  Graphical Analysis 9

Newton’s Second Law

(Force and Acceleration Sensor)

How does a cart change its motion when you push and pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart’s velocity related to the force you apply? Or, is the force related to something else? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

A force sensor and an accelerometer will let you measure the force on a cart simultaneously with the cart’s acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton’s second law of motion.

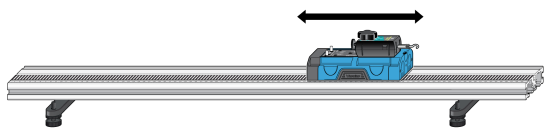


Figure 1

Objectives

* Collect force and acceleration data for a cart as it is moved back and forth.
* Compare force vs. time and acceleration vs. time graphs.
* Analyze a graph of force vs. acceleration.
* Determine the relationship between force, mass, and acceleration.

Materials

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct Force and Acceleration

Vernier Dynamics Track

Vernier Dynamics Cart

extra mass

Preliminary questions

Use a tennis ball and a flexible ruler to investigate these questions.

1. Apply a small amount of force to the ball by pushing the flat end of the ruler against the ball (see Figure 2). Maintain a constant bend in the ruler. You may need a lot of clear space, and you may need to move with the ruler. Does the ball move with a constant speed?
2. Apply a larger force and keep a constant larger bend in the ruler. Does the ball move with a constant speed?
3. What is the difference between the movement when a small force is applied versus a large force?

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| Figure 2 | Figure 3 |

Procedure

Trial I

1. Set up the equipment for data collection.
   1. Attach the Go Direct Force and Acceleration to a Dynamics Cart so you can apply a horizontal force to the hook, directed along the sensitive axis of the sensor (see Figure 3).
   2. Find the mass of the cart with the sensor attached. Record the mass in the data table.
   3. Launch Graphical Analysis.
   4. Connect the sensor to your Chromebook, computer, or mobile device.
   5. Click or tap Sensor Channels and select X-axis acceleration to turn on the X-axis acceleration channel. Note: Both the Force channel and the X-axis acceleration channel should be selected.
   6. Click or tap Done.
   7. Click or tap Mode to open Data Collection Settings. Change End Collection to 10 s. Click or tap Done.
2. Place the cart on the Dynamics Track on a level surface to prepare to zero the sensors. Verify the cart is not moving. To zero the force sensor, click or tap the Force meter and choose Zero. Then, before moving the cart, click or tap the X-axis acceleration meter and choose Zero to zero the accelerometer. The readings for both sensors should be close to zero.
3. You are now ready to collect force and acceleration data. Grasp the force sensor hook. Click or tap Collect to start data collection and roll the cart back and forth along the track covering a distance of about 10 cm. Vary the motion so that both small and large forces are applied. Your hand must touch only the hook and not the sensor nor the cart. Only apply force along the track so that no frictional forces are introduced.
4. Acceleration and force data are displayed on separate graphs. Sketch the graphs in your notes. How are the graphs similar? How are they different?
5. Examine the shape of the force vs. time and acceleration vs. time graphs. When the force is maximum, is the acceleration maximum or minimum?
6. One way to see how similar the acceleration and force data are is to make a new plot of force vs. acceleration, with no time axis.
   1. Click or tap View, , and choose 1 Graph to view a single graph.
   2. Click or tap Graph Tools, , and choose Edit Graph Options. Select Points as the Appearance. This removes the line connecting the data points on the graph. Dismiss the Graph Option box.
   3. Click or tap the axes labels and change the x-axis to X-axis acceleration and the y-axis to Force.
   4. Sketch the graph in your notes.
7. Fit a line to the graph of force vs. acceleration.
   1. Click or tap Graph Tools, , and choose Apply Curve Fit.
   2. Select Linear as the curve fit and click or tap Apply.
   3. Record the equation for the regression line and print or sketch your graph.

Trial II

1. Add extra mass to the cart. If you are using a green metal cart, attach the 0.50 kg mass to the cart (see Figure 4). If you are using a plastic cart, add 1–4 hexagonal bar masses to the cart (see Figure 5). Record the total mass of the cart, sensor, and additional mass in the data table.
2. Repeat Steps 3–7 for the cart with the additional mass. Note: The previous data set is automatically saved.

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| Figure 4 | Figure 5 |

Data Table

Trial I

|  |  |
| --- | --- |
| Mass of cart with sensors (kg) |  |

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| --- |
| Regression line for force vs. acceleration data |
|  |

Trial II

|  |  |
| --- | --- |
| Mass of cart with sensors and additional mass (kg) |  |

|  |
| --- |
| Regression line for force vs. acceleration data |
|  |

Analysis

1. Are the net force on an object and the acceleration of the object directly proportional? Explain, using experimental data to support your answer.
2. What are the units of the slope of the force vs. acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).
3. For each trial, compare the slope of the regression line to the mass being accelerated. What does the slope represent?
4. Write a general equation that relates all three variables: force, mass, and acceleration.

Extension

Use this apparatus as a way to measure mass. Place an unknown mass on the cart. Measure the acceleration and force and determine the mass of the unknown. Compare your answer with the actual mass of the cart, as measured using a balance.