AP Lab #11: Exploring Static Equilibrium- The Ladder Problem (Big Idea 3)

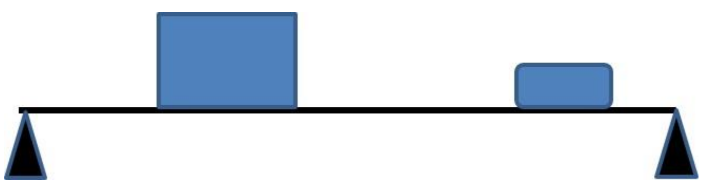
Question: How can I investigate static equilibrium using a model ladder?

In this investigation you will explore the concept of static equilibrium. You will use a model ladder to determine the coefficient of friction necessary to keep the ladder in static equilibrium. The learning objectives in this lab include the application of your understanding of the first and second conditions of equilibrium in analyzing the forces that act on an object in static equilibrium. You will also determine the coefficient of friction between two surfaces and analyze experimental results to evaluate their validity.

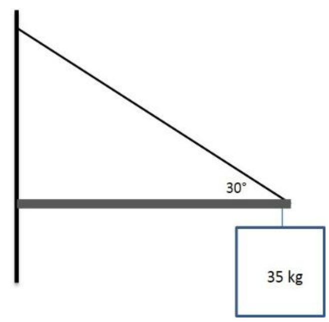
Exploring Static Equilibrium Pre-Lab:

When the sum of the forces and the sum of the torques acting on an object are equal to zero, the object is in static equilibrium. Examples of objects in static equilibrium include a bridge spanning a gap, a traffic light suspended by a cable and beam, and a ladder leaning up against a wall. All of these objects could fall if it wasn't for the forces and torques that are in balance. Before beginning the experiment, you should be able to complete the following three problems that involve objects in static equilibrium.

1) A uniform beam with a mass of 450 kg spans the distance of 7.0 m between the piers of a small bridge, as shown in the diagram below. Two objects sit on the beam. The first object has a weight of 3400 N and is located 2.0 meters from one end of the beam, while the second object has a weight of 1200 N and is located 1.0 meter from the opposite end of the beam. (a) Sketch a free body diagram of the beam, showing all of the forces acting on a beam and the points at which these forces act. Be sure to label the center of gravity off the beam. (b) Identify the two forces acting upward on the beam and the three forces acting downward. (c) Identify the pivot point that will serve as the reference point for the measuring torque in this problem. The pivot point is usually located at one of the unknown forces. In addition to identifying this point, also explain why we place the pivot at a point where the force is unknown. (d) State the equilibrium force equation for this object. (e) State the torque equation for this object. (f) Use these two equations to determine the force acting on each pier. (F_{N1} = 4850 N; F_{N2} = 4250 N)



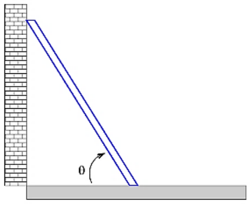
2) A 35-kg sign is suspended from the end of a uniform horizontal beam that has a mass of 25-kg and a length of 3.0 meters. The beam is attached to a wall by a hinge. A cable with negligible mass is attached to the end of the beam just above the sign and extends to the wall, forming an angle of 30° with the beam as shown below. (a) Sketch the free body diagram of the beam showing all of the resolved forces acting on the beam and the points at which these forces act. (b) Identify the two forces acting in the x-direction and the four forces acting in the y-direction. (c) Identify the pivot point that will serve as the reference point for measuring torque in this problem. (d) State the equilibrium force equations for the beam (e) State the torque equation for this object. (f) Use the equations you wrote above to determine the tension in the cable. (T = 950 N) (g) Use the equations you wrote above to determine the horizontal and vertical components of the force acting on the hinge. (F_{wy} = 125 N; F_{wx} = 823 N)



3) A 5.0-meter-long ladder is leaning against a smooth wall. The ladder is uniform in composition and has a mass of 15-kg. Assume the friction between the ladder and the smooth wall is negligible. The foot of the ladder

is resting on a concrete floor at an angle of ϴ = 50° as shown in the diagram below. (a) Sketch the free body diagram of the ladder showing all of the forces acting on the beam and the points at which these forces act.

(b) Identify the four forces acting on the ladder (c) Identify the pivot point (d) State the equilibrium force equations for the beam in the x- and y-directions (e) State the torque equation for this object. (f) Use the equations you wrote above to determine the coefficient of static friction maximum ($\mu_{sfmax} = 0.42$). Show all of your calculations.



Exploring Static Equilibrium Lab:

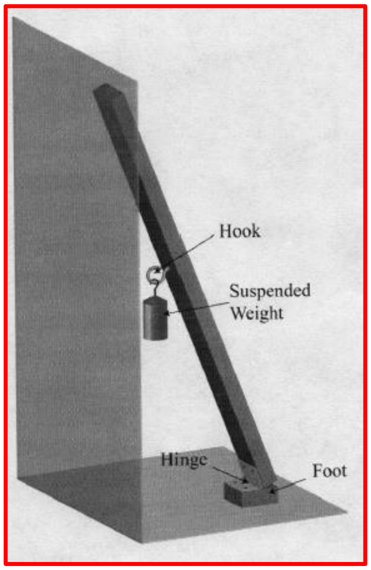
Materials: model of ladder, various friction boards, aluminum flashing, masking tape, mass set, level app on smart device, force probe, drag block, electronic scale, computer with Logger Pro (optional).

Part 1: Measuring the Coefficient of Friction Indirectly

In this activity you will determine the coefficient of friction between a block of wood and a surface by measuring the minimum angle required to keep a ladder from slipping from its equilibrium position.

1) Determine the length and mass of the ladder (including its foot). Record the numbers in a data table.

2) Lean the ladder against a wall so that it forms an angle with the floor that is greater than 60°. The ladder has a hinged foot that should be in contact with the horizontal surface. Please view the figure to the right.



3) Slip a friction board under the foot of the ladder so that the foot can slide across the friction board. Identify the type of surface you have chosen.

4) Use a piece of masking tape to secure a piece of aluminum flashing to the wall. The finishing will ensure a smooth, relatively low-friction surface.

5) Hang a 200-gram mass from one of the hooks on the ladder. Adjust the angle of the ladder and identify the minimum angle required to keep the ladder from slipping across the surface. Use the level or protractor application on your smart device to measure the angle of the ladder. Repeat this process several times and record your data in a data table.

6) Sketch a free body diagram of the model ladder.

7) Use the data collected above to calculate the coefficient of static friction between the foot of the ladder and the surface upon which it rests.

8) Repeat this experiment with a different surface under the foot.

Part 2: Measuring the Coefficient of Friction Directly

In this activity you will determine the coefficient of friction between the surfaces explored in Part 1 in order to verify the accuracy of the results obtained in Part 1.

9) Using the materials and equipment provided, measure the static friction between two surfaces. Summarize the method you chose and organize the data. Show all calculations.

10) Plot a graph of the static friction versus the normal force and draw a best-fit line.

11) Use your best-fit line and the equation y = mx + b to determine the coefficient of static friction. Show work.

Write your claims and summary based on evidence collected during this investigation.