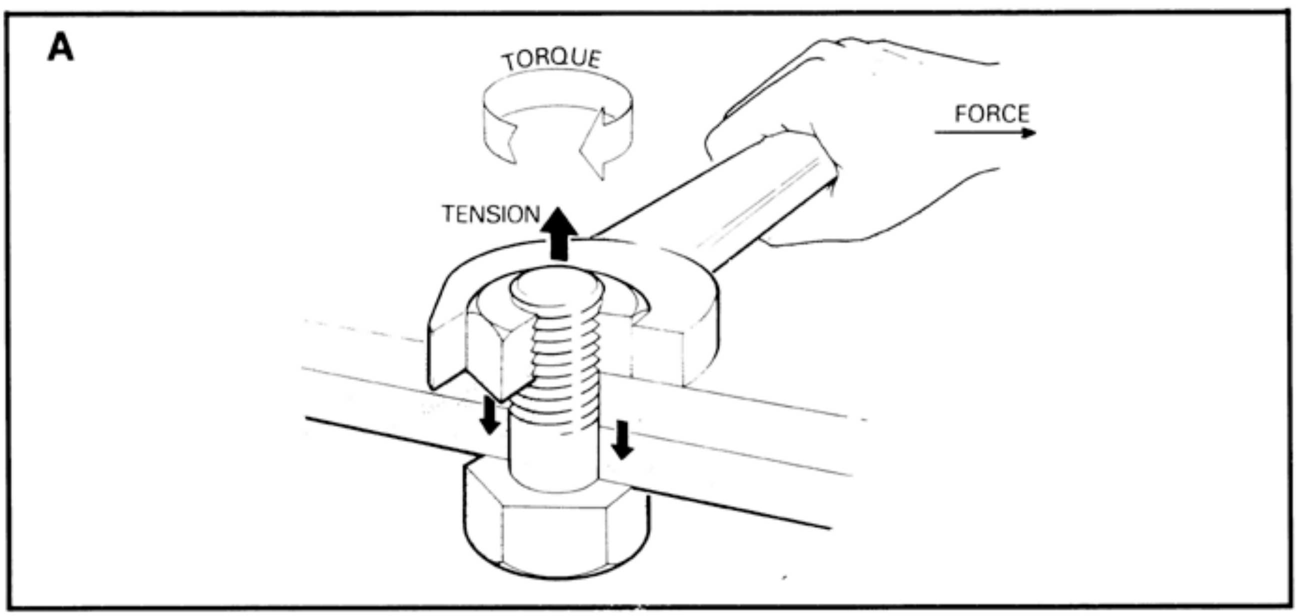
Experiment # 8

Torque and the Second Condition of Equilibrium



Experiment

EXTENDED BODY STATIC EQUILIBRIUM

PURPOSE: The purpose of this experiment is (a) to study the conditions of equilibrium for a rigid bar (meter stick); (b) to locate its center of gravity; and (c) to determine experimentally the mass of the bar (meter stick) using the Second Condition of Equilibrium for comparison with its actual mass.

APPARATUS: Meter stick, support stand, one knife-edge clamp, two hooked clamps, and two hooked weights (100g and 200g).

BACKGROUND:

When an extended body (one with definite mass and considerable dimensions) exists in static equilibrium, all forces acting on the body must be balanced (First Condition of Equilibrium). Although the forces acting must be balanced, each force, when considered separately, has a tendency to rotate the extended body. Torque, as concept, is used to quantify how much rotation a force is capable of producing around an arbitrary axis. Even the weight of an extended body (product of its mass and the acceleration due to gravity) is a force acting in producing the equilibrium and contributes to the overall torque on the body. The weight of an extended body is represented vectorially as an arrow pointing straight down from a point called the center of gravity (c.g.) of the body. The c.g. is the geometric center if the body has a regular geometric shape and uniform density.

Mathematically, the amount of torque (τ) produced by a force around an axis is defined as:

$$\tau = F \times l$$

where F is the magnitude of the force and l is the perpendicular distance between the axis and line of action of the force. Torques can have one of two directions with respect to any arbitrary axis around which rotation occurs: *clockwise* (designated *negative*) and *counterclockwise* (designated *positive*). Hence, the use of either a positive or negative sign in the calculation of torque denotes the direction of the rotation that it causes.

Consider the meter stick diagrammed below. It exists in static equilibrium when supported at point P under the forces indicated (note that its weight is included).

In most instances, where extended bodies are in static equilibrium under parallel forces, the torque (Second Condition) expression is sufficient for the mathematical analysis required. Although point P was used in this analysis, *any arbitrary point in space* could have been used for torque analysis.

Your instructor will assist you with preparing the diagrams necessary for setting up the torque (Second Condition) expressions required in making the calculations needed in this exercise. He/she will further discuss the calculation of torques and the application of the Second Condition of Equilibrium prior to data collection in class.

PROCEDURE:

(a) Determine the actual mass of the meter stick using a laboratory balance. Record this mass.

(b) Measure the mass of the two hooked clamps on a balance. Record this mass.

(c) Place the meter stick on the support stand by means of the knife-edge clamp. Note that the knife edge is rested on the support. Determine the center of gravity by adjusting the position of the clamp until the meter stick is balanced in a horizontal position. Record this position of the knife-edge clamp as the center of gravity of the meter stick.

(d) Place a hooked clamp at the 10-cm mark on the meter stick and suspend a mass of 100g from it. Adjust the meter stick until it is again in a horizontal position. Record this position as an axis of rotation.

(e) Now suspend a second mass of 200g at the 85-cm mark on the meter stick. Bring the system to static equilibrium again as in step (d). Record this position as a second axis of rotation.

CALCULATIONS:

In calculating torques, the average mass of each clamp should be added to each suspended mass in determining forces acting on the meter stick.

(1) Determine the average mass of each clamp.

(2) Use the data in procedure (e) to show that the sum of counterclockwise torques is equal to the sum of clockwise torques.

(3) Compute the percent difference between the sum of counterclockwise and clockwise torques.

(4) Determine the mass of the meter stick by using the data collected in procedure (d).

(5) Compute the percent difference between the actual and the calculated value of the mass of the meter stick.

Sum of counterclockwise torques:

Sum of clockwise torques:

Percent difference between counterclockwise and clockwise torques: