Experiment: Static and Kinetic Friction

OBJECTIVES

- Use a Force Sensor to measure the force of static friction.
- Determine the relationship between force of static friction and the weight of an object.
- Measure the coefficients of static and kinetic friction for a particular block and track.
- Use a Smart Pulley to independently determine the coefficient of kinetic friction for the same block and track
- Determine if the coefficient of kinetic friction depends on weight.

INTRODUCTION

If you try to slide a heavy box resting on the floor, you may find it difficult to get the box moving. *Static friction* is the force that is acting against the box. If you apply a light horizontal push that does not move the box, the static friction force is also small and directly opposite to your push. If you push harder, the friction force increases to match the magnitude of your push. There is a limit to the magnitude of static friction, so eventually you may be able to apply a force larger than the maximum static force, and the box will move. The maximum static friction force is sometimes referred to as *starting friction.* We model static friction, F_{static}, with the inequality $F_{static} \leq \mu_s N$ where μ_s is the coefficient of static friction and N the *normal* force exerted by a surface on the object. The normal force is defined as the perpendicular component of the force exerted by the surface. In this case, the normal force is equal to the weight of the object.

Once the box starts to slide, you must continue to exert a force to keep the object moving, or friction will slow it to a stop. The friction acting on the box while it is moving is called *kinetic friction.* In order to slide the box with a constant velocity, a force equivalent to the force of kinetic friction must be applied. Kinetic friction is sometimes referred to as *sliding friction.* Both static and kinetic friction depend on the surfaces of the box and the floor, and on how hard the box and floor are pressed together. We model kinetic friction with $F_{kinetic} = \mu_k N$, where μ_k is the coefficient of kinetic friction.

In this experiment, you will use a Force Sensor to study static friction and kinetic friction on a wooden block. A Smart Pulley will also be used to analyze the kinetic friction acting on a sliding block, by measuring the acceleration.

MATERIALS

- Windows PC
- LabPro Interface
- Logger *Pro Software*
- string
- Graphical Analysis Software
- Smart Pulley
- Photogate
- Force Sensor
- block of wood with hook
- gram scale
- mass set

PRELIMINARY QUESTIONS

1. In pushing a heavy box across the floor, is the force you need to apply to start the box moving greater than, less than, or the same as the force needed to keep the box moving? On what are you basing your choice?

2. How do you think the force of friction is related to the weight of the box? Explain.

PROCEDURE

Part I Starting Friction

1. Measure the mass of the block and record it in the data table.
2. Connect the Force Sensor to the Channel 1 input of the LabPro Interface
3. Open "Exp 12a" in the *Physics with Computers* experiments folder. Set the range switch on the Force Sensor to 50 N. One graph will appear on the screen. The vertical axis will have force scaled from 0 to 20 Newtons. The horizontal has time scaled from 0 to 5 seconds.
4. Tie one end of a string to the hook on the Force Sensor and the other end to the hook on the wooden block then place 1 kg on top of the block. Be sure the mass is fastened so they cannot shift.
5. Practice pulling the block and masses with the Force Sensor using this straight-line motion. Slowly and gently pull horizontally with a small force. Very gradually, taking one full second, increase the force until the block starts to slide, and then keep the block moving at a constant speed for another second.
6. Sketch a graph of force *vs.* time for the force you felt on your hand in step 5. Label the portion of the graph corresponding to the block at rest, the time when the block just started to move, and the time when the block was moving at constant speed.

7. Hold the Force Sensor in position, ready to pull the block, but with no tension in the string. Click on Zero at the top of the graph to set the Force Sensor to zero.

8. Click Collect to begin collecting data. Pull the block as before, taking care to increase the force gradually. Repeat the process as needed until you have a graph that reflects the

desired motion, including pulling the block at constant speed once it begins moving. Copy-and-Paste the graph into a Word document and print it for later reference.

9. Choose Store Latest Run from the Data Menu to store the run as Run 1 for later analysis.

Part II Peak Static Friction and Kinetic Friction

In this section, you will measure the peak static friction force and the kinetic friction force as a function of the normal force on the block. In each run, you will pull the block as before, but by changing the masses on the block, you will vary the normal force on the block.

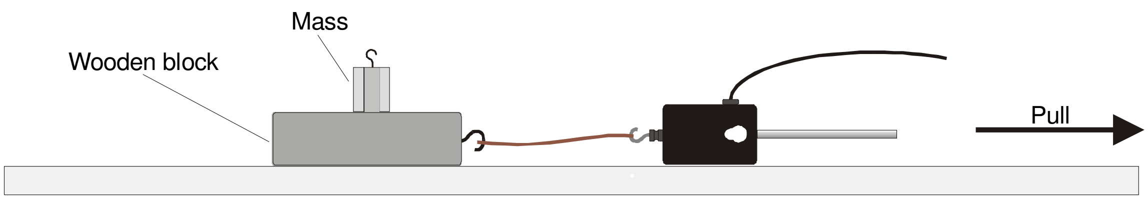

Figure 1

1. Remove all masses from the block.

2. Click Collect to begin collecting data and pull as before to gather force *vs.* time data.

3. Examine the data by clicking the Statistics button, . The maximum value of the force occurs when the block started to slide. Read this value of the *maximum* force of static friction from the floating box and record the number in your data table.

4. Drag across the region of the graph corresponding to the block moving at constant velocity. Click on the Statistics button again and read the average force during the time interval. This force is the magnitude of the kinetic frictional force.

5. Repeat Steps 2-4 two more measurements. Record the values in the data table.

6. Average the results to determine the reliability of your measurements.

7. Add masses totaling 250 g to the block. Repeat Steps 2 – 6, recording values in the data table.

8. Repeat for additional masses of 500, 750, and 1000 g. Record values in your data table.

Part III: Kinetic Friction Again

In this section, you will measure the coefficient of kinetic friction a second way and compare it to the measurement in Part II. Using the Motion Detector, you can measure the acceleration of the block as it slides to a stop. This acceleration can be determined from the velocity *vs.* time graph. While sliding, the only force acting on the block in the horizontal direction is that of friction. From the mass of the block and its acceleration, you can find the frictional force and finally, the coefficient of kinetic friction.

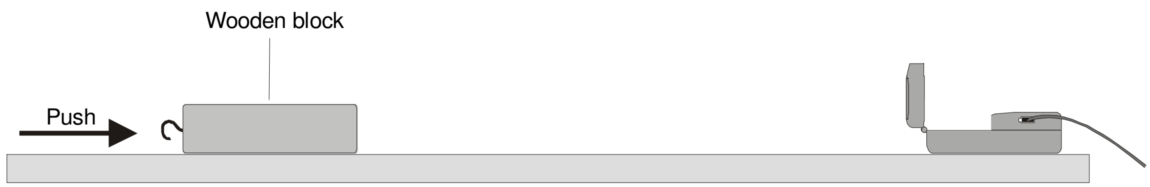

Figure 2

1. Connect the Motion Detector to DIG/SONIC 1 of the LabPro interface. Disconnect the Force Sensor. Open "12b Static Kinetic Friction" from the *Physics with Computers* experiment files of Logger *Pro.* Two graphs will appear on the screen. The vertical axis of the top graph will have distance scaled from 0 to 3 m, and the lower graph has velocity scaled from – 2 to 2 m/s. The horizontal has time scaled from 0 to 5 s.

2. Place the Motion Detector on the lab table 2 – 3 m from a block of wood, as shown in Figure 2. Position the Motion Detector so that it will detect the motion of the block as it slides toward the detector.

3. Practice sliding the block toward the Motion Detector so that the block leaves your hand and slides to a stop. Minimize the rotation of the block. After it leaves your hand, the block should slide about 1 m before it stops and it must not come any closer to the Motion Detector than 0.4 m.

4. Click Collect to start collecting data and give the block a push so that it slides toward the Motion Detector. The velocity graph should have a portion with a linearly decreasing section corresponding to the freely sliding motion of the block. Repeat if needed.

5. Select a region of the velocity *vs.* time graph that shows the decreasing speed of the block. Choose the linear section. The slope of this section of the velocity graph is the acceleration. Drag the mouse over this section and determine the slope by clicking the Linear Regression button, . Record this value of acceleration in your data table.

6. Repeat Steps 4 – 5 four more times.

7. Place masses totaling 500 g on the block. Fasten the masses so they will not move. Repeat Steps 4 – 5 five times for the block with masses. Record acceleration values in your data table.

DATA TABLE

Part I Starting Friction

Mass of block	**kg**

Part II Peak Static Friction and Kinetic Friction

Total mass (m)	Normal force (N)	Peak static friction			Average peak static friction (N)
		Trial 1	Trial 2	Trial 3	

Total mass (m)	Normal force (N)	Kinetic friction			Average kinetic friction (N)
		Trial 1	Trial 2	Trial 3	

Part III Kinetic Friction

Data: Block with no additional mass			
Trial	**Acceleration (m/s^2)**	**Kinetic friction force (N)**	μ_k
1			
2			
3			
4			
5			
		Average coefficient of kinetic friction:	
Data: Block with 500 g additional mass			
Trial	**Acceleration (m/s^2)**	**Kinetic friction force (N)**	μ_k
1			
2			
3			
4			
5			
		Average coefficient of kinetic friction:	

ANALYSIS

1. Observe the print out for the force *vs.* time graph from Part I. Label the portion of the graph corresponding to the block at rest, the time when the block just started to move, and the time when the block was moving at constant speed.

2. In the graph in (1), compare the force necessary to keep the block sliding compared to the force necessary to start the slide. How does your answer compare to your answer to question 1 in the Preliminary Questions?

3. The *coefficient of friction* is a constant that relates the normal force between two objects (blocks and table) and the force of friction. Based on your graph (Run 1) from Part I, would you expect the coefficient of static friction to be greater than, less than, or the same as the coefficient of kinetic friction?

4. For Part II, calculate the *normal force* of the table on the block alone and with each combination of added masses. Record the values in the Part II data tables.

5. Create a graph of the maximum static friction force (*y* axis) *vs*. the normal force (*x* axis) using Graphical Analysis (or similar software package) or graph paper.

6. Since $\left|\vec{f}_{static}^{max}\right| = \left|\mu_s \vec{F}_N\right|$, the slope of this graph should yield the coefficient of static friction μ_s. Obtain the numeric value of the slope, including any units. Should a line fitted to these data pass through the origin? Explain.

7. In a similar graphical manner, find the coefficient of kinetic friction $_{k.}$ Use a plot of the average kinetic friction forces *vs.* the normal force (recall that $\left|\vec{f}_{kinetic}\right| = \left|\mu_k \vec{F}_N\right|$). Should a line fitted to these data pass through the origin? Explain.

8. How do the coefficients of kinetic friction determined in Part III compare to that determined in Part II? Would you expect them to be the same or different?