Static Equilibrium

College Physics lab I

PH 141

Equilibrium of an Extended Object

Purpose: To investigate the relationship between interactions when a rigid body is in static equilibrium.

Discussion: A system in equilibrium satisfies two conditions:

Translational equilibrium

\[ \overrightarrow{F_{\text{net}}} = 0 \]  [linear acceleration of the system = 0.]

Rotational equilibrium

\[ \overrightarrow{\tau_{\text{net}}} = 0 \]  [angular acceleration of the system = 0.]

Both of the preceding relationships are vector relationships because forces and torques are vector quantities. This means that the stated relationship applies to each component direction:

\[ \overrightarrow{F_{\text{net}}} = 0 \text{ means } F_{\text{net},x} = 0 \& F_{\text{net},y} = 0 \& F_{\text{net},z} = 0 \]

\[ \overrightarrow{\tau_{\text{net}}} = 0 \text{ means } \tau_{\text{net},x} = 0 \& \tau_{\text{net},y} = 0 \& \tau_{\text{net},z} = 0 \]

In order to analyze a system for translational equilibrium, you need to consider the following steps:

1. Identify the system to be analyzed and confirm that its linear acceleration is zero.

2. Identify the forces (magnitudes and directions) that act on your chosen system. A sketch indicating the size and direction of these forces qualitatively is useful. Create a "force table" organizing the components of the forces.

3. Apply "\( \overrightarrow{F_{\text{net}}} = 0 \)" to each component direction.

In order to analyze a system for rotational equilibrium, you need to consider the following steps:

1. Identify the system to be analyzed and confirm that its angular acceleration is zero.
2. Identify the forces (magnitudes and directions) that act on your chosen system. A sketch indicating the size and direction of these forces qualitatively is useful. Carefully identify the point at which the force is applied.

3. Select a point to serve as the center of rotation for your analysis. This is the point from which the moment arm for each force is determined. The point you pick need not be the actual physical point around which the system is able to rotate. Any point can serve as the center of rotation, whether or not there is a natural physical pivot at that point of the system.

4. Determine the moment arm for each force. Calculate the size of the torque created by each force. Determine the direction of the moment arm and the torque.

5. Apply $\tau_{net} = 0$ to each component direction.

In this activity you will investigate static equilibrium of a meter stick which is constrained to rotate about a single axis (z-axis) as depicted in the figure. The forces that you will apply will be constrained to the x-y plane. Therefore, in analyzing equilibrium for the system, you will need to consider three relationships:

\[ F_{net,x} = 0 \quad F_{net,y} = 0 \quad \tau_{net,z} = 0 \]

In each experiment you perform you will want to verify that these relationships are satisfied. As a means for evaluating whether empirical data satisfies a theoretical relationship we typically consider the percentage difference between two quantities which are expected to have the same value. Here because the quantity of interest (e.g. $F_{net,x}$, $F_{net,y}$, $\tau_{net,z}$) is expected to have the value "0," a somewhat different tack will be taken. Each of the three relationships above can be rewritten in a way which compares positive quantities to negative quantities:

\[ F_{net,x} = 0 \text{ becomes } F_{net,left} = F_{net,right} \]

\[ F_{net,y} = 0 \text{ becomes } F_{net,up} = F_{net,down} \]

\[ \tau_{net,z} = 0 \text{ becomes } \tau_{net,clockwise} = \tau_{net,clockwise} \]
Static Equilibrium

For each of these reformulated relationships it is possible to compare (using a %-difference calculation) the value of the left side of the equation with the value of the right side of the equation.

**Procedure:**

1. For each situation investigated identify all of the real forces that act on the system (meter stick). Clearly indicate these forces in a careful sketch of the experimental situation. Identify each with a symbolic label.

2. Determine by measurement and record neatly in a table the magnitude and direction of each force.

3. Determine the moment arm \( (r) \) corresponding to each force. Recall that the value of the moment arm depends upon which point you have selected as the center of rotation for your analysis.

4. Analyze your data to verify that the equilibrium relationships are valid for your situation.

**Experimental situations:**

1. Set the meter stick on the fulcrum off center. Place at least two other weights at different positions on the meter stick so that the meter stick balances.

2. Attach a string to the stick at some position. Have the string pull up at some angle to the stick. The other end of the string should pass over a pulley. The tension in the string should be provided by masses hanging from this other end of the string. Place three or more additional weights on the meter stick.