

Static and Kinetic Friction

Introduction:

Friction can be thought of as a force that opposes motion. It never pushes! When friction is strong enough to prevent an object from moving, we call it static friction. In this lab, you will measure the coefficients of friction between the block and a wooden board. To study how an inclined plane affects motion, you will draw force diagrams that relate gravity, friction, and the normal force.

Static friction has a maximum value – it can only hold back so much force. Frictional force is related to the normal force on an object by μ_s (the coefficient of static friction): $F_f \leq \mu_s N$. If an object is moving with frictional effects, we call this kinetic friction and use μ_k (the coefficient of kinetic friction). The relationship between kinetic friction and normal force is $F_f = \mu_k N$.

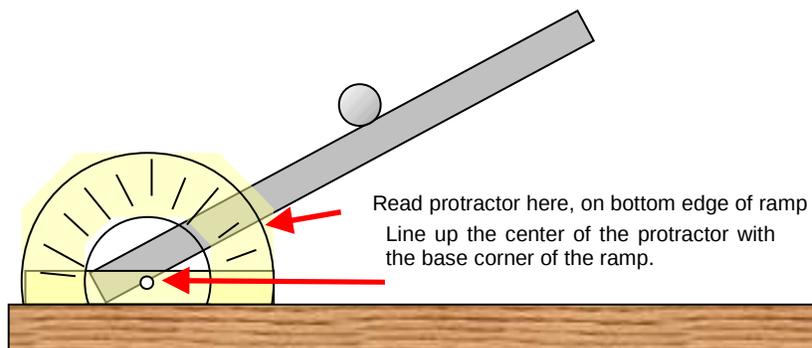
Study I: Using the worksheet (page 5) draw and label the force diagram for the block. Determine the relationship between μ_s and θ . Don't forget to find $\delta \mu_s$. **Have a TA check your work.**

Study II: Measuring Static Friction (μ_s).

Imagine pushing on a very heavy box. You can push quite hard without any movement at all. Then suddenly you reach the “break away” point and the box starts sliding.

1. Set up your inclined plane using the materials provided. Adjust your ramp so it is at a fairly small angle (the block shouldn't slide when set down).
2. Choose one side of your block for all measurements. Place the block on it and carefully lift until it begins to slide. Once you've got a rough idea of the angle, use a lab jack to do a fine adjustment and get the “just slipping” point. Use the blue tape to reduce random uncertainty.

3. Measure the sliding angle with the large wooden protractor. There are a few different types of protractors in lab and it is easy to misuse them and introduce a systematic uncertainty in your data. Get a lesson in protractor reading if necessary.



4. Repeat this measurement 5 times (remember to always use the same side of the block). If there are any obvious outliers in your data set, feel free to retake a measurement. This is a measurement with a lot of natural variation, so repeating this measurement 50 times would be appropriate (but not necessary).

Trial	1	2	3	4	5
θ					

5. Use Graphical Analysis to do a quick statistical analysis:
 - a. Make a Manual Column numbered 1-5, name it Index.
 - b. Make a second Manual Column, θ , and enter your five values
 - c. Plot Index vs. θ and hit the "STAT" button on the top bar. This will give you $\bar{\theta}$ and $\sigma(\theta)$
 - d. Calculate the standard deviation of the mean. Remember that the uncertainty: $\delta\theta = \sigma(\bar{\theta})$.
 - e. Don't bother to print the GA graph.

Average $\bar{\theta}$	Standard Deviation $\sigma(\theta)$	Standard Deviation of the Mean $\sigma(\bar{\theta}) = \sigma(\theta) / \sqrt{N}$

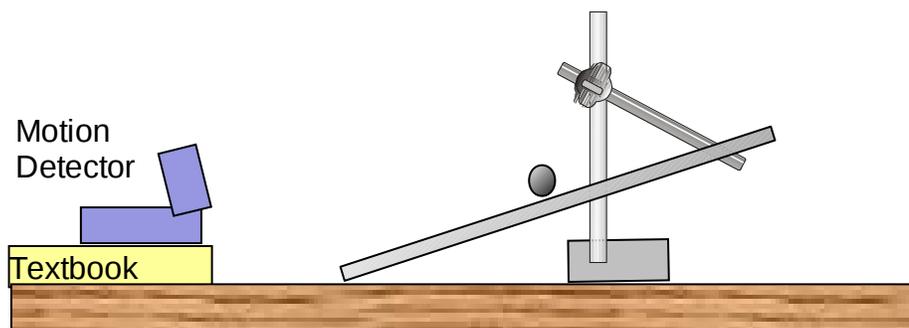
6. Using your formulas from Study I, calculate μ_s and $\delta\mu_s$ from $\bar{\theta}$ and $\delta\theta$. Use radians in your calculation of the uncertainty.

Study III: Measuring Kinetic Friction (qualitative)

1. If you were to repeat calculation for $\mu(\theta)$, this time to measure the kinetic friction on an object, what would change in the equations? What would remain the same?
2. If a block is sliding down a ramp, is $\Sigma F = 0$? Always? Sometimes? Never?
3. To measure μ_k , you want to eliminate any complications to make it as much like the static case as possible, i.e. when $\Sigma F = 0$. What is the acceleration of the block for this?
4. Lower your ramp a couple of degrees and set down the block. Does it slide? Play around with this a little. Your block will slide at angles less than the one you measured for the limit of static friction. Why?
5. Try to find the smallest angle the block slides down on its own (you may have to nudge it to overcome static friction). You will be surprised at how slowly the block moves when it isn't accelerating.

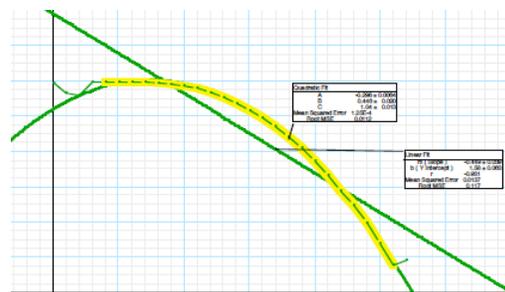
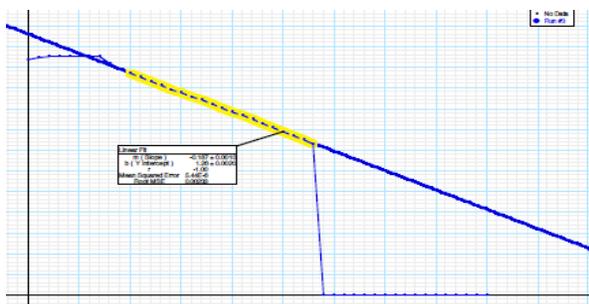
Study III: Measuring Kinetic Friction (quantitative)

6. You can check whether you've really gotten a constant velocity with a blue motion sensor. Set it at the base of the ramp on a textbook (to get a better measurement and protect the motion sensor). It should be plugged into a port on the blue **PowerLink** Pasco Sensor Box. Make sure the motion sensor is switched to the cart (not the walking figure). The switch is on the top of the sensor.



7. Open **DataStudio**. You should see a position vs. time graph and **Position (m)** icon in the **Data** box in the upper lefthand corner. You can collect data with the motion sensor by pressing **Start**. Once you've hit start, wave your hand back and forth in front of the sensor to make sure it is working.
8. Adjust the angle of the motion sensor to pick up things moving on the ramp. Use your hand moving up and down the ramp. Don't bother using the block until the sensor is picking up your hand.
9. Make a flag for your block out of an index card and some tape. This will allow the motion sensor to easily pick up the movement of the block.
10. The angle of the motion sensor will be sensitive. It is not uncommon for the sensor to be misaligned and not read the block. Be patient. You will have several data runs that are not usable. Delete any of these with **Experiment->Delete Last Data Run** or **Experiment->Delete ALL Data Runs**.

You're looking for a part of the motion that clearly shows the block sliding. Use the **Autoscale** button in the uppermost left corner of the graph. The zoom buttons will also be helpful. In the figures below, you can see examples of the motion sensor clearly detecting the motion for about 2 seconds. The left figure shows a constant velocity slide. The right figure shows a slide with acceleration.



11. Once the motion sensor is measuring the movement of the block down the ramp, keep adjusting the angle until you get a constant velocity. Check this with a linear fit in **DataStudio**: Use the drop down **"Fit"** menu at the top of the graph.

12. Once your position versus time graph is truly a straight line, you've got constant velocity! Record the equation of constant velocity from the **DataStudio** curve fit. You do not need to print the graph.

$$x(t) = \underline{\hspace{15cm}}$$

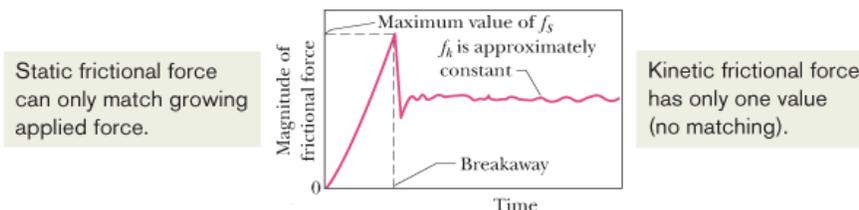
13. Measure the angle corresponding to constant velocity $\theta = \underline{\hspace{2cm}}$ +/- $\underline{\hspace{2cm}}$
Here $\delta\theta$ can be taken to be the uncertainty in reading the protractor.

14. Calculate $\mu_k = \underline{\hspace{2cm}}$ +/- $\underline{\hspace{2cm}}$. The formula is the same as μ_s , you'll need to explain why as you write up this lab. $\delta\mu_k$ can be calculated given θ and $\delta\theta$ (from #14)

Bonus Experiments: You must convincingly design an experiment and provide compelling (graphical) evidence to receive any bonus points for the following experiments. Furthermore, you must clearly explain the physics on the graph using appropriate labels (such as those in the figure below).

I: (5 points) Use two force sensors to prove Newton's 3rd Law.

II: (5 points) Use one force sensor and a heavy mass to study the transition from static to kinetic friction. You should see a figure that resembles the following from section 6-2 of Halliday, **Fundamentals of Physics**, 9e.



Before you leave the lab:

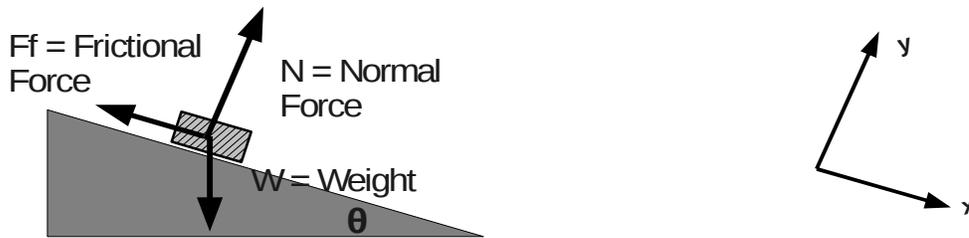
1. Calculation of μ_s and μ_k and their errors.
2. Completed **Study I** – this is important for your theory section.
3. Statistical Analysis for Study II.
4. Printed graphs from Bonus experiments.

Lab Report: For your report, you must explain the phenomena of static and kinetic friction. Clearly show all your calculations, especially your derivation of μ_s , and your error propagation calculation. Your work on the included sheets should be sufficient for this, but you should rewrite it if your calculations are hard to follow.

Discussion questions:

1. Explain why θ had a large spread of values in Study II.
2. Why did you only perform Study III once instead of 5 times? If you were to repeat the experiment, how would the spread in values of θ compare to those from Study II?
3. Compare the coefficients of kinetic and static friction – are they the same? Should they be? Why?
4. If you flipped the board (or block) over, would you expect to measure the same values for the coefficients of static and kinetic friction?

Study I: As demonstrated in class, develop a formula for $\mu_s(\theta)$ using free body diagrams. Draw a good force diagram showing the components of W in the x- and y-directions:



<p>1. Write down the weight in the x- and y-directions:</p> <p>$W_x =$</p> <p>$W_y =$</p>	<p>2. What are a_x and a_y? If $\Sigma F_x = ma_x$ and $\Sigma F_y = ma_y$, what are F_x and F_y?</p> <p>$a_x =$ $F_x =$</p> <p>$a_y =$ $F_y =$</p>
<p>3. Using the force diagram, sum the forces in terms of N, F_f, and W:</p> <p>$F_x =$</p> <p>$F_y =$</p>	
<p>4. Plug $F_f = \mu_s N$ in for the frictional force in the appropriate equation from box #3.</p>	<p>5. If you haven't yet, set F_x and F_y in box #3 to zero (from box #2).</p>

6. You should have two equations with two unknowns. Eliminate the normal force and solve for μ_s in terms of the angle θ symbolically. *Get a TA to check this before moving on to step #7!*

7. Calculate the uncertainty in μ_s (you should have an answer with $\bar{\theta}$ and $\delta\theta$). Here's how: You've solved for μ_s in terms of a variable θ , so μ_s is a function of θ , or simply put $\mu_s(\theta) = f(\theta)$. The general formula for the uncertainty is

$$X = f(A), \text{ then } \delta X = \left. \frac{df}{dA} \right|_{A_0} \delta A$$

Where $\left. \frac{df}{dA} \right|_{A_0}$ means take the derivative and afterwards plug in A_0 . This translates to:

$$\text{If } \mu = f(\theta), \text{ then } \delta \mu = \left. \frac{df}{d\theta} \right|_{\bar{\theta}} \delta \theta$$

So to get a general expression for $\delta \mu_s$, take a derivative. After you take your measurements, you can plug in $\bar{\theta}$ and $\delta\theta$. One more big hint: μ_s is a dimensionless quantity. Use radians (NOT degrees) to calculate the uncertainty.