

Newton's Second Law of Motion

Objectives

In this lab you will:

- Calculate acceleration by measuring the rate of change of velocity.
- Measure mass and calculate weight.
- Verify Newton's Second Law by plotting your data and analyzing it using Excel.

Equipment

Mobile cart on wheels, pulley and pulley clamp, paper clips, stopwatch, standard masses, string, weighing balance, wooden block to act as a bumper.

Theory

Newton's Second Law of Motion states that the acceleration of an object of constant mass is proportional to the force applied on it.

$$a \propto F_{\text{external}} \quad \text{Equation 1}$$

Upon further experimental investigation, Newton discovered that the acceleration of an object is inversely proportional to its mass if the Force is constant.

$$a \propto \frac{1}{m} \quad \text{Equation 2}$$

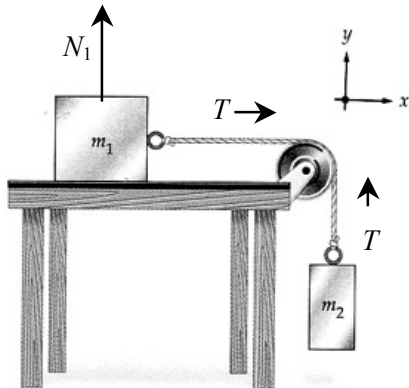
Newton hypothesized that Equations 1 & 2 are connected and came up with his (now famous) law of motion.

$$a = \frac{F}{m} \quad \text{Equation 3}$$

$$F = ma$$

The brilliant idea of Newton was setting mass as a constant of proportionality in Equation 1. Mass is the quantitative measure of the property known as *inertia*. Inertia is described as a resistance to motion. We will be testing Equations 1 & 2 by direct measurements.

The basic-setup is as shown in the figure below. Where m_1 is the mass of the cart and m_2 is the hanging mass. We assume that the table is frictionless.



The equations of motion along the y -axis are:

$$N_1 - m_1g = 0 \quad \text{Equation 4a}$$

$$T - m_2g = -m_2a \quad \text{Equation 4b}$$

The equation of motion along the x -axis is:

$$T = m_1a \quad (\text{Force on the Cart}) \quad \text{Equation 5}$$

Solving Equations 4-5 algebraically for the acceleration we get

$$a = \frac{m_2g}{m_1 + m_2} \quad \text{Equation 6}$$

This is the **theoretical value** of acceleration. Note that the acceleration scales linearly with the hanging mass m_2 .

In the experiment, **the hanging mass m_2 provides the force**, while **the cart and any additional mass (m_1) on it is the object under study**.

The cart is released from rest and is allowed to accelerate over a distance x . Using a stopwatch, you will determine how long it takes (t), on an average to cover the distance x . An **experimental value** for the car's acceleration can be determined as:

$$a_{\text{exp}} = \frac{2x}{t^2} \quad \text{Equation 7}$$

The Experiment

Part I: Initial Setup

- 1) Weigh the cart and record its mass on the worksheet.
- 2) Locate the spring-loaded extension on the cart. Pointing the cart away from your body, release the extension by depressing the tiny release button. The attachment pops out with considerable force, so take care when you disengage the mechanism.
- 3) Tie a piece of string to the cart. Although the length of the string does not matter, use a length greater than 75 cm.
- 4) Setup the pulley system and ensure that the clamp is securely tightened to fix the pulley to the edge of the table.
- 5) Proceed to Part II

Part II: Constant Object Mass - Varying Applied Force

We keep the mass of the cart constant and increase the hanging mass (effectively increasing the force).

- 1) Load the cart with two 250-g masses. Weigh the system and record its mass in your worksheet. Place a book in front of the cart to keep it from moving.
- 2) Place the wooden stop at the base of the pulley.
- 3) Select a paperclip and record its weight.
- 4) Attach the paperclip to the string. This is your hanging mass.
- 5) Remove the book you placed in front of the cart and let the hanging mass descend. The cart should begin to move.
- 6) If the cart does not move, repeat Steps 3 & 4 till the cart just begins to move. (Since rolling friction is negligible, a simple repositioning of the cart in line with the pulley ought to suffice.)
- 7) Once you get the cart moving, stop it and reposition the system for a timed run. Measure the distance from the front of the extension to the wooden stop. Note down this distance x in your worksheet.
- 8) Practice releasing the cart without giving it an additional push or pull.
- 9) Once you are ready, keep the cart still at the pre-determined distance x and start your stopwatch the instant you let the cart go. Stop the timer as soon as the cart hits the wooden stop. Record the time in your datasheet.
- 10) Repeat the above steps by increasing the hanging mass.
- 11) Once you are done, proceed to Part III

Part III: Constant Applied Force - Varying Object Mass

In this part, we are going to keep the hanging mass constant and increase the mass of the cart system. Thus, the applied force is constant while the object mass increases.

- 1) Load the cart with a 100-g mass. Weigh the system and record it in Column 2.
- 2) Place the wooden stop at the base of the pulley.
- 3) Weigh 5 paperclips and attach them to the end of the string. This serves as the constant hanging mass.
- 4) Record the distance x .
- 5) Practice releasing the cart without giving it an additional push or pull.
- 6) Once you are ready, keep the cart still at the pre-determined distance x and start your stopwatch the instant you let the cart go. Stop the timer as soon as the cart hits the wooden stop. Record the time in your datasheet.

Each student is required to submit a completed data sheet in order to receive full credit. Your lab group needs to submit only one Excel graph. This graph is to be stapled to the data sheet of one of your lab partners – Each lab partner does not need to submit his/her own graph.

Data Sheet – Newton’s Second Law of Motion

Name _____ Date _____

Partners’ Names _____

I. Initial Setup

Mass of empty cart alone = _____ Kg

II. Constant Object Mass - Varying Applied Force

Mass of the loaded cart (m_1) = _____ Kg

| Trial | Hanging Mass m_2 [Kg] | Distance x [m] | Time t [s] | a_{exp} (From Eq 7) | a (From Eq 6) | % Discrepancy |
|-------|----------------------------|---------------------|-----------------|--------------------------|--------------------|------------------|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |

In Excel, plot a force vs. acceleration graph with F on the y axis and a_{exp} on the x axis. Add a trendline and display the equation on your graph. The slope of this graph gives us the mass of the loaded cart (m_1).

Slope from the Excel graph = _____ Kg

Percent discrepancy between m_1 (accepted value) and the slope = _____

Questions:

- 1) What is the y-intercept from your trendline? What is the expected value of the y-intercept? What would a non-zero y-intercept signify?

III. Constant Applied Force - Varying Object Mass

Mass of the hanging object (m_2) = _____ Kg

| Trial | Cart m_1 [Kg] | Distance x [m] | Time t [s] | a_{exp} (From Eq 7) | a (From Eq 6) | % Discrepancy |
|-------|--------------------|---------------------|-----------------|--------------------------|--------------------|------------------|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |

In Excel, plot a graph of acceleration (a_{exp}) on the Y-axis vs. ($1/m_1$) on the X-axis. Add a trendline and display the equation on your graph. The slope of this graph gives us the exerted force on the loaded cart due to the hanging mass m_2 .

Slope from the Excel graph = _____ N

Copy Equation 6. Circle the terms that indicate a constant applied force on the cart.

Percent discrepancy between accepted value of the force and the slope = _____

Questions:

- 1) What is the y-intercept from your trendline? What is the expected value of the y-intercept? What would a non-zero y-intercept signify?