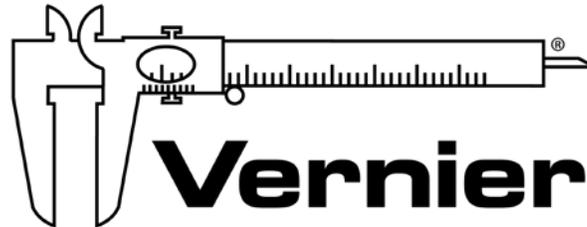


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Atlanta, GA

HANDS-ON ACTIVITIES

Hot Hand

- Go Direct Temperature

Boyle's Law

- Go Direct Gas Pressure

Graph Matching

- Go Direct Motion Detector

Impulse and Momentum

- Go Direct Sensor Cart

Cell Respiration

- Go Direct CO₂ Gas

A Hot Hand

You will measure the temperature of the palm of your hand and the palm temperatures of your teammates in this experiment. In the process, you will learn how to use the data-collection equipment you will be using throughout the school year. You will also get to know your teammates better.

OBJECTIVES

- Use a Temperature Probe to measure temperature.
- Calculate temperature averages.
- Compare results.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Temperature
beaker
water
paper towel



Figure 1

PROCEDURE

1. Launch Graphical Analysis. Connect the Temperature Probe to your Chromebook, computer, or mobile device.
2. Click or tap Mode to open Data Collection Settings. Set End Collection to 60 s. Click or tap Done.
3. Measure the temperature of the palm of your hand.
 - a. Click or tap Collect to start data collection.
 - b. Pick up the Temperature Probe and hold its tip in the palm of your hand as shown in Figure 1. Data collection will end when 60 seconds have gone by.
4. Record your highest temperature.
 - a. When data collection is complete, a graph of temperature vs. time will be displayed. To examine the data pairs on the displayed graph, click or tap any data point. As you tap each data point, the time and temperature values of the point are displayed. **Note:** You can also adjust the Examine line by dragging the line.
 - b. Record your highest temperature.

A Hot Hand

5. Prepare the Temperature Probe for the next run.
 - a. Cool the Temperature Probe by placing it into a beaker of room-temperature water until its temperature reaches the temperature of the water. The temperature of the probe is displayed in a meter on the screen.
 - b. Use a paper towel to dry the probe. Be careful not to warm the probe as you dry it.
6. Repeat Steps 3–5 for each person in your team.

DATA

Student name	Maximum temperature (°C)
Team average	

PROCESSING THE DATA

1. Calculate the team average for the highest temperatures. Record the result in the data table.
2. How did the maximum temperatures of your teammates compare?
3. Who had the “hottest hand”?

EXTENSION

Determine the class average for maximum temperature.

Boyle's Law: Pressure-Volume Relationship in Gases

The primary objective of this experiment is to determine the relationship between the pressure and volume of a confined gas. The gas we use will be air, and it will be confined in a syringe connected to a Gas Pressure Sensor (see Figure 1). When the volume of the syringe is changed by moving the piston, a change occurs in the pressure exerted by the confined gas. This pressure change will be monitored using a Gas Pressure Sensor. It is assumed that temperature will be constant throughout the experiment. Pressure and volume data pairs will be collected during this experiment and then analyzed. From the data and graph, you should be able to determine what kind of mathematical relationship exists between the pressure and volume of the confined gas. Historically, this relationship was first established by Robert Boyle in 1662 and has since been known as Boyle's law.

OBJECTIVES

- Use a Gas Pressure Sensor and a gas syringe to measure the pressure of an air sample at several different volumes.
- Determine the relationship between pressure and volume of the gas.
- Describe the relationship between gas pressure and volume in a mathematical equation.
- Use the results to predict the pressure at other volumes.

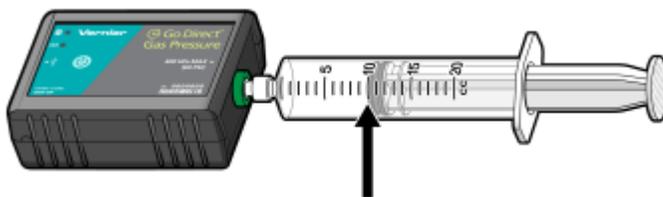


Figure 1

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Gas Pressure
20 mL gas syringe

PROCEDURE

1. Prepare the data-collection equipment and an air sample for data collection.
 - a. Launch Graphical Analysis. Connect the Gas Pressure Sensor to your Chromebook, computer, or mobile device.
 - b. With the 20 mL syringe disconnected from the Gas Pressure Sensor, move the piston of the syringe until the front edge of the inside black ring (indicated by the arrow in Figure 1) is positioned at the 10.0 mL mark.
 - c. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.
2. Set up the data-collection mode.
 - a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
 - b. Enter **Volume** as the Event Name and **mL** as the Units. Click or tap Done.
3. To obtain the best data possible, you will need to correct the volume readings from the syringe. Look at the syringe; its scale reports its own internal volume. However, that volume is not the total volume of trapped air in your system since there is a little bit of space inside the pressure sensor.

To account for the extra volume in the system, you will need to add 0.8 mL to your syringe readings. For example, with a 5.0 mL syringe volume, the total volume would be 5.8 mL. It is this total volume that you will need for the analysis.

4. You are now ready to collect pressure and volume data. It is easiest if one person takes care of the gas syringe and another enters volumes.
 - a. Click or tap Collect to start data collection.
 - b. Move the piston so the front edge of the inside black ring (see Figure 2) is positioned at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value displayed on the screen stabilizes.
 - c. Click or tap Keep and enter **5.8**, the gas volume (in mL). Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Click or tap Keep Point to store this pressure-volume data pair.



Figure 2

- d. Continue this procedure using syringe volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.
 - e. Click or tap Stop to stop data collection.
5. When data collection is complete, a graph of pressure vs. volume will be displayed. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the pressure and volume values are displayed to the right of the graph. Record the pressure and volume data values in your data table.

6. Based on the graph of pressure vs. volume, decide what kind of mathematical relationship exists between these two variables, direct or inverse. To see if you made the right choice:

- a. Click or tap Graph Tools, , and choose Apply Curve Fit.
- b. Select Power as the curve fit and Dismiss the Curve Fit box. The curve fit statistics are displayed for the equation in the form

$$y = ax^b$$

where x is volume, y is pressure, a is a proportionality constant, and b is the exponent of x (volume) in this equation. **Note:** The relationship between pressure and volume can be determined from the value and sign of the exponent, b .

- c. If you have correctly determined the mathematical relationship, the regression line should very nearly fit the points on the graph (that is, pass through or near the plotted points).
 - d. Rescale the axes on your graph by clicking or tapping Graph Tools, . Choose Edit Graph Options and set the x-axis to display 0 to 25 mL and the y-axis to display 0 to 300 kPa. Dismiss the Graph Options box.
 - e. (optional) Export, download, or print the graph with the curve fit displayed.
7. With the best-fit curve still displayed, proceed directly to the Processing the Data section.

DATA AND CALCULATIONS

Volume (mL)	Pressure (kPa)	Constant, k (P / V or $P \cdot V$)

PROCESSING THE DATA

1. With the best-fit curve still displayed, click or tap Graph Tools, , and turn on Interpolate. Dismiss the Graph Tools box and click the graph to interpolate. Move along the regression line until the volume value is 5.0 mL. Note the corresponding pressure value. Now move to the point where the volume value is doubled (10.0 mL). What does your data show happens to the pressure when the volume is *doubled*? Show the pressure values in your answer.
2. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *halved* from 20.0 mL to 10.0 mL? Show the pressure values in your answer.
3. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *tripled* from 5.0 mL to 15.0 mL? Show the pressure values in your answer.
4. From your answers to the first three questions *and* the shape of the curve in the plot of pressure *vs.* volume, do you think the relationship between the pressure and volume of a confined gas is direct or inverse? Explain your answer.
5. Based on your data, what would you expect the pressure to be if the volume of the syringe was increased to 40.0 mL? Explain or show work to support your answer.
6. Based on your data, what would you expect the pressure to be if the volume of the syringe was decreased to 2.5 mL? Explain or show work to support your answer.
7. What experimental factors are assumed to be constant in this experiment?
8. One way to determine if a relationship is inverse or direct is to find a proportionality constant, k , from the data. If this relationship is direct, $k = P/V$. If it is inverse, $k = P \cdot V$. Based on your answer to Question 4, choose one of these formulas and calculate k for the seven ordered pairs in your data table (divide or multiply the P and V values). Show the answers in the third column of the Data and Calculations table.
9. How *constant* were the values for k you obtained in Question 8? Good data may show some minor variation, but the values for k should be relatively constant.
10. Using P , V , and k , write an equation representing Boyle's law. Write a verbal statement that correctly expresses Boyle's law.

EXTENSION

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure *vs.* *reciprocal of volume* ($1/\text{volume}$) may also be plotted. To do this, it is necessary to create a new column of data, reciprocal of volume, based on your original volume data:
 - a. Click or tap More Options, , in the Volume column header in the table. Choose Add Calculated Column.
 - b. Enter **1/volume** as the Name and **1/mL** as the Units.

- c. Click or tap Insert Expression and choose A/X as the expression.
 - d. Enter **1** as Parameter A and select Volume as the Column.
 - e. Click or tap Apply.
2. Plot a best-fit regression line on your graph of pressure vs. $1/\text{volume}$:
- a. Click or tap Graph Tools, , and choose Edit Graph Options.
 - b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis.
 - c. Dismiss the Graph Options box. Your graph should now include the origin (0,0).
 - d. Click or tap Graph Tools, , and choose Apply Curve Fit.
 - e. Select Linear as the curve fit and Dismiss the Curve Fit box. The linear-regression statistics are displayed in the form:

$$y = mx + b$$

where x is $1/\text{volume}$, y is pressure, m is a proportionality constant, and b is the y-intercept.

- f. If the relationship between P and V is an inverse relationship, the graph of pressure vs. $1/\text{volume}$ should be direct; that is, the curve should be linear and pass through (or near) the origin. Examine your graph to see if this is true for your data.

Graphing Your Motion

Graphs made using a Motion Detector can be used to study motion. A Motion Detector measures the distance to the nearest object in front of it by emitting and receiving pulses of ultrasound. The data-collection software uses the position and time measurements to calculate velocity. In this experiment, you will use a Motion Detector to produce graphs of your own motion.

OBJECTIVES

- Use a Motion Detector to measure position and velocity.
- Analyze and interpret graphs of your motion.

CHOOSE A METHOD

Method 1: Bluetooth Connection—Use Method 1 if you are using a mobile device, such as a tablet or a phone, and connecting to a Go Direct Motion Detector via Bluetooth. You will hold the Motion Detector and measure your position and velocity relative to a wall.

Method 2: USB Connection—Use Method 2 if you are using a computer or Chromebook, and connecting the Motion Detector via USB. You will measure your position and velocity relative to a stationary Motion Detector.

MATERIALS

Materials for both Method 1 (Bluetooth connection) and Method 2 (USB connection)

Graphical Analysis 4 app
Go Direct Motion
meter stick
masking tape

Materials required only for Method 1 (Bluetooth connection)

mobile device

Materials required only for Method 2 (USB Connection)

computer or Chromebook

PROCEDURE

Method 1 Bluetooth Connection

Part I Position

1. Find an open area at least 2 m long in front of a wall. Use short strips of masking tape on the floor to mark distances of 0.5 m, 1 m, 1.5 m, and 2 m from the wall. You will be measuring your position from the Motion Detector in your hands to the wall.
2. Launch Graphical Analysis. Connect the Motion Detector to your mobile device.
3. Set up the software for data collection.
 - a. Click or tap Mode to open Data Collection Settings. Change End Collection to 5 s. Click or tap Done.
 - b. Click or tap View, , and choose 1 Graph.
4. Practice walking toward the wall holding the Motion Detector and mobile device. During data collection, the sensor portion of the Motion Detector should always point directly at the wall as shown in Figure 1. Sometimes you will have to walk backwards.

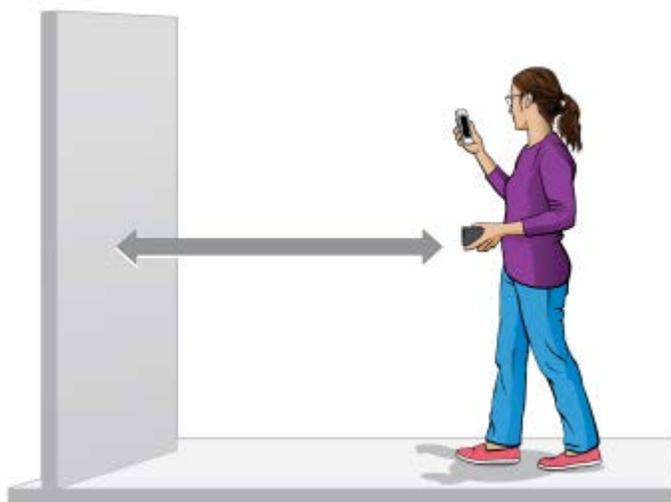


Figure 1

5. Create a position vs. time graph of your motion.
 - a. Stand at the 0.5 meter mark with the Motion Detector facing the wall.
 - b. Click or tap Collect to start data collection, and start walking slowly away from the wall.
 - c. After data collection is complete, discuss the graph with your partners.
6. Repeat Step 5, moving faster this time.
7. To display both data sets on a single graph, click or tap the y-axis label and select the data sets you want to display. Dismiss the box to view the graph. Print or sketch the graph of both data sets.

8. Match a position *vs.* time graph.
 - a. Click or tap Graph Tools, , and choose Add Graph Match. Then choose Position. A target graph will be displayed.
 - b. Examine the graph and plan what you will do to match it.
 - c. Take your starting position in front of the wall.
 - d. Start data collection and walk to match the graph on the screen.
 - e. When data collection is complete, examine the graph of the results. If you would like to try matching the same graph, start data collection again when you are ready to stalk walking.
 - f. Sketch or print a graph of your results in the space provided. **Important:** Include *both* the target line *and* the graph of your motion. Then, describe what you had to do to match the first graph.
9. Repeat Step 8 so everyone in your group has a chance to match a position *vs.* time graph. **Note:** Each time you choose Add Graph Match > Position, a new target graph will be displayed.

PROCESSING THE DATA (PART I)

1. Describe the difference between the two lines on your graph made in Steps 5–6. Explain why the lines are different.
2. How would the graph change if you walked toward the wall rather than away from it? Test your answer using the Motion Detector.
3. What did you have to do to match the graph you were given in Step 8?
4. Sketch a position *vs.* time graph for a car that moves slowly down the street, stops at a stop sign, then moves slowly again in the same direction as before.



Part II Velocity

10. Remove the position motion match from your graph and display a velocity *vs.* time graph.
 - a. Tap the y-axis label and deselect the Position Target data.
 - b. Before dismissing the box, select the most recent velocity data. When you dismiss the box, ensure a graph of velocity *vs.* time is displayed.

Graphing Your Motion

11. Create a velocity vs. time graph of your motion.
 - a. Stand at the 0.5 meter mark with the Motion Detector facing the wall.
 - b. Start data collection, and start walking slowly away from the wall.
 - c. After data collection is complete, discuss the graph with your partners.
12. Repeat Step 11, moving faster this time.
13. To display both data sets on a single graph, click or tap the y-axis label and select the data sets you want to display. Dismiss the box to view the graph. Print or sketch the graph of both sets.
14. Graphical Analysis can also generate random target velocity graphs for you to match. Click or tap Graph Tools, , choose Add Graph Match, and then choose Velocity.
15. Write down how you would walk to produce this target graph.
16. To test your prediction, choose a starting position and stand at that point. Start data collection, and walk in such a way that the graph of your motion matches the target graph on the screen. It will be more difficult to match the velocity graph than it was for the position graph .
17. If you were not successful and want to match the same target graph again, start data collection when you are ready to start walking. Repeat this process until your motion closely matches the graph on the screen. Print or sketch the graph with your best attempt.
18. Repeat Steps 13–17 so everyone in your group has a chance to match a velocity vs. time graph. **Note:** When you click or tap Graph Tools, , choose Add Graph Match, and then choose Velocity, a new match will be displayed.

PROCESSING THE DATA (PART II)

5. Describe the difference between the two lines on the graph made in Steps 11–12. Explain why the lines are different.
6. What is the definition of velocity?
7. What did you have to do to match the graph you were given in Step 14? How well does your graph agree with the graph provided?



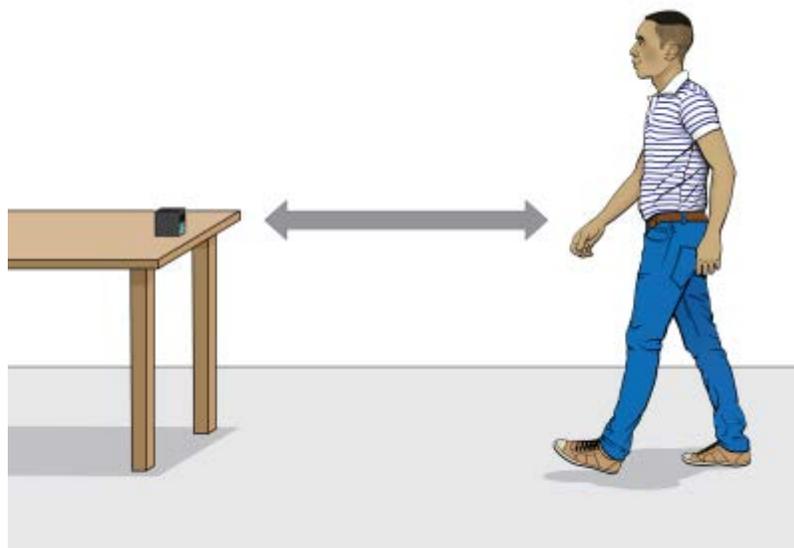
8. Sketch a velocity vs. time graph for a person who walks, stops for a few seconds, and then runs.



Method 2 USB Connection with Computers or Chromebooks

Part I Position

1. Place the Motion Detector so that it points toward an open space at least 2 m long. Use short strips of masking tape on the floor to mark distances of 0.5 m, 1 m, 1.5 m, and 2 m from the Motion Detector.
2. Launch Graphical Analysis. Connect the Motion Detector to your Chromebook or computer.
3. Set up the software for data collection.
 - a. Click or tap Mode to open Data Collection Settings. Change End Collection to 5 s. Click or tap Done.
 - b. Click or tap View, , and choose 1 Graph.
4. Practice walking in front of the Motion Detector. During data collection, you will walk back and forth in front of the Motion Detector, while always facing toward the sensor. Sometimes you will have to walk backwards.



Graphing Your Motion

5. Create a position *vs.* time graph of your motion.
 - a. Stand at the 0.5 meter mark facing the Motion Detector.
 - b. Click or tap Collect to start data collection, and start walking slowly away from the Motion Detector.
 - c. After data collection is complete, discuss the graph with your partners.
6. Repeat Step 5, moving faster this time.
7. To display both data sets on a single graph, click or tap the y-axis label and select the data sets you want to display. Dismiss the box to view the graph. Print or sketch the graph of both data sets.
8. Match a position *vs.* time graph.
 - a. Click or tap Graph Tools, , and choose Add Graph Match. Then choose Position. A target graph will be displayed.
 - b. Examine the graph and plan what you will do to match it.
 - c. Take your starting position in front of the Motion Detector.
 - d. Start data collection and walk to match the graph on the screen.
 - e. When data collection is complete, examine the graph of the results. If you would like to try matching the same graph, start data collection again when you are ready to start walking.
 - f. Sketch or print a graph of your results in the space provided. **Important:** Include *both* the target line *and* the graph of your motion. Then, describe what you had to do to match the first graph.
9. Repeat Step 8 so everyone in your group has a chance to match a position *vs.* time graph. **Note:** Each time you choose Add Graph Match > Position, a new target graph will be displayed.

PROCESSING THE DATA (PART I)

1. Describe the difference between the two lines on your graph made in Steps 5–6. Explain why the lines are different.
2. How would the graph change if you walked toward the Motion Detector rather than away from it? Test your answer using the Motion Detector.
3. What did you have to do to match the graph you were given in Step 8?
4. Sketch a position *vs.* time graph for a car that moves slowly down the street, stops at a stop sign, then moves slowly again in the same direction as before.



Part II Velocity

10. Remove the position motion match from your graph and display a velocity *vs.* time graph.
 - a. Tap the y-axis label and deselect the Position Target data.
 - b. Before dismissing the box, select the most recent velocity data. When you dismiss the box, ensure a graph of velocity *vs.* time is displayed.
11. Create a velocity *vs.* time graph of your motion.
 - a. Stand at the 0.5 meter mark facing the Motion Detector.
 - b. Start data collection, and start walking slowly away from the wall.
 - c. After data collection is complete, discuss the graph with your partners.
12. Repeat Step 11, moving faster this time.
13. To display both data sets on a single graph, click or tap the y-axis label and select the data sets you want to display. Dismiss the box to view the graph. Print or sketch the graph of both sets.
14. Graphical Analysis can also generate random target velocity graphs for you to match. Click or tap Graph Tools, , choose Add Graph Match, and then choose Velocity.
15. Write down how you would walk to produce this target graph.
16. To test your prediction, choose a starting position and stand at that point. Start data collection, and walk in such a way that the graph of your motion matches the target graph on the screen. It will be more difficult to match the velocity graph than it was for the position graph .
17. If you were not successful and want to match the same target graph again, start data collection when you are ready to start walking. Repeat this process until your motion closely matches the graph on the screen. Print or sketch the graph with your best attempt.
18. Repeat Steps 13–17 so everyone in your group has a chance to match a velocity *vs.* time graph. **Note:** When you click or tap Graph Tools, , choose Add Graph Match, and then choose Velocity, a new match will be displayed.

PROCESSING THE DATA (PART II)

5. Describe the difference between the two lines on the graph made in Steps 11–12. Explain why the lines are different.
6. What is the definition of velocity?
7. What did you have to do to match the graph you were given in Step 14? How well does your graph agree with the graph provided?



8. Sketch a velocity vs. time graph for a person who walks, stops for a few seconds, and then runs.



Impulse and Momentum (Sensor Cart)

The impulse-momentum theorem relates impulse, the average force applied to an object times the length of time the force is applied, and the change in momentum of the object:

$$\overline{F}\Delta t = mv_f - mv_i$$

Here, we will only consider motion and forces along a single line. The average force, \overline{F} , is the *net* force on the object, but in the case where one force dominates all others, it is sufficient to use only the large force in calculations and analysis.

For this experiment, a Sensor Cart equipped with a hoop string will roll along a level track. Its momentum will change as it collides with the end stop at the end of the track. The hoop will compress and apply an increasing force until the cart stops. The cart then changes direction and the hoop expands back to its original shape. The force applied by the spring and cart velocity throughout the motion are measured by the Sensor Cart. You will then use data-collection software to find the impulse to test the impulse-momentum theorem.

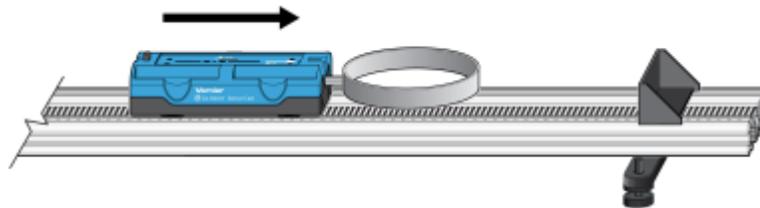


Figure 1

OBJECTIVES

- Measure a cart's momentum change and compare it to the impulse it receives.
- Compare average and peak forces in impulses.

MATERIALS

Chromebook, computer, **or** mobile device
 Graphical Analysis 4 app
 Go Direct Sensor Cart
 Vernier Dynamics Track
 Accessories from the Bumper and Launcher Kit, including Hoop Bumper, clay, and clay holder

PRELIMINARY QUESTIONS

1. In a car collision, the driver's body must change speed from a high value to zero. This is true whether or not an airbag is used, so why use an airbag? How does it reduce injuries?
2. Two playground balls, the type used in the game of dodgeball, are inflated to different levels. One is fully inflated and the other is flat. Which one would you rather be hit with? Why?

PROCEDURE

1. Attach the hoop spring to the Sensor Cart. Measure the mass of the cart and record the value in the data table.
2. Attach the End Stop to the end of the track as shown in Figure 1.

Place the track on a level surface. Confirm that the track is level by placing the cart on the track and releasing it from rest. It should not roll. If necessary, adjust the track to level it.

3. Launch Graphical Analysis. Connect the Go Direct Sensor Cart to your Chromebook, computer, or mobile device.
4. Enable the Force channel in addition to the Position channel.
5. Zero the Force channel.
 - a. Remove all force from the hoop spring.
 - b. Click or tap the Force meter and choose Zero.
 - c. Dismiss the Force meter box.
6. Set up the data-collection mode.
 - a. Click or tap Mode to open data-collection settings.
 - b. Change the Rate to 250 samples/s and End Collection to 5 s.
 - c. Click or tap Done.

Part I Elastic collisions

7. Practice releasing the cart so it rolls toward the end stop, bounces gently, and returns to your hand. The cart must stay on the track.
8. Position the cart so that the cart is approximately 50 cm from the end stop. Click or tap Collect to start data collection, then roll the cart as you practiced in the previous step..
9. Study your graphs to determine if the run was useful. Confirm that you can see a region of constant velocity before and after the impact. If necessary, repeat data collection.

10. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse. To find these values, work with the graph of velocity *vs.* time.
 - a. On the Velocity graph, select an interval corresponding to a time before the impulse, when the cart was moving at approximately constant speed toward the end stop.
 - b. Click or tap graph Tools, , and choose View Statistics. Read the average velocity before the collision (v_i) and record the value in the data table.
 - c. Dismiss the Statistics box.
 - d. Repeat parts a–c of this step to determine the average velocity just after the impulse, when the cart was moving at approximately constant speed away from the end stop. Record this value in the data table.
11. Now you will calculate the value of the impulse. Use the first method if you have studied calculus and the second if you have not.

Method 1 Calculus version

Calculus tells us that the expression for the impulse is equivalent to the integral of the force *vs.* time graph, or

$$\bar{F}\Delta t = \int_{t_{\text{initial}}}^{t_{\text{final}}} F(t) dt$$

Calculate the integral of the impulse on your force *vs.* time graph.

- a. Select the region that represents the impulse (begin at the point where the force becomes non-zero).
- b. Click or tap graph tools, , and choose View Integral.
- c. Read the value of the integral of the force data, the impulse value, and record the value in the data table.

Method 2 Non-calculus version

Calculate the impulse from the average force on your force *vs.* time graph. The impulse is the product of the average (mean) force and the length of time that force was applied, or $\bar{F}\Delta t$.

- a. Select the region that represents the impulse (begin at the point where the force becomes non-zero).
- b. Click or tap Graph Tools, , and choose View Statistics.
- c. Record this value for the average (mean) force in the data table.
- d. Read the duration of the time interval. To determine this value, note the number of points used in the average (N), and multiply by 0.004 s, the time interval between points. Record this product, Δt , in your data table.
- e. From the average force and time interval, determine the impulse, $\bar{F}\Delta t$, and record this value in your data table.

Impulse and Momentum (Sensor Cart)

- Repeat Steps 8–11 two more times to collect a total of three trials; record the information in your data table.

Part II Inelastic collisions

- Replace the hoop spring bumper with one of the clay holders from the Bumper and Launcher Kit. Attach cone-shaped pieces of clay to both the clay holder and to the end stop, as shown in Figure 2. Measure the mass of the cart and record the value in the data table.

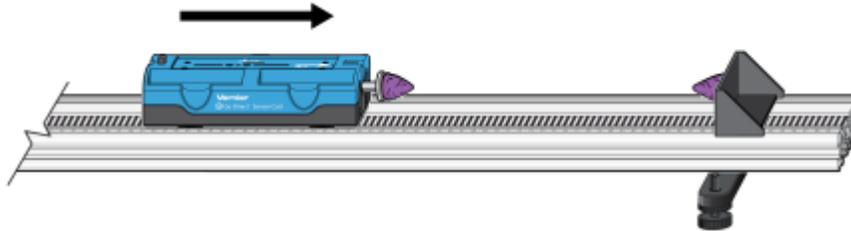


Figure 2

- Click or tap the Force meter and choose *Zero* to zero the Force Sensor.
- Practice launching the cart so that when the clay on the front of the cart collides with the clay on the end stop, the cart comes to a stop without bouncing.
- Position the cart so that the cart is approximately 50 cm from the spring. Click or tap *Collect* to start data collection, then roll the cart so that the clay pieces impact one another.
- Study your graphs to determine if the run was useful. Confirm that you can see a region of constant velocity before and after the impact. If necessary, reshape the clay pieces and repeat data collection.
- Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse.
 - On the Velocity graph, Select the interval corresponding to the time before the impact. Click or tap Graph Tools, , and choose *View Statistics*. Record the average velocity in the data table.
 - Dismiss the Statistics box.
 - Select the interval corresponding to the time after the impact. Click or tap Graph Tools, , and choose *View Statistics*. Record the average velocity in the data table.
 - Dismiss the Statistics box.
- Now you will calculate the value of the impulse. Similar to Step 11, use the first method if you have studied calculus and the second if you have not.

Method 1 Calculus version

Calculate the integral of the impulse on your force vs. time graph.

- Select the impulse, then click or tap graph Tools, , and choose *View Integral*.
- Record the impulse value in the data table.

Method 2 Non-calculus version

Calculate the impulse from the average force on your force vs. time graph.

- a. Select the impulse. Click or tap Graph Tools, , and choose View Statistics. Record the average force in the data table.
 - b. Read the length of the time interval. To determine this value, note the number of points used in the average (N), and multiply by 0.004 s, the time interval between points. Record this product, Δt , in your data table.
 - c. From the average force and time interval, determine the impulse, $\bar{F}\Delta t$, and record this value in your data table.
20. Repeat Steps 16–19 two more times to collect a total of three trials; record the information in your data table. **Note:** You will need to reshape the clay pieces before each trial.

DATA TABLE

Mass of cart	kg
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Method 1 Calculus version						
Trial	Final velocity v_f (m/s)	Initial velocity v_i (m/s)	Change of velocity Δv (m/s)	Impulse (N·s)	Change in momentum (kg·m /s) or (N·s)	% difference between Impulse and Change in momentum
Elastic 1						
2						
3						
Inelastic 1						
2						
3						

Impulse and Momentum (Sensor Cart)

Method 2 Non-calculus version								
Trial	Final velocity v_f (m/s)	Initial velocity v_i (m/s)	Change of velocity Δv (m/s)	Average force \bar{F} (N)	Duration of impulse Δt (s)	Impulse $\bar{F}\Delta t$ (N·s)	Change in momentum (kg·m /s) or (N·s)	% difference between Impulse and Change in momentum
Elastic 1								
2								
3								
Inelastic 1								
2								
3								

ANALYSIS

1. Calculate the change in velocities and record the result in the data table. From the mass of the cart and the change in velocity, determine the change in momentum that results from the impulse. Make this calculation for each trial and enter the values in the data table.
2. If the impulse-momentum theorem is correct, the change in momentum will equal the impulse for each trial. Experimental measurement errors, along with friction and shifting of the track or Dual-Range Force Sensor, will keep the two from being exactly the same. One way to compare the two is to find their percentage difference. Divide the difference between the two values by the average of the two, then multiply by 100%. How close are your values, percentage-wise? Do your data support the impulse-momentum theorem?
3. Look at the shape of the last force vs. time graph. Is the peak value of the force significantly different from the average force? Is there a way you could deliver the same impulse with a much smaller force?
4. Revisit your answers to the Preliminary Questions in light of your work with the impulse-momentum theorem.

Cell Respiration

(CO₂ Gas Sensor)

Cell respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available by the following equation:



All organisms, including plants and animals, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. It is known that peas undergo cell respiration during germination. Do peas undergo cell respiration before germination? The results of this experiment will verify that germinating peas do respire. Using your collected data, you will be able to answer the question concerning respiration and non-germinating peas.

Using the CO₂ Gas Sensor, you will monitor the carbon dioxide produced by peas during cell respiration. Both germinating and non-germinating peas will be tested. Additionally, cell respiration of germinating peas at two different temperatures will be tested.

OBJECTIVES

- Use a CO₂ Gas Sensor to measure concentrations of carbon dioxide.
- Study the effect of temperature on cell respiration.
- Determine whether germinating and non-germinating peas respire.
- Compare the rates of cell respiration in germinating and non-germinating peas.



Figure 1

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct CO₂ Gas
250 mL respiration chamber
25 germinating peas
25 non-germinating peas
ice water
thermometer
100 mL beaker
paper towels
goggles

PROCEDURE

1. Launch Graphical Analysis. Connect the CO₂ Gas Sensor to your Chromebook, computer, or mobile device.
2. Set up the data-collection mode.
 - a. Click or tap Mode to open Data Collection Settings.
 - b. Change End Collection to 300 s. Click or tap Done.
3. Measure the room temperature using a thermometer and record the temperature in Table 1.
4. Obtain 25 germinating peas and blot them dry between two pieces of paper towel.
5. Place the germinating peas into the respiration chamber.
6. Place the shaft of the CO₂ Gas Sensor in the opening of the respiration chamber. Gently push the sensor down into the chamber until it stops. The sensor is designed to seal the chamber without the need for unnecessary force.
7. Wait one minute, then click or tap Collect to start data collection. Data will be collected for 5 minutes.
8. When data collection has finished, remove the CO₂ Gas Sensor and peas from the respiration chamber. Place the peas in a 100 mL beaker filled with cold water and an ice cube.
9. Use a notebook or notepad to fan air across the openings in the probe shaft of the CO₂ Gas Sensor for 1 minute.
10. Fill the respiration chamber with water and then completely empty it to remove residual gas from the peas. Thoroughly dry the inside of the respiration chamber with a paper towel.
11. Perform a linear regression to calculate the rate of respiration.
 - a. Click or tap Graph Tools, , and choose Apply Curve Fit.
 - b. Select Linear as the curve fit. Click or tap Apply.

- c. Enter the slope, m , as the rate of respiration in Table 2.
 - d. Dismiss the Linear curve fit box.
12. Obtain 25 non-germinating peas and place them in the respiration chamber.
 13. Repeat Steps 6–11 with non-germinating peas. In Step 8 place the non-germinating peas on a paper towel and not in the ice bath. **Note:** The previous data set is automatically saved.

Part II germinating peas, cool temperatures

14. Remove the peas from the cold water and blot them dry between two paper towels.
15. Use the thermometer to measure the temperature of the ice water. Record the temperature in Table 1.
16. Repeat Steps 5–11 using the cold peas. In Step 9 place the cold germinating peas on a paper towel and not back in the ice bath.
17. To display multiple data sets on a single graph, click or tap the y-axis label and select the data sets you want to display. Dismiss the box to view the graph. Continue to the Analysis Questions.

DATA

Table 1	
Condition	Temperature (°C)
Room	
Ice water	

Table 2	
Peas	Rate of respiration (ppm/s)
Germinating, room temperature	
Non-germinating, room temperature	
Germinating, cool temperature	

Cell Respiration

QUESTIONS

1. Do you have evidence that cell respiration occurred in peas? Explain.
2. What is the effect of germination on the rate of cell respiration in peas?
3. What is the effect of temperature on the rate of cell respiration in peas?
4. Why do germinating peas undergo cell respiration?

EXTENSIONS

1. Compare the respiration rate among various types of seeds.
2. Compare the respiration rate among seeds that have germinating for different time periods, such as 1, 3, and 5 days.
3. Compare the respiration rates of various small animal types, such as insects or earthworms.