## *Physics I – Lab #5*

# Part I – Static and Kinetic Friction

If you try to slide a heavy box resting on the floor, you may find it difficult to get the box moving. *Static friction* is the force that is counters your force on the box. If you apply a light horizontal push that does not move the box, the static friction force is also small and directly opposite to your push. If you push harder, the friction force increases to match the magnitude of your push. There is a limit to the magnitude of static friction, so eventually you may be able to apply a force larger than the maximum static force, and the box will move. The maximum static friction force is sometimes referred to as *starting friction.* We model static friction, $F_{static}$, with the inequality $F_{static} \leq \mu_s N$ where $\mu_s$ is the coefficient of static friction and $N$ the *normal* force exerted by a surface on the object. The normal force is defined as the perpendicular component of the force exerted by the surface. In this case, the normal force is equal to the weight of the object.

Once the box starts to slide, you must continue to exert a force to keep the object moving, or friction will slow it to a stop. The friction acting on the box while it is moving is called *kinetic friction.* In order to slide the box with a constant velocity, a force equivalent to the force of kinetic friction must be applied. Kinetic friction is sometimes referred to as *sliding friction.* Both static and kinetic friction depend on the surfaces of the box and the floor, and on how hard the box and floor are pressed together. We model kinetic friction with $F_{kinetic} = \mu_k N$, where $\mu_k$ is the coefficient of kinetic friction.
In this experiment, you will use a Force Sensor to study static friction and kinetic friction on a wooden sled. A Motion Detector will also be used to analyze the kinetic friction acting on a sliding sled.

### PRELIMINARY QUESTIONS

1. In pushing a heavy box across the floor, is the force you need to apply to start the box moving greater than, less than, or the same as the force needed to keep the box moving? On what are you basing your choice?

2. How do you think the force of friction is related to the weight of the box? Explain.

### PROCEDURE

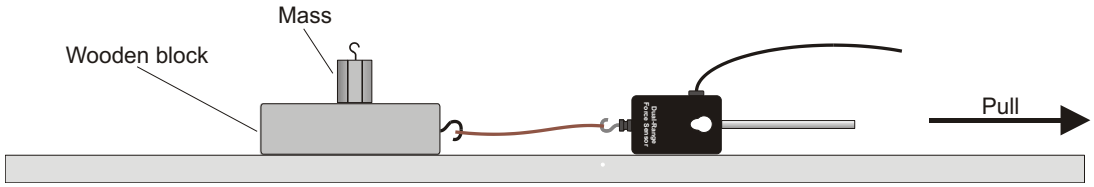
### Part I Starting Friction

1. Measure the mass of the sled and record it in the data table.

2. Connect the Dual-Range Force Sensor to Channel 1 of the interface. Set the range switch on the Force Sensor to 50 N.

3. Open the file "12a Static Kinetic Frict" from the *Physics with Vernier* folder.

4. Tie one end of a string to the hook on the Force Sensor and the other end to the hook on the wooden "sled". Place a total of 1 kg mass on top of the sled, fastened so the masses cannot shift. Practice pulling the sled and masses with the Force Sensor using this straight-line motion: Slowly and gently pull horizontally with a small force. Very gradually, taking one full second, increase the force until the sled starts to slide, and then keep the sled moving at a constant speed for another second.




5. Sketch a graph of force *vs.* time for the force you felt on your hand. Label the portion of the graph corresponding to the sled at rest, the time when the sled just started to move, and the time when the sled was moving at constant speed.

6. Hold the Force Sensor in position, ready to pull the sled, but with no tension in the string. Click Zero to set the Force Sensor to zero.

7. Click Collect to begin collecting data. Pull the sled as before, taking care to increase the force gradually. Repeat the process as needed until you have a graph that reflects the desired motion, including pulling the sled at constant speed once it begins moving. Print or copy the graph for use in the Analysis portion of this activity.

### Part II Peak Static Friction and Kinetic Friction

In this section, you will measure the peak static friction force and the kinetic friction force as a function of the normal force on the sled. In each run, you will pull the sled as before, but by changing the masses on the sled, you will vary the normal force on the sled.

8. Remove all masses from the sled.

9. Click Collect to begin collecting data and pull as before to gather force *vs.* time data.

10. Examine the data by clicking the Statistics button, STAT. The maximum value of the force occurs when the sled started to slide. Read this value of the *maximum* force of static friction from the floating box and record the number in your data table.

11. Drag across the region of the graph corresponding to the sled moving at constant velocity. Click on the Statistics button again and read the average (or mean) force during the time interval. This force is the magnitude of the kinetic frictional force.

12. Repeat Steps 9-11 for two more measurements and average the results to determine the reliability of your measurements. Record the values in the data table.

13. Add masses totaling 250 g to the sled. Repeat Steps 9–12, recording values in the data table.

14. Repeat for additional masses of 500, 750, and 1000 g. Record values in your data table.

## ANALYSIS

1. Inspect the printout or sketch of force *vs.* time graph from Part I. Label the portion of the graph corresponding to the sled at rest, the time when the sled just started to move, and the time when the sled was moving at constant speed.

2. Still using the force *vs.* time graph you created in Part I, compare the force necessary to keep the sled sliding compared to the force necessary to start the slide. How does your answer compare to your answer to question 1 in the Preliminary Questions section?

3. The *coefficient of friction* is a constant that relates the normal force between two objects (sleds and table) and the force of friction. Based on your graph (Run 1) from Part I, would you expect the coefficient of static friction to be greater than, less than, or the same as the coefficient of kinetic friction?

4. For Part II, calculate the *normal force* of the table on the sled alone and with each combination of added masses. Since the sled is on a horizontal surface, the normal force will be equal in magnitude and opposite in direction to the weight of the sled and any masses it carries. Fill in the Normal Force entries for both Part II data tables.

5. Plot a graph of the maximum static friction force (vertical axis) *vs*. the normal force (horizontal axis). Use either Logger *Pro* or graph paper.

6. Since $F_{maximum\ static} = \mu_s N$, the slope of this graph is the coefficient of static friction $\mu_s$. Find the numeric value of the slope, including any units. Should a line fitted to these data pass through the origin?

7. In a similar graphical manner, find the coefficient of kinetic friction $\mu_k$. Create a plot of the average kinetic friction forces *vs.* the normal force. Recall that $F_{kinetic} = \mu_k N$. Should a line fitted to these data pass through the origin?

8. Draw a free body diagram of the sled with the masses on it as it pulled. Which forces need to be equal to each other over different parts of the experiement?

# DATA TABLE

### Part I Starting Friction

| | |
|---|---|
| Mass of sled | kg |

### Part II Peak Static Friction and Kinetic Friction

| Total mass (m) | Normal force (N) | Peak static friction | | | Average peak static friction (N) |
|---|---|---|---|---|---|
| | | Trial 1 | Trial 2 | Trial 3 | |
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| | | | | | |
| | | | | | |

| Total mass (m) | Normal force (N) | Kinetic friction | | | Average kinetic friction (N) |
|---|---|---|---|---|---|
| | | Trial 1 | Trial 2 | Trial 3 | |
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# Part II: Modified Atwood Machine

## Introduction

In your discussion of Newton's first law, you learned that when the sum of the forces acting on an object is zero, its velocity does not change. However, when a net force acts on the object, it accelerates. In this experiment, you will determine the relationship between the net force acting on an object and its acceleration.

For this experiment, you will use a "modified Atwood's machine." A weight is connected to a cart by a string over a pulley. When the weight is allowed to fall, you will observe the motion of the cart. A force sensor mounted on the cart will enable you to measure the force acting on the cart when it is moving.

## OBJECTIVES

In this experiment, you will

- Identify the forces acting on an object both when its change in velocity, $\Delta v$, is zero and when it is accelerating.
- Collect force, velocity, and time data as a cart is accelerated on a track.
- Use graphical methods to determine the acceleration of the cart.
- Determine the relationship between the cart's acceleration and the net force applied to it.
- Determine the effect of the mass on the relationship between acceleration and force.

## MATERIALS

| | |
|---|---|
| Vernier data-collection interface | Hooked mass set |
| Logger *Pro* or LabQuest App | Vernier Dynamics Track |
| Dual-Range Force Sensor | standard cart |
| Vernier Photogate and Bracket | Ultra Pulley and Pulley Bracket |

## PRELIMINARY QUESTIONS

1. Predict how does the acceleration of the cart will vary as the force applied to the cart increases.

2. In your notebooks, draw a sketch of the acceleration *vs.* net force graph based on your predictions.

## PART A: FLAT TRACK

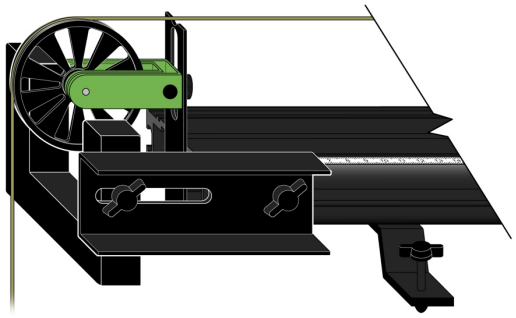
## PROCEDURE

1. Attach an Ultra Pulley to the Pulley Bracket; attach this assembly to one end of the Dynamics Track. Make sure that you have adjusted the track to make frictional forces negligible.

2. Connect the Dual-Range Force Sensor (DFS) and a Photogate to the interface; then start Logger Pro. You will need only graphs of force *vs.* time and velocity *vs*. time, so you can delete others and then re-size graphs to make them easier to see.

3. Attach the force sensor to the cart.

4. Attach the photogate to the track using a bracket so that the spokes on the pulley interrupt the beam, as shown in Figure 2.



5. Select a range of masses to use to apply the force that will accelerate the cart. Determine the total mass of your cart, force sensor, and any additional mass you may use.

6. Set up data collection.
    a. Choose Set Up Sensors ► Show All Interfaces from the Experiment menu.
    b. Click the image of the Photogate, select Set Distance or Length, then select Ultra Pulley (10 Spoke) Inside from the list of devices.
    c. It may be helpful to shorten the time interval of data collection – from the "Experiment" menu select "Data Collection"; you can change the time interval to 3 or 4 seconds. You may find it helpful to modify this several times to optimize your experiment.
    d. You may also find it helpful to delete the position graph and expand the other three graphs on the screen.

7. Disconnect the hanging mass from the force sensor, then zero the sensor from the "Set-Up-Sensors" interface.

8. Re-connect the hanging mass to the force sensor. Position the cart so that the hanger has about 30 cm to fall. Use something to cushion the hanging weight when it strikes the floor.

9. Begin collecting data, then release the cart. Stop data collection after the weight hits the cushion on the floor.

10. To determine the force acting on the cart, select the portion of the force *vs*. time graph corresponding to the interval during which the cart's velocity was changing smoothly. Find the statistics for this interval. Manual scaling of your graph is more helpful for doing this than Autoscaling.

11. To determine the acceleration of the cart, perform a linear fit on the portion of the velocity-time graph during which the velocity is changing smoothly. Be sure to record the values of force and acceleration for this hanging mass in your lab notebook.

12. Repeat Steps 9–11 until you have three pairs of force *vs*. acceleration data that are reasonably consistent for that mass.

13. Increase the hanging mass and continue until you have acceleration-force data for at least five different hanging masses.

## EVALUATION OF DATA

1. To evaluate the relationship between acceleration and force, disconnect the sensors and choose New from the File menu.

2. Even though you investigated how acceleration responded to changes in the force, in order to facilitate your analysis of data, plot a graph of force *vs.* acceleration.

3. If the relationship between force and acceleration appears to be linear, fit a straight line to your data. Print a copy of your data table and graph.

4. Write the equation that represents the relationship between the force, *F,* acting on the cart and the cart's acceleration, *a*. Be sure to record the value of the mass of the cart, sensor and any additional masses you used.

5. Write a statement that describes the relationship between the force acting on the cart and the cart's acceleration.

6. Compare your results to those obtained by others in class. What relationship appears to exist between the slope of the graph of *F vs. a* and the mass that was accelerated?

7. Assuming that the conclusion you reached in Step 6 is correct, express the SI unit of force, N, in terms of the fundamental units of mass, length and time.

8. Why does the force measured by the force sensor drop when you release the cart?

## PART B: MODIFIED MODIFIED ATWOOD MACHINE (WITH FRICTION!)

1. Repeat the experiment again but, instead of hooking up the end of the string to a cart on the track, hook it up to the wooden "sled" resting on your lab bench (you will have to re-configure the pulley/photogate setup to get this to work).

2. Slowly add masses to the "hanging" side of the pulley until the sled *just* starts to move. What is the mass ratio of the mass on the "hanging" side of the pulley to the total mass on the "sled" side (make sure to count the mass of the sled itself when calculating the mass on the "sled" side)? What physical quantity should this ratio be? Comment.

3. Next, conduct a series of experiments where you run the sled along the surface of the lab bench with a variety of weights on the "sled."

4. Use an experimental procedure with a force balance calculation to determine the coefficient of kinetic friction between your "sled" and the lab bench. How does this compare with the coefficient of kinetic friction you determined in the first experiment today?