

Clutch...

Student Instruction Sheet

Challenge

In this activity, use the Force Sensor to investigate static friction and kinetic (sliding) friction of felt and cork trays on an aluminium track. Discover which combination of materials – felt and aluminium or cork and aluminium – has greater friction. Investigate how the friction force between two surfaces changes as the two surfaces are pressed together.

Equipment and Materials

<ul style="list-style-type: none"> • Computer with USB Port • PASPORT USB interface • PASPORT Force Sensor • DataStudio software • 1.2 m PAScar Dynamics System • Discover Friction Accessory 	<ul style="list-style-type: none"> • Braided Physics String • Ohaus Triple-beam Balance • <i>Student Instruction Sheet</i> • <i>Student Response Sheet</i>
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Safety Precautions

Remember, follow the directions for using the equipment.

Background

"Ignore Friction."

Either explicitly or implicitly, this simplification has probably applied to every physics problem you've solved so far. However, in this activity, you'll directly investigate the phenomenon of friction, which is pervasive in the real world but is virtually banished from your introductory physics problems.

Friction forces resist the motion of two surfaces sliding past each other. Friction forces arise because even smooth looking surfaces are rough on a microscopic scale.

Imagine a large, half-filled cardboard box resting on a flat concrete floor (in the real, friction-filled world). If you press lightly on the box horizontally, the box does not move. Since the box's acceleration is 0, it must be experiencing a force that is equal in magnitude and opposite in direction to the force you are applying to it. This opposing force is due to the friction between the bottom surface of the box and the floor. When the box is stationary, we call this force the *static friction force*, F_s .

If you press slightly harder on the box and it still does not move, the static friction force must have also increased slightly to continue to exactly oppose the force you exert. Interestingly, the static friction force will change to exactly match the force you exert, up to a point. If you keep pressing with increasing force, you know from experience that at some point the box will slip and begin to slide. Just before the box slips, some *maximum static friction force*, $F_{s\ max}$, is applied. When the force of your pressing finally exceeds the maximum static friction force, the box slips and begins to slide.

Once the box has slipped and begins to slide, you need to exert a force to keep the box moving at a constant speed. From experience, you may know that the force required to keep the box moving is often different in magnitude from the force required to start it moving. When the box is sliding along the floor, the force of friction between the bottom surface of the box and the floor is called the *kinetic (or sliding) friction force*, F_k . If the box is moving at a constant speed, this kinetic friction force must be exactly opposing the force of your push on the box. From experiment, it turns out that the kinetic friction force between two objects is fairly independent of the speed.

In this activity you will use a Force Sensor to drag a felt-covered tray and a cork-covered tray along an aluminum track to determine the maximum static friction forces and the kinetic friction forces between the trays and the track. Then you will add masses to the trays to increase the force with which the surfaces of the trays and track press against each other—the *normal force*, F_N —and again measure the friction forces. From these measurements, you will determine the mathematical relationship between the normal force and the friction forces.

Predict

Before beginning the eLab, complete the prediction portion of the *Student Response Sheet*.

Explore

Computer Setup

1. Plug the PASPORT USB interface into the computer's USB port.
2. Plug the Force Sensor into the USB interface. This will automatically launch the PASPortal window.



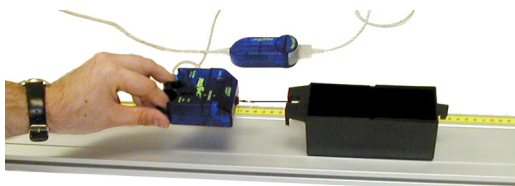
3. Choose the appropriate DataStudio configuration file entitled

08 Friction Forces CF.ds

Note: Configuration files automatically launch the appropriate display(s), sampling rate(s), etc.

Equipment Setup

1. Set up the equipment as shown in the figure and described below.



- Place the track on a flat, horizontal surface.
- Place the felt friction accessory tray on the track with the felt down.
- Tie a short piece of string between the friction tray and the hook on the Force Sensor.

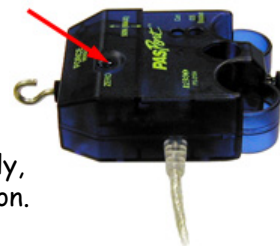
Record Data



Record Data: Felt Friction Tray

1. Make sure you can see the graph labeled **Friction Forces vs Time**.

2. Hold the Force Sensor horizontally a few inches above the track. With slack in the string, press the **zero** button on the sensor.

To zero the Force Sensor when measuring horizontally, with the Force Sensor oriented horizontally, press the **zero** button.



3. Click the **Start** ( Start) button. Gradually pull on the sensor with an increasing force. Once the tray starts moving, it is very important to pull so the tray moves with constant velocity. Why?
4. Click the **Stop** ( Stop) button after taking 5 seconds of acceptable data.
5. For a second run, add a 250-gram mass bar to the friction tray and perform the above procedure again. Don't forget to zero the sensor before recording data.
6. For a third run, add a second 250-gram mass bar to the friction tray and perform the above procedure again.

Record Data: Cork Friction Accessory

1. Replace the felt friction tray with the cork friction tray and perform the same procedure above starting with no additional masses. Remember to Zero the sensor before each run.
2. For a second run, add a 250-gram mass bar.
3. For the third run, add a second 250-gram mass bar.

You should now have six runs of data total.



Analyze

You will now determine the normal force (F_N), the maximum static friction force ($F_{s\ max}$), and the kinetic friction force (F_k) for each run of the felt and cork trays. From this data, you will create graphs of each of the friction forces versus the normal forces.

Part 1: Complete the Graph of Static vs Normal

Felt Friction Tray

Use your data to create a graph of Max Static Friction Force versus Normal Force for the felt friction tray.

1. Enter the values "0" and "0" in the first row of **Table 1 - Felt**. Can you justify the use of this as a data point?
2. Weigh the empty felt friction tray and enter its weight as the Normal Force value in the second row of **Table 1**. Remember that the magnitude of the Normal Force (in N) for an object on a horizontal surface is the mass (in kg) multiplied by g (acceleration due to gravity; in m/s^2). If you wish, use the Weight Data Table on the *Student Response Sheet* to write down your mass measurements and weight calculations before entering the normal force in the DataStudio table.
3. Select the **Friction Forces** graph. The *maximum* force value for each run will appear in the Legend box. Enter the *maximum* force value for **Run #1** as the Max Static Friction Force in the second row of **Table 1**.
4. Similarly obtain the Normal Force and the Max Static Friction Force for **Run #2** (250-gram mass bar added to tray) and **Run #3** (a second 250-gram mass bar added to tray). Record your results in **Table 1**. **Table 1** should have four rows of data.
5. Look at the graph labeled **Static vs Normal**. The data points you entered into **Table 1** should be plotted on this graph of Max Static Friction Force versus Normal Force. Ensure that **Table 1 - Felt Max Static Friction Force** is highlighted in the graph Legend box; if it isn't active, click on its name. Click the **Scale to Fit** () button if necessary.
6. Press the **Fit** () button. Select a fit type that is most appropriate for your data. Experiment with multiple fits if necessary. Once you have

obtained the best fit, write the fit type and equation in the Fit Data Table on your *Student Response Sheet*.

Cork Friction Tray

You will now perform the same procedure as above to create a graph of Max Static Friction Force versus Normal Force for the cork friction tray.

1. Choose **Table 2 - Cork**. Insert the values of "0" and "0" in the first row of **Table 2**.
2. Weigh the felt friction accessory alone and enter the Normal Force value in the second row of the table.
3. Select the **Friction Forces vs Time** graph. The *maximum* force value for each run will appear in the Legend box. Enter the value for **Run #2** as the Max Static Friction Force in the second row of **Table 2**.
4. Similarly obtain the Normal Force and the Max Static Friction Force for **Run #5** (250-gram mass bar added to tray) and **Run #6** (a second 250-gram mass bar added to tray). Record your results in **Table 2**. **Table 2** should have four rows of data.
5. Look at the graph of **Static vs Normal**. Ensure that **Table 2 - Cork Max Static Friction Force** is highlighted in the graph legend; if it isn't active, click on its name. Click the **Scale to Fit** button if necessary.
6. Press the **Fit** button. Select a fit type that is most appropriate for your data. Experiment with multiple fits if necessary. Once you have obtained the best fit, write the fit type and equation in the Fit Data Table on your *Student Response Sheet*.

Part 2: Complete the Graph of Kinetic vs Normal

Felt Friction Tray

1. Choose **Table 3 - Felt**. Insert the values of "0" and "0" in the first row.
2. Fill in the first column with the same Normal Force values as in **Table 1 - Felt**.
3. In the graph **Friction Forces**, ensure that **Run #1** is highlighted in the legend; if it isn't active, click on its name. Click and drag a box around the flat portion of **Run #1** which corresponds to the tray sliding at a constant velocity. The *mean* force value will appear in the Legend box. Enter this *mean* force value as the Kinetic Friction Force in the second row of **Table 3**.

4. Repeat the process to obtain the Kinetic Friction Force for **Run #2** (250-gram mass bar added to tray) and **Run #3** (a second 250-gram mass bar added to tray). Record your results in **Table 3**. **Table 3** should have four rows of data.
5. Look at the graph **Kinetic vs Normal**, which should plot the data points you just entered into the table. Ensure that **Table 3 - Felt Kinetic Friction Force** is active in the graph Legend box; if it isn't, click on its name. Click the **Scale to Fit** button if necessary.
6. Press the **Fit** button. Select a fit type that is most appropriate for your data. Experiment with multiple fits if necessary. Once you have obtained the best fit, write the fit type and equation in the Fit Data Table on your *Student Response Sheet*.

Cork Friction Tray

1. Choose **Table 4 - Cork**. Repeat the process above to obtain the Normal Force and the Kinetic Friction Force for **Run #4** (cork tray alone), **Run #5** (250-gram mass bar added to tray) and **Run #6** (a second 250-gram mass bar added to tray). Record your results in **Table 4**. **Table 4** should have four rows of data.
2. In the graph **Kinetic vs Normal**, ensure that **Table 4 - Cork Kinetic Friction Force** is active in the graph Legend box; if it isn't, click on its name. Click the **Scale to Fit** button if necessary.
3. Press the **Fit** button. Select a fit type that is most appropriate for your data. Experiment with multiple fits if necessary. Once you have obtained the best fit, write the fit type and equation in the Fit Data Table on your *Student Response Sheet*.
4. Save your DataStudio file (on the **File** menu, click **Save Activity As...**) to the location specified by your teacher.
5. Answer the questions and define the vocabulary words on the *Student Response Sheet*.
6. Follow you teacher's instructions regarding cleaning up your work space.

Student Response Sheet

Clutch...



Vocabulary

Use available resources to find the definitions of the following terms:

friction: _____

kinetic (sliding) friction: _____

normal force: _____

static friction: _____

Predict

1. Does it take more force to make a stationary object start sliding or to make a sliding object continue sliding?

2. How do you expect the friction between felt and aluminum to compare to the friction between cork and aluminum?

3. How do you expect the friction between the trays and the track to change as the trays and track are pressed more firmly against each other (that is, as the normal force increases)?

Data

Record your mass measurements and calculated weights below, or enter the weights directly into the tables in DataStudio.

Object	Mass (kg)	Weight (N)

Record your best fits in the table below.

	Max Static Friction Force Versus Normal Force		Kinetic Friction Force Versus Normal Force	
Materials	fit type	fit equation	fit type	fit equation
Felt-Aluminium				
Cork-Aluminium				

Note: Discuss your fits with your teacher before proceeding to the Analyze section.

Analyze

- After discussing your fit equations with your teacher, rewrite your fits (with any approved modifications) in the table below, replacing any generic variables with $F_{s\ max}$, F_k , or F_N , as appropriate. Use the space below the table to justify any modifications you made to your original fit equations.

	Max Static Friction Force Versus Normal Force	Kinetic Friction Force Versus Normal Force
Materials	relationship	relationship
Felt-Aluminium		
Cork-Aluminium		

Justify any modifications:

2. The slope of the fit line for $F_{s\ max}$ versus F_N is given the name *coefficient of static friction*, μ_s . The slope of the fit line for F_k versus F_N is given the name *coefficient of kinetic friction*, μ_k . Use the relationships you determined in the Fit Data Table to fill in the table below with the friction coefficients.

	coefficient of static friction, μ_s	coefficient of kinetic friction, μ_k
Felt-Aluminium		
Cork-Aluminium		

3. What are the units of μ_s and μ_k ? Describe in words the meaning of μ_s and the meaning of μ_k .

4. Compare the values of μ_s to the corresponding values of μ_k . Evaluate your prediction #1 in light of this comparison.

5. Compare the friction coefficients for felt on aluminum to the coefficients for cork on aluminum. Evaluate your prediction #2 in light of this comparison.

6. What happens to the friction forces as the normal force between the tray and track is increased? Evaluate your prediction #3.
