Name:

Lab Section Number:

Pre-Lab Questions:

1. What type of data will we be using to determine the acceleration of the cart up and down the ramp this week? What type of fit will we be performing on this data?

2. How will we adjust our fitting procedure to compensate for fact that the acceleration differs depending on the direction of motion?

3. Draw the free-body diagram for an object of mass $m$ with coefficient of kinetic friction $\mu_k$ sliding down a ramp inclined by an angle $\Theta$.

4. Draw the free-body diagram for an object of mass $m$ with coefficient of kinetic friction $\mu_k$ sliding up a ramp inclined by an angle $\Theta$. 
The Coefficient of Kinetic Friction

Materials:
Science Workshop interface
Dynamics Track and Cart
Friction Boxes
Motion Sensor
Bubble Levels
Wood Blocks
Masses
Balance (500 grams +)
Meterstick

The purpose of this experiment is to begin our treatment of friction. This week we will explore kinetic friction, which is the friction between two surfaces that slide upon each other. You will do this by measuring the acceleration due to a constant net force while using an inclined plane, the motion sensor, and a dynamics cart. Remember, you will be graded on all bold-faced items.

1. Setting up the equipment.
   1.1 Connect the Science Workshop interface to the computer and the Motion Sensor to the interface. Use the Create Experiment option and configure it to collect Position and Velocity data at a trigger rate of 50. (Detailed instructions regarding this were included in the previous laboratory handout.)
   1.2 Under the display window on the lower left, select the type of display you would like. For this experiment we will select “graph” we will be primarily interested in Velocity data, although you are free to include the Position data if you wish.

2. Measuring the displacement
   Note: these first few steps are similar to the last lab activity. It is important to determine a base-line acceleration before the friction carts are attached.
   2.1 Level the track, and adjust the angle of the track as you did during the last experiment (three or four blocks of height should be sufficient).
   2.2 Calculate the above angle, as well as its sine and cosine.
   2.3 Connect the motion sensor to the end of the track without the bumper, which will be the higher end of the track.
   2.4 Place the cart on the low end of the track and practice pushing and releasing the cart so that it moves up the track and does not get closer than 20 cm to the motion sensor.
   2.5 Press the Start button in DataStudio and then push the cart up the track. Let the cart move up the track and then back down. Stop recording once the cart has returned to its initial position.
2.5.1 Your position-time graph should resemble one bounce of the bouncing ball experiment. Your velocity-time graph should contain a straight line of constant slope.

2.5.2 If the position-time plot is not smooth, check the alignment of the motion sensor and retake data. There may be some jitter in the lines on the velocity-time graph. This should not interfere with the quality of your results.

2.5.3 Re-scale the graph as necessary to provide a good picture of the motion. Note: Review the data manipulation section 3 before proceeding.

2.5.4 Perform a linear fit on the data in the velocity-time graph that corresponds to the constantly accelerating graph to obtain the baseline acceleration for this cart. The slope of this line will be the measured value \( g \sin(\theta) \) in the formulas below. This value might differ from the expected value for \( g \sin(\theta) \).

2.6 Print the velocity-time graph you used to obtain your baseline acceleration. Make sure it has the trend-line, along with the fit parameters, as well as proper labels and titles.

2.7 Calculate the value you obtain for \( g \) in this case.

2.8 What is the percent difference from the expected value?

2.9 Perform the same experiment with the friction box attached to the dynamics cart as was performed with the dynamics cart alone.

2.9.1 Find the mass of both the cart and the friction boxes.

2.9.2 Attach the friction box with the plastic bottom to the rear of the cart.

2.9.3 Start taking data by pressing the start button and push the cart and friction box up the incline twice. You will see a graph similar to the ones below.

2.9.4 You will notice that the velocity-time graph contains areas of constant slope, but that the slope changes when the cart reaches its maximum height. This indicates that the acceleration of the system for the case of the cart moving up the ramp differs from the case of the cart moving down the ramp. As such you will need to perform two linear fits for each trial, one on either side of the break in the line. You will need to perform a total of four fits for each velocity-time graph you collect.

2.9.5 Why does the acceleration differ between the upward moving and downward moving cases?

Fit for carts moving up the plane
Fit for carts moving down the plane

For carts moving up the plane

\[ \mu_k = \frac{(m_i + m_z)}{m_z} \left[ \frac{a_y - g \sin(\Theta)}{g \cos(\Theta)} \right] \]

For carts moving down the plane

\[ \mu_k = \frac{(m_i + m_z)}{m_z} \left[ \frac{g \sin(\Theta) - a_y}{g \cos(\Theta)} \right] \]

2.9.6 Repeat the two trials for the following combinations of masses on the dynamics cart and in the friction box. Where the box contains no black masses, place approximately 100 grams into the box so that it comes in complete contact with the ramp:
- Black Masses in Cart: 1
- Black Masses in Friction Box: 0 (plus ~100 grams)
- Black Masses in Cart: 1
- Black Masses in Friction Box: 1

Make sure the mass on the cart is not on top of the friction box.

2.9.7 Print one fitted velocity-time graph for each different material for the case of one mass in the box.

Note: In order to determine the kinetic coefficient of friction for each system, you will need to perform a separate calculation for each change in the mass.

2.9.8 Repeat this experiment using both the cork friction box and the felt friction box.

You will need three different graphs at the end of this experiment (the one mentioned by step 2.9.7) for the case of a plastic-bottomed, felt-bottomed, and cork-bottomed friction box.

3. Data manipulation

3.1 On the velocity versus time graph: Using the mouse, highlight the data you would like to "fit". Keep in mind that you should have a different acceleration when the cart is moving up versus when the cart is moving down the plane, so you will need to fit each constantly sloping line separately. You will have greater success fitting the line if your selected data doesn’t include the breaks in the slope.

3.2 Select the Curve Fit button from the main toolbar and then select the quadratic fit button. From the pull down menu select Linear.

3.3 Data studio will determine the linear equation that best fits the data you have taken. The data studio will then supply the slope and the y-intercept the equation. One will represent the acceleration and the other the initial velocity for the portion of the line you selected.

When you’ve completed this experiment, you could have as many as twenty-four values for the acceleration of the cart. (Two for the trip up the ramp and two for the trip down the ramp for each combination of masses.) As such, we need a way to automate the calculation of the coefficient of kinetic friction. Although it is recommended that you learn to enter a formula in Excel (or another convenient spreadsheet) prior to coming to
The Coefficient of Kinetic Friction

lab, your lab instructor can show you how to do so. There is a copy of Excel on most University-owned computers on campus for you to practice on. As a summary, if you wish to enter a formula that uses the value at a certain cell on the spreadsheet, simply refer to that cell by its address (A4, B5, etc.) and multiply or divide it as you would any other number. Using a spreadsheet will make performing the repeated \( \mu_k \) calculations much quicker and easier. If you use a spreadsheet to perform repeated calculations, you must ensure that you print the spreadsheet along with the formulas in the form you entered them into the computer that you used for each set of calculations. (e.g., “=((A3+B3)/B3)\times\sin(D3))” But be careful, if the cart stops moving, you won't be measuring the coefficient of kinetic friction anymore!

3.4 Be sure to print your final spreadsheet of results.

Note: This is only an example spreadsheet, and only includes the calculations for the plastic box. You will need to include both the felt-bottomed and cork-bottomed friction box trials in the spreadsheet you hand in.

Questions to be addressed in your conclusion:

1) Perform one hand-calculation for the coefficient of friction using your measured acceleration due to gravity and the measured acceleration of the cart for the case of the system moving up the ramp. (You may write the answer to this question by hand if you wish.)
2) Repeat the above hand-calculation for the case of the cart moving down the ramp. (You may write the answer to this question by hand if you wish.)

3) Derive the formula that you used to calculate $\mu_k$ while the cart is moving up the ramp. (You may write the answer to this question by hand if you wish.)

4) Derive the formula that you used to calculate $\mu_k$ while the cart is moving down the ramp. (You may write the answer to this question by hand if you wish.)

5) What difficulties arise when the normal force on the friction box becomes larger than $(m_1+m_2)g\sin(\Theta)/\mu_k$?

6) What could you have done to avoid this problem?

7) Does the coefficient of kinetic friction seem to depend on the mass in the friction box? The direction of motion? Attempt to provide a physical justification for each.