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Physics Essentials: Getting Started with Vernier

Experiments

Ball Toss

- Go Direct® Motion Detector

Newton's Third Law

- Go Direct Force and Acceleration Sensor

Impulse and Momentum

- Go Direct Sensor Cart

Ohm's Law

- Go Direct Current Probe
- Go Direct Voltage Probe

Workshop Presenter

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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.

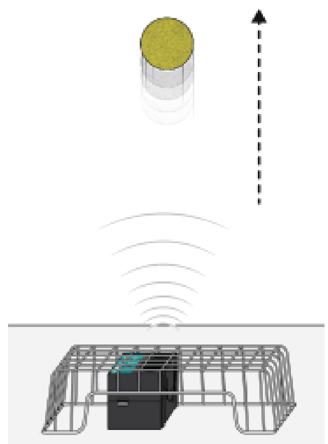

Figure 1

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 $y = ½ gt^2 + v_0t + y_0$ 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.

Newton's Third Law

You may have learned this statement of Newton's third law: "To every action there is an equal and opposite reaction." What does this sentence mean? This experiment will help you investigate this question.

Unlike Newton's first two laws of motion, which concern only individual objects, the third law describes an interaction between two bodies. For example, what if you pull on your partner's hand with your hand? To study this interaction, you can use two Force Sensors. As one object (your hand) pushes or pulls on another object (your partner's hand), the Force Sensors will record those pushes and pulls. They will be related in a very simple way as predicted by Newton's third law.

The *action* referred to in the phrase above is the force applied by your hand, and the *reaction* is the force that is applied by your partner's hand. Together, they are known as a *force pair*. This short experiment will show how the forces are related.

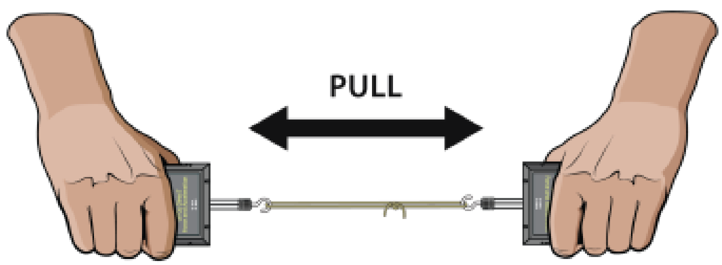

Figure 1

OBJECTIVES

- Observe the directional relationship between force pairs.
- Observe the time variation of force pairs.
- Explain Newton's third law in simple language.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
two Go Direct Force and Acceleration Sensors
500 g mass
string
rubber band

PRELIMINARY QUESTIONS

Answer these questions as best you can. You will have a chance to revisit your answers after the activity.

1. You are driving down the highway and a bug splatters on your windshield. Which is greater: the force of the bug on the windshield or the force of the windshield on the bug?

2. Hold a rubber band between your right and left hands. Pull with your left hand. Does your right hand experience a force? Does your right hand apply a force to the rubber band? What direction is that force compared to the force applied by the left hand?

3. Pull harder with your left hand. Does this change any force applied by the right hand?

4. How is the force of your left hand, transmitted by the rubber band, related to the force applied by your right hand? Write a rule, in words, for the force relationship.

PROCEDURE

1. Launch Graphical Analysis. Connect both Go Direct Force and Acceleration Sensors to your Chromebook, computer, or mobile device.

   Force sensors measure force only along one direction; if you apply a force along another direction, your measurements will not be meaningful. The force sensor responds to force directed parallel to the long axis of the sensor.

2. (Optional) Because you will be comparing the readings of two different force sensors, it is important that they both read force accurately. To increase the accuracy of the sensors, you will calibrate them.

   a. Identify the force sensor connected to the first Force meter. Click or tap the first Force meter and choose Calibrate.
   b. Hold the force sensor so that you can hang a weight from it, but do not attach weight yet.
   c. Enter **0** (zero) as the first known value, and then click or tap Keep.
   d. Hang a 4.9 N weight (500 g) from the sensor.
   e. Enter **4.9** as the second known value, and then click or tap Keep.
   f. Click or tap Apply.
   g. Repeat this step for the second force sensor.

3. Set up the force sensors so they read the same magnitude under the same force, but with opposite signs. To do this, you will zero both sensors and then reverse the direction of one of them. When you are done, a pull on one sensor produces a positive reading while a pull on the other produces a negative reading.

   a. Place both sensors on a flat surface so the measurement axis is horizontal and there is no force applied to either hook.
   b. Click or tap the first Force meter and choose Zero. With the sensors in the same position, click or tap the second Force meter and choose Zero. The readings for the sensors should be close to zero.
   c. Click or tap the second Force meter and turn on Reverse to change the sign.

4. Make a loop of string with a circumference of about 30 cm. Use it to attach the hooks of the force sensors. Hold one force sensor in your hand and have your partner hold the other so you can gently pull on each other using the string as an intermediary. Be careful to apply force only along the sensitive direction of your particular force sensor.

5. Click or tap Collect to start data collection. *Gently* tug on your partner's force sensor with your force sensor. Also, have your partner tug on your sensor. You will have 10 seconds to try different pulls.

6. After data collection is complete, examine the graph of force *vs.* time. If either plot has force peaks with flat tops, you pulled too hard. Try again, pulling with less force. To take more data, start data collection again. **Note**: The previous data set is automatically saved.

7. Export, print, or sketch your graph.

8. What would happen if you used the rubber band instead of the string? Would some of the force get "used up" in stretching the band? Sketch a prediction graph of the two force readings in your notes, and repeat Steps 5–7 using the rubber band instead of the string.

ANALYSIS

1. Examine the two data sets. What can you conclude about the two forces (your pull on your partner and your partner's pull on you)? How are the magnitudes related? How are the signs related? **Note**: To display other data sets, click or tap the y-axis label and select only the columns you want to display.

2. How does the rubber band change the results—or does it change them at all?

3. While you and your partner are pulling on each other's force sensors, do your force sensors have the same positive direction? How does your answer affect the analysis of the force pair?

4. Is there any way to pull on your partner's force sensor without your partner's force sensor pulling back? Try it.

5. Reread the statement of the third law given at the beginning of this activity. The phrase *equal and opposite* must be interpreted carefully, since for two vectors to be equal ($\vec{A} = \vec{B}$) and opposite ($\vec{A} = -\vec{B}$) then we must have $\vec{A} = \vec{B} = 0$; that is, both forces are always zero. What is really meant by *equal and opposite*? Restate Newton's third law in your own words, not using the words "action," "reaction," or "equal and opposite."

6. Re-evaluate your answers to the preliminary questions.

EXTENSIONS

1. Fasten one force sensor to your lab bench and repeat the experiments. Does the bench pull back as you pull on it? Does it matter that the second force sensor is not held by a person?

2. Use a rigid rod to connect your force sensors instead of a string and experiment with mutual pushes instead of pulls. Repeat the experiments. Does the rod change the way the force pairs are related?

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 average *net* force on the object, but in the case where one force dominates and other forces are negligible, it is sufficient to use only the large force in calculations and analysis.

For this experiment, a Sensor Cart equipped with a hoop bumper 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. Both the force applied to the spring and the cart velocity throughout the motion are measured by the Sensor Cart. You will then use data-collection software to determine the impulse in order to test the impulse-momentum theorem.

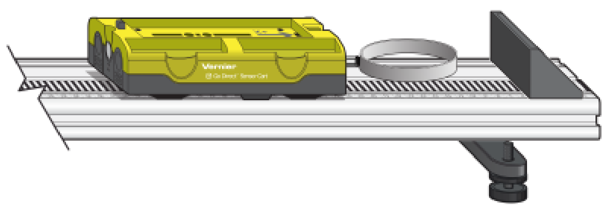

Figure 1

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 app
Go Direct Sensor Cart
Vernier Dynamics Track
accessories from the Bumper and Launcher Kit: 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 bumper to the 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.

3. 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.

4. Set up the sensor and data-collection software.

   a. Launch Graphical Analysis.
   b. Connect the Go Direct Sensor Cart to your Chromebook, computer, or mobile device.
   c. Click or tap Sensor Channels.
   d. Enable the Force channel in addition to the Position channel. Click or tap Done.

5. Zero the Force channel.

   a. Remove all force from the hoop bumper.
   b. Click or tap the Force meter and choose Zero.

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. 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 Options, , and choose View Statistics. Read the average velocity before the collision (v_i) and record the value in the data table.
    c. Dismiss or collapse 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

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

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 Options, , 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 Options, , and choose View Statistics.
c. Record the average (mean) force value in the data table.
d. Since time is on the horizontal axis of the graph, the Δx provided in the statistics is the Δt for the selected region. Record this value as 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.

12. 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

13. Replace the hoop 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.

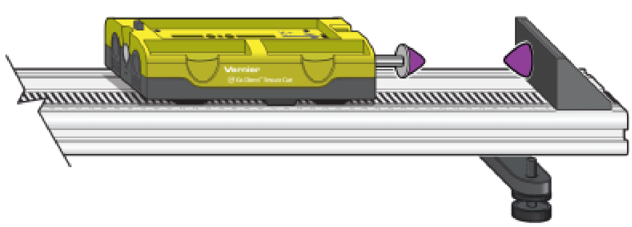

Figure 2

14. Place the cart on the track as shown in Figure 2. Click or tap the Force meter and choose Zero to zero the Force Sensor.

15. 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.

16. 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 so that the clay pieces collide and stick together.

17. 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.

18. 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.

    a. On the Velocity graph, select the interval corresponding to the time before the impact. Click or tap Graph Options, , and choose View Statistics. Record the average velocity in the data table.
    b. Dismiss the Statistics box.
    c. Select the interval corresponding to the time after the impact. Then, click or tap Graph Options, , and choose View Statistics. Record the average velocity in the data table.
    d. Dismiss the Statistics box.

19. 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.

    a. If needed, select a region of the graph that includes the impulse and click or tap Zoom to Selection, .
    b. Select the region that represents the impulse (begin at the point where force becomes non-zero).
    c. Choose View Integral in the menu.
    d. 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. If needed, select a region of the graph that includes the impulse and click or tap Zoom to Selection, .
    b. Select the region that represents the impulse (begin at the point where force becomes non-zero).
    c. Choose View Statistics from the menu. Record the average force in the data table.
    d. Since time is on the horizontal axis of the graph, the Δx provided in the statistics is the Δt for the selected region. Record this value as 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.

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 TABLES

Mass of cart (elastic collision)	kg
Mass of cart (inelastic collision)	kg

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						

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, 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.

Ohm's Law

The fundamental relationship among the three important electrical quantities *current*, *potential difference (voltage)*, and *resistance* was discovered by Georg Simon Ohm. The relationship and the unit of electrical resistance were both named for him to commemorate this contribution to physics. One statement of Ohm's law is that the current through a resistor is proportional to the potential difference, in volts, across the resistor. In this experiment, you will see if Ohm's law is applicable to several different circuits using a Go Direct Current Probe and a Go Direct Voltage Probe.

Current and potential difference can be difficult to understand because they cannot be observed directly. To clarify these terms, some people make the comparison between electrical circuits and water flowing in pipes. Here is a chart of the three electrical units we will study in this experiment.

Electrical quantity	Description	Unit	Water analogy
Potential Difference or Voltage	A measure of the energy difference per unit charge between two points in a circuit.	volt (V)	Difference in water pressure between two points
Current	A measure of the flow of charge in a circuit.	ampere (A)	Rate of water flow
Resistance	A measure of how difficult it is for current to flow in a circuit.	ohm (Ω)	A measure of how difficult it is for water to flow through a pipe.

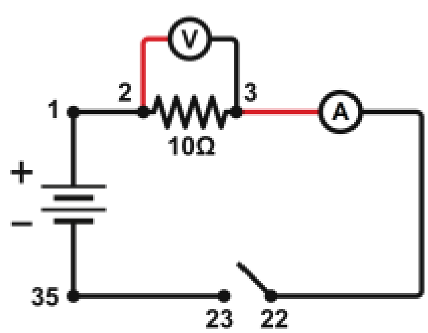

Figure 1

OBJECTIVES

- Determine the mathematical relationship between current, potential difference, and resistance in a simple circuit.
- Compare the potential *vs.* current behavior of a resistor to that of a light bulb.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Current
Go Direct Voltage
Extech Digital DC Power Supply
connecting wires with clips
light bulb (7.5 V)
Vernier Circuit Board 2 **or** switch and two resistors (about 10 and 50 Ω)

PRELIMINARY SET UP AND QUESTIONS

1. Set up the sensors and data-collection app.
    a. Set the switch on the Current Probe to ±1 A.
    b. Launch Graphical Analysis. Connect Go Direct Current and Go Direct Voltage to your Chromebook, computer, or mobile device.
    c. Click or tap View Options, , and choose Meter.
2. Zero the sensors.
    a. Connect together the two voltage probe leads (red and black).
    b. When the voltage readings stabilize, click or tap the Voltage meter and choose Zero.
    c. When the current readings stabilize, click or tap the Current meter and choose Zero.
3. Set up the equipment.
    a. With the power supply turned off, connect the power supply to terminals J1 and J2. Connect the circuit with connecting wires as shown in Figure 1. **Note**: The numbers in the figure refer to the numbered terminals on the Vernier Circuit Board.
    b. Connect the current and voltage probes if they are not yet connected (see Figure 1). **Note**: The red leads from the current and voltage probes should be toward the positive terminal of the power supply.
    c. Set Switch 1, SW 1, located below the battery holder on the Vernier Circuit Board, to External.
4. Have your instructor check the arrangement of the wires before proceeding. Then, turn the control on the DC power supply to 0 V and then turn on the power supply. Close the switch and monitor the meter in Graphical Analysis. Slowly increase the voltage to 5 V. Describe what happens to the current through the resistor as the potential difference across the resistor changes.

    If the potential doubles, what happens to the current? What type of relationship do you predict exists between potential difference and current?

PROCEDURE

1. Set up the data-collection app.
    a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

   b. Change Event Mode to Selected Events, so that the potential and current will be recorded only at times you specify. Click or tap Done.
   c. Click or tap View Options, , and choose 2 Graphs.
2. Record the value of the resistor in the data table.
3. Collect your first point of current and potential data.
   a. Start data collection.
   b. Set the power supply to 0 V, and then click or tap Keep to record the current and potential.
4. Take additional data.
   a. Increase the potential on the power supply to approximately 0.5 V.
   b. Click or tap Keep to record another data pair.
   c. Increase the potential by about 0.5 V and click or tap Keep to record the data pair.
   d. Repeat this process until you reach a potential of 5.0 V. After the last point, stop data collection.
5. Set the power supply back to 0 V.
6. Two graphs are displayed on the screen. View a single graph of potential *vs.* current.
   a. Click or tap View Options, , and choose 1 Graph.
   b. Click or tap the y-axis label and select Potential.
   c. Click or tap the x-axis label and select Current.
7. Are the potential difference and current proportional for this resistor? If so, fit a straight line to the data.
   a. Click or tap Graph Options, , and choose Apply Curve Fit.
   b. Select Linear as the curve fit and click or tap Apply.
   c. Record the slope and y-intercept in the data table.
8. Repeat Steps 2–7 using a different resistor.
9. Are the potential difference, in volts, and current proportional for this resistor? If so, fit a straight line to the data.
   a. Click or tap Graph Options, , and choose Apply Curve Fit.
   b. Select Linear as the curve fit and click or tap Apply.
   c. Record the slope and y-intercept in the data table.
10. Replace the resistor in the circuit with a 7.5 V light bulb. Repeat Steps 2–7, but this time, increase the voltage in 0.1 V steps up to 5.0 V.

11. Click or tap the graph to examine the data. Is the slope constant? Compare slopes of data at different parts of the curve:

    a. Select the first three points on the graph.
    b. Click or tap Graph Options, 📈, and choose Apply Curve Fit.
    c. Select Linear as the Curve Fit and click or tap Apply.
    d. Record the slope in the data table.
    e. Select the last 10 points on the graph.
    f. Click or tap Graph Options, 📈, and choose Apply Curve Fit.
    g. Select Linear as the Curve Fit and click or tap Apply.
    h. Record the slope in the data table.

DATA TABLE

	Slope (V/A)	Y-intercept (V)
Resistor ___________ Ω		
Resistor ___________ Ω		
Light bulb (first 3 pts)		
Light bulb (last 10 pts)		

ANALYSIS

1. As the potential across the resistor increased, the current through the resistor increased. If the change in current is *proportional* to the potential difference, the data should be in a straight line and the y-intercept should be zero. In the two resistor examples how close is the y-intercept to zero? Is there a proportional relationship between potential difference and current? If so, write the equation for each resistor data set in the form $V = mI$. Use a numerical value for the proportionality constant, m.

2. Compare the constant in each of the above equations to the resistance of each resistor.

3. Resistance, R, is defined using $R = V/I$ where V is the potential across a resistor, and I is the current. R is measured in ohms (Ω), where 1 Ω = 1 V/A. The constant you determined in each equation should be similar to the resistance of each resistor. However, resistors are manufactured such that their actual value is within a tolerance. For many common resistors, the tolerance is 5% or 10%. Check with your instructor to determine the tolerance of the resistors you are using. Calculate the range of possible values for each resistor. Does the constant in each equation fit within the appropriate range of values for each resistor?

4. Do your resistors follow Ohm's law? Base your answer on your experimental data.

5. Describe what happened to the current through the light bulb as the potential increased. Was the change linear? Since the slope of the linear regression line is a measure of resistance, describe what happened to the resistance as the voltage increased. Since the bulb gets brighter as it gets hotter, how does the resistance vary with temperature?

6. Does your light bulb follow Ohm's law? Base your answer on your experimental data.

EXTENSIONS

1. Investigate Ohm's law for reverse currents in resistors. Turn off the power supply and reverse the connections on the power supply. Turn the power supply back on and take data from 5.0 V to 0 V. Do not stop data collection. Turn off the power supply, restore the connections to the circuit to their original configuration, and turn the power supply back on. Take data from 0 to 5 V as before. Is the current still proportional to the potential across the resistor?

2. Investigate the behavior of other electrical devices such as diodes, LEDs, and Zener diodes. Make one run, then reverse the direction of the device and repeat.

3. Use a low-voltage AC power supply and measure current and potential difference, in volts, as a function of time in a simple circuit. Compare the two graphs. Create a graph of potential difference *vs.* current. Perform a linear regression over these data and compare to the resistance in the circuit.