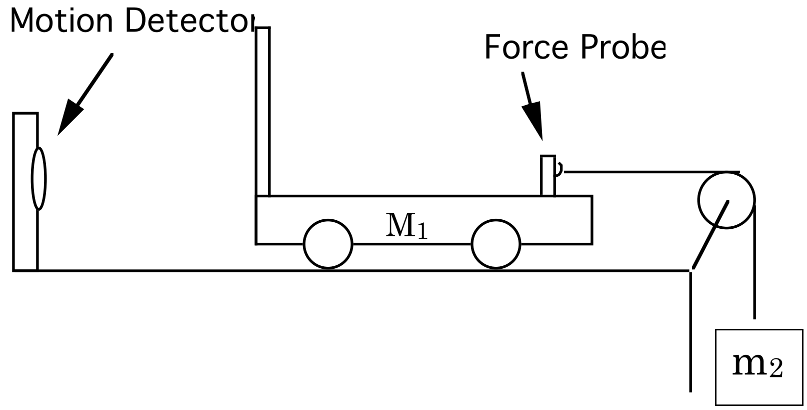
Experiment 5
Newton's Second Law

(Fall 2018 version 2)



Advanced Reading:

Newton's 2^{nd} Law

Equipment:

1 LABPRO interface
1 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 $\mathbf{a}$ 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, a LABPRO 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 LabPro.* **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.**

Estimation of the cart friction

5. All rolling objects have a certain amount of friction associated with its motion. Friction (i.e., frictional force) cannot be eliminated but it can be quantified. You will do so as follows.

6. Place a small amount of mass (around 5 grams) on the end of the string that is attached to the force probe & runs over the pulley.

Give the cart a gentle tap. If the cart slows down after the tap then the weight (i.e., the mass times acceleration of gravity) on the string is less than the force of friction. If the cart speeds up after the tap, then the mass on the string is too much.

7. If the correct (mass is added to the string) then the cart will roll at a constant speed and the frictional force will be equal to the weight hanging on the string. Adjust the mass as necessary.

Calculate the frictional force (i.e., the weight of the mass) that makes cart roll at constant speed and record this value on the data sheet. *This is the friction force used in Equation* 2.

Measurement of acceleration

8. Remove the frictional mass. Hang 50 grams on the string **(i.e., mass hanger only)**. Using eq. 2, calculate the applied tension of the string caused by the 50g mass. Use this tension, the force of friction (from step 7) 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 cart (approximately 40 cm) in front of motion detector with. 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. **Print plot.**

11. Repeat steps 8-10 but this time use 100g for total mass (hanger + 50g). 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. Remove the 50 g mass from mass hanger.

Add enough mass to the cart so that it is twice its empty mass. *(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.)*

Measure the cart's acceleration using 50g hanger only. Record the value for the force and the acceleration in your lab notebook/data sheet.

13. Add 50g to the hanger (hanging mass is again 100g). Measure the cart's acceleration and tension force as before. Record the value for the force and the acceleration in your lab notebook/data sheet.

14. Plot net force vs. acceleration for both sets of runs (i.e., runs with cart only and with added mass). Be sure & include 0,0 as data.

Post lab Questions (Show all work to receive full credit)

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

2. The product of force times time is

Impulse $= F\Delta t$.

The Momentum Principle is defined as;

The change in momentum of a system is equal to the net impulse applied to the system or

$$\Delta p = F_{net}\Delta t \quad \Rightarrow \quad \Delta(mv) = F_{net}\Delta t$$

Utilizing the equation above and the printout of one of your runs **determine the mass of the cart.**

Net force is measured tension (during the run) minus friction.

Change in time is amount of time the tension acted on the cart while it was accelerating (mark on printout of plot).

The velocity is the maximum velocity the cart had at the end of the acceleration.

You must show time and maximum velocity on your printout to receive full credit.

3. Why are we so insistent that you include the origin in your plot points when plotting Equation 3. There are two very good reasons. One has to do with the (NSL) equation itself and the 2nd has to do with what happens when you apply a linear fit to only two points.

4. There are two forms of Newton's 2nd Law. What are those two forms and what are the differences between the two forms?