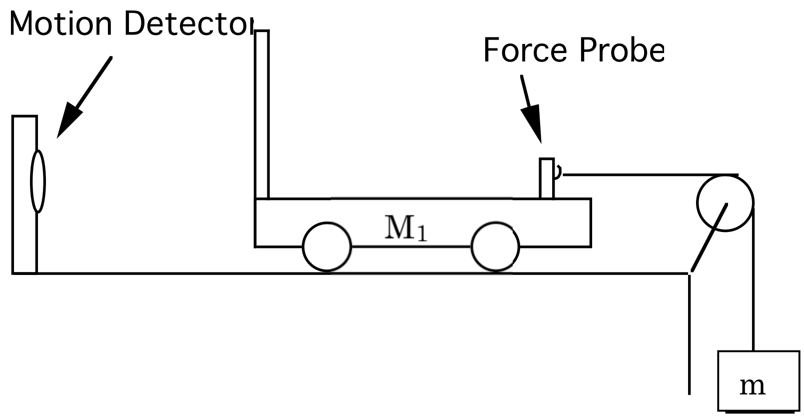
Experiment 5
Newton's Second Law



Advanced Reading:
Halliday, Resnick & Walker,
Chapter 5

Equipment:
1 ULI interface and motion detector
1 low-friction cart
1 pulley
string
1 mass hanger
masses

Objective:
The objective of this lab will be to measure the acceleration of a cart caused by an applied force and to examine the effect of friction on the system. By varying the force on, and the mass of a system, the relationship between force, mass and acceleration can be determined.

Theory:
According to Newton's Second Law the acceleration of a body is directly proportional to the sum of the forces applied to the body or:

$$\Sigma \mathbf{F} = m\mathbf{a} \qquad \text{eq. 1}$$

where $\Sigma \mathbf{F}$ is the vector sum of the forces, m is the mass of the body, and **a** is the acceleration of the body.

In this experiment, you will apply forces to a low-friction cart and measure its acceleration with a computer, an ULI interface and a motion detector. The forces will be applied to the cart using a weight hanging on a string that runs over a pulley. *The tension in the string supplies the force used to accelerate the cart.*

The experimental configuration used in this experiment is a variation of *Atwood's machine*. The applied tension T in the string (including friction) is given by the equation

$$T = \left(\frac{m_1 m_2 g + m_2 f_f}{m_1 + m_2} \right) \qquad \text{eq. 2}$$

where m_1 is the mass of the cart, m_2 is some mass hanging on the string and f_f is the *experimentally measured* force of friction

Newton's Second Law applied to the cart yields

$$\Sigma F = T - f_f = m a_1 \qquad \text{eq. 3}$$

From this relationship it can be seen that the experimental acceleration of the cart a_1 is given by

$$a_1 = \frac{T - f_f}{m_1} \qquad \text{eq. 4}$$

If friction forces are small, a doubling of the applied tension on the cart, approximately doubles the cart's acceleration. Correspondingly, if the mass of the cart is doubled and the applied tension is the same as before its mass is doubled, the acceleration of the cart is (approximately) halved.

A force probe will be used to measure directly the force applied to the cart. *The tension obtained from eq. 2 should be equal to the force as recorded by the force probe connected to the ULI.* **Compare the two.**

If the force of friction is zero (i.e., $f_f = 0$), eq. 2 simplifies to (the ideal case)

$$T = \frac{m_1 m_2}{m_1 + m_2} g \quad \text{eq. 5}$$

Procedure:

1. **With the cart turned on its side** and with the force probe attached, place the cart on the triple beam balance pan and record its mass. There will be some uncertainty caused by the electrical cord attached to the force probe. When 'weighing' the cart, place the cord on the table next to the balance so that a minimal amount of additional mass is caused by the cord.

2. Tie a string to the hook on the force probe mounted on the front of the cart. Place the string over the pulley.

3. Open the experiment folder and double click click on the experiment called **Newton's Second Law.** Four graphs should appear. These are force vs. time, distance vs. time, velocity vs. time and acceleration vs. time.

Calibration of the force probe

4. Calibrate the force probe by going to the menu bar and clicking (on the following path)- **Setup/Sensors/Sensor setup**(choose the port which has the force probe e.g., DIN#1) /**Calibrate/Perform**. Follow the directions given to you on the screen. When the computer asks you to apply a known force, hang 50 grams on the force probe. Do this by holding the cart still on the table and putting the mass on the weight hanger on the string. **Be sure to convert this to units of force and not mass.**

Measurement of the cart friction

5. Take off 50g hanger. Place a small mass (around 5 grams) on the end of the string tied to the force probe. Place the cart about 1/2 a meter in front of the motion detector. Hold the sensor cord from the ULI to the force probe so that it does not interfere with the rolling of the cart. Click the start button. Tap the cart to start it rolling. If the cart rolls without accelerating the sum of the forces on the cart must be zero. To determine whether or not the cart is accelerating, look at the velocity vs. time and acceleration vs. time graphs. What should these two graphs look like if the cart is not accelerating?

6 Move the cursor down to the graph and highlight the section that has a constant force. Pull down the **Analyze** menu and highlight **Statistics.** Read the "mean force" (the average force) of the highlighted section and record in your notebook.

7. The frictional force will be equal to the weight hanging on the string. Calculate the frictional force and record this value in your lab notebook. *Compare this to the value obtained using the computer*.

Measurement of acceleration

8. Remove the frictional mass. Hang 50 grams on the string. Using eq. 2, calculate the applied tension of the string caused by the 50g mass. Use this tension, the force of friction and the mass of the cart to calculate the acceleration of the cart **(use eq. 4)**. Record this value in your notebook. This value will be *compared to the measured value* of acceleration.

9. Place the trash can so the weights will fall into it when the cart is released. Push the start button. When you hear the motion detector begin to click, let the cart go. **Do not let the cart hit the pulley.**

10. Use the **Analyze** and **Statistics** functions to obtain the acceleration and tension of the cart. Compare the calculated acceleration value for step 8 to the value obtained from the computer. Use both the acceleration vs. time plot and the *slope* of the velocity vs. time plot.

11. Repeat steps 8-10 but this time use 100g for the hanging mass. You are now approximately doubling the force applied to the cart. Is the value of the acceleration approximately twice the previous value?

Changing the mass of the cart while holding the force on the cart constant

12. Keep the 100 grams on the hanger. Add enough mass to the cart so that it is twice its empty mass. Measure the cart's acceleration. (It will be necessary to change the force needed to overcome friction. Do this just as before, but with the added masses on the cart.) Record the value for the force and the acceleration in your lab notebook.

13. Remove 50g from the hanging mass. Measure the cart's acceleration and tension force as before. Record the value for the force and the acceleration in your lab notebook.

Questions

1. Draw force diagrams for the cart-mass system in Fig. 5-1 and *include* friction. Use these diagrams to derive equation 2.

2. What is the tension in the string when the cart is held motionless? Is this value equal to, less to, or greater than the tension in Eq. (5)? Explain.

3. Qualitatively sketch distance vs. time and velocity vs. time for the cart starting from rest at t=0. Include times after the hanging mass has fallen in the trash can until it stops. Label all when the cart is accelerating, when the mass is hitting the trash can and when the cart is stopped.