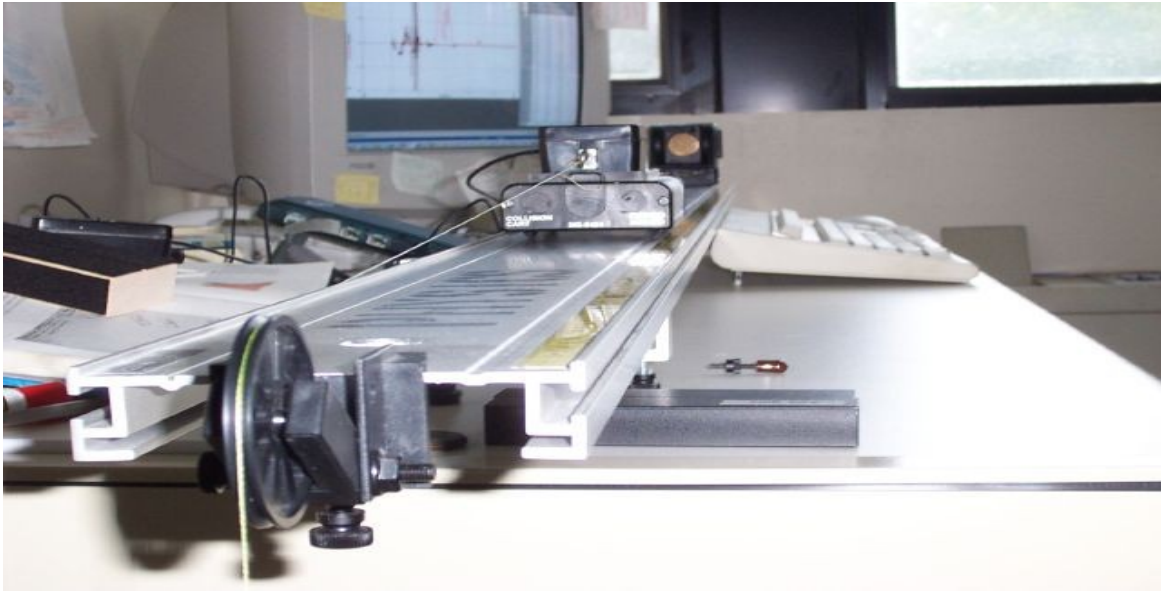


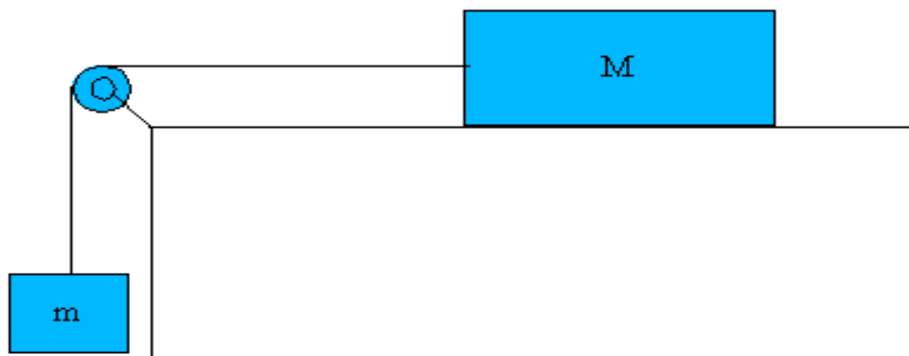
Applications of Newton's Laws



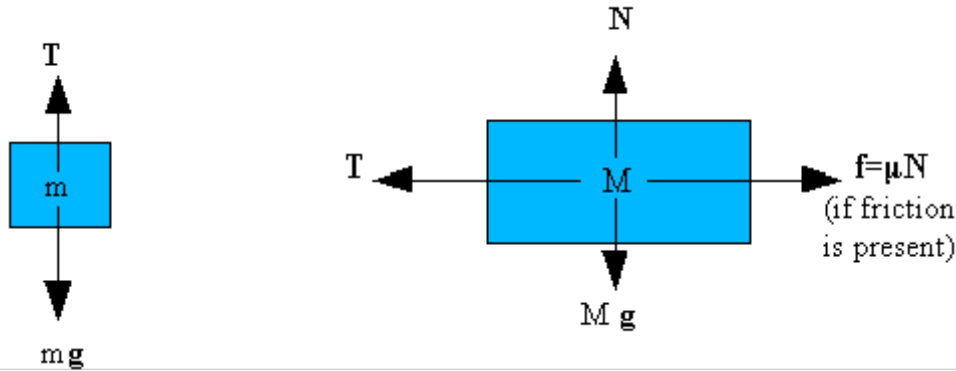
Purpose: To apply Newton's Laws by applying forces to objects and observing their motion; directly measuring these forces that we will apply.

Apparatus: Pasco track, Pasco cart, LabPro interface and cables, friction block, force sensor (2), cart-force sensor adapter, motion sensor, pulley, mass bucket & long thin string, thicker short string, assorted mass hanger weights, one sheet of printer paper

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 counter-clockwise 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:

$$F_y = 0 = N - mg \quad (1)$$

There is, however, acceleration in the X direction:

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

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

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

Note that the acceleration for the large mass is the same as that of 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:

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

Tension T can be gotten directly from (2) once you have solved for a .

For the case **with** kinetic friction $\mu_k \neq 0$:

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

What you will do in this lab:

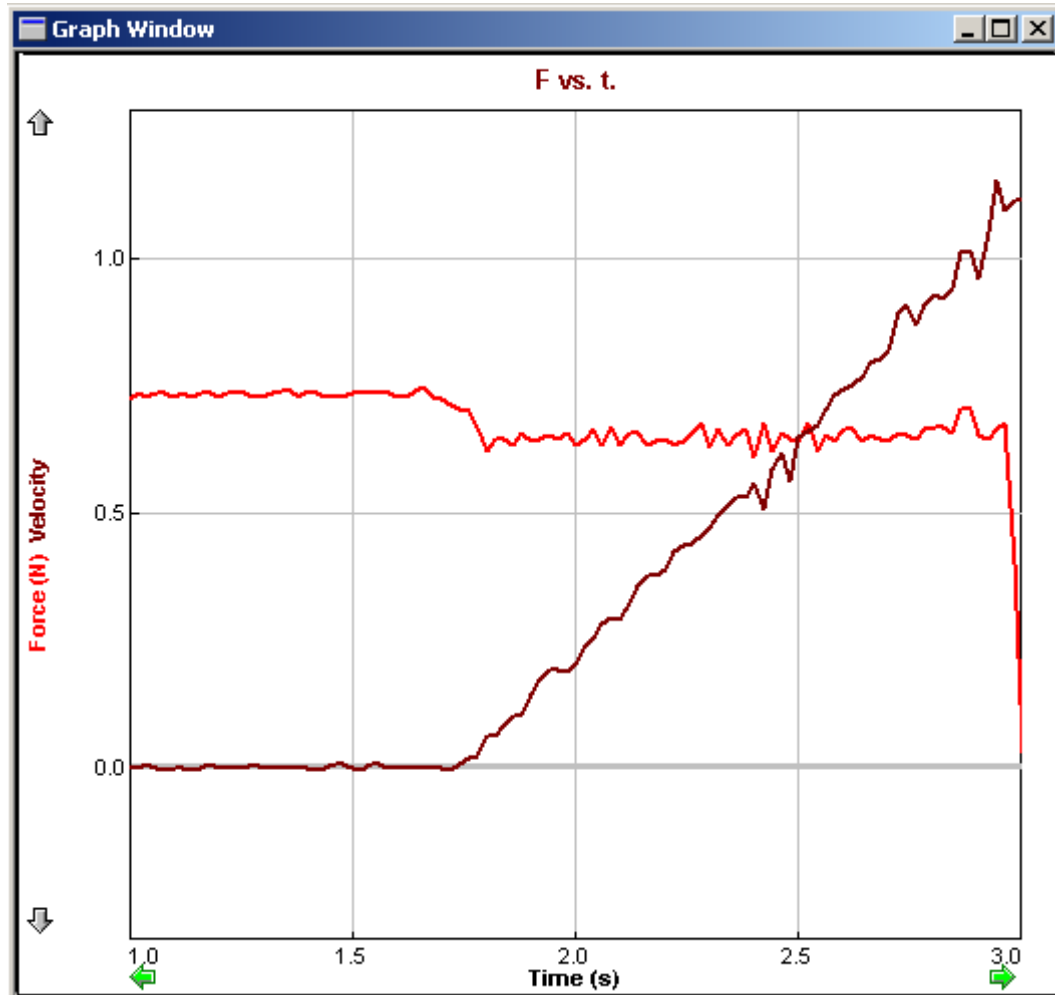
- A) Predict the *acceleration* of a low-friction two-mass system and the *tension* in the connecting string . Measure both simultaneously using a force and motion sensor.
- B) Measure the *coefficients of static and kinetic* friction of a block using a force sensor.
- C) Confirm that *frictional force* is proportional to *normal force*; determine whether or not friction is actually independent of *contact area*.

Procedure

A) Measure acceleration and tension simultaneously using a force and a motion sensor.

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, using the actual cart + sensor mass as measured on the scale, and the actual total mass of the mass bucket + masses you are planning on using. You will need about 60-80g of driving mass (m) to get good results. Remember that cart mass is M , bucket + masses is m .
2. Open “Force + Motion.cmb1” 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. Calibrate your force sensor before taking data: In menu bar, click on Experiment-->Zero--> Zero Force. You may need to recalibrate 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 bucket 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.
5. After the run, you should get a plot of F vs. t superimposed over V vs. t - by matching the two, you should be able to mark the times at which you:

- a) started data collection
- b) released the cart
- c) caught the cart
- d) stopped data collection



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-->Automatic Curve Fit. At the bottom, choose "Velocity Latest" in the "Perform Fit On" drop down menu. Click Linear in the list of fit equations and click "Try 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. To find the average force (tension), 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 force.

7. Repeat, for a total of five runs, to obtain average acceleration and tension each time. 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 & Uncertainty lab write-up you did early in the semester.**

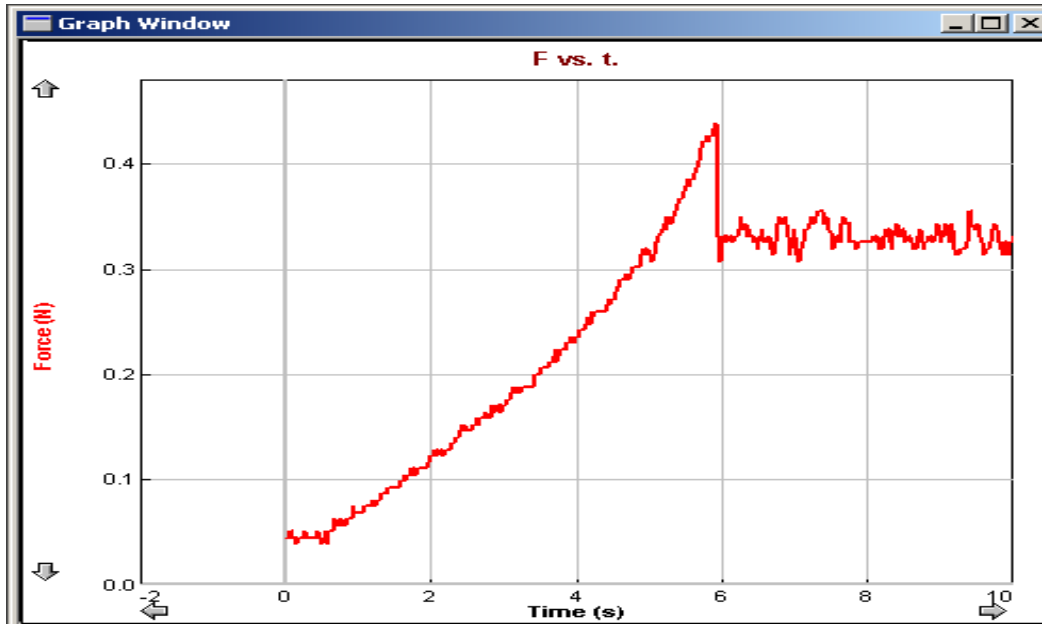
B) Measure the *coefficients of static and kinetic* friction of a block using a force sensor.

1. Detach the force sensor from the cart by loosening the single black thumbscrew that attaches the two; put the cart aside (see photo below). Place the sensor flat on the 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/truck 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. Space the sensor and block so there is some slack in the string. 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**. 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**. (See diagram on next page) From the forces, calculate the coefficients of static friction μ_s and kinetic friction μ_k between the wooden surface-paper. Record in hand-in sheet.

3. 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. Record in hand-in sheet.



C) Confirm that *frictional force* is proportional to *normal force*; determine whether or not friction is actually independent of *contact area*.

(There will be no instructions in this section, other than the requirement that you must use Graphical Analysis to prove or disprove that $f = \mu N$. Use the skills and techniques you learned in Part B to devise your own experiment. Choose either wood or felt, and do for both static and kinetic cases. You may place the block on the paper or on the track. Summarize what you did and your findings in the hand-in sheet.

There are no graphs to print out and submit. Just give you hand-in sheet to your TA.