5.11: Friction

Name: ____________________________________

Date: ____________________

Partners:____

Equipment

• *LabPro* Interface • Motion detector • Force sensor • *Force* software file	• Wooden tracks • Wooden block • Hanging masses

Introduction

The sliding friction between two surfaces is characterized by a single number, the *coefficient of friction*. The coefficient of friction depends on the materials used—for example, ice on metal has a very low coefficient of friction while rubber on pavement has a very high coefficient of friction.

In the standard model of sliding friction, the frictional force is given by the product of the coefficient and the contact force between the two surfaces. In this model, the relative speed between the surfaces and the contact area between the surfaces have no effect on the frictional force. The coefficient of friction is strictly an empirical measurement (i.e., it has to be measured experimentally) and cannot be found through calculations.

I. Static vs. Kinetic Friction

Open the file *Force*. Replace the acceleration graph with a velocity graph.

Set the force sensor to the ±50 N setting and calibrate it using a 1.0 kg mass.

You are going to use the force sensor to pull a wooden block along the track as shown below.

Zero the force sensor with the string slack. Press **Collect** and then very slowly increase the force you apply to the block. It is very important for you to very slowly increase the force, especially in the moments prior to movement of the block. Once the block begins to slide, maintain a constant force on the block in order to keep the block sliding with constant velocity. Repeat the data collection until you feel you have clean data illustrating both the "release" of the block and the motion at constant speed.

Question: Your force vs. time graph should show a clear drop in force when the block first moves. Clearly explain why the force decreases when the block first moves.

Use **Analyze/Statistics** to determine the mean force when the block is moving at constant speed.

Use **Analyze/Examine** to determine the peak force at the moment the block begins to move.

Record your results below and print your graph with the relevant statistics and data displayed. Make sure your velocity graph clearly indicates constant velocity. Attach your graph to the end of this activity.

To get a reasonable idea of the uncertainty involved in these measurements, repeat each trial three times and complete the following tables. (You do not need to record the uncertainty in each individual measurement.) Each of the three trials must be a clean run! If you cannot clearly see the decrease in force, repeat the measurement.

Measure the mass of your wooden block. Record it below.

mass of wooden block, m_{block} = ____________ kg

System	**$F_{surface}$ (N)**	**Force at Impending Motion (N)**			
		Trial 1	**Trial 2**	**Trial 3**	**Average**

block + 4.0 kg					±
block + 3.0 kg					±
block + 2.0 kg					±
block + 1.0 kg					±

System	**$F_{surface}$ (N)**	**Force at Constant Speed (N)**			
		Trial 1	**Trial 2**	**Trial 3**	**Average**
block + 4.0 kg					±
block + 3.0 kg					±
block + 2.0 kg					±
block + 1.0 kg					±

Question: At the instant of impending motion, how does the force measured by the force sensor compare to the maximum possible static frictional force? Explain.

Question: When the block moves at constant speed, how does the force measured by the force sensor compare to the kinetic frictional force? Explain.

Create a graph, with error bars, of Maximum Static Friction vs. Surface Force. Based on your data, select an appropriate best-fit function (**Analyze/Linear Fit** or **Curve Fit**) and display it on your graph. Remember, a best-fit function should be the *simplest possible function* that accurately matches your data.

Finish preparing your graph, then print and attach it to the end of this activity.

Question: Record each constant in your best-fit function below. Each numerical value must have both uncertainties and units.

Question: What is the physical meaning of each of the numerical constants in your best-fit function? Explain.

Create a graph of Kinetic Friction vs. Surface Force. Include appropriate error bars and create a best-fit function to your data. Print your graph and attach it to the end of this activity.

Question: Record each constant in your best-fit function below. Each numerical value must have both uncertainties and units.

Question: What is the physical meaning of each of the numerical constants in your best-fit function? Explain.

II. Kinetic Friction, Again

Since frictional coefficients can only be measured experimentally, it's not possible to compare a measured value to a "theoretical" result. Typically, an independent measurement of the coefficient by a different method can be used to corroborate the initial result.

For this activity, the force needed to pull the block up an incline at constant speed will be compared to the force needed to lower the block down the same incline at constant speed. These measurements can be used to determine the kinetic frictional force acting on the block, and hence the coefficient of kinetic friction between the block and the incline.

Question: Draw a free-body diagram for a block of mass m being pulled up an incline θ at constant speed by a force $F_{pulledup}$. Apply Newton's Second Law in the direction parallel to the incline. (Label the frictional force F_{kf} and do not include in your equation.)

Question: Draw a free-body diagram for a block of mass m being lowered down an incline θ at constant speed by a force $F_{lowereddown}$. Apply Newton's Second Law in the direction parallel to the incline. (Label the frictional force F_{kf} and do not include in your equation.)

Question: Combine your two equations above into a single equation for F_{kf} involving only $F_{pulledup}$ and $F_{lowereddown}$. Using this equation, the kinetic friction force can be determined by measuring $F_{pulledup}$ and $F_{lowereddown}$.

Place 1.0 kg on the block and set the incline to 20°.

Carefully pull the block up the incline at constant speed. Repeat this measurement three times and then carefully lower the block down the same incline at constant speed. Complete the tables below. Note that you are *not* trying to determine the maximum static frictional force in this activity.

Incline (°)	**$F_{pulledup}$ (N)**			
	Trial 1	**Trial 2**	**Trial 3**	**Average**
20				±
30				±
40				±
50				±
60				±
70				±

Incline (°)	**$F_{lowereddown}$ (N)**			
	Trial 1	**Trial 2**	**Trial 3**	**Average**
20				±
30				±
40				±
50				±
60				±
70				±

Question: Based on your free-body diagrams above, apply Newton's Second Law in the direction perpendicular to the incline and determine the surface force between the block and the incline.

Using the results derived above, complete the following table.

Incline (°)	**Kinetic Friction Force (N)**	**Surface Force (N)**
20	±	
30	±	
40	±	
50	±	

60	±	
70	±	

Create a graph of Kinetic Friction vs. Surface Force. Include appropriate error bars and create a best-fit function to your data. Print your graph and attach it to the end of this activity.

Question: Record each constant in your best-fit function below. Each numerical value must have both uncertainties and units.

Question: What is the physical meaning of each of the numerical constants in your best-fit function? Compare these values to those determined earlier.

III. Static Friction, Again

Just as for kinetic friction, you need a measurement of the coefficient of static friction by a different method to corroborate your initial result.

To do this, you will place the block at rest on the horizontal wooden track. As you slowly increase the incline of the track, you will reach a point at which the block begins to slide down the incline. Carefully measuring this *angle of slippage* will allow you to determine the coefficient of static friction.

Question: Draw a free-body diagram for a block of mass m that is *almost* slipping down an incline θ. Apply Newton's Second Law in the direction parallel to the incline. (Since the block is almost slipping, the static friction force is at its maximum value. Use this fact to express the static frictional force in terms of the surface force.)

Question: Apply Newton's Second Law in the direction perpendicular to the incline to determine an expression for the surface force.

Question: Substitute your expression for the surface force into your original expression and solve for the coefficient of static friction in terms of the angle at which the block is almost slipping down the incline. Using this equation, the coefficient of friction can be determined by carefully measuring this angle.

Place the block on the horizontal wooden track. Slowly and carefully increase the angle of the track until the block just begins to slide. Record the angle at which the block begins to slide and complete the table below.

Angle of Slippage					
Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Average**
					±

Question: Using the equation you derived above, use your data to determine the coefficient of static friction, with uncertainty. Compare this value to the value determined earlier.