Two major types of friction are static friction and kinetic (also called sliding) friction. Static friction exists when two surfaces haven’t moved with respect to each other, and kinetic friction exists once the two surfaces are in motion relative to each other; generally static friction is greater than kinetic friction. For example, if you push on a large heavy box, it is hard to get it to move. However, once you have “broken” it loose, it is easier to keep it moving.

In this lab, you will investigate these two different types of friction and calculate the coefficient of friction for two different surface interactions. The goals of the lab are to:

1. Analyze the four forces acting on a system of a wooden block and a mass.
2. Calculate the total support force acting on the system.
3. Measure the static and kinetic friction for two different surface interactions.
4. Use the support force and the frictional forces to calculate the coefficients of friction.
5. Predict what the frictional force would be for a different system using the coefficients of frictions calculated and compare it to measured results of that system.
6. Use the skills gained in this lab to properly analyze and describe forces and motion in situations involving friction.

Introduction and Theory

Experiments show that when solids that are not lubricated slide against each other, the magnitude of the frictional force \( f \) is proportional to the support force \( N \). The constant of proportionality is called coefficient of friction \( \mu \), either static \( \mu_s \) or kinetic \( \mu_k \). The magnitude of the frictional force \( f \) can be found by using the following equations:

- Static frictional force \( \leq \) coefficient of static friction \( \times \) Support force OR in symbols: \( f_s \leq \mu_s N \)
- Kinetic frictional force \( \leq \) coefficient of kinetic friction \( \times \) Support force OR in symbols: \( f_k = \mu_k N \)

As you know from class, the support force \( N \) is the force which pushes back on an object in the opposite direction of it’s weight \( W \) and has equal magnitude to the weight \( W \).

Some typical values of coefficients of friction are listed below. The coefficient of friction is always dimensionless i.e. it has no units.

<table>
<thead>
<tr>
<th>Surface</th>
<th>( \mu_s )</th>
<th>( \mu_k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>steel on steel</td>
<td>.15</td>
<td>.09</td>
</tr>
<tr>
<td>wood on stone</td>
<td>.50</td>
<td>.40</td>
</tr>
<tr>
<td>steel on stone</td>
<td>.25</td>
<td>.20</td>
</tr>
<tr>
<td>rubber on concrete</td>
<td>1.00</td>
<td>.70</td>
</tr>
</tbody>
</table>

\( * \) This force is also called the Normal Force because it is always perpendicular (normal) to the support surface. That is why it has the symbol \( N \), which is not to be confused with the \( N \) which stands for Newtons—the unit we use for force.
In our experiment, we will measure and calculate the forces involved and then find the coefficient of friction by rewriting the equations to:

\[
\text{coefficient of friction} = \frac{\text{frictional force}}{\text{Support force}} \quad \text{OR in symbols:} \quad \mu = \frac{f}{N}
\]

**The Lab Experiment**

In this lab you’ll work with these two surface interactions:

- a wood block with rubber feet down and a mass on top. (rubber against table)
- a wood block with rubber feet up and a mass on top. (wood against table)

A computer readout will measure the force with which you are pulling the block and by analyzing the graph on the computer screen you will be able to determine the friction force right before the block starts moving and while it is moving.

1. **Analyzing the Forces Involved**

   In physics, it is always a good idea to draw a picture to clearly show which forces it is that we are dealing with.

   ► In the picture below, correctly identify the *Support Force, Weight, Friction, and Pulling Force* by labeling the arrows acting on the system (block and mass together inside dashed lines).

   ![Diagram](image)

   ► If the system is in equilibrium:
   a) What can you tell me about the acceleration of the system?

   b) What can you tell me about the velocity of the system?

   c) How does the size of Weight and Support Force compare?

   d) How does the size of the Pulling Force and Friction compare?
3. Calculating the Total Support Force

Our system has two parts: the 1 kg mass on top of the block and the block itself. To find the total support force of the system, we have to find the support force of each part and then add the two together.

We know that the Weight of the 1 kg mass is going to be the same size as the Support Force. To calculate the Weight we use Newton’s 2nd Law of Motion (F=ma).

\[
\text{Weight of Mass} = \text{mass} \times \text{gravitational acceleration} \ (\text{use } g=9.8 \text{ m/s}^2)
\]

\[
\text{► Weight of Mass} = \text{Support Force of Mass} = \underline{______} \text{ kg} \times \underline{______} \text{ m/s}^2 = \underline{______} \text{ Newtons}
\]

We could use the triple beam balance scale to find the mass of the block and then calculate the weight of it by using Newton’s 2nd Law of Motion. However, since we have a force probe, why not just measure how much gravity pulls on the block by hanging it straight down on the force probe?

Note: The force detector is very sensitive and calibrated just right to measure the frictional force when pulled in one direction. Do not rotate the hook on the end of the detector, or your readings will no longer be correct since the calibration will be off.

Here’s how to use the computer:

1. If not already done, turn on the ULI
2. If not already done, turn on the computer.
3. Double-click Mac Hard drive.
4. Double-click Student labs X.100 (where X = 1, 2, 3, or 4).
5. Double click Friction X (where X = 1, 2, 3, or 4).
6. A prompts will ask if you want calibration, click Yes.
7. On the computer screen, click Zero to nullify your probe.
8. Hang the block from the force detector and click Start.
9. Navigate to Data -> Analyze Data.
10. Place the vertical line somewhere on the flat line on the graph.
11. At the lower end of the screen read the force reading: this is your support force of the block by itself, i.e. without the mass on top.
12. Record your reading.

\[
\text{► Support Force of Block: } \underline{___________} \text{ Newtons}
\]

\[
\text{► Total Support Force} = \text{Support Force of Block} + \text{Support Force of Mass} = \underline{______} \text{ Newtons}
\]

3. Measuring the Kinetic and Static Friction Force

Starting from rest and with the string slack, you pull the block across the table with a constant velocity. The force probe will read the force you use to overcome the static and kinetic friction. Since you know the system is in equilibrium, you also know that the frictional force will be equal to the pulling force. The computer display will give you both the static and kinetic friction readout on the same graph.
Here’s how to do the measurement:
1. Place the wooden block with feet down on the table surface.
2. Place the 1 kg weight on top of it.
3. Hook the force detector to the end of the string attached to the block.
4. Select Data -> Clear Data A (also each selection of start will clear data)
5. On the computer screen, click Zero.
6. Click Start.
7. With the string slack, start pulling the block until the force graph on your computer screen is flat for a little while.
8. Select to Data -> Analyze Data A.
9. Place the vertical line at the top of the highest peak on the graph.
10. At the lower end of the screen read the force reading: this is the magnitude of your static friction force.
11. Record the reading.
   ► Feet Down Static Friction = ____________ Newtons
12. Place the vertical line somewhere on the flat line on the graph.
13. At the lower end of the screen read the force reading: this is the magnitude of your kinetic friction force.
14. Record the reading.
   ► Feet Down Kinetic Friction = ____________ Newtons
15. Repeat the procedure with the block with feet up, sliding on the wood.
   ► Feet Up Static Friction = ____________ Newtons
   ► Feet Up Kinetic Friction = ____________ Newtons

4. Calculating the Coefficient of Friction
By using the data and calculations from the previous sections, you can calculate the coefficient of friction for the two different surface interactions using:

\[
\text{Coefficient of friction} = \frac{\text{frictional force}}{\text{Support force}} \quad \text{OR in symbols:} \quad \mu = \frac{f}{N}
\]

Calculate the four different coefficients of frictions: one for each surface interaction and for static and kinetic friction.

Feet Down
► Coefficient of Static Friction = _______________

► Coefficient of Kinetic Friction = _______________

Feet Up
► Coefficient of Static Friction = _______________

► Coefficient of Kinetic Friction = _______________
5. Predicting and Testing the Frictional Force for a Different System

Now that you have the coefficient of friction for wood on table top and rubber on table top interactions, you can determine the frictional force for any other systems that are made of the same materials—no matter what the weight of that system is.

In this part of the lab, you predict what the friction would be if the mass on top of the block was 0.5 kg.

► Support Force of the Block = ___________________ Newtons (Hint: Will this change from before?)

► Support Force of the Mass = _____ kg x _______ m/s² = _____________ Newtons

► Total Support Force of the New System: _________________ Newtons

Using the relationship between the support force, the coefficient of friction, and the friction force, predict what the static and kinetic friction force will be for this new system:

\[ \text{frictional force} = \text{coefficient of friction} \times \text{support force} \text{ OR in symbols: } f = \mu N \]

► Feet Down Predictions

Static Friction = _____________ Newtons
Kinetic Friction = _____________ Newtons

► Feet Up Predictions

Static Friction = _____________ Newtons
Kinetic Friction = _____________ Newtons

Pull the new system across the table top and use the force probe and the computer to see how close your predicted values are to the actual values.

► Feet Down Measurements

Static Friction = _____________ Newtons
Kinetic Friction = _____________ Newtons

► Feet Up Measurements

Static Friction = _____________ Newtons
Kinetic Friction = _____________ Newtons

Calculate the percent difference between your predictions and measurements. Since we don’t have a accepted, or published value to compare our test results to, we don’t call this a percent error. This value may be higher than our normal 10%.

\[ \% \text{ difference} = \frac{\text{Predicted Value} – \text{Measured Value} \times 100}{\text{Predicted Value}} \]

► Feet Down % difference

Static = _____________ %
Kinetic = _____________ %

► Feet Up % difference

Static = _____________ %
Kinetic = _____________ %

► How could you change the experiment design to make it more accurate?
6. Some Questions about Friction

Complete these exercises before turning in your lab. *In each picture, draw the different forces that acts on the safe.*

A) One person pushes: the safe is not moving
Bill pushes on a safe full of money. The safe doesn’t move at all. Please explain what forces are acting on the safe (there should be 4 of them) what their size and directions are relative to each other and why the safe isn’t moving.

B) Two people push: the safe is moving with slow, constant velocity
Bill gets his buddy Fred to help him push the safe. Once they get it moving, the safe moves with a slow constant velocity. Please explain what forces are acting on the safe what their size and directions are relative to each other and why the safe has a constant velocity.

C) Three people push on the safe
Bill and Fred ask Peter to help them push the safe. With three people helping, the net force is larger than when only Bill and Fred were pushing. Please explain what forces are acting on the safe, what their size and directions are relative to each other, and if the safe has any acceleration.