Experiment 6
The Coefficient of Friction

Equipment:
1 LABPRO with force probe
1 Inclined plane (see Fig. 6-1)
1 Wooden block
1 Triple beam balance
Masses
Pulley

Objectives:
To measure the coefficients of static and kinetic friction between a wooden block and a wooden plane.

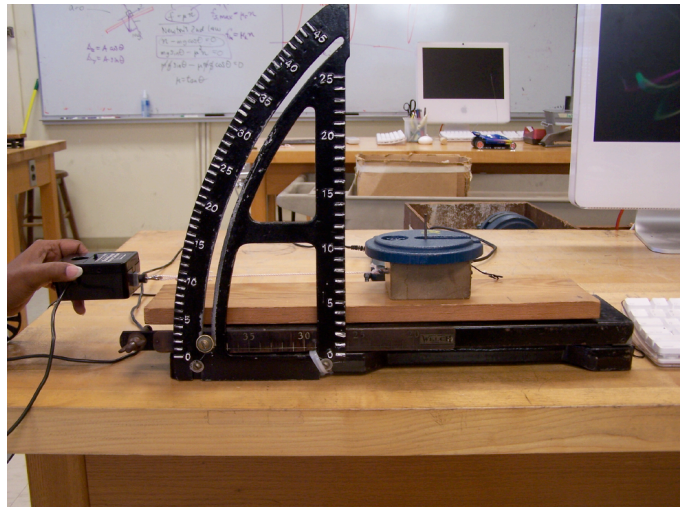

Figure 1- Block on Incline plane

Theory

Friction is the force that resists the relative motion of one surface in contact with another. There are two types of friction: static and kinetic. Usually, the kinetic frictional force is less than the maximum value of the static frictional force. The maximum value of static frictional force is given by $f_{s,\max} = \mu_s N$ and the kinetic frictional force is given by $f_k = \mu_k N$, where μ_s is the coefficient of static friction, μ_k is the coefficient of kinetic friction and N is the normal force.

If f_k versus N is graphed, the slope of the line is μ_k for the system. Similarly, if $f_{s,\max}$ versus N is graphed, the slope of the line is μ_s.

The *angle of repose* is defined as the angle at which an object just starts to slide down an inclined plane. If θ is the angle of repose, it can be shown that $\mu_s = \tan\theta$. We will call this method to determine the static coefficient of friction the *angle of repose method*. It can also be shown that when an object slides down an incline at constant velocity, $\mu_k = \tan\theta$.

In this experiment, the frictional force between a wooden block and the wooden surface of a horizontal and inclined plane will be measured, and from these plotted data, the coefficients of *static and kinetic friction* will be obtained.

The angle of repose method will also be used to determine the coefficient of static friction. Lastly, the coefficient of kinetic friction will be determined by a second method *(called constant velocity method)* by noting the angle θ that the block slides down an incline without accelerating and then using $\mu_k = \tan\theta$.

Procedure:
1. Turn on the LABPRO and the computer. Open the *Logger Pro* application. Go to the **Experiment/Setup sensors/LabPro1** menu and choose the port which force probe sensor is plugged in. Go through

list of probes and highlight Dual Range 50N Force Probe.

2. Calibrate the force probe by using the path **Experiment/Calibrate/LabPro1: Dual Range Force**. Click on calibrate now and follow the directions given to you on the screen. Use 1/2 kilogram on the weight hanger for the calibration. **Be sure to use units of force (not mass) when calibrating the force probe.**

3. Measure the mass of the wooden block with the Triple-Beam balance and calculate its weight in newtons.

4. With plane in the horizontal position, place 500 grams on the block and pull the block across the plane at a constant speed with the force probe. Be sure to pull horizontally. Note the "bump" at the start of the graph. This peak represents a maximum force which can be used to calculate μ_s. See fig 6-2 below and theory section.

5. Highlight the constant force portion of your run. Determine the mean force. *The force needed to pull the block is your* **frictional force** *and the combined weight of the block and mass is your* **normal force**. Note that normal force here is also used in step 4 to determine μ_s.

6. Repeat steps 4 & 5, adding 500 grams each time until a total of 3000 grams has been added to the block. *Record the frictional and normal forces needed for* **each trial**.

7. Plot a graph of the frictional force vs. the normal force using *Graphical Analysis*, with the frictional force on the Y axis and the normal force on the X axis. Plot a "best fit line" between the points by pulling down the **Graph** menu to **Regression line.** To obtain the slope of this line, pull down the **Graph** menu to **Statistics**. This will print the value of the slope at the bottom of the graph. If F_{fr}, the frictional force is proportional to F_N, the normal force ($F_{fr}=\mu_k F_N$), then the slope of this line should be the coefficient of kinetic friction between the two surfaces. Determine this value from the graph.

Block on an inclined plane

8. Calculate the force needed to pull the block up a plane inclined to 30^0 at a constant speed when loaded with 500 grams. Draw a force diagram labeling all the forces acting on the block as it moves up the inclined plane. Use the coefficient obtained from your graph.

9. Measure the force needed to pull the block up the plane (same angle as part 8) at a constant speed. If there is a large difference between the calculated and the experimental values, check the calculations carefully. (Common mistakes: Neglecting the mass of the block and improper force diagrams) Calculate the percentage difference between this value and the calculated value.

Angle of repose method

10. Add 500 g to block. Find the coefficient of *static friction* by slowly raising the incline plane until the block just starts to slide. Note the angle and use $\mu_s = \tan\theta$. Repeat with 1000g total added to block. Remove mass(es).

Constant Velocity Method

11. Add 500g to block. Find *kinetic coefficient* of friction by tilting the inclined plane and noting the angle at

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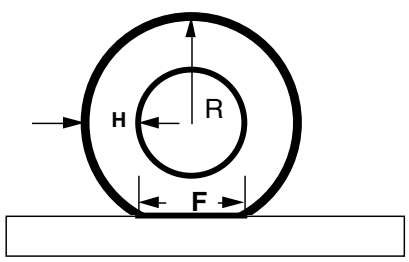
which the block slides at a constant speed. You should have to tap the block in order to get it started. Use $\mu_k = \tan\theta$. Add a total of 1000g to block and repeat this step.

Post Lab Questions:

1. If a tire rolls normally (instead of skidding) the type friction between the tire and the road is static friction.

This can readily be seen the case if you examine a tire and see that the tire has a flat spot that contacts the road. See figure below.



Google "what is the radius of a tire" to find R and assume that the flat spot F is 6 inches. Be sure and include ULR of webpage used to obtain your tire radius.

Assuming the speed of the car is 60 mph (miles per hour) determine the time a specific point on the flat spot stays in contact with the ground.

Steps on how to do:

a) Once you have a radius and since you know R you can construct a triangle with vertex at center of tire and base composed of F. **Draw a diagram**. The angle at the center of the tire will give you the fraction of 360 degrees (i.e., 2π radians) that the tire spends in contact with the ground.

b) Determine the circumference of the tire and the distance the car travels in one second. Use these two numbers to get how many revolutions per second the tire rotates and correspondingly how many seconds per revolution.

c) Using answers from a) and b) the final answer can be obtained. Please note that the part a) answer is essentially what fraction of a single revolution is taken up by the flat spot.

2. When the mass on the block was doubled, what happened to the angle of repose? Were your results as expected. Explain.

3. Examine your two plots (i.e., the plot of static friction vs. normal force and kinetic friction vs. normal force).

Which of the two plots has less scattered data (i.e., plotted points). Based upon what you observed in the lab, explain why one plot should be smoother than the other. *It should primarily have to do with how much of the board is sampled in each measurement in each part.*

4. Compare the respective % differences between the coefficients of friction obtained by the plots to what you obtained by the angle of repose method and the sliding method. What do you think might be the reason for any difference. See # 3 above.

5. Show that $\mu_k = \tan\theta$ for the constant velocity method. Include a diagram of all the forces on the block as it slides down the inclined plane.