DataQuest

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# 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 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 $\mu_s$ 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 in magnitude 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 $\mu_k$ 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 Motion Detector will also be used to analyze the kinetic friction acting on a sliding block.

## OBJECTIVES

- Use a 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

TI-Nspire handheld **or**
  computer and TI-Nspire software
data-collection interface
Vernier Force Sensor
Motion Detector *or* CBR 2 *or*
  Go!Motion
string
block of wood with hook
balance or scale
mass set
graph paper (optional)

## PRE-LAB 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 what1 are you basing your choice?

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

## PROCEDURE

### Part I Investigating 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 the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the Experiment menu. Choose Collection Setup from the Experiment menu. Enter **5** for the duration. The number of points collected should be 251. Select OK.

4. Zero the Force Sensor.
   a. Hold the Force Sensor so the working axis is horizontal.
   b. With the Force Sensor axis held horizontally and no force applied, choose Set Up Sensors ► Zero from the Experiment menu. When the process is complete, the readings for the sensors should be close to zero.

5. 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. 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.

6. 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.

7. Hold the Force Sensor in position, ready to pull the block, but with no tension in the string.

8. Start data collection (). Wait a moment, then pull the block as before, taking care to increase the force gradually.

9. Inspect your graph. Repeat Step 8 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 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.

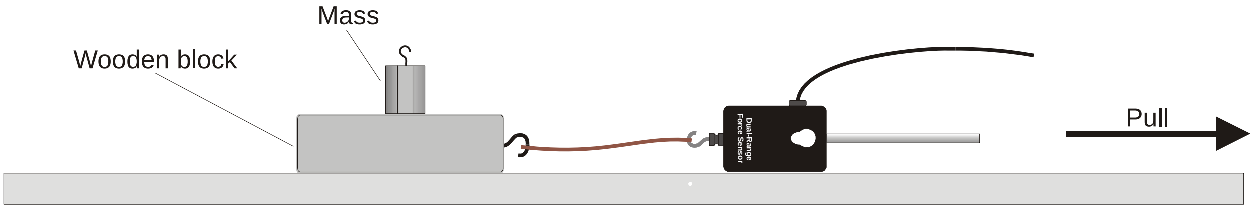


*Figure 1*

10. Remove all masses from the block.

11. Insert a new Problem into your TI-Nspire document and add a DataQuest App to the problem. Choose New Experiment from the Experiment menu. Choose Collection Setup from the Experiment menu. Enter **5** for the duration. The number of points collected should be 251. Select OK.

12. Zero the force sensor (see Step 4).

13. Collect force *vs.* time data using the procedure described in Steps 7–9.

14. The maximum value of the force occurs when the block started to slide. Click near this point and use ► and ◄ to highlight the point. The coordinates of the point are displayed in the Graph View details box. Record the maximum force in your data table.

15. Determine the average friction force while the block was moving at constant velocity.
    a. Select the data in the approximately constant-force region.
    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.

16. Repeat Steps 13–15 for two more measurements. Be sure to Store the Latest Data Set () before each new run. Average the results to determine the reliability of your measurements. Record the values in the data table.

17. Add masses totaling 500 g to the block. Repeat Steps 13–16. Be sure to Store the Latest Data Set () before each new run.

18. Add an additional 500 g and repeat Steps 13–16. Be sure to Store the Latest Data Set () before each new run.

### 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 a 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.

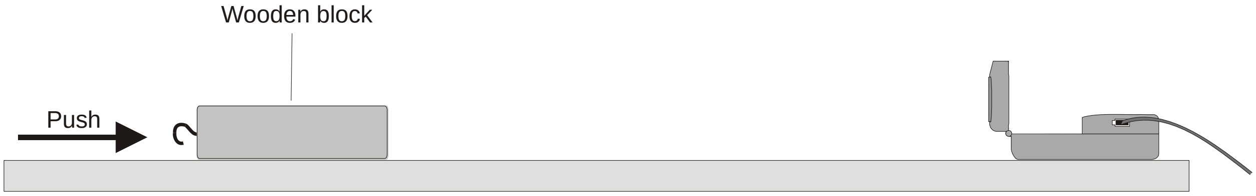


*Figure 2*

19. Disconnect the Force Sensor and interface from the TI-Nspire handheld or computer.

20. Place the Motion Detector on the lab table about 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.

21. If your Motion Detector has a switch, set it to Normal. Connect the Motion Detector to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using a CBR 2 or Go! Motion, you do not need a data-collection interface.)

22. Insert a new **Problem** into your TI-Nspire document and add a DataQuest App to the problem.

23. Choose New Experiment from the Experiment menu. For this part of the experiment, the default data-collection parameters for a motion detector will be used (Rate: 20 samples per second; Duration: 5 seconds).

24. Click on the Graph View tab ( ). Choose Show Graph ►Graph 2 from the Graph Menu. The graph display should now only show the velocity *vs*. time graph.

25. Practice sliding the block toward the Motion Detector by giving the block a very short push, 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 for Motion Detectors with a switch or 0.5 m for those without.

26. Start data collection ( ). After a moment, give the block a brief push so that it slides toward the Motion Detector.

27. Examine the graph of velocity *vs*. time. The velocity graph should have a portion with a linearly changing section before the block comes to rest corresponding to the freely sliding motion of the block. Repeat data collection if needed.

28. Fit a straight line to this portion of the data, the slope of which is the block's acceleration.
    a. Select the data in the region of the graph that is decreasing linearly.
    b. Choose Curve Fit ►Velocity ►Linear from the Analyze menu to fit a straight line to the velocity data.
    c. Record the magnitude of the slope of the fitted line, which is the block's acceleration, in your data table.

29. Repeat Steps 26–28 two more times. Be sure to Store the Latest Data Set ( ) before each collection.

30. Fasten masses totaling 500 g so they will not separate from the block. Store the Latest Data Set ( ), and repeat Steps 26–29. Record acceleration values in your data table.

# DATA

### Part I Investigating 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 | |
| Block | | | | | | |
| Block + 0.5 kg | | | | | | |
| Block + 1.0 kg | | | | | | |

| | Total mass (kg) | Normal force (N) | Kinetic friction | | | Average kinetic friction (N) |
|---|---|---|---|---|---|---|
| | | | Trial 1 | Trial 2 | Trial 3 | |
| Block | | | | | | |
| Block + 0.5 kg | | | | | | |
| Block + 1.0 kg | | | | | | |

### Part III Kinetic Friction

| Data: Block with No Additional Mass | | | |
|---|---|---|---|
| Trial | Acceleration ($m/s^2$) | Kinetic friction force (N) | $\mu_k$ |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| Average coefficient of kinetic friction: | | | |

| Data: Block with 500 g Additional Mass | | | |
|---|---|---|---|
| Trial | Acceleration ($m/s^2$) | Kinetic friction force (N) | $\mu_k$ |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| Average coefficient of kinetic friction: | | | |

# PROCESSING THE DATA

### Part I Investigating Friction

1. Inspect your graph of the force *vs*. time graph drawn in 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.

### Part II Peak Static Friction and Kinetic Friction

2. 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 Total Mass and Normal Force entries for both Part II Data Tables.

3. Plot a graph of the maximum static friction force (*y*-axis) *vs*. the normal force (*x*-axis).
   a. Disconnect all sensors from your handheld or computer.
   b. Insert a new problem in your TI-Nspire document and insert the DataQuest App.
   c. Click on the Table View tab () to view the table.
   d. Double-click on the x-column to open the column options.
   e. Change the Name to **Normal Force**. Enter **Normal** as the Short Name and **N** as the units. Select OK.
   f. Double-click on the y-column.
   g. Change the Name to **Friction Force**. Enter **Friction** as the short name and **N** as the units. Select OK.
   h. Double-click the run name and enter **Static Friction** as the Data Set name. Select OK.
   i. Enter the data in the table.

4. Since $F_{maximum\ static} = \mu_s N$, the slope of this graph is the coefficient of static friction $\mu_s$. Find the numeric value of the slope, including any units. Should a line fitted to these data pass through the origin?
   a. Click on the Graph View tab () to view the graph.
   b. Select Curve Fit ► Linear from the Analyze menu.

5. In a similar graphical manner, find the coefficient of kinetic friction, $\mu_k$. Use a plot of the average kinetic friction forces *vs*. the normal force. Recall that $F_{kinetic} = \mu_k N$. Should a line fitted to these data pass through the origin?
   a. Click on the Table View tab () to view the table.
   b. Select New Data Set from the Data menu.
   c. Double-click the run name and enter **Kinetic Friction** as the Data Set name. Select OK.
   d. Enter the data in the table.
   e. Switch to Graph View to view the data.
   f. Select Curve Fit ► Linear from the Analyze menu.

### Part III Kinetic Friction

6. Your data from Part III also allow you to determine $\mu_k$. 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.

7. 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.

## QUESTIONS

### Part I  Starting Friction

1. Consider 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 question 1 in the Pre-Lab Questions section?

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 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?

### Part II  Peak Static Friction and Kinetic Friction

3. Should the graph of the maximum static friction force *vs*. the normal force (see Processing the Data Step 3) pass through the origin? Explain.

4. Should the graph of the average kinetic friction force *vs*. the normal force (see Processing the Data Step 5) pass through the origin? Explain.

### Part III  Kinetic Friction

5. Draw a free-body diagram for the sliding block.

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

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

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

9. 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?