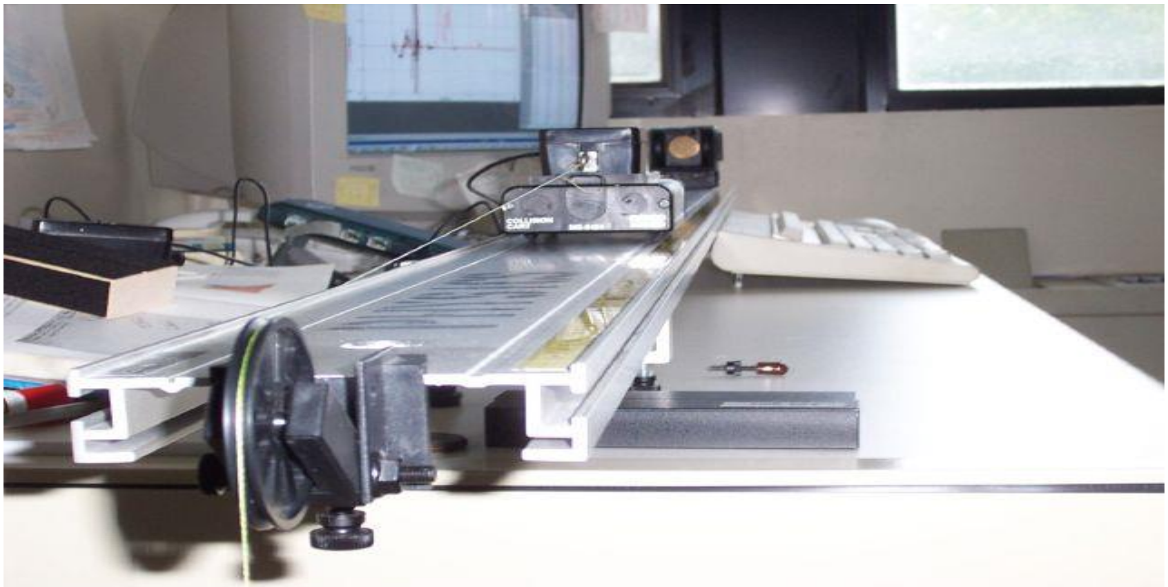
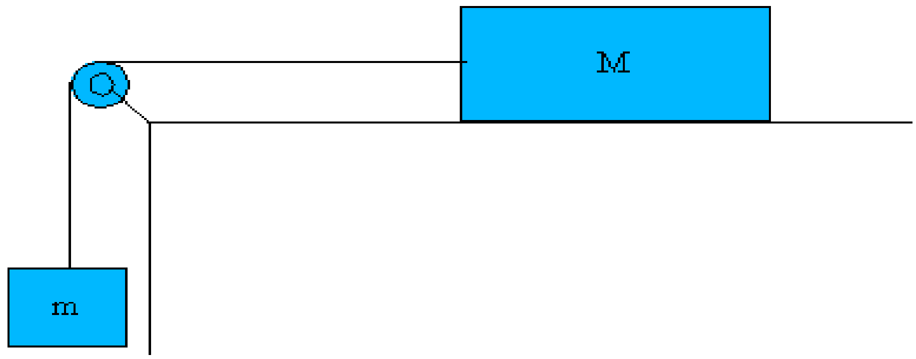
Newton's Laws II



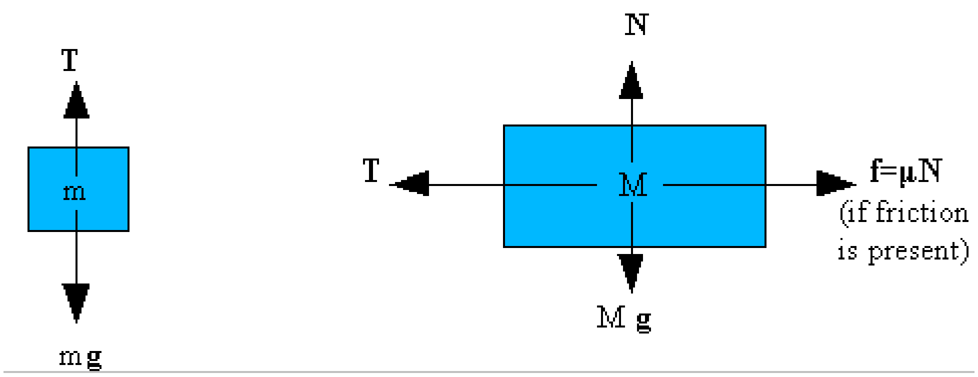
Purpose: To apply Newton's Laws by applying forces to objects and observing their motion; directly measuring these forces that we will apply.

Apparatus: Pasco track, Pasco cart, LabPro interface and cables, friction block, force sensor, cart-force sensor adapter, motion sensor, pulley, mass holder (blue, 5g) & long thin string, thicker short string, assorted mass hanger weights, one sheet of printer paper, protractor

Introduction: In last week's lab, we confirmed Newton's Third Law by having two force sensors interact with each other and verified Newton's Second law in a static situation. This week, you will apply these laws to some dynamic situations, as well as static ones. The power of the Second Law is its ability to predict the motion of objects based on their properties and the forces to which they are subjected. We hope that in this lab you will gain hands-on experience with those generic blocks, masses, pulleys, rough and frictionless surfaces that you have been subjected to so many times in lecture, in recitation and in your textbook. Here is one such example - the problem of a mass on surface, attached by a string to another mass hanging over a pulley:



If gravity is present and the surface is frictionless, the system (M + m) will no doubt accelerate, with the pulley turning in the counterclockwise direction (M goes left, m goes down). What is the acceleration of the system? What is the tension in the string before it starts to move and after it starts to move? How would the presence of friction change these values? A critical part of your problem-solving process is setting up a free-body diagram: isolate each mass and identify the forces acting on it.:



We then add up the forces in X and Y directions and equate them to ma**.** Since the larger mass does not accelerate in the Y direction, Newton's second law for M reads:

$F_y = 0 = N - Mg$ (1)

There is, however, acceleration in the X direction:

$F_x = Ma = T$ (2) where we have given positive signs to forces that tend to make the pulley turn in the direction we expect, i.e. counterclockwise

For the smaller mass, there are no forces in the X direction, only the Y direction:

$F_y = ma = mg - T$ (3)

Note that the acceleration for the large mass is the same as that or the small mass, so they share the same variable a. If assume the pulley to be massless and frictionless, another variable they will share is tension T. Combining (2) and (3) to eliminate T, we get:

$a = \frac{m}{M+m} g$ (4) (acceleration of two-mass system **without** friction, $\mu_k = 0$)

Tension T can be gotten directly from (2) once you have solved for a.
For the case **with** kinetic friction $\mu_k \neq 0$:

$a = \frac{m - \mu_k M}{M+m} g$ (5) Notice that when μ_k --> 0, equation (5) reduces to (4)

What you will do in this lab:

A) Predict the *acceleration* of a low-friction two-mass system and the *tension* in the connecting string. Measure both simultaneously using a force and motion sensor.

B) Measure the *coefficients of static and kinetic* friction of a block using a force sensor.

C) Confirm that *frictional force* is proportional to *normal force;* determine whether friction is actually independent of *contact area*.

Procedure

As usual, answer all questions and include data, plots (with curve fit) and analysis in your Google Docs lab report, to be shared with all lab partners, your TA and LA (if you have one)

<u>A) Measure acceleration and tension simultaneously using a force and a motion sensor (40 pts)</u>

0. First, test the four wheels on the Pasco cart by spinning each one by hand to see if it spins for at least 3 seconds before stopping. If it stops quickly, try pushing the wheels (along their axes) away from the side walls of the cart since rubbing up against the side internally could be causing friction. If it is not touching the cart walls, it may be the bearing inside – show your TA so that he/she can get a replacement.

1. Predict (calculate), using equations (4) and (2), the acceleration of the system and predict the tension on the string using the actual cart + sensor mass as measured on the scale, and the actual total mass of the mass holder + masses you are planning on using. You will need about 70g of driving mass (m) to get good results. Remember that cart mass is M, holder + masses is m, and that the holder (blue) has a mass of 5g.
(6 + 6 pts)

2. Open "Force + Motion.cmbl" Logger Pro file, which is in the same folder as this write-up on the PC. You will see blank plots with Force and Velocity labeled on the Y-Axis, time on the X-axis, as well as a Data window. Once you press the Collect button in

Logger Pro, you will be simultaneously gathering Force (tension in string) and Velocity (acceleration of cart) data.

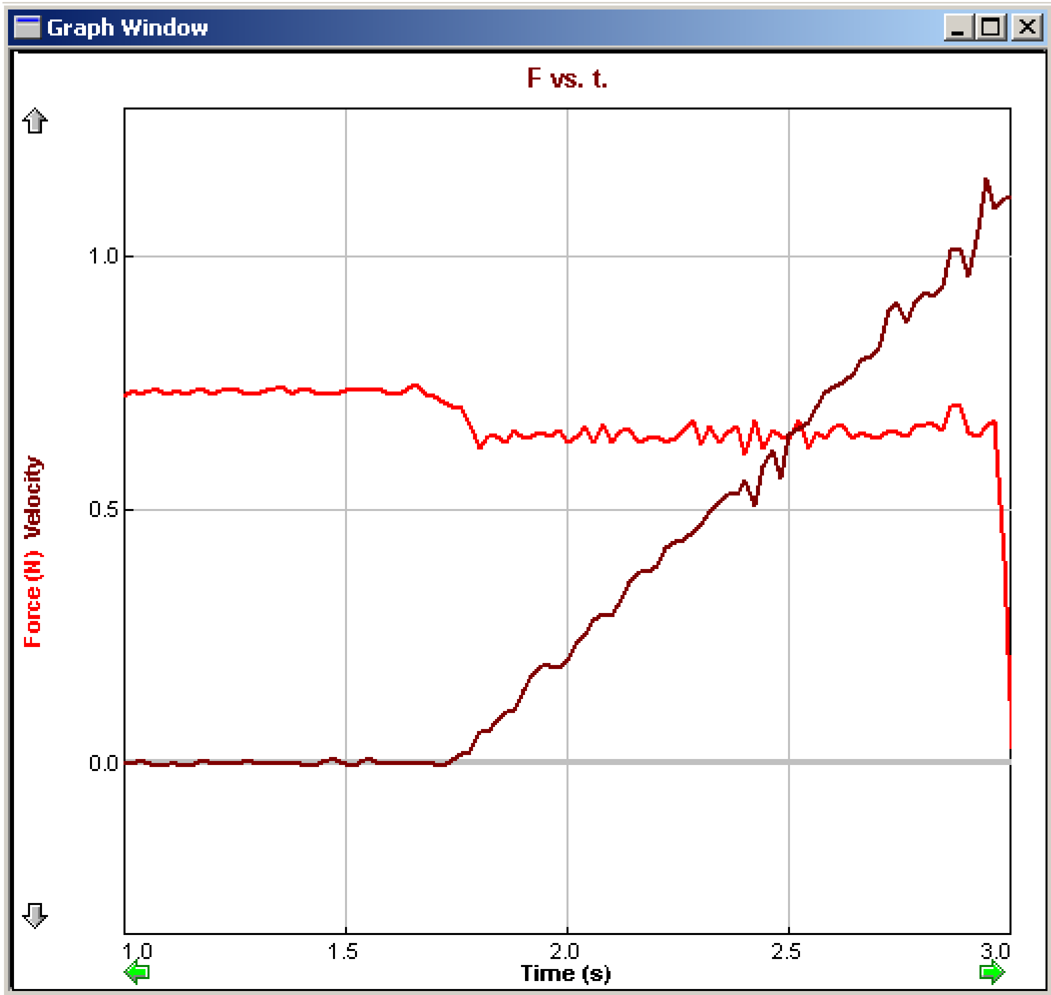
3. **Zero your force sensor before taking data**: In menu bar, click on Experiment-->Zero--> Zero Force. You may need to zero your sensor every few readings. Remember to calibrate a sensor in the orientation (upright, laying down, etc) it will be taking measurements.

4. Load the mass holder with the weight you used in part (1). Practice looping the string around the pulley, slowly drawing back the cart on the track towards the motion sensor (no closer than 25 cm), holding it motionless, then pressing the Collect button. Have one partner practice releasing the cart after data collection has started; the other partner should practice catching the cart at the end of the track. Make sure there is nothing in between the motion sensor and the cart that interferes with the sound pulses.

NOTE: If you cannot get a good plot of v vs. t, try moving the motion sensor to the cart (but not closer than 15cm, which is the sensor's lower limit). Also make sure that there are no obstructions between the sensor and the cart, such as your laptop, the computer monitor, and other items which could fool the sensor into thinking it's the cart.

5. After the run, you should get a plot of F vs. t superimposed over V vs. t - by matching the two; take a screenshot (or a photo of the screen) and mark the times at which you:

a) started data collection
b) released the cart
c) caught the cart
d) stopped data collection (8 pts)



Try to isolate the data between (b) and (c) - here the Force will be roughly constant (although lower than before you released the cart) and the Velocity will have a steady upward slope (constant acceleration). Do this by clicking and dragging your cursor across that area on the plot. After you highlight this region, go to the menu bar and click Analyze--> Curve Fit, choosing Linear Fit. You should get a fairly close fit to your Velocity slope; if not, there may be some unusually large spikes in your graph - consider redoing your run.

You should see the slope of the line in the "Y=" box; it is the coefficient of time t in the fit equation. This is your average acceleration, since v=at.

6. Find the average tension force. First exit the Curve Fit window by clicking Cancel. Then go back to the menu bar, select Analyze-->Statistics and choose Force for your "Statistics Selection". After you click OK, a little window will display the mean force for your selected data range - this is your average tension force. (5 pts)

7. Repeat for a total of five runs. Using the average accelerations and tensions measured across all your trials, calculate the mean and standard deviation of the mean for your experimental acceleration and tension Calculate mean, uncertainty (standard deviation of

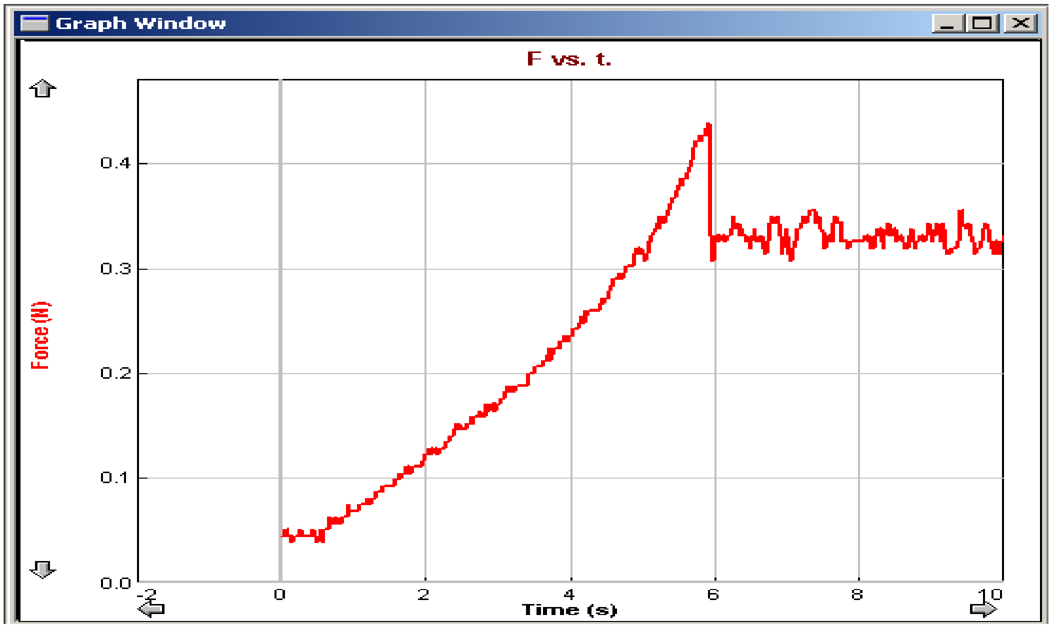
the mean) and record in hand-in sheet. **You can use a statistics-equipped calculator or refer to the Measurement & Uncertainly lab write-up you did early in the semester.** (15 pts)

B) Measure the *coefficients of static and kinetic* friction of a block using a force sensor. (30 pts)

1. Detach the force sensor from the cart by loosening the single thumbscrew that attaches the two; put the cart aside (see photo below). Place the sensor flat on a piece of paper on the table (tape the paper to the table if necessary), with the label face up. Place the friction block lengthwise on a piece of paper on the lab table (you can ignore the block/track illustration above), *wooden* side flat down (large contact area); place about 500g of mass (a cart mass) on the center of the block. Tie one end of the short string to the force sensor hook; tie the other end to the hook on the friction block.

2. Use the same "Force + Motion.CMBL" Logger pro file as you did in part B but click on the Force/Velocity (horizontal axis) graph labels and select only Force, since you will not need the motion sensor in this experiment.

3. Space the sensor and block so there is some slack in the string. **Remember to zero your sensor in the orientation you'll use it.** Press Collect, then start moving the sensor away from the block *very slowly*. Once the string is taut, you will get a steadily rising trace representing the force of static friction between block and paper. At the point where the block *just* starts to move, you should get a peak corresponding to the **maximum static friction force**; record this value**.** (5 pts) Keep moving past that point, trying to pull with constant velocity. The trace should jump down and level out. Use the Analyze->Statistics function to find the mean force over the region after the maximum static friction force - this average is the **kinetic friction force.** (5 pts) (see photo below) From the forces, calculate the coefficients of static friction μ_s and kinetic friction μ_k between the wooden surface-paper, knowing that $f = \mu N = \mu mg$. (10 pts)



4. Repeat your measurements, this time with the black felt side flat down (large contact area). Determine μ_s and μ_k between the felt surface-paper. (10 pts)

C) Confirm that *frictional force* is proportional to *normal force;* determine the dependence of *frictional force* on *contact area*. (30 pts)

There will be no instructions in this section, other than the requirement that you must use Logger Pro and the available equipment to prove or disprove that **f=μN** and also to find the dependence of frictional force on contact area**.** Use the skills and techniques you learned in Part B to devise your own experiment, **detailing your experimental plan and procedure.** (15pts) Remember that in an experiment to test or discover a mathematical relationship, typically *only one quantity at a time is varied.* and that *you must consider both static and kinetic friction*. **Also remember that you can vary the normal force using the black bar weights on your lab table**. Finally, do the experiment and include your data and analysis. (15 pts)

WHEN DONE WITH YOUR LAB, PLEASE MAKE SURE THE FORCE SENSOR IS AGAIN SCREWED INTO THE CART, WHICH IS BACK ON THE TRACK, AND THE STRING AGAIN STRUNG HORIZONTALLY, CONNECTING THE SENSOR HOOK TO THE MASS HANGER OVER THE TABLE EDGE.