# EXPERIMENT 9
# MOMENTS - CENTER OF GRAVITY

## I. THEORY

The purpose of this experiment is to test the validity of the Second Condition of Equilibrium and of the concept of the center of gravity.

The Second Condition of Equilibrium states that when a rigid body is in equilibrium vector sum of all torques (moments) is zero.

$$\sum \vec{\tau} = 0$$

In this experiment, all forces lie in a single plane, so that all torques are either clockwise or counterclockwise. By convention, counterclockwise torques will be considered positive and clockwise torques negative. Thus, the vector sum becomes a scalar or algebraic sum.

The center of gravity of a body may be defined as the one point at which a body may be supported so as to balance in any orientation. Although the gravitational attraction of the earth acts downward on all parts of the body, we may treat it as acting at a single point, the center of gravity.

If two or more bodies are connected together and balance on a fulcrum, the torque equation can be rewritten

$$\sum w_i l_i = 0 .$$

In which, $w_i$ is the weight of the $i^{th}$ body, and $l_i$ is the lever arm (in this case, the horizontal distance from the fulcrum to the position of the $i^{th}$ body). In keeping with the sign convention mentioned above, torques should be considered positive for bodies to the left of the fulcrum, negative for bodies to the right of the fulcrum.

The apparatus for this experiment consists of a meter stick whose center of gravity has been shifted, either by loading with lead near one end, or by drilling holes near one end. A knife-edge fulcrum supports the meter stick, and masses are hung from the meter stick by using loops of string.

## II. LABORATORY PROCEDURE

1. Record the number of the meter-stick.

2. Make a data table containing step number and the positions of the fulcrum, the center of gravity of the meter stick, the 50.0 g mass, the 100.0 g mass and the "unknown" body. Some columns will be unused in some steps of the laboratory procedure.

3. Attach the fulcrum to the meter stick, with the thumbscrew below the stick. Balance the meter stick on the pedestal, with the meter stick right side up and 0 cm on the left. Record the position of the center of gravity of the meter stick.

4. Leave the fulcrum at the center of gravity of the meter stick for this and the following two steps. Place the 50-g mass and the “unknown” mass on opposite sides of the fulcrum, suspended by loops of string. Move them until balance is obtained, using the largest lever arms possible, for precision. Record the position of each mass, not the lever arms.

5. Repeat step 4 using the 100-g mass and the “unknown” mass.

6. Repeat step 4 using the 50-g mass, 100-g mass and the “unknown” mass, all at different positions. The two standard masses may be on the same or opposite sides of the fulcrum.

7. Place the fulcrum approximately 10.0 cm to the left of the center of gravity of the meter stick for this and the following two steps. Do not include the “unknown” mass. Balance the meter stick by placing the 100-g mass to the left of the fulcrum. Record the positions of the fulcrum and the standard mass.

8. Repeat step 7 using both of the standard masses to the left of the fulcrum, at different positions.

9. Repeat step 7 using the 100-g mass to the left the fulcrum and the 50-g mass to the right of the fulcrum.

10. Remove the fulcrum from the meter stick. Use a triple-beam balance to measure the mass of the meter stick and the “unknown” body.

11. Estimate the possible absolute error in setting and reading positions on the meter stick. There is no one “correct” answer but all members of your laboratory group should agree on the estimate chosen. Briefly explain how you decided on your estimate.

## III. CALCULATIONS

Use SI units for all forces and torques.

All torques should be calculated about the fulcrum, since it exerts an unknown upward force on the meter stick.

<u>Include a force diagram in each case</u>, showing the position and magnitude of each known force.

1. Define a symbol to represent each mass and each lever arm for the system of II-4. Write the torque equation using these symbols and solve algebraically for the mass of the "unknown" body. Plug in the data of II-4 to obtain a numerical value for the mass of the "unknown" body.

2. Repeat Calculation 1 for the system of II-5.

3. Repeat Calculation 1 for the system of II-6.

4. Average the three preceding results and find the percent difference between this value and the mass of the "unknown" body measured with the balance.

5. Repeat Calculation 1for the system of II-7 with the meter stick replacing the "unknown" body.

6. Repeat Calculation 5 for the system of II-8.

7. Repeat Calculation 5 for the system of II-9.

8. Average the three preceding results and find the percent difference between this value and the mass of the meter stick measured with the balance.

9. Using your group's estimate of the possible absolute error in position readings, calculate the possible absolute error in lever arms, remembering that each lever arm is the difference of two position readings. Actual lever arms need not be listed. Refer to the introduction in this manual for a discussion of possible absolute errors and possible relative errors.

10. Assume that the standard masses are accurate to within ± 0.5 %. Determine the possible relative error (in percent) in the mass of the meter stick for the system of II-9. Show all work.