LAKE FOREST COLLEGE
Department of Physics

PHYS 114 **Experiment 7: Friction** Fall 2024

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Preliminary Instructions
Create a folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the Excel template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment
Determine the coefficient of kinetic friction and the coefficient of static friction between pairs of surfaces, and to test the dependence of these coefficients of friction on the magnitude of the normal force between the objects and the area of contact.

Pedagogical purpose of today's experiment
Study forces of friction.

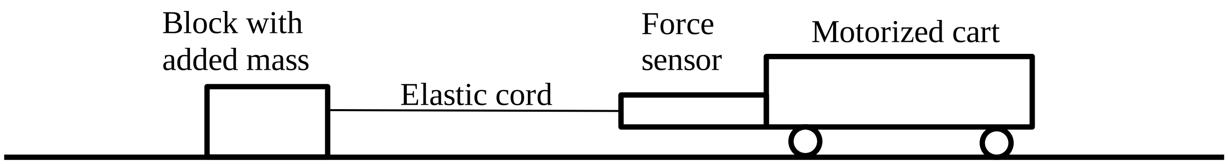
Background
When two surfaces touch, each exerts a contact force on the other. The component of this force that is perpendicular to the surface is called the normal force (symbol $\vec{F}_{\mathrm{N}}$), while the component parallel to the surface is called the friction force (symbol $\vec{F}_{\mathrm{f}}$).

The direction of the normal force is so as to push the surfaces apart. The magnitude of the normal force takes on whatever value is necessary to keep one surface from breaking through the other. When the surfaces lose contact, the normal force goes to zero.

If the surfaces have no relative motion, then the friction is called static friction. The direction of the static friction force on one of the surfaces is opposite to the direction of the relative velocity the surface would have if there were no friction. The magnitude of the static friction takes on whatever value is necessary to keep the two surfaces from slipping with respect to one other, up to a maximum value. This relationship is expressed by an inequality: $0 \le F_{\mathrm{sf}} \le F_{\mathrm{sf\,max}}$ where $F_{\mathrm{sf\,max}} = \mu_{\mathrm{s}} F_{\mathrm{N}}$. The coefficient of static friction, μ_s, depends on the materials of the two surfaces.

If the surfaces are in relative motion, the friction is called kinetic friction. The direction of the kinetic friction force on one of the surfaces is opposite to the direction of the relative velocity of that surface. The magnitude of the kinetic friction is given by $F_{\mathrm{kf}} = \mu_{\mathrm{k}} F_{\mathrm{N}}$. The coefficient of kinetic friction, μ_k, depends on the materials of the two surfaces.

We will apply a horizontal force to a block on a horizontal surface. By slowly increasing this force until the block starts to move, we can measure the maximum force of static friction and find the coefficient of static friction. By measuring the force necessary to keep it moving at a constant speed, we can measure the force of kinetic friction and find the coefficient of kinetic friction.



Procedure

Calibration

1. Make sure that the slider switch on the force sensor is set to 10 N. Place the cart/sensor combination in front of the pulley and place a 500 g mass on top of the cart. Hang a 200 g mass from a string running over the pulley and attached to the force sensor. Make sure that the string pulls exactly horizontally on the sensor.

2. Start Logger Pro. Go to Experiment->Calibrate and choose the Dual Range Force sensor. The click “Calibrate Now.” Remove the weight from the string and enter 0 N under “Reading 1” then click “Keep.” Now put the 200 g mass back on the string and enter 1.96 N (0.2 kg * 9.80 m/s^2) under “Reading 2” then click “Keep.”

Part I. Large Area and Large Mass

3. We will measure μ_s and μ_k by slowly increasing the horizontal force applied to the block until it breaks free from the surface and then continues at a constant velocity. Place the Pasco Motorized Cart with the force sensor at one end of the coated board. Set the speed knob near its slowest setting. Place the block behind it with its wide surface of pads on the board. Place a 1 kg mass on top of the block.

4. Zero the force sensor with nothing touching it (last entry under the “Experiment” tab or use the shortcut “control+0”) and then attach it to the block with an elastic band. Make sure that the sensor is at the same height as the hook on the block. Rotate the hook on the force sensor to be parallel to the hook on the block.

5. Start the Logger Pro data collection and turn on the motorized cart. The cart will move, stretching the elastic band. Eventually the block will break free and slide.

6. The maximum static friction force, $F_{\text{sf max}}$, occurs just before the block moves. You should observe a peak on the Logger Pro plot of force versus time. Use the statistics function to measure this <u>maximum</u> force and record it in your table.

7. The kinetic friction force, F_{kf} , occurs while the block is moving. After the block breaks free it should eventually move at a constant velocity. This will create a horizontal (constant) line on the Logger Pro plot of force versus time. Measure and record the <u>mean</u> force during the constant velocity section of the plot and record it in your table.

8. **Paste a picture of the apparatus here.** Label the important pieces, including model numbers of equipment where appropriate. Include a caption.

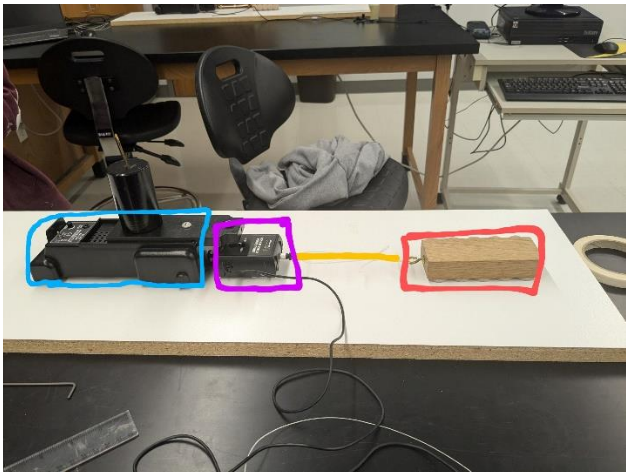


Figure 1 Friction Testing Apparatus. The Pasco ME-9781 Variable Speed Motorized Cart is outlined in blue. The Vernier Dual range force sensor is outlined in purple. The Cart made from a wooden block with furniture anti-slip pads facing down is outlined in red. The elastic band between the wooden block and force sensor is represented by the yellow line. Not picture is the weights, 1kg and 500g depending on the part, that were placed on top of the block.

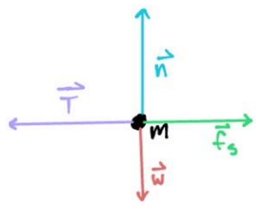
9. Draw a free-body diagram for the block. Apply Newton's Second Law for a non-accelerating block on a horizontal surface.

10. Assuming the object is at rest relative to the surface, derive an equation for the coefficient of static friction in terms of the maximum pulling force and the object's mass.

11. Assuming the object slides at a constant velocity across the surface, derive an equation for the coefficient of kinetic friction in terms of the mean pulling force and the object's mass.

12. **Paste pictures of your free-body diagram and your derivations here**. Include a caption.

$$f_s \le \mu_s n$$
$$f_k = \mu_k n$$
$$w = mg$$
$$\Sigma F = ma$$



Kinetic (μ_k):

$$n - w = ma_y = 0$$
$$n = w$$
$$n = mg$$
$$f_k - T = ma_x$$
$$f_k - T = 0$$
$$f_k = T$$
$$\mu_k n = T$$
$$\mu_k = \frac{T}{mg}$$

Static (μ_s):

$$n - w = ma_y$$
$$n = w = mg$$
$$f_s - T = ma_x$$
$$f_s = T$$
$$\mu_{s\,max}\, n = T$$
$$\mu_{s\,max} = \frac{T}{mg}$$

Uncertainty: $\frac{\delta A}{|A|}$ = relative uncertainty

Figure 2 Free Body Diagram and Friction Equation Derivation. In the free body diagram, the weight force vector is in pink, the normal force vector is in blue, the tension force vector is in purple, and the friction force vector is in green. The friction force vector represents both static and kinetic friction depending on at what point in the trail is being represented. The letters (n, w, T, and f) represent the magnitude of the respective vectors.

In the free body diagram the vector f (color) represents both static and kinetic friction.

μ_k represents the kinetic friction constant and μ_s represents the static friction constant. When the static friction is overcome the cart starts moving.

13. Measure the mass of the block and weight together. Use your derived equations to calculate the coefficients of static and kinetic friction for your block on your coated wooden board.

14. Perform eight of these trials. Put the block back at the same location on the board for each measurement. Save each of these LoggerPro files to your folder. **Paste one of the graphs here.** Include a caption.

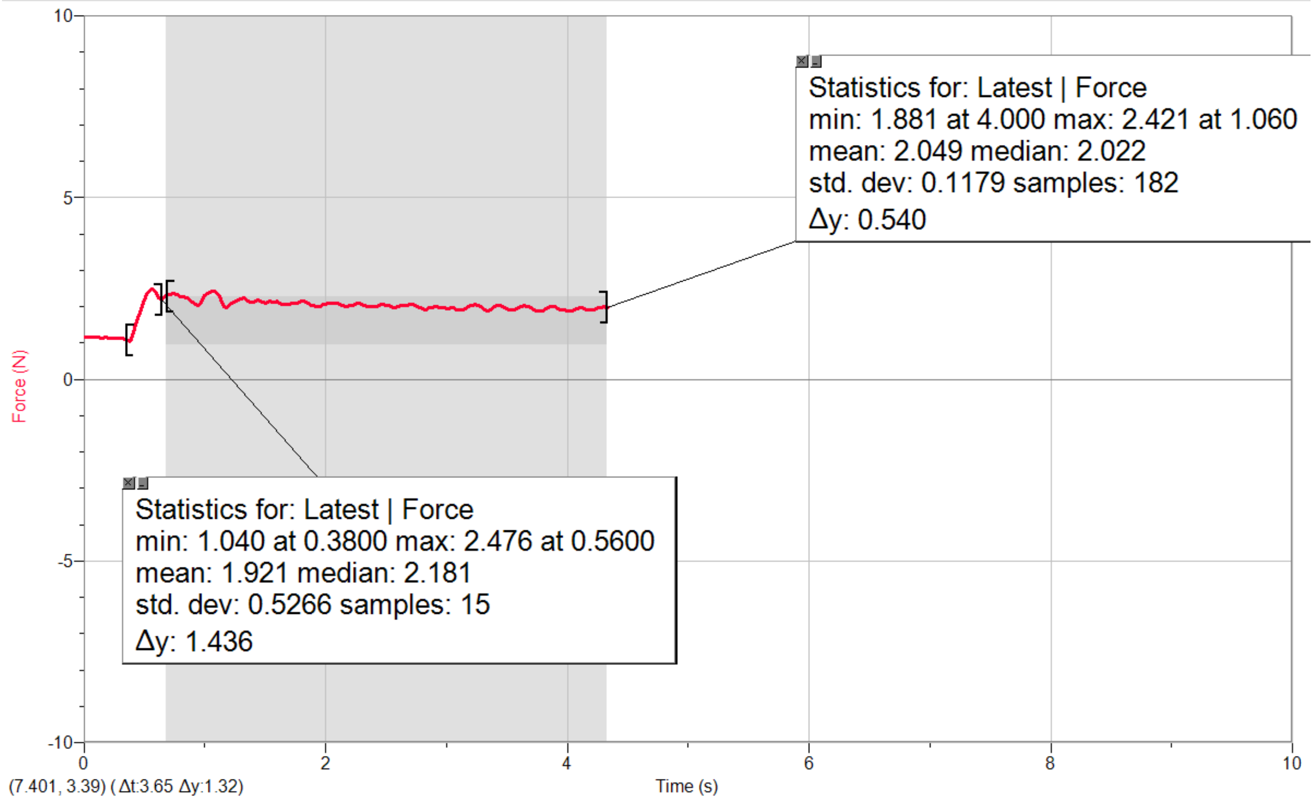


Figure 3 Large Area Large Mass LoggerPro Graph This graph represents the force (N) over time (s) it takes to pull a cart with a large high friction area being weighed down by a large (1kg) weight. This graph comes from the first out of 8 trials with these conditions. The max at the first peak represents $F_{fs\ max}$, the max static friction force. In this trial $F_{fs\ max}$ was 2.476N. This occurs right after the motorized cart is turned on before the block starts moving. The mean the remainder of the graph represents $F_{fk\ avg}$, the average kinetic friction force. In this trial $F_{fk\ avg}$ was 2.049N. This occurs when the motorized cart is pulling the block. Data collection was stopped before the motorized cart was turned off.

15. Calculate the two coefficients of friction for each trial separately. Take the average and standard deviation of the values of μ_s and μ_k for the eight measurements. Use the standard deviations as the uncertainties for the friction coefficients. (This analysis assumes that the uncertainties of the total mass and g are small and may be neglected.)

16. **Paste your table for part I here.** Include a caption.

Total mass (g)	Total mass (kg)	g (m/s^2)
1144.07	1.14407	9.803

Trial	$F_{sf\ max}$ (N)	μ_s	$F_{kf\ avg}$ (N)	μ_k
1	2.476	0.2208	2.049	0.1827
2	2.722	0.2427	1.987	0.1772
3	2.985	0.2662	2.006	0.1789
4	2.648	0.2361	2.175	0.1939
5	2.740	0.2443	1.998	0.1781
6	2.900	0.2586	1.967	0.1754
7	2.789	0.2487	2.041	0.1820
8	2.771	0.2471	2.035	0.1814
	average	0.2455	average	0.1812
	st. dev.	0.0137	st. dev.	0.0057

Table 1 Large Area Large Mass Table. 8 trials were performed with the large high friction side of the block facing the lab bench and a large mass of 1kg placed on the block. The total mass includes the mass of the block, 144.15g and the mass of the 1kg weight, 999.92g. $F_{sf\ max}$ and $F_{kf\ avg}$ values come from LoggerPro (Figure 3). μ_s and μ_k values were calculated using the equations derived above (Figure 2). The average represents the average of all 8 trials and the standard deviation represents the absolute uncertainty of our calculations.

Part II. Large Area and Small Mass

17. Repeat steps (11)-(13) with a 500 g mass on top of the block.

18. Save each of these LoggerPro files to your folder. **Paste one of the graphs here.** Include a caption.

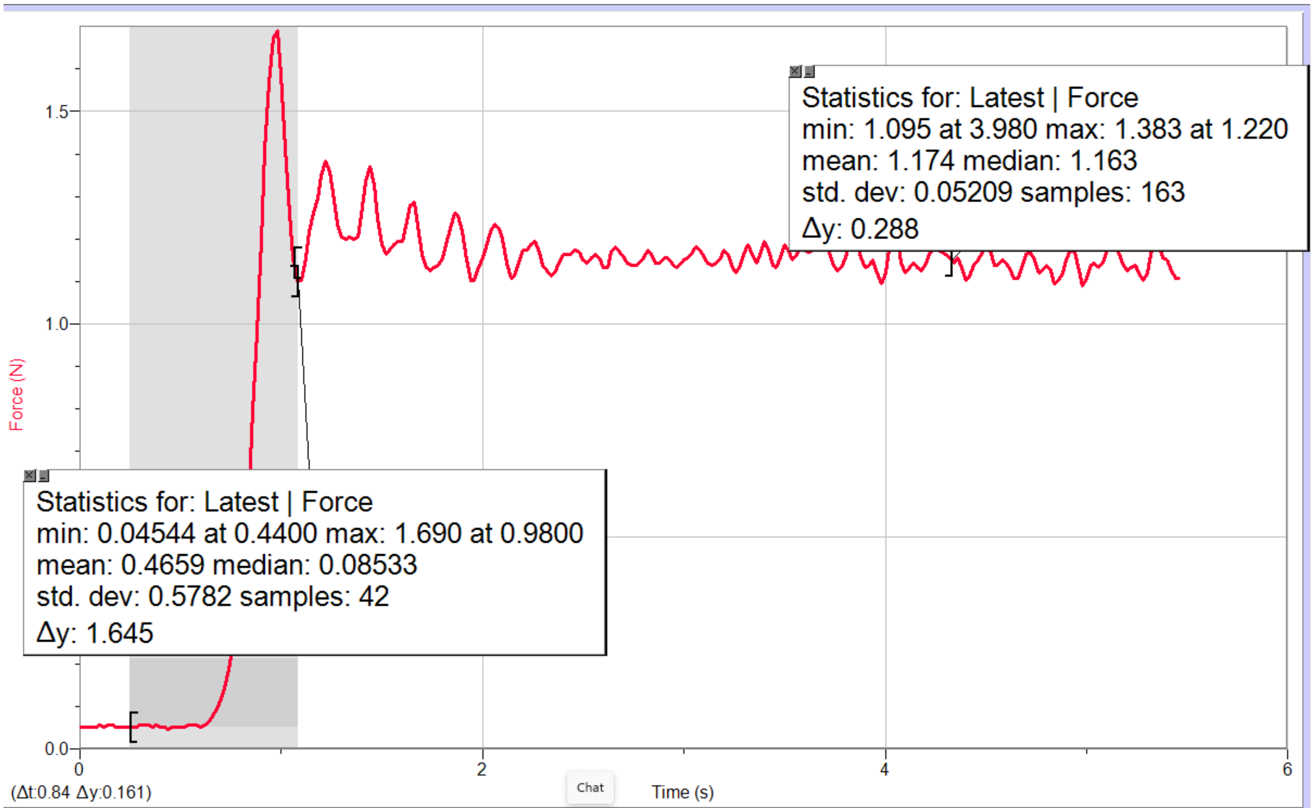


Figure 4. Large Area Small Mass LoggerPro Graph This graph represents the force (N) over time (s) it takes to pull a cart with a large high friction area being weighed down by a small (500g) weight. This graph comes from the 7th trial out of 8 trials with these conditions. The max at the first peak represents $F_{fs\ max}$, the max static friction force. In this trial $F_{fs\ max}$ was 1.690N. This occurs right after the motorized cart is turned on before the block starts moving. The mean the remainder of the graph represents $F_{fk\ avg}$, the average kinetic friction force. In this trial $F_{fk\ avg}$ was 1.174N. This occurs when the motorized cart is pulling the block. Data collection was stopped before the motorized cart was turned off.

19. **Paste your table for part II here.** Include a caption.

Total mass (g)	Total mass (kg)	g (m/s^2)
643.76	0.64376	9.803

Trial	$F_{sf\ max}$ (N)	μ_s	$F_{kf\ avg}$ (N)	μ_k
1	1.924	0.3049	1.173	0.1859
2	1.868	0.2960	1.215	0.1925
3	1.672	0.2649	1.169	0.1852
4	1.660	0.2630	1.158	0.1835
5	1.617	0.2562	1.153	0.1827
6	1.911	0.3028	1.157	0.1833
7	1.690	0.2678	1.174	0.1860
8	1.776	0.2814	1.155	0.1830
	average	0.2796	average	0.1853
	st. dev.	0.0194	st. dev.	0.0032

Table 2 Large Area Small Mass LoggerPro Graph. 8 trials were performed with the large high friction side of the block facing the lab bench and a small mass of 500g placed on the block. The total mass includes the mass of the block, 144.15g and the mass of the 1kg weight, 499.61g. $F_{sf\ max}$ and $F_{kf\ avg}$ values come from LoggerPro (Figure 4). μ_s and μ_k values were calculated using the equations derived above (Figure 2). The average represents the average of all 8 trials and the standard deviation represents the absolute uncertainty of our calculations.

Part III. Small Area and Large Mass

20. Repeat steps (11)-(13) with the narrow side of the block in contact with the board and the 1 kg mass on top of the block. You will need to readjust the height of the force sensor so that it is level with the hook on the block.

21. Save each of these LoggerPro files to your folder. **Paste one of the graphs here.** Include a caption.

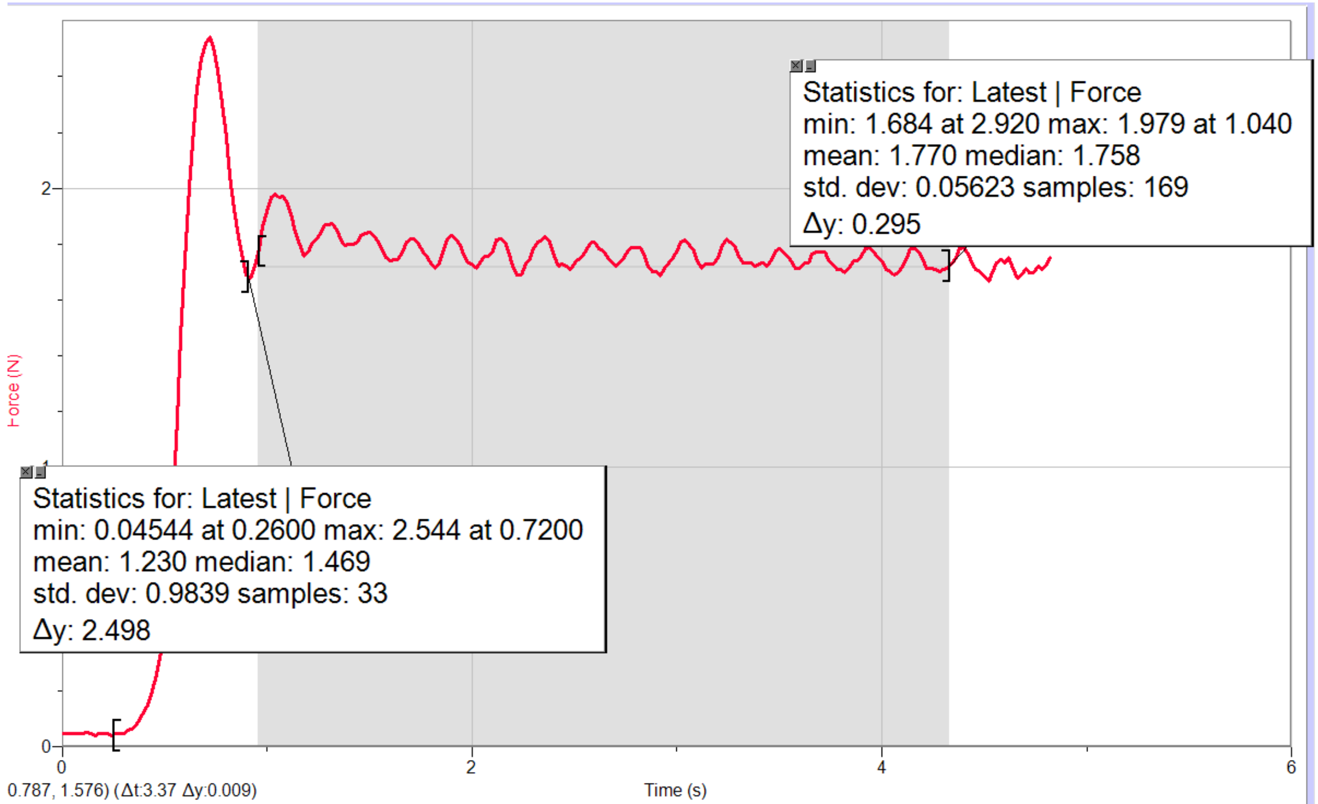


Figure 5. Small Area Small Mass LoggerPro Graph. This graph represents the force (N) over time (s) it takes to pull a cart with a small high friction area being weighed down by a large (1kg) weight. This graph comes from the 1st trial out of 8 trials with these conditions. The max at the first peak represents $F_{fs\ max}$, the max static friction force. In this trial $F_{fs\ max}$ was 2.544N. This occurs right after the motorized cart is turned on before the block starts moving. The mean the remainder of the graph represents $F_{fk\ avg}$, the average kinetic friction force. In this trial $F_{fk\ avg}$ was 1.770N. This occurs when the motorized cart is pulling the block. Data collection was stopped before the motorized cart was turned off.

22. **Paste your Excel table for part III here.** Include a caption.

Total mass (g)	Total mass (kg)	g (m/s^2)
1144.07	1.14407	9.803

Trial	$F_{sf\ max}$ (N)	μ_s	$F_{kf\ avg}$ (N)	μ_k
1	2.544	0.2268	1.770	0.1578
2	2.464	0.2197	1.804	0.1609
3	2.323	0.2071	1.789	0.1595
4	2.568	0.2290	1.797	0.1602
5	2.482	0.2213	1.800	0.1605
6	2.482	0.2213	1.773	0.1581
7	2.513	0.2241	1.770	0.1578
8	2.513	0.2241	1.787	0.1593
	average	0.2217	average	0.1593
	st. dev.	0.0066	st. dev.	0.0012

Table 3 Small Area Small Mass LoggerPro Graph. 8 trials were performed with the large high friction side of the block facing the lab bench and a large mass of 1kg placed on the block. The total mass includes the mass of the block, 144.15g and the mass of the 1kg weight, 999.92g. $F_{sf\ max}$ and $F_{kf\ avg}$ values come from LoggerPro (Figure 5). μ_s and μ_k values were calculated using the equations derived above (Figure 2). The average represents the average of all 8 trials and the standard deviation represents the absolute uncertainty of our calculations.

Part IV. Comparisons and data analysis

23. Table IV organizes all your coefficients and uncertainties into a single table.

a. Calculate the relative uncertainty of the two friction coefficients for each part.

b. Perform the ratio test to compare the coefficients found in part I to those found in part II.

c. Perform the ratio test to compare the coefficients found in part I to those found in part III.

d. Perform the ratio test to compare the kinetic and static coefficients found in part I.

24. **Paste your Excel table for part IV here.** Include a caption.

Part IV.
Comparisons

	Total mass (kg)	contact area	μ_s	absolute uncertainty of μ_s	relative uncertainty of μ_s
Part I	1.14407	Large	0.2455	0.0137	0.0559
Part II	0.64376	Large	0.2796	0.0194	0.0692
Part III	1.14407	Small	0.2217	0.0066	0.0299

	Total mass (kg)	contact area	μ_k	absolute uncertainty of μ_k	relative uncertainty of μ_k
Part I	1.14407	Large	0.1812	0.0057	0.0316
Part II	0.64376	Large	0.1853	0.0032	0.0173
Part III	1.14407	Small	0.1593	0.0012	0.0077

	μ_s	μ_k
Ratio test comparing Parts I and II	1.030	0.456
Ratio test comparing Parts I and III	1.173	3.152

Ratio test comparing μ_k and μ_s for Part I	3.307

Table 4 Calculation Table. This table combines data from all data tables above (Table 1, Table 2, Table 3). Part I had a large surface area and a large mass (1kg). Part II had a large surface area and a small mass (500g). Part III had a small surface area and a large mass (1kg). Ratio tests were performed to compare agreement of results. The absolute uncertainty comes from the standard deviation of the 8 trials in each part. The relative uncertainty was calculated using a known equation (Figure 2).

Excel functions:

AVERAGE() – get the average of a sample

STDEV.S() – get the standard deviation of a sample

25. **Write an analysis here.** Were there any aspects of the experiment that contributed significantly to random uncertainties or systematic errors?

The static friction(μ_s) was similar for all conditions. The kinetic friction (μ_k) was similar for both parts with a large surface but was much lower when the surface decreased. The kinetic friction changed easily in each trail depending on the start and end points. The points were hard to keep constant because they depend on when the motorized cart started moving relative to when data collection started.

26. **Write a brief conclusion here.** Our predictions state that the coefficient of friction does not depends on the mass or contact area. Does your data agree with this? The predictions state that the coefficient of kinetic friction is less than the coefficient of static friction. Do your results agree with this?

The coefficient of friction depends on the contact area but not the the mass of the object. This makes sense because the weigh force has vertical components while the friction for is horizontal (Figure 2). It may be interesting to try with a larger difference in weight as well. The max static friction is higher then the kinetic friction in all trails. The static friction must be overcome before the block starts moving but after it starts moving it is easier to keep it moving.

27. Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

28. Clean up your lab station. Put the equipment back where you found it. Make sure that you logout of Moodle and your email. Ensure that the laptop is plugged in.

29. Check with the lab instructor to make sure that they received your submission before you leave.