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 $f_{static} \leq \mu_s F_N$ where μ_s is the coefficient of static friction and F_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 $f_{kinetic} = \mu_k F_N$, 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. An applied force pushes against a 40 kg box resting on a flat horizontal floor surface. When the magnitude of the force just exceeds 100 N its "grip" to the floor is broken and the box begins to move forward. Once the box is in motion, it travels at a constant velocity when the applied force is maintained at 45 N.
   a. Sketch a free body diagram for the resting box just before it begins to move.

   b. Apply Newton's 2nd Law to the box in (a) to express the equation for net force in component form, including all of the individual forces present.

   c. What is the magnitude of the (static) frictional force exerted on the box just before it begins to move?

   d. Calculate the ratio of the (static) frictional force in (c) to the normal force. *This value is referred to as the coefficient of static friction or* μ_s^{max} *.*

   e. Apply Newton's 2nd Law to the box to write out the equation for net force exerted on the box in component form, including all of the individual forces present.

   f. What is the corresponding ratio of friction force to normal force exerted for the box in (e), i.e. the coefficient of kinetic friction, μ_k , between the box and floor?

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. Set the range switch on the Force Sensor to 50 N.
3. Open "12a Static Kinetic Friction" in the *Physics with Vernier* folder.
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 <u>gently</u> 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 then zero the Force Sensor.

8. Begin data collection. 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 Experiment 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.

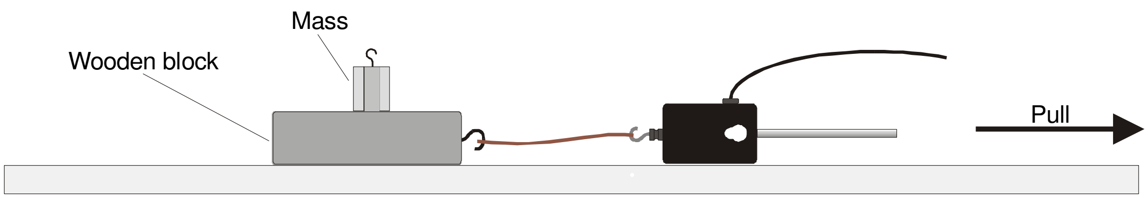

Figure 1

1. Remove all masses from the block.

2. Begin data collection and pull as before to gather force *vs.* time data.

3. Examine the data using 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.

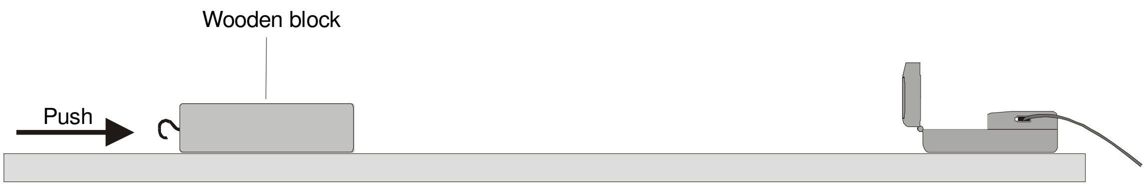

Figure 2

1. Connect the Motion Detector to DIG/SONIC 1 of the LabPro interface and disconnect the Force Sensor. Open the "12b Static Kinetic Friction" experiment file.

2. Place the Motion Detector on the lab table 1 to 2 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 0.5 to 1 m before it stops and it must not come any closer to the Motion Detector than 0.4 m.

4. Start data collection then 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. Observe the region of the velocity *vs.* time graph that shows the decreasing speed of the block and select 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 using 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 TABLES

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**	
		Slope of Graph	±		
		Y-Intercept	±		

Total mass (m)	**Normal force (N)**	**Kinetic friction**			**Average Kinetic friction (N)**
		Trial 1	**Trial 2**	**Trial 3**	
		Slope of Graph	±		
		Y-Intercept	±		

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. 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?

3. 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.

4. 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.

5. Since $f_{static}^{max} = \mu_s^{max} F_N$, the slope of the graph in (4) should yield the coefficient of static friction, μ_s^{max}. Obtain the numeric value of the slope, including any units and uncertainty. Record this value in the corresponding data table.

6. In a similar graphical manner, plot of the average kinetic friction force *vs.* normal force. Use the graph to obtain the coefficient of kinetic friction, μ_k, and uncertainty. Record this value in the Part II data table. Note: $f_k = \mu_k F_N$

7. Would you expect the coefficient of kinetic friction, from Part III to be the same or different to that determined in Part II? Why or why not?