Fig. 9-1 Torque Apparatus

Equipment
Fulcrum
Meter stick
3 Hangers
Masses
3 Hanger clamps
1 Knife-edge clamp
Triple beam balance
Block of wood
Rock of unknown mass

Experiment 9
Torques and Rotational Motion

Advance Reading: Serway and Jewett, Chapter-section 10-6, Chapter-section 12-1, 12-3

Objectives: To measure the torque on a rigid body, to determine the conditions necessary for static equilibrium to occur, and to perform error analysis.

Theory: When a force (F) is applied to a rigid body at some point away from the axis of rotation a torque (τ, tau) is produced. Torque is a vector and is defined as the tendency to cause rotation. The magnitude of the vector is given by:

$$\tau = Fr\sin\phi \qquad\qquad\qquad \text{(Eq 1)}.$$

where r is the distance from the point where the force is applied from the axis of rotation and the angle ϕ is the angle between the vector $\vec{F}$ and vector $\vec{r}$. Note that $r\sin\phi$ is the perpendicular distance from the rotation to the line of action (see figure 10-12 in text).

In this experiment, all forces will be acting perpendicular to the meter stick (i.e., $\phi = 90°$and thus $\sin\phi = 1$). The equation for torque simplifies, and is given by:

$$\tau = Fr \qquad\qquad\qquad \text{(Eq 2)}.$$
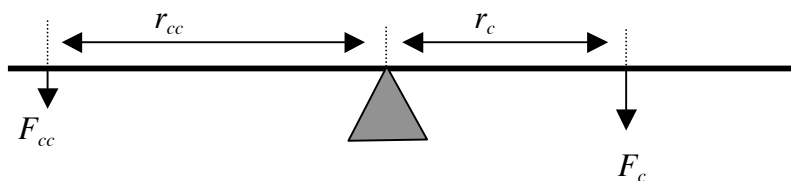
Fig 9-2 Torque components, F (force) and r (moment arm).
Note subscripts: "cc" is counterclockwise and "c" is clockwise.

Procedure
Part 1: Qualitative Analysis of Torques.
1. Hold the meter stick as close to the zero end of the meter stick as possible. Place a hanger clamp at the 10 cm position and place 50g on the mass hanger. The mass will produce a torque acting on your hand: $\tau = (.050\ \text{kg} + \text{mass of mass hanger})(\text{distance from the fulcrum})$. Note how difficult it is to hold this set-up. Now place 100g on the mass pan. Note how this feels compared to the first time.

2. Move the mass hanger and the 100g mass out to the 100 cm mark of the meter stick in 20 cm increments, holding the meter stick as before. Note your observations. Is it easy to feel the torque increasing as the force moves further from the axis of rotation (your wrist)?

Part 2: Quantitative Analysis of Torque

   In your lab data notebook sketch *each* experimental set-up you used (position and magnitude of all forces).

3. With the meter stick oriented such that the zero end is on the left and the 100 cm end is to the right, place the knife-edge clamp at the 50 cm position of the meter stick with the screw pointing down, and place this set-up on the fulcrum. (See Fig. 9-1.) Carefully adjust the fulcrum position by moving the knife-edge clamp until the meter stick is balanced: the meter stick should be horizontal. Record the position. This position is x_{cm}.

4. Measure and record the mass of the hanger clamps. Place a clamp at the $x_{cc} = 15$ cm position and another clamp at the $x_c = 75$ cm position. Place 200 g on the clamp at 15 cm and enough mass on the clamp at 75 cm to make the system balance (static equilibrium). If small fractional masses are not available to you, it may be necessary to adjust the position of the 75 cm clamp in order to balance the system.

5. Determine the force acting at each position and the length of each moment arm. From this information, calculate the torque (and the uncertainty of torque) acting on each side of the fulcrum (i.e., you are determining $\tau_{cc} \pm \delta\tau_{cc}$ and $\tau_c \pm \delta\tau_c$.)

 6. Calculate the sum of the torques (i.e., $\Sigma\tau=\tau_{cc} \pm \delta\tau_{cc} + \tau_c \pm \delta\tau_c$) acting on the meter stick. Use the convention that torques acting clockwise (τ_c) are negative and torques acting counterclockwise (τ_{cc}) are positive. Calculate $\delta\tau$ for $\Sigma\tau$. Is $\Sigma\tau$ zero within experimental uncertainty?

7. *Add* a hanger clamp at the 5 cm position and hang a 50 g mass hanger from it. Adjust the mass on the hanger at the 75 cm position to achieve static equilibrium. Calculate the torque(s) and the uncertainty of torque(s) acting on each side of the fulcrum.

8. Calculate the sum of the torques (i.e., $\Sigma\tau=\tau_{cc} \pm \delta\tau_{cc} + \tau_c \pm \delta\tau_c$) acting on the meter stick. Calculate $\delta\tau$ for $\Sigma\tau$. Is $\Sigma\tau$ zero within experimental uncertainty?

One-Person See-Saw:

9. Remove all clamps from the meter stick; measure and record the mass of the meter stick.

10. Place the fulcrum at the 20 cm position on the meter stick and place a mass hanger as close to the zero end as possible. Add enough mass to the mass hanger to attain static equilibrium. Calculate the torque(s) and the uncertainty of torque(s) acting on each side of the fulcrum.

Calculate $\Sigma\tau$. The meter stick can be treated as if all of its mass is concentrated at one point (the center of mass), so when the stick is supported in a position other than the center of mass, a torque is produced. Disassemble the setup and put fulcrum back at center of mass.

Determination of an Unknown Mass (No uncertainty calculation in this part)

11. Determine the mass of the marble block *(plus string and paper clip)* experimentally by balancing (i.e., sum of torques is zero) the block on one side of the fulcrum and a known mass on the other side. Sketch the arrangement used, noting the positions and magnitudes of the forces. Measure the mass of the block *(plus string and paper clip)* with the balance. Compare the values.

Questions:

1. Explain how a triple-beam balance works. Would such a balance that functions properly on the earth yield the correct mass of an object on the moon? Why or why not?

2. Rotating the dial of a Dial-o-gram balance coils or uncoils a spiral spring that is attached to the beam. Explain how this is employed to measure mass. Would such a balance that functions properly on the earth yield the correct mass of an object on the moon? Why or why not?

3. In steps 6, 8 and 10 of part 2, is the sum of the torques equal to zero within experimental error? That is, does zero lie in the interval $\tau_{net} \pm \delta\tau_{net}$, where τ_{net} is the sum of the torques and $\delta\tau_{net}$ is the uncertainty of τ_{net}? If not, what could be responsible for the discrepancy?