Static and Kinetic Friction

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 counters your force on 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 $F_{static} \le \mu_s N$ where μ_s is the coefficient of static friction and N is 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 Dual-Range Force Sensor to study static friction and kinetic friction on a wooden block. A Motion Detector will also be used to analyze the kinetic friction acting on a sliding block.

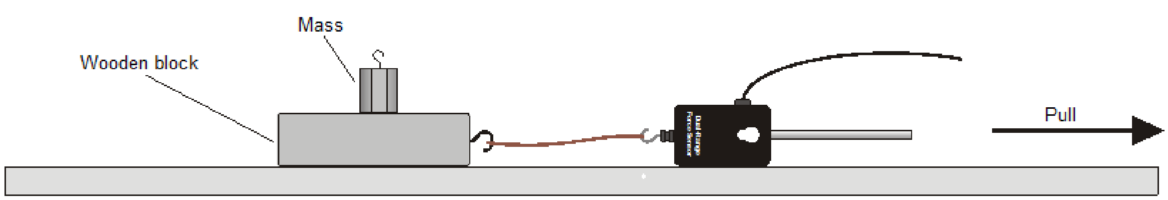


Figure 1

OBJECTIVES

- Use a Dual-Range Force Sensor to measure the force of static and kinetic 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 Motion Detector to independently measure the coefficient of kinetic friction and compare it to the previously measured value.
- Determine if the coefficient of kinetic friction depends on weight.

MATERIALS

LabQuest
LabQuest App
Vernier Motion Detector
Vernier Dual-Range Force Sensor
string
block of wood with hook
balance **or** scale
mass set
(optional) Logger *Pro* **or** graph paper

PRELIMINARY QUESTIONS

1. In everyday life, you often experience one object sliding against another. Sometimes they slip easily and other times they do not. List some things that seem to affect how easily objects slide.

2. Consider a box sitting on a table. It takes a large force to move it at constant speed. List at least two ways you could reduce the force needed to move the box at constant speed.

3. 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 answer?

PROCEDURE

Part I Starting Friction

1. Measure the mass of the block and record it in the data table.

2. Set the range switch on the Force Sensor to 10 N. Connect the Force Sensor to LabQuest. Choose New from the File menu.

3. Tie one end of a string to the hook on the Force Sensor and the other end to the hook on the wooden block. Place a total of 1 kg mass on top of the block, fastened so the masses cannot shift. Before you collect data, practice pulling the block and masses with the Force Sensor using a 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.

4. Sketch a graph of force *vs.* time for the force you felt on your hand. 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.

5. Zero the Force Sensor before collecting data.
   a. Hold it so the working axis is horizontal.
   b. With the Force Sensor axis held horizontally and no force applied, choose Zero from the Sensors menu.
6. Hold the Force Sensor in position, ready to pull the block, but with no tension in the string.
7. Start data collection. Wait a moment, then pull the block as before, taking care to increase the force gradually.
8. Inspect your graph. Start data collection and 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. Print or sketch the graph for later reference.

Part II Peak Static Friction and Kinetic Friction

In this part, you will measure the peak static friction force and the kinetic friction force as a function of the normal force on the block, as shown in Figure 1. 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.

9. Remove all masses from the block.
10. Using the same procedure as before, collect force *vs.* time data.
11. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the force and time values are displayed to the right of the graph. The maximum value of the force occurs when the block started to slide. Read this value of the peak static friction force and record the number in your data table.
12. Next you need to determine the average friction force while the block was moving at constant velocity.
    a. Tap and drag your stylus across the approximately constant-force region to select the data points.
    b. Choose Statistics from the Analyze menu. The statistics for the selected region will be displayed.
    c. Record the mean force value in your data table.
13. Repeat Steps 10–12 for two more measurements and average the results to determine the reliability of your measurements. Record the values in the data table.
14. Add masses totaling 500 g to the block. Repeat Steps 10–13, recording values in the data table. Add another 500 g and repeat.

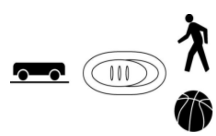
Part III Kinetic Friction Again

In this part, 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

15. Place the Motion Detector on the lab table 1–2 m from a block of wood, as shown in Figure 2. Use the same surface you used in Part II. Position the Motion Detector so that it will detect the motion of the block as it slides toward the detector.

16. Tap Meter. Disconnect the Force Sensor. Set the Motion Detector sensitivity switch to Track. Connect the Motion Detector to a digital (DIG) port on LabQuest. Choose New from the File menu.



17. 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 0.15 m.

18. Collect data for the sliding block.
    a. Start data collection.
    b. After a moment, give the block a brief push so that it slides toward the Motion Detector.

19. Inspect your graph.
    a. Examine the graph of velocity *vs.* time.
    b. The velocity graph should have a portion with a linearly decreasing section corresponding to the freely sliding motion of the block. Repeat data collection if needed.

20. Fit a straight line to this portion of the data, the slope of which is the block's acceleration.
    a. Tap and drag across the region of linear decrease to select the data points.
    b. Choose Curve Fit ► Velocity from the Analyze menu.

c. Select Linear as the Fit Equation to fit a straight line to the velocity data.

d. Record the magnitude of the slope of the fitted line, which is the block's acceleration, in your data table.

e. Select OK.

21. Repeat Steps 18–20 two more times.

22. Place masses totaling 500 g on the block. Fasten the masses so they will not separate from the block. Repeat Steps 18–20 three 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 (kg)	Normal force (N)	Peak static friction			Average peak static friction (N)
		Trial 1	Trial 2	Trial 3	

Total mass (kg)	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			
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			
Average coefficient of kinetic friction:			

ANALYSIS

1. Inspect your 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. Still using the force *vs.* time graph you created in Part I, 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 Preliminary Question 3?

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 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. Since the block is on a horizontal surface, the normal force will be equal in magnitude and opposite in direction to the weight of the block and any masses it carries. Fill in the Normal Force entries for both Part II data tables.

5. Plot a graph of the maximum (peak) static friction force (y axis) *vs.* the normal force (x axis). Use LabQuest, Logger *Pro*, or graph paper.

6. Since $F_{maximum\ static} = \mu_s N$, the slope of this graph is the coefficient of static friction μ_s. Find the numeric value of the slope, including any units, by adding a Proportional Curve Fit. The Proportional Curve Fit passes through the origin.

7. In a similar graphical manner, find the coefficient of kinetic friction μ_k. Use a plot of the average kinetic friction forces vs. the normal force. Recall that $F_{kinetic} = \mu_k N$. The Proportional Curve Fit passes through the origin.

8. Your data from Part III also allow you to determine μ_k. Draw a free-body diagram for the sliding block. The kinetic friction force can be determined from Newton's second law, or $\Sigma F = ma$. From the mass and acceleration, find the friction force for each trial, and enter it in the data table.

9. From the friction force, determine the coefficient of kinetic friction for each trial and enter the values in the data table. Also, calculate an average value for the coefficient of kinetic friction for the block and for the block with added mass.

10. Does the coefficient of kinetic friction depend on speed? Explain, using your experimental data.

11. Does the force of kinetic friction depend on the weight of the block? Explain.

12. Does the coefficient of kinetic friction depend on the weight of the block?

13. Compare your coefficients of kinetic friction determined in Part III to that determined in Part II. Discuss the values. Do you expect them to be the same or different?

EXTENSIONS

1. How does the surface area of the block affect the force of friction or the coefficient of friction? Devise an experiment that can test your hypothesis.

2. Examine the force of static friction for an object on an incline. Find the angle that causes a wooden block to start to slide. Calculate the coefficient of friction and compare it to the value you obtain when the angle of the incline is 0°.

3. Try changing the coefficient of friction by using wax or furniture polish on the table. How much does it change?