PHY 151/251

Lab 7 – Equilibrium of a Rigid Object

Objectives:

The objective of this lab is to examine the conditions for the equilibrium of a rigid object under the action of several forces.

Theory:

When a rigid object is acted upon by a system of forces which do not all pass through the same point, a change may be produced in the linear velocity of the object, or in the angular velocity of the object, or both. Under certain conditions, the object will be in equilibrium.

The torque (τ) is a measure of the tendency of a force to produce rotation. It is equal to the product of the distance from the axis of rotation to the point where the force acts on the object and the component of the force perpendicular to this displacement. In computing torques, the rules of coordinate geometry are used: forces causing clockwise rotations produce negative torques, and forces causing counterclockwise rotations produce positive torques.

A rigid object is an object whose particles do not change their distances from one another. If a system of forces is acting on a rigid object and the forces considered collectively have no tendency to produce any motion of translation or rotation, then the object is in equilibrium. That is, a rigid object is in equilibrium when it has no linear or angular acceleration. The two conditions for the equilibrium of a rigid object are 1) the vector sum of all the forces acting on the object must be zero; 2) the sum of all the torques about any axis must be zero. The first condition means that the sum of the forces in any direction must be equal to the sum of the forces in the opposite direction. The second condition means that the sum of the clockwise torques around any point must be equal to the sum of the counterclockwise torques around the same point.

Consider a horizontal bar being supported near its middle and having various forces acting upward and downward on it. The torque of each force is calculated, and by making use of the two conditions for the equilibrium of a rigid object, unknown quantities such as forces or distances may be computed. This process can be called the method of moments. The weight of the bar itself has to be considered. The weight of an object is the gravitational force with which the Earth pulls on the object; it is made up of the sum of the weights of its particles and acts throughout the object, but in computing moments it is convenient to use the concept of center of gravity. This is the point in an object where the entire weight may be regarded as concentrated, in so far as the force action due to the weight is concerned. Thus, the moment of force exerted by the weight of the bar is the same as if all its weight was concentrated at the center of gravity and is calculated accordingly.

In this experiment, a long rod will be balanced on a single support point when the center of mass of the rod and any point masses attached to it lies at the support point. It can be shown that the total torque and total force acting on such a rod are zero.

Note about units: Mass should be measured in kilograms. Then, the force of gravity on this mass (weight) can be calculated by the formula $w = mg$ and proper units for torque are Nm.

Procedure:

1. Measure and record the mass of the meter stick.

2. Measure and record the masses of the three clamps. Number each clamp by writing on it with a pencil.

3. Find the center of mass of the meter stick to the nearest 0.5 mm by balancing it in one of the clamps and record the position (mount the meter stick so that as you look at it, it reads normally, left to right, right-side-up, with the support clamp mounted so that the screw is down).

4. Put another clamp near one end of the stick and suspend a total mass of 100 g from it. Slide the stick through the supporting clamp until the position of balance is found. Record the position of the point of support, the position of the mass, and the number of the clamp.

5. Leaving the other mass in place, put another clamp near the other end of the stick and suspend a total mass of 200 g from it. Find the new position of balance by again sliding the meter stick through the support clamp. Record the position of the 200 g mass, the new point of support, and the number of the clamp.

6. Remove the masses and clamps. Clamp the meter stick in the support clamp at its center of mass. Put another clamp near one end of the stick and suspend an object of unknown mass from it. Slide another clamp, with a 200 g mass attached, along the other end of the stick until the position of equilibrium is found. Record the positions and the clamp numbers of both masses.

7. Measure and record the mass of the object of unknown mass.

Calculations:

1. Using the center of mass found in Procedure 3, compute two values for the mass of the meter stick from the data of Procedures 4 and 5 by summing the torques about the axis of rotation (the point of support). Compare the result with the known mass of the meter stick (Procedure 1) by calculating the percent error between these values.

2. Calculate the mass of the unknown object used in Procedure 6. Compare the actual mass of the object (Procedure 7) to the computed mass (express in terms of percent error).