19 Rotational Equilibrium

Solitary See-Saw

Purpose

To use the principle of balanced torques to find the value of an unknown mass and to investigate the concept of center of gravity.

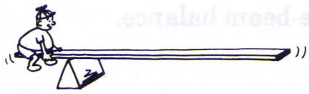
Required Equipment and Supplies

meterstick
standard masses with hook
slotted weights
rock
triple-beam balances
fulcrum
fulcrum holder
string
masking tape

Discussion

An object at rest is in *equilibrium* (review rotational equilibrium in your text). The sum of the forces exerted on it is zero. The resting object also shows another aspect of equilibrium. Because the object has no rotation, the sum of the *torques* exerted on it is zero. When a force produces a turning or rotation, a non-zero *net* torque is present.

A see-saw balances when any torques on it add up to zero. A see saw is a form of lever, a simple mechanical device that rotates about a pivot or fulcrum. Although the work done by a device such as a lever can never be more than the work or energy invested in it, levers make work *easier* to accomplish for a variety of tasks. A knowledge of torques can also help us to calculate the location of an object's *center of gravity*.



Earth's gravity pulls on every part of an object. It pulls more strongly on more massive parts and more weakly on less massive parts. The sum of all these pulls is the weight of the object. The average position of the weight of an object is its center of gravity, or CG.

The CG of a uniform meterstick is at the 50-cm mark. In this experiment you will balance a meterstick with a known and an unknown mass, and compute the mass of the unknown. Then you will simulate a "solitary see-saw."

Procedure

Step 1. Balance the meter stick horizontally on the fulcrum with nothing hanging from it. Record the position of the CG of the meter stick.

position of meterstick CG = ________

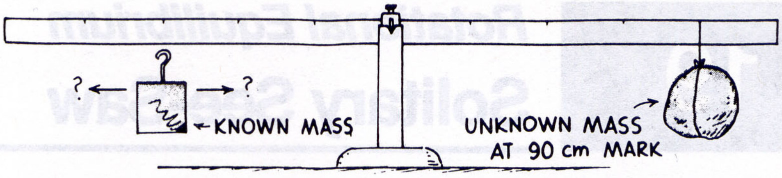


Figure 19.1

Using a string, attach an object of unknown mass, such as a rock, at the 90-cm mark of the meterstick, as shown in Figure 19.1. Place a known mass on the other side to balance the meterstick. Record the mass used and its position.

mass = ________ position = ________

Step 2. Compute the distances from the CG to each object.

distance from CG to unknown mass = ________

distance from CG to known mass = ________

In the following space, write an equation for balanced torques, first in symbols and then with the known values. Compute the unknown mass.

$\text{mass}_{\text{computed}}$ = ________

Step 3. Measure the unknown mass, using a triple-beam balance.

$\text{mass}_{\text{measured}}$ = ________

Step 4. Compare the measured mass to the value you computed in Step 2, and calculate the percentage difference.

percentage difference = ________

Step 5. Remove the unknown mass and place the fulcrum exactly on the 85-cm mark. Balance the meterstick using a single mass hung between the 85-cm and 100-cm marks, as in Figure 19.2. Record the mass used and its position.

mass = ________ position = ________

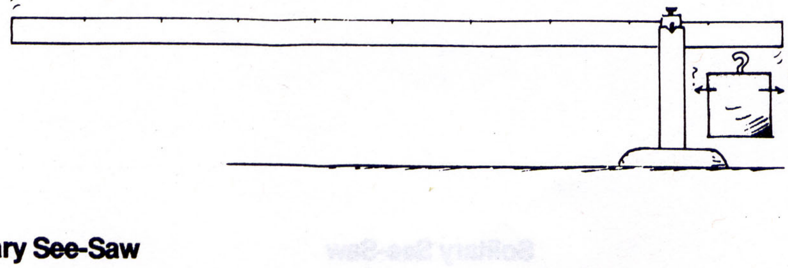
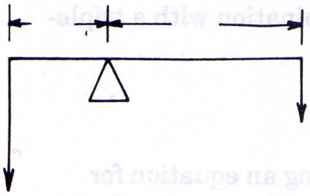


Figure 19.2



Step 6. Draw a lever diagram of your meterstick system in the following space. Be sure to label the fulcrum, the masses giving rise to torques on each side of the fulcrum, and the lever-arm distance for each mass.

1. Where is the entire mass of the meterstick *effectively* located?

Write a torque equation using your lever-arm diagram as a guide. Then compute the mass of the meterstick. Show your work in the following space.

$\text{mass}_{\text{computed}}$ = ________

Step 7. Remove the meterstick and measure its mass on a triple-beam balance.

$\text{mass}_{\text{measured}}$ = ________

Step 8. Assume measuring the mass involved no error and calculate the percentage error for the computed value of the mass of the meterstick.

percentage error = ________

Going Further

For a uniform, symmetrical object, the CG is located at its geometrical center. The CG of a uniform meterstick is at the 50-cm mark. But for an asymmetrical object such as a baseball bat, the CG is nearer the heavier end. In this part of the experiment you will learn how to find the location of the center of gravity for an asymmetrical rigid object.

Step 9. If a rock is attached to your meterstick away from the midpoint, the new CG of the combined meterstick plus rock is not in the center. Use masking tape to attach the rock to the meter stick between the 0-cm and 50-cm mark. Move the fulcrum to the 60-cm mark, as shown in Figure 19.3. Hang a known mass between the 60-cm and 100-cm mark to balance the meterstick. Record the mass used and its position.

mass = ________ position = ________

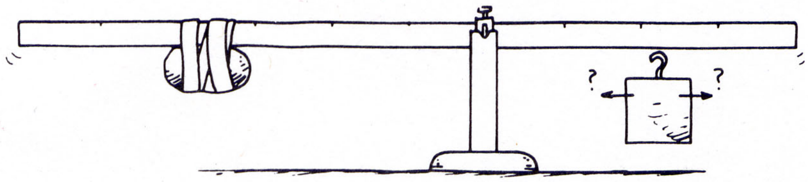


Figure 19.3

Step 10. Find the mass of the meterstick-rock combination with a triple-beam balance.

mass of meterstick-rock combination = ________

Find the CG of the meterstick-rock combination using an equation for balanced torques. In the following space, write down the equation first in symbols and then with known values.

torque equation:

distance from CG to fulcrum = ________

computed position of CG on meterstick = ________

Step 11. Verify the location of the CG by removing the added known mass and placing the fulcrum at the predicted CG point and see where it balances.

2. Does the meterstick balance at the predicted location of the CG?

3. How far was your predicted location of the CG from its actual location? Calculate the percentage error.

percentage error = ________

Extra for Experts

Extend a stack of four metersticks cantilevered over the edge of a table as far as you can. Make a sketch of the arrangement which gives the maximum extension. How far does the stack extend beyond the edge of the table? Do you think there is a limit to how far the metersticks could extend given an infinite number of metersticks?