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Introduction to Vernier: Tools, Training, and Resources for Educators

Experiments

A Hot Hand

- Go Direct® Temperature Probe

Boyle's Law: Pressure-Volume Relationship in Gases

- Go Direct Gas Pressure Sensor

Ball Toss

- Go Direct Motion Detector

Workshop Presenter

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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 app
Go Direct Temperature
beaker
water
paper towel

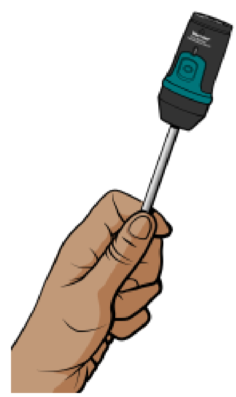

Figure 1

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 s 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.

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 group.

DATA

Student name	Maximum temperature (°C)
Group average	

PROCESSING THE DATA

1. Calculate the group average for the highest temperatures. Record the result in the data table.

2. How did the maximum temperature for each person 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.

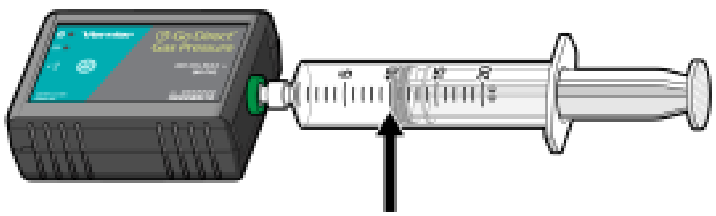

Figure 1

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.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 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.

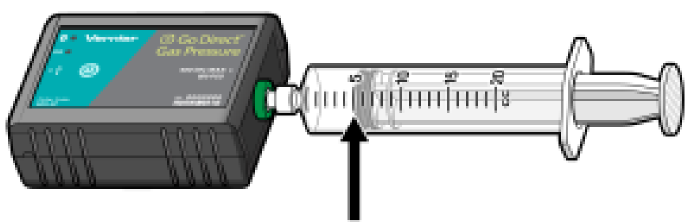

Figure 2

   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 Options, 📈, 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 Options, . 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 • V)

PROCESSING THE DATA

1. With the best-fit curve still displayed, click or tap Graph Options, , and turn on Interpolate. Dismiss the 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, $k = P \bullet V$. 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/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/volume:

   a. Click or tap Graph Options, 📈, 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 Options, 📈, 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/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/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.

Ball Toss

When a juggler tosses a ball straight upward, the ball slows down until it reaches the top of its path. The ball then speeds up on its way back down. A graph of its velocity *vs.* time would show these changes. Is there a mathematical pattern to the changes in velocity? What is the accompanying pattern to the position *vs.* time graph? What would the acceleration *vs.* time graph look like?

In this experiment, you will use a motion detector to collect position, velocity, and acceleration data for a ball thrown straight upward. Analysis of the graphs of this motion will answer the questions asked above.

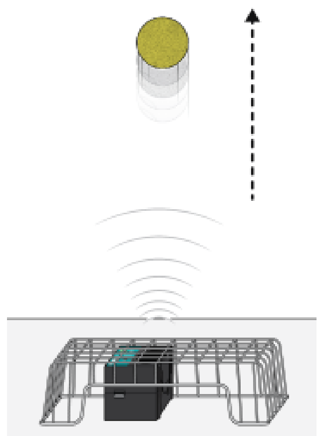

Figure 1

OBJECTIVES

- Collect position, velocity, and acceleration data as a ball travels straight up and down.
- Analyze position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best-fit equations for the position *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Motion
volleyball **or** basketball
wire basket

PRELIMINARY QUESTIONS

1. Consider the motion of a ball as it travels straight up and down in freefall. Sketch your prediction for the position *vs.* time graph. Describe in words what this graph means.

2. Sketch your prediction for the velocity *vs.* time graph. Describe in words what this graph means.

3. Sketch your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

PROCEDURE

1. Launch Graphical Analysis. Connect the motion detector to your Chromebook, computer, or mobile device.

2. Place the motion detector on the floor and protect it by placing a wire basket over it.

3. Collect data. During data collection you will toss the ball straight upward above the motion detector and let it fall back toward the motion detector. It may require some practice to collect clean data. To achieve the best results, keep in mind the following tips:

   - Hold the ball approximately 0.5 m directly above the motion detector when you start data collection.
   - A toss so the ball moves from 0.5 m to 1.0 m above the motion detector works well.
   - After the toss, catch the ball at a height of 0.5 m above the motion detector and hold it still until data collection is complete.
   - Use two hands and pull your hands away from the ball after it starts moving so they are not picked up by the motion detector.

   When you are ready to collect data, click or tap Collect to start data collection and then toss the ball as you have practiced.

DATA TABLE

Curve fit parameters	A	B	C
Position ($Ax^2 + Bx + C$)			
Velocity ($Ax + B$)			
Average acceleration			

ANALYSIS

1. Export, print, or sketch the three motion graphs. To display an acceleration *vs*. time graph, change the y-axis of the velocity graph to Acceleration. The graphs you have recorded are fairly complex and it is important to identify different regions of each graph. Record your answers directly on your copy of the graphs.

   a. Identify the region when the ball was being tossed but was still in your hands.

   - Examine the velocity *vs*. time graph and identify this region. Label this on the graph.
   - Examine the acceleration *vs*. time graph and identify the same region. Label this on the graph.

   b. Identify the region where the ball is in free fall.

   - Label the region on each graph where the ball was in free fall and moving upward.
   - Label the region on each graph where the ball was in free fall and moving downward.

   c. Determine the position, velocity, and acceleration at these specific points.

   - On the velocity *vs*. time graph, locate where the ball had its maximum velocity, after the ball was released. Mark the spot and record the value on the graph.
   - On the position *vs*. time graph, locate the maximum height of the ball during free fall. Mark the spot and record the value on the graph.
   - What was the velocity of the ball at the top of its motion?
   - What was the acceleration of the ball at the top of its motion?

2. The motion of an object in free fall is modeled by $y = \frac{1}{2} gt^2 + v_0t + y_0$ where y is the vertical position, g is the magnitude of the free-fall acceleration, t is time, and v_0 is the initial velocity. This is a quadratic equation whose graph is a parabola.

   Examine the position *vs*. time graph to see if it is a parabola in the region where the ball was in freefall. If it is, fit a quadratic equation to your data.

   a. Select the data in the region that corresponds to when the ball was in freefall.

   b. Click or tap Graph Options, , for the position *vs*. time graph and choose Apply Curve Fit.

   c. Select Quadratic as the curve fit and click or tap Apply.

   d. Record the parameters of the curve fit in the data table.

3. How closely does the coefficient of the x^2 term in the curve fit compare to ½ g?

4. What does a linear segment of a velocity *vs*. time graph indicate? What is the significance of the slope of that linear segment?

5. Display a graph of velocity *vs*. time. This graph should be linear in the region where the ball was in freefall. Fit a linear equation to your data in this region.

   a. Select the data in the region that corresponds to when the ball was in freefall.

   b. Click or tap Graph Options, , for the velocity *vs*. time graph and choose Apply Curve Fit.

   c. Select Linear as the curve fit and click or tap Apply.

   d. Record the parameters of the curve fit in the data table.

6. How closely does the coefficient of the *x* term compare to the accepted value of *g*?

7. Examine the graph of acceleration *vs.* time. During free fall, the acceleration graph should appear to be more or less constant. Note that because the graph is automatically scaled to fill the screen vertically, small variations may appear large. A good way to analyze the acceleration data is to find the mean (average) of these data points.

   a. Click or tap Graph Options, , and choose View Statistics.
   b. Record the mean acceleration value in your data table.

8. How closely does the mean acceleration value compare to the values of *g* found in Steps 3 and 6?

9. List some reasons why your values for the ball's acceleration may be different from the accepted value for *g*.

EXTENSIONS

1. Determine the consistency of your acceleration values and compare your measurement of *g* to the accepted value of *g*. Do this by repeating the ball toss experiment five more times. Each time, fit a straight line to the free-fall portion of the velocity graph and record the slope of that line. Average your six slopes to find a final value for your measurement of *g*. Does the variation in your six measurements explain any discrepancy between your average value and the accepted value of *g*?

2. The ball used in this lab is large enough and light enough that a buoyant force and air resistance may affect the acceleration. Perform the same curve fitting and statistical analysis techniques, but this time analyze each half of the motion separately. How do the fitted curves for the upward motion compare to the downward motion? Explain any differences.

3. Perform the same lab using a beach ball or other very light, large ball.

4. Use a smaller, more dense ball where buoyant force and air resistance will not be a factor. Compare the results to your results with the larger, less dense ball.

5. Instead of throwing a ball upward, drop a ball and have it bounce on the ground. (Position the motion detector above the ball.) Predict what the three graphs will look like, then analyze the resulting graphs using the same techniques as this lab.