Friction

Equipment

- Computer, PASCO Interface
- PASCO Force Sensor
- PASCO Photogate with Pulley and clamp for edge of table.
- Dual-surface block with a string (~ 50 cm) tight to it.
- Mass Hanger and mass set.
- Capstone Setup file: Friction Experiment Setup
- *The lab benches tend to accumulate grease from fingerprints, debris from erasers, and dust. This causes wide variations in the coefficient of friction, even for places a few centimeters apart. For that reason, the experiment works best if the part of the lab bench being used is cleaned and dried immediately before the experiment.*

Objectives

- *To compare the coefficients of static and kinetic friction for two given surfaces.*

Introduction

Friction is a resisting force that acts along the tangent to two surfaces in contact with each other when one body slides or attempts to slide across another. The direction of the frictional force is opposite the body's motion or attempted motion. Our simple model is that the available frictional force (f_s or f_k) is directly proportional to the normal force (F_N). (We're referring to the force magnitudes, so no arrow or boldface font is necessary.)

There are two different kinds of friction: the static friction force f_s and the kinetic friction force f_k

When two surfaces are still at rest, but attempt to slide one over another, static friction is present. The static frictional force f_s is has a magnitude that can have any value, up to a limit:

$$f_s \leq \mu_s F_N \tag{1}$$

Here, F_N is the magnitude of the normal force between the surfaces.

When two surfaces are moving with respect to each other, the other kind of friction occurs. It is the kinetic friction. The kinetic frictional force f_k has a specific magnitude:

$$f_k = \mu_k F_N \tag{2}$$

In the expressions above, μ_s is the static friction coefficient and μ_k is the kinetic friction coefficient. In general, $\mu_s > \mu_k$. This means that when enough force is exerted on an object to overcome the static frictional force and the object starts moving, the kinetic frictional force will be less than the applied force and the object will accelerate. Another way of thinking of this is that it is harder to get something moving than it is to keep it moving.

Part 1: Static Friction Coefficient

In this experiment, you will determine the static friction coefficient of a block sitting on the lab bench. To do this, first measure the limit of the static friction force with a force sensor by pulling **very gently** on the force sensor until block moves. Second, calculate the normal force by assuming that the table surface is perfectly horizontal so that the normal force and gravitational forces on the block are equal in magnitude. Since $f_{smax} = \mu_s F_N$, the slope of the graph friction vs. normal force should be the coefficient of static friction.

Data Recording

1. Measure and record the mass of the dual-surface block.
2. Plug the Force Sensor into the PASCO Interface box.
    - Be ***VERY CAREFUL*** about the orientation of the pins. Make sure they line up correctly with the socket.
    - The sensor ***MUST*** be "zeroed" before each recording. To do this, make sure that the sensor exert ***no force*** on the hook before pressing the "zero" button.
3. Connect the sensor to the string and place the block near the edge of the table (Figure 1).

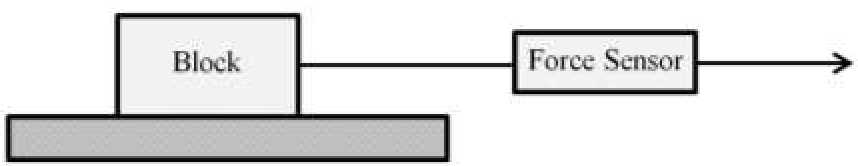

Figure 1. Schematic setup for measuring the limit of the static friction.

4. Start recording and ***gently*** pull the block until it starts sliding. Keep the string parallel to the table as shown in Figure 1. Once the block moves stop recording. This is a measurement of static friction, not sliding friction, so do not drag the bock across the table.
5. In Capstone, use a cross-wire tool to determine the coordinates of the peak on the graph. Record the maximum force **magnitude** as the limit of the static friction force.
6. Repeat the measurement a few times to see if you are getting a consistent value. If not, try pulling more gently and increase the force more gradually.
7. Repeat the measurements while increasing the mass of the block in increments of 50 g by place the additional mass on top of the block.
8. Flip the block over and repeat the experiment with the ***other side*** down.

Side touching Table	Mass of the block (kg)	Added mass(kg)	Total mass (kg)	Normal force (N)	Limit of Static Friction Force (N)
		0			
		0.05			
		…			

Table 1. Measured and Calculated values for Part 1.

9. For each data run, calculate the normal force assuming it equals the gravitational force on the total mass.
10. Make 2 graphs, one for each side that was sliding against the table. Graph the limit of the friction force f_s vs. the normal force F_N. Determine the linear trendline. Interpret the slope of this line as the coefficient of static friction. Put both sets of data on the same graph.

Part 2: Kinetic Friction Coefficient

Measuring the kinetic friction coefficient is trickier because we can only measure the pulling force, not the friction force directly. They are only equal if the block is moving with zero acceleration and it is difficult for a person to pull on the force sensor with a zero acceleration.

Fortunately, we can set up a situation with a constant acceleration. A block of mass m_{block} is placed on the table top, and a weight hanger of mass m_{hang} is tied to a string, which is passed over a pulley paired with a photogate and tied to the block, see Figure 2. When the weight hanger is released, the entire system will accelerate and we will get to measure that acceleration.

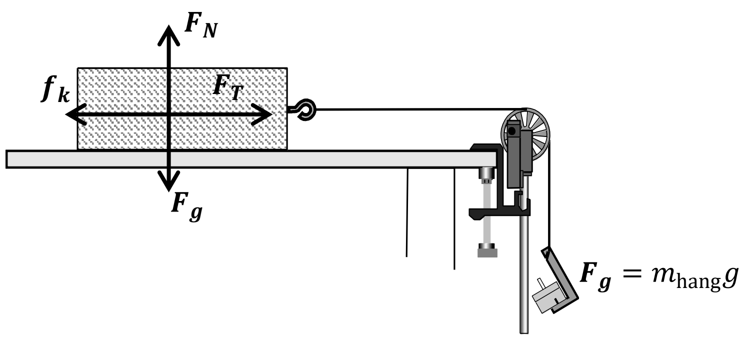

Figure 2. Schematic setup for Part 2

The external forces affecting the acceleration of the system are:

- F_g, or $m_{\text{hang}}g$, pulling down on the suspended mass.
- f_k resisting the motion

Since these forces are in opposite directions, the sum of the forces is the difference of their magnitudes. This must equal the total mass times the acceleration.

$$\sum F = m_{\text{hang}}g - f_k = m_{\text{total}}a \tag{3}$$

The vertical forces on the block are just gravity and the normal force and assuming a perfectly horizontal table top, they are equal and opposite.

$$F_g = F_N \tag{4}$$

In this part of the experiment, the system is set in motion by the release of the suspended mass. An electronic sensor, smart pulley, monitors the motion and the Capstone software displays the recording as speed vs. time graph where the slope of the graph represents the acceleration of the moving system. After recording m_{block}, m_{hang}, and acceleration a, the kinetic friction force could be calculated based off equation (3). Since $f_k = \mu_k F_N$, the slope of the graph kinetic friction force vs. normal force is the coefficient of kinetic friction.

Data Recording

1. Tie a string between the block and a mass hanger, and pass the string over a smart pulley. Make sure the string is not rubbing against anything.
2. Place 200 grams on the hanger to make suspended mass 250 gram.
3. Hold the block so it doesn't slide on the table.
4. In Capstone, go to the next page "Kinetic friction" and start recording.
5. Let go of the block and let the computer record the velocity graph. Stop the block before it hits the clamp and stop recording.
6. Select the linear portion of the graph (yellow highlighted icon) and fit it into linear function (drop fitting menu and choose "linear").
7. Record the value of the slope as the acceleration in Table 2.
8. Add weight to the block in increments of 50 g and repeat 5-7 for five additional weights or until block does not move. Keep m_{hang} the same in all runs.
9. For each run, record m_{block}, m_{added}, and the acceleration a.
10. Flip the block over and repeat the experiment with the ***other side*** down.
11. For each data run, calculate f_k from the experiment by solving Equation (3)
12. For each data run, calculate the normal force assuming it equals the gravitational force on the ***total mass of the block plus added mass***.
13. Make 2 graphs, one for each side that was sliding against the table. Graph the kinetic friction force f_s vs. the normal force F_N. Determine the linear trendline. Interpret the slope of this line as the coefficient of kinetic friction. Put both sets of data on the same graph.

Side touching Table	Mass of the block (kg)	Added mass(kg)	Suspended mass (kg)	Acceleration (m/s2)	Normal force (N)	Kinetic Friction force (N)
		0	0.25			
		0.05	0.25			
		...	0.25			

Table 2. Measured and Calculated values for Part 2.

Part 3: Final Comparison

Organize the results in a summary table such that it would be easy to compare the experimental values of coefficients of static and kinetic friction for each surface.

Type of the surface	Coefficient of static friction	Coefficient of kinetic friction

Table 3. Summary of the results

Requirements for the Report (also consult the rubric):

Save your Excel files through Canvas Group File Exchange

- The **abstract section** must contain the following explanations in paragraph form:
  - How the data was collected and calculated for Table 1 (m_a, m_b, F_N, and f_{smax})
  - How the data from Table 1 was analyzed including interpretation of the trendlines (use f_{smax} equation to explain how you found μ_s from the graph)
  - How the data was collected and calculated for Table 2 (m_a, m_b, m_h, F_N, a_{exp}, and f_k); explain how f_k equation was constructed and include a brief explanation of a_{exp}
  - How the data from Table 2 was analyzed including interpretation of the trendlines (how you found μ_k from the graph)
  - Compare the static and kinetic friction coefficients of the same surfaces in Table 3. We expect that μ_s is larger than μ_k, was that the case in this experiment?

- The **data section** must include
  - 3 Tables (labeled and captioned)
  - 2 Graphs (titled, axis labels, units, labeled and captioned)
    - f_{smax} vs F_N
    - f_k vs F_N