# 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 $F_{static} \le \mu_s N$ 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 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 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-82, 83, 86, 89, 92, or 92 Plus | Vernier Force Sensor |
| CBL System | block of wood with hook |
| PHYSICS program loaded in calculator | balance or scale |
| string | mass set |
| Vernier Motion Detector | Graphical Analysis or graph paper |
| Vernier adapter cable | (optional) |

## 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 CH 1 input of the CBL unit. Use the black link cable to connect the CBL unit to the calculator. Firmly press in the cable ends.

3. Turn on the CBL unit and the calculator. Start the PHYSICS program and proceed to the MAIN MENU.

4. Set up the calculator and CBL for the Force Sensor.

   - Select SET UP PROBES from the MAIN MENU.
   - Select ONE as the number of probes.
   - Select FORCE from the SELECT PROBE menu.
   - Select STUDENT FORCE, DUAL-RANGE 5N, or DUAL-RANGE 10N as appropriate for your force sensor.
   - If using a Dual-Range Force Sensor, set the range switch to ±5N or ±10N as appropriate for your sensor.
   - Confirm that the Force Sensor is attached to CH 1, and press ENTER.
   - Select USE STORED from the CALIBRATION menu.

5. Next you will zero the Force Sensor. Hold it so the sensitive axis is horizontal.

   - Select ZERO PROBES from the MAIN MENU.
   - Select CHANNEL 1 from the SELECT CHANNEL menu.
   - With no force applied to the Force Sensor, press TRIGGER on the CBL.

6. Set up the calculator and CBL for data collection.

   - Select COLLECT DATA from the MAIN MENU.
   - Select TIME GRAPH from the DATA COLLECTION menu.
   - Enter "0.05" as the time between samples, in seconds.
   - Enter "99" as the number of samples (the CBL will collect data for about 5 seconds).
   - Press ENTER, then select USE TIME SETUP to continue. If you want to change the sample time or sample number, select MODIFY SETUP instead.

7. 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 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.

8. 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.

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

10. Press ENTER to begin collecting data. Pull the block as before, taking care to increase the force gradually.

11. Press ENTER to view your graph. Press ENTER, and select YES to 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 copy 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.
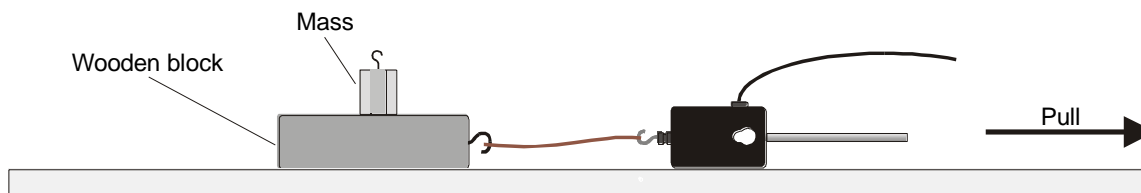


*Figure* 1

12. Remove all masses from the block.

13. Using the same procedure as before with the calculator and for pulling the block, collect force *vs.* time data.

14. Trace along your graph using the cursor keys. 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.

15. Next you need to determine the average friction force while the block was moving at constant velocity.
    - Press ENTER and select NO to return to the MAIN MENU.
    - Select ANALYZE from the MAIN MENU.
    - Select STATS/INTEGRAL from the ANALYZE MENU.
    - Select STATISTICS from the STATS/INTEGRAL menu.
    - Select CHANNEL 1 from the SELECT GRAPH menu.
    - Select a portion of the force graph for averaging. Using the cursor keys, move the lower bound cursor to the left side of the approximately constant-force region. Press ENTER.
    - Now select the other edge. Move the cursor to the right edge of the approximately constant-force region. Press ENTER.
    - Press ENTER, and read the mean force from the calculator. Record the value in your Data Table.
    - Press ENTER to return to the MAIN MENU.

16. Repeat Steps 13 – 15 for two more measurements and 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, recording values in the Data Table. Add another 500 g and repeat.

### 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.

Wooden block

Push

*Figure* 2

18. 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.

19. Set up the calculator and CBL for the Motion Detector.

   - Connect the Motion Detector to the SONIC port of the CBL.
   - Select SET UP PROBES from the MAIN MENU.
   - Select ONE as the number of probes.
   - Select MOTION from the SELECT PROBE menu.

20. 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.

21. Set up the calculator and CBL for data collection, and then collect data.

   - Select COLLECT DATA from the MAIN MENU.
   - Select TIME GRAPH from the DATA COLLECTION menu.
   - Enter "0.05" as the time between samples, in seconds.
   - Enter "99" as the number of samples (the CBL will collect data for a total of 5 seconds).
   - Press ENTER, then select USE TIME SETUP to continue. If you want to change the sample time or sample number, select MODIFY SETUP instead.
   - Press ENTER to start collecting data.
   - Give the block a push so that it slides toward the Motion Detector.

22. Inspect your graph.

   - Press ENTER and select VELOCITY from the SELECT GRAPH menu.
   - 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.

23. Next you will fit a straight line to this portion of the data, the slope of which is the block's acceleration. To do this,

   - Press ENTER, and select NEXT from the SELECT GRAPH menu.
   - Select NO to return to the MAIN MENU.
   - Select ANALYZE from the MAIN MENU.
   - Select SELECT REGION from the ANALYZE MENU.
   - Select VELOCITY from the SELECT GRAPH menu.
   - Select a region of the velocity *vs.* time graph that shows the decreasing speed of the block by choosing the linear section. Using the cursor keys, move the lower bound cursor to where the linear decrease of velocity begins. Press ENTER.

- Now select the other edge. Move the cursor to just where the linear region ends. Press ENTER.
- Select VELOCITY from the SELECT GRAPH menu to see the selected region.
- Press ENTER and select NEXT to go back to the main menu.

24. The slope of this section of the velocity graph is the acceleration. Find the slope of the section:

- Select ANALYZE from the MAIN MENU.
- Select CURVE FIT from the ANALYZE MENU.
- Select LINEAR L1, L5 from the CURVE FIT menu, to fit a straight line to the velocity data.
- Record the magnitude of the slope of the fitted line, the block's acceleration, in your Data Table.
- Press ENTER to see the velocity graph with the fitted line.
- Press ENTER to return to the MAIN MENU.

25. Repeat Steps 21 – 24 two more times.

26. Place masses totaling 500 g on the block. Fasten the masses so they will not move. Repeat Steps 21 – 24 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 (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) | $\mu_k$ |
| 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: | | | |

## ANALYSIS

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.

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 question 1 in the Preliminary Questions section?

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 static friction force (*y* axis) *vs.* the normal force (*x* axis). Use your calculator, Graphical Analysis, or graph paper.

6. 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?

7.  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?

8.  Your data from Part III also allow you to determine $\mu_k$. 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 is the force of friction or the coefficient of friction affected by the surface area of the block? 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?