the ratio of the load to the effort and can have a value greater than, less than, or equal to one.

Our specific objectives:

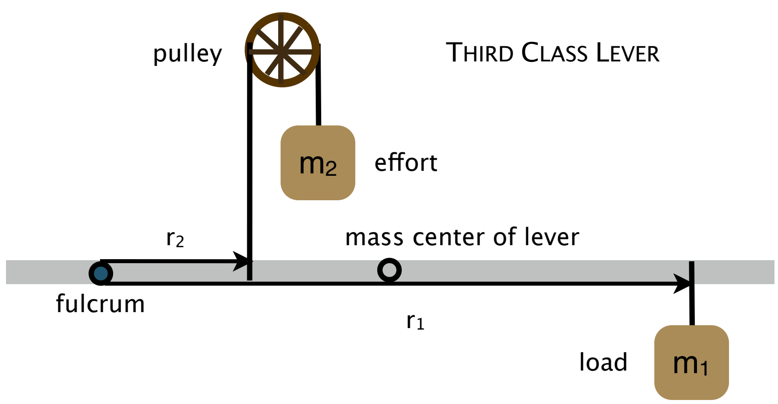
- Determine the mass center of an irregular object
- Apply the definition of torque and the associated sign conventions for rotational motion
- Identify and apply the conditions for static equilibrium
- Construct and observe the differences between first, second, and third class levers
- Define mechanical advantage and develop a graphical method for determining it



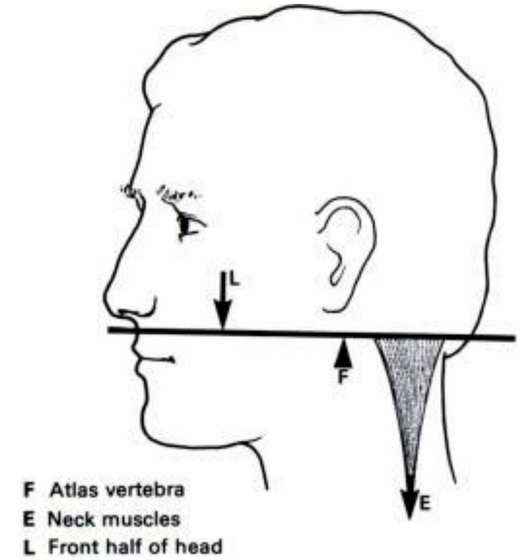


The Procedure

- Measure and record the mass of the meterstick. Attach a pivot clamp to serve as a fulcrum (measuring the mass of this clamp is not necessary).
- Find the mass center of your meterstick by balancing it without any added mass. Adjust the fulcrum clamp until the stick is level and balanced, then record its position on the stick.
- Set up a First Class Lever, using a 100g load (you must include the mass of the hanger clamp here!) located 5cm from the left end of the meterstick. Balance the lever with a 150g effort (including clamp) located to the right of the fulcrum.
- Using the sign convention that the **fulcrum** is the **origin** and to the to the right is positive, record the positions r_1 and r_2 of the load and the effort.
- Move the load m_1 5 cm to the right (closer to the fulcrum). Reposition m_2 for equilibrium, and record the new values of r_1 and r_2. Continue to move m_1 in 5cm increments until you have at least five data pairs of r_1 and r_2 values.
- Reposition the fulcrum to 10 cm from the left end of the meterstick. Construct a Second Class Lever as shown in the diagram above, making sure not to switch the hanger clamps. Attach the 100g load 40cm to the *right* of the fulcrum. Balance the lever by attaching the effort hanger 5 or 10 cm from the right end of the meterstick, and adding mass until the system is in equilibrium. Make sure to record the amount of mass m_2.



- Using the same sign convention as before, record the positions r_1 and r_2 of the load and the effort. Slide the load 5cm to the *left*, and rebalance the effort. Continue to decrease r_1 in 5cm increments until you have at least five data pairs of r_1 and r_2 values.
- Repeat the experiment once more, constructing a Third Class Lever. Begin with the 100g load located 5cm from the *right* end of the meterstick, and position the effort clamp 50cm from the fulcrum. Measure and record the mass m_2 required to balance the lever, then move m_1 to the *left* in 5 cm increments until you have at least five pairs of data.

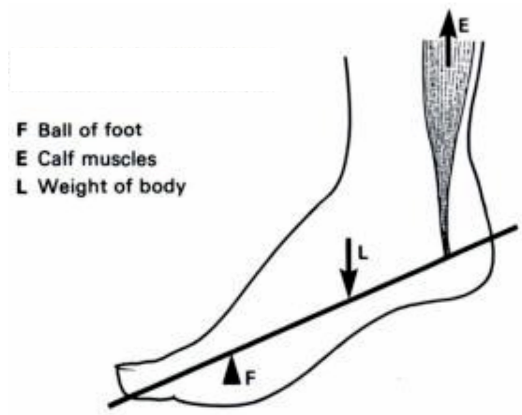


The Data

If you have not already, summarize all of your data in a neat table. Setting up an Excel worksheet is advisable, since the data reduction will be quick and simple if you can type a formula once, then copy and paste it down a column.

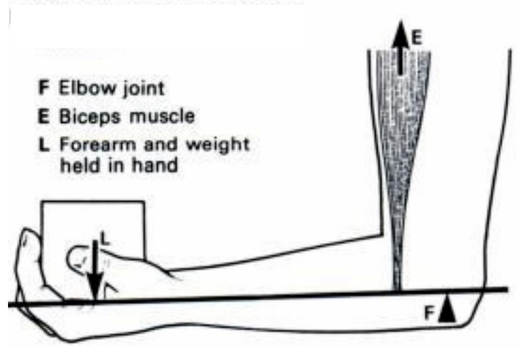
The Reduction

Using the sign convention that a *positive* torque creates a *counterclockwise* rotation (*negative* torque creates *clockwise* rotation), calculate the individual torques acting on each type of lever. You should remember to include torque due to the meterstick itself if the pivot is not located at the mass center of the stick.



The Analysis

1. For each type of lever, draw a complete free-body diagram. Include all forces acting on the lever, then identify which forces actually create a torque with respect to the pivot.
2. For the second-and third-class levers, examine the effort in particular. Notice that the clamp exerts a *downward* force while the tension in the string exerts an *upward* force at the same point. Summarize the torques algebraically, and if necessary, edit your spreadsheet to account for the weight of the effort hanger and its torque.
3. For each type of lever, prepare a graph of r_2 (y–axis) as a function of r_1 (x–axis). Perform a linear regression, and compare the resulting equations of the lines to your algebraic summaries of the torques. Identify the physical meaning of the slope and intercept of each graph, and compare those values to the values predicted by your torque summaries.
4. Are the deviations in your graphical results random, or do you detect some systematic effect? You should be able to construct a qualitative argument from examining your graphs, and you should be able to support your arguments quantitatively by calculating percent error values for both slope and intercept.
5. For the anatomical examples shown on the right, identify the type of lever illustrated. Comment specifically on the relationship of load and effort (think about muscle strength).



The Conclusions

Comment on any outstanding issues with data or results, and suggest methods for improvement if appropriate. Briefly address how the graphical method could be used to facilitate the design of a mechanical system requiring the use the levers.