Name _____ **Date** _____

Partners _____ _____ _____

Experiment 9

Objects in Static Equilibrium – The Ladder Problem

Student Guide

Materials (per group, unless otherwise noted)

- Model of a ladder
- Friction board (board with various friction surfaces: 200 grit sandpaper, anti-slip step tread, vinyl floor tile, and aluminum flashing)
- 3" x 5" aluminum flashing
- Masking tape (shared among groups)
- Mass set
- Protractor
- Force probe (preferably a digital force probe connected to a computer)
- Drag block: 1" x 2" x 2" block of wood, with a hook attached
- Centigram balance, 1-2 shared among groups

Safety Precautions

There are no specific safety concerns in this activity. However, you should always follow the general safety rules outlined at the beginning of this manual.

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.

What To Do

General Set-up

1) Determine the length and mass of the ladder (including its foot). Record the numbers below.

   Mass of ladder = _____ kg

   Length of ladder = _____ m

2) See **Figure 4**, below. 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.

3) Slip the friction board under the foot of the ladder so that the foot can slide across one of the surfaces on the friction board. Identify the type of surface below.

   Surface type: _____

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

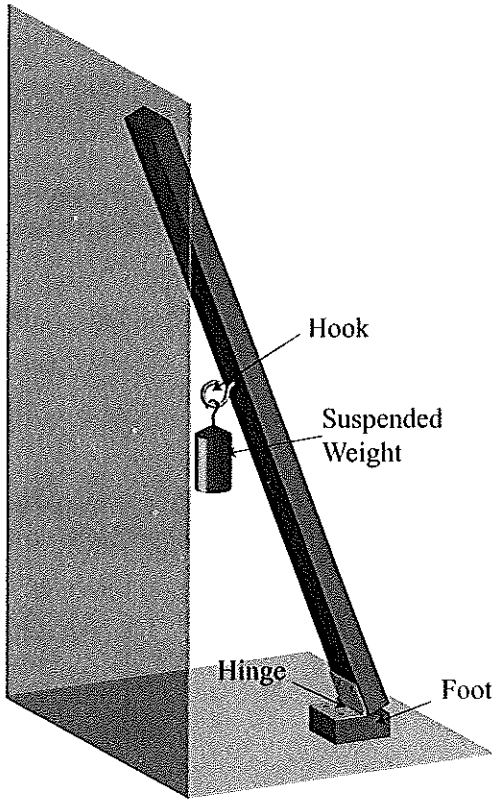


Figure 4

Measure the Minimum Angle

5) Hang a 200 gram weight 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 a protractor to measure the angle of the ladder. Repeat this process a number of times and record your data in a table in the space below.

Average Minimum Angle to Prevent Slipping = _____

6) Sketch a free body diagram of the ladder described above, in the space below.

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.

Coefficient of static friction = _____

Optional

8) Repeat this experiment using a different surface under the foot of the ladder.

Part 2: Measuring the Coefficient of Friction Directly

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

What To Do

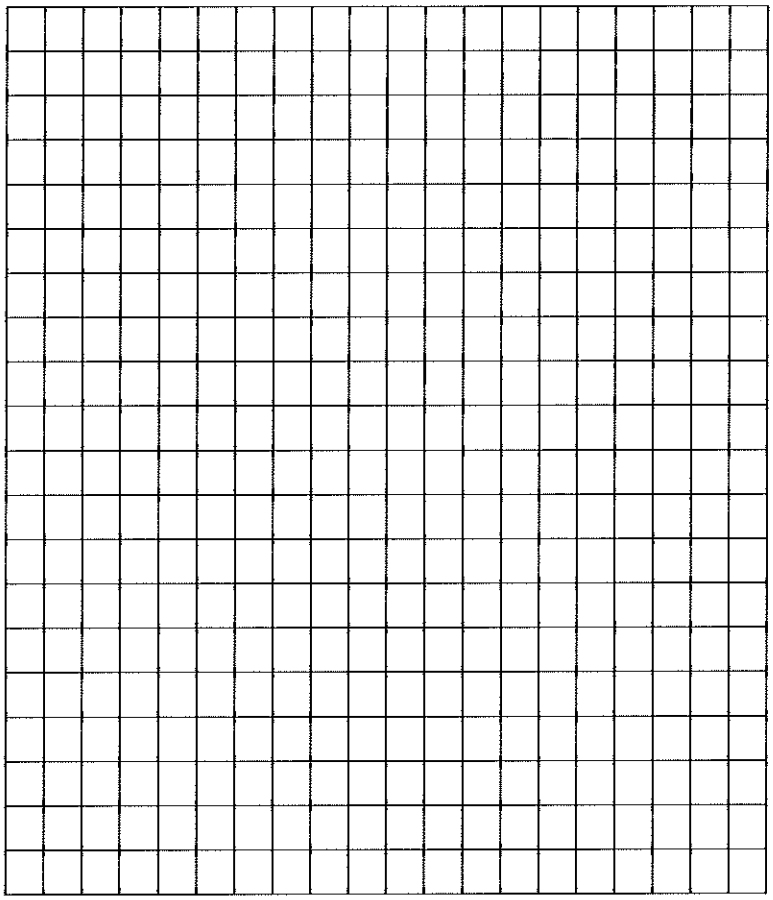
Measuring Friction Force

9) Using the materials and equipment provided, measure the static friction between two surfaces. If necessary, review Experiment 5 (Newton's Laws: Determine the Coefficient of Friction – Part 1) of this lab manual to help guide you through this procedure.

   Summarize your data in a table and show all steps of your calculations in the space below.

Plot Static Friction versus Normal force

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



11) The coefficient of friction is equal to the slope of the graph of friction versus the normal force. Calculate the coefficient of static friction. In the space below, show your work and answer.

Coefficient of static friction = _____

Name _____ **Date** _____

Partners _____ _____ _____

Experiment 9

Objects in Static Equilibrium – The Ladder Problem

Post-Lab Assignment

Write a persuasive essay that comments on the results you obtained in parts 1 and 2. What are your thoughts? Are the results you obtained in each part reasonably consistent with one another? Explain how you judge "reasonably consistent". Calculate the percent difference between the results from each part and use this answer in your analysis. Include tables and graphs in the essay and refer to these to support your position. Limit your essay to 1200 words.

If upon reflection you determine that you should repeat parts of the experiment to obtain better data or, perhaps, additional data, feel free to repeat the experiment. Perhaps something was overlooked or assumed. You will have to make arrangements with your instructor so that you can access the laboratory with proper supervision.

Name _____ **Date** _____

Partners _____ _____ _____

Experiment 9

Objects in Static Equilibrium – The Ladder Problem

Pre-Lab Assignment

In this activity you will work with a model of a ladder to determine the coefficient of friction necessary to keep the ladder in static equilibrium.

Learning Objectives

1. Apply your understanding of the first and second conditions of equilibrium in analyzing the forces that act on an object in static equilibrium.
2. Determine the coefficient of friction between two surfaces.
3. Analyze experimental results and evaluate their validity.
4. Write a persuasive essay, using student-gathered experimental data, to support and/or explain the validity of your experimental results.

Pre-Lab Questions

(Complete this assignment prior to beginning the activity)

When the sum of the forces and the sum of the torques acting on an object are equal to zero, the object is said to be 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 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) See **Figure 1**. A uniform beam with a mass of 450 kg spans the distance of 7.0 m between the piers of a small bridge. 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.

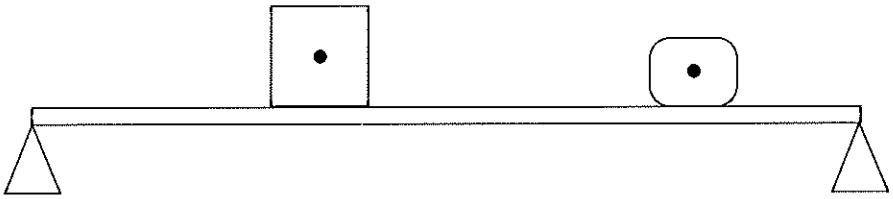


Figure 1

a) Sketch a free body diagram of the beam, showing all the forces acting on the beam and the points at which these force act. Be sure to label the center of gravity of the beam.

b) Identify the forces acting on the beam.

Upward	Downward
1)_____	3)_____
2)_____	4)_____
	5)_____

c) Identify the pivot point that will serve as the reference point for measuring torque in this problem. The pivot point is usually located at one of the unknown forces.

Location of pivot point = _____

d) State the equilibrium force equation for this object.

_____

e) State the torque equation for this object.

_____

f) Use the equations you wrote above to determine the force acting on each pier.

2) See **Figure 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 m. 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.

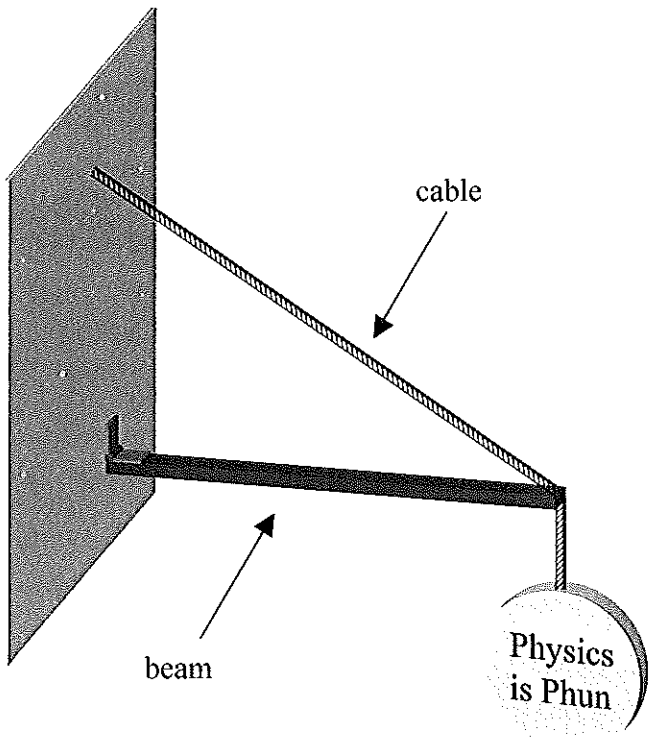
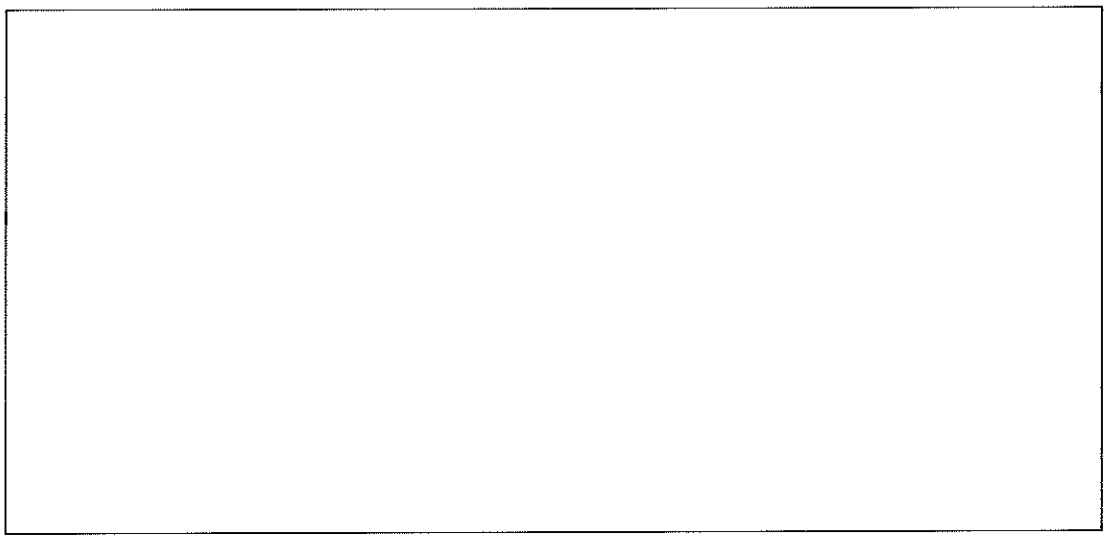


Figure 2

a) Sketch a free body diagram of the beam showing all of the resolved forces acting on the beam and the points at which these force act.



b) Identify the forces acting on the beam.

x-direction (right and left)	y-direction (up and down)
1)_____	3)_____
2)_____	4)_____
	5)_____
	6)_____

c) Identify the pivot point that will serve as the reference point for measuring torque in this problem. The pivot point is usually located at one of the unknown forces.

Location of pivot point = _____

d) State the equilibrium force equations for the beam.

$\Sigma F_x =$ _____

$\Sigma F_y =$ _____

e) State the torque equation for this object.

_____

f) Use the equations you wrote above to determine the tension in the cable.

g) Use the equations you wrote above to determine the horizontal and vertical components of the force acting on the hinge.

3) See **Figure 3**. A 5.0 m 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 50.0°.

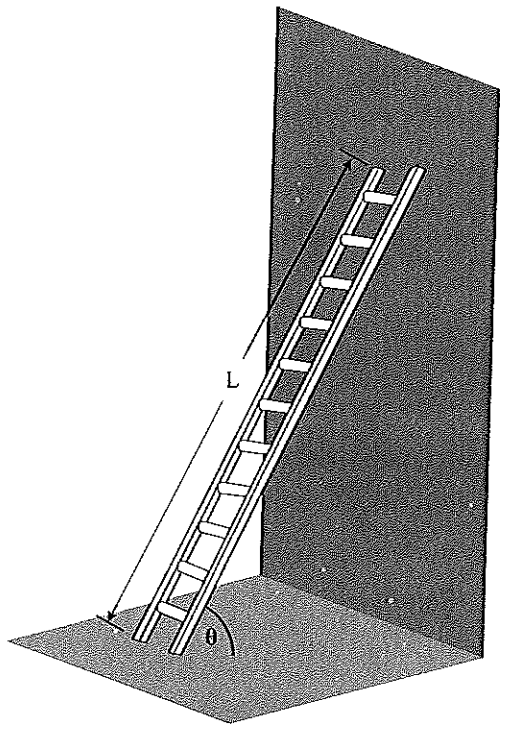


Figure 3

a) Sketch a free body diagram of the ladder showing all of the forces acting on the ladder and the points at which these forces act.

b) Identify the forces acting on the ladder.

1) _____

2) _____

3) _____

4) _____

c) Identify the pivot point: _____

d) State the equilibrium force equations for the beam.

$\Sigma F_x =$ _____

$\Sigma F_y =$ _____

e) State the torque equation for this object.

_____

f) Use the equations you wrote above to determine the minimum force of friction required to prevent the ladder from slipping. Show your calculations in the space below.

4) Read the Student Guide prior to coming to class to conduct your experiment.