Physics with Vernier

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HANDS ON ACTIVITIES

Picket Fence Free Fall
- Vernier Photogate

Magnetic Field of a Permanent Magnet
- Go Direct 3-Axis Magnetic Field

EXPERIMENT STATIONS

Series and Parallel Circuits
- Differential Voltage Probe/Go Direct Voltage
- Current Probe/Go Direct Current

Cart on Ramp
- Dynamics Cart and Track System with Motion Encoder

OR
- Go Direct Sensor Cart

Conservation of Angular Momentum
- Rotary Motion Sensor/Go Direct Rotary Motion

Sound Waves and Beats
- Microphone

Impulse and Momentum
- Dynamics Cart and Track System with Motion Encoder
- Dual-Range Force Sensor

OR
- Go Direct Sensor Cart

α, β, and γ
- Go Direct Radiation Monitor

The Magnetic Field in a Slinky
- Go Direct 3-Axis Magnetic Field

Force and Acceleration
- Go Direct Force and Acceleration
- Go Direct Acceleration
- Go Direct Sensor Cart

Picket Fence Free Fall

We say an object is in *free fall* when the only force acting on it is the Earth's gravitational force. No other forces can be acting; in particular, air resistance must be either absent or so small as to be ignored. When the object in free fall is near the surface of the Earth, the gravitational force on it is nearly constant. As a result, an object in free fall accelerates downward at a constant rate. This acceleration is usually represented with the symbol, g.

Physics students measure the acceleration due to gravity using a wide variety of timing methods. In this experiment, you will have the advantage of using a very precise timer and a Photogate. The Photogate has a beam of infrared light that travels from one side to the other. It can detect whenever this beam is blocked. You will drop a piece of clear plastic with evenly spaced black bars on it, called a Picket Fence. As the Picket Fence passes through the Photogate, the interface measures the time from the leading edge of one bar blocking the beam until the leading edge of the next bar blocks the beam. This timing continues as all eight bars pass through the Photogate. From these measured times, the software calculates and plots the velocities and accelerations for this motion.

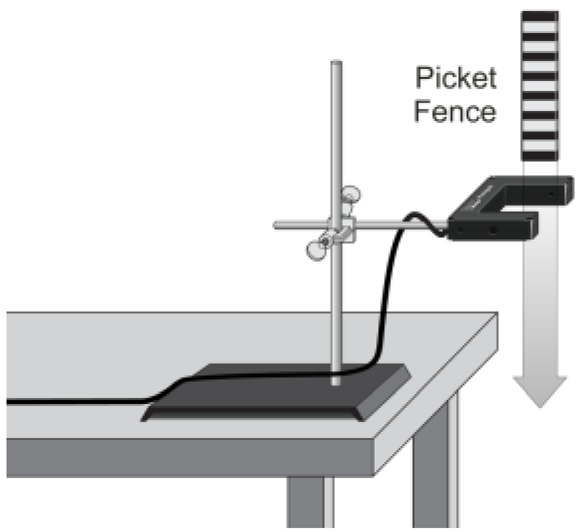

Figure 1

OBJECTIVE

- Measure the acceleration of a freely falling body, g, to better than 0.5% precision using a Picket Fence and a Photogate.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Photogate
Picket Fence
clamp **or** ring stand to secure Photogate

PRELIMINARY QUESTIONS

1. Inspect your Picket Fence. You will be dropping it through a Photogate to measure *g*. The distance, measured from one edge of a black band to the same edge of the next band, is 5.0 cm. What additional information is needed to determine the average speed of the Picket Fence as it moves through the Photogate?

2. If an object is moving with constant acceleration, what is the shape of its velocity *vs.* time graph?

3. Does the initial velocity of an object have anything to do with its acceleration? For example, compared to dropping an object, if you throw it downward would the acceleration be different after you released it?

PROCEDURE

1. Fasten the Photogate rigidly to a ring stand so the arms extend horizontally, as shown in Figure 1. The entire length of the Picket Fence must be able to fall freely through the Photogate. To avoid damaging the Picket Fence, provide a soft landing surface (such as carpet).

2. Connect the Photogate to the digital (DIG) port of the Vernier computer interface.

3. Open the file “05 Picket Fence Free Fall” in the *Physics with Vernier* folder.

4. Observe the reading in the status bar of Logger *Pro* at the top of the screen. Block the Photogate with your hand; note that the GateState is shown as Blocked. Remove your hand and the display will change to Unblocked.

5. Click ▶ Collect to prepare the Photogate for data collection. Hold the top of the Picket Fence between two fingers, allowing the Picket Fence to hang freely just above the center of the Photogate, without blocking the gate. Release the Picket Fence so it leaves your grasp completely before it enters the Photogate. The Picket Fence must remain vertical and should not touch the Photogate as it falls.

6. Examine your graphs. The slope of a velocity *vs.* time graph is a measure of acceleration. If the velocity graph is approximately a straight line of constant slope, the acceleration is constant. If the acceleration of your Picket Fence appears constant, fit a straight line to your data. To do this, click the velocity graph once to select it, then click Linear Fit, , to fit the line, $y = mt + b$, to the data. Record the slope in the data table.

7. To establish the reliability of your slope measurement, repeat Steps 5 and 6 five more times. Do not use drops in which the Picket Fence hits or misses the Photogate. Record the slope values in the data table.

DATA TABLE

Trial	1	2	3	4	5	6
Slope (m/s^2)						

	Minimum	Maximum	Average
Acceleration (m/s^2)			

Acceleration due to gravity, *g*	±	m/s^2
Precision		%

ANALYSIS

1. From your six trials, determine the minimum, maximum, and average values for the acceleration of the Picket Fence. Record them in the data table.

2. Describe in words the shape of the position *vs.* time graph for the free fall.

3. Describe in words the shape of the velocity *vs.* time graph. How is this related to the shape of the position *vs.* time graph?

4. The average acceleration you determined represents a single best value, derived from all your measurements. The minimum and maximum values give an indication of how much the measurements can vary from trial to trial; that is, they indicate the precision of your measurement. One way of stating the precision is to take half of the difference between the minimum and maximum values and use the result as the uncertainty of the measurement. Express your final experimental result as the average value, ± the uncertainty. Round the uncertainty to just one digit and round the average value to the same decimal place.

   For example, if your minimum, average, and maximum values are 9.12, 9.93, and 10.84 m/s^2, express your result as $g = 9.9 \pm 0.9$ m/s^2. Record your values in the data table.

5. Express the uncertainty as a percentage of the acceleration. This is the precision of your experiment. Enter the value in your data table. Using the example numbers from the last step, the precision would be

$$\frac{0.9}{9.9} \times 100\,\% = 9\,\%$$

6. Compare your measurement to the generally accepted value of *g* (from a textbook or other source). Does the accepted value fall within the range of your values? If so, your experiment agrees with the accepted value.

7. Inspect your velocity graph. How would the associated acceleration *vs.* time graph look? Sketch your prediction on paper. Now change the upper graph to acceleration *vs.* time. To do this, click the y-axis label and select Acceleration. Comment on any differences. You may want to rescale the graph so that the acceleration axis begins at zero.

8. Use the Statistics tool and the acceleration graph to find the average acceleration. How does this compare with the acceleration value for the same drop, determined from the slope of the velocity graph?

EXTENSIONS

1. Use the position *vs.* time graph and a parabolic fit to determine *g*.

2. Would dropping the Picket Fence from higher above the Photogate change any of the parameters you measured? Try it.

3. Would throwing the Picket Fence downward, but letting go before it enters the Photogate, change any of your measurements? How about throwing the Picket Fence upward? Try performing these experiments.

4. How would adding air resistance change the results? Try adding a loop of clear tape to the upper end of the Picket Fence. Drop the modified Picket Fence through the Photogate and compare the results with your original free-fall results.

5. Investigate how the value of *g* varies around the world. For example, how does altitude affect the value of *g*? What other factors cause this acceleration to vary at different locations? For example, is *g* different at high altitudes such as Svalbard, an archipelago north of Norway?

6. Collect *g* measurements for your entire class, and plot the values in a histogram. Is there a most common value? Are the measurements consistent with one another?

The Magnetic Field of a Permanent Magnet

A bar magnet is called a *dipole* because it has two poles (commonly labeled north and south). Breaking a magnet in two does not produce two isolated poles; each fragment still has two poles. Similarly, two magnets together still exhibit only two poles. Since, to our knowledge, there are no magnetic monopoles, the dipole is the simplest possible magnetic field source.

The dipole field is not limited to bar magnets, for an electrical current flowing in a loop also creates this common magnetic field pattern.

The magnetic field, B_{axis} (measured in tesla), of an ideal dipole measured along its axis is

$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2\mu}{d^3}$$

where μ_0 is the permeability constant ($4\pi \times 10^{-7}$ T m/A), d is the distance from the center of the dipole in meters and μ is the magnetic moment. The magnetic moment, μ, measures the strength of a magnet, much like electrical charge measures the strength of an electric field source. Note that the distance dependence of this function is an inverse-cube function, which is different from the inverse-square relationship you may have studied for other situations.

In this experiment, you will examine how the magnetic field of a small, powerful magnet varies with distance, measured along the axis of the magnet. A Magnetic Field Sensor will be used to measure the magnitude of the field.

Simple laboratory magnets are approximately dipoles, although magnets of complex shapes will exhibit more complex fields. By comparing your field data to the field of an ideal dipole, you can see if your magnet is very nearly a dipole in its behavior. If it is nearly a dipole, you can also measure its magnetic moment.

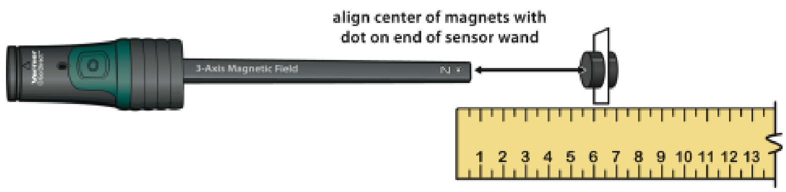

Figure 1

OBJECTIVES

- Use a Magnetic Field Sensor to measure the field of a small magnet.
- Compare the distance dependence of the magnetic field to the magnetic dipole model.
- Determine the magnetic moment of a magnet.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct 3-Axis Magnetic Field
masking tape
2 neodymium **or** ceramic magnets
tape measure **or** meter stick
index card

PRELIMINARY QUESTION

Place one magnet on a table and hold the other in your palm, well above the first. From directly above, slowly lower the upper magnet toward the first. Watch for the moment when the lower magnet jumps toward the back of your hand. Try it again. From the sudden jump of the lower magnet, what can you conclude about the way the magnetic force between the magnets varies with distance?

PROCEDURE

1. Launch Graphical Analysis. Connect the Magnetic Field 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. Change Mode to Event Based.

    b. Enter **Distance** as the Event Name and **m** as the Units. Click or tap Done.

3. Position the meter stick and the Magnetic Field Sensor as shown in Figure 1. The body of the Magnetic Field Sensor should be parallel to the meter stick, with the x-axis tip of the wand pointing in the direction of increasing distance. Identify the location of the sensor (marked with dots approximately 0.5 cm back from the tip) and align this location with the zero mark on your meter stick. When everything is in place, tape the sensor and meter stick to the table.

4. As a convenient way to measure to the center of the magnet, and to ease handling of the small magnets, allow the two magnets to attract one another through the card, about 0.5 cm from either edge near the corner. The magnets should stay in place on the card. The card will serve to mark the center of the magnet pair.

5. Zero the sensor when the magnets are far away from the sensor in order to remove the effect of the Earth's magnetic field and any local magnetism. The sensor will be zeroed only for this location. Instead of moving the sensor in later steps, you will move the magnet.

    a. Move the magnets at least 1 m from the sensor.

    b. Click or tap the X Magnetic Field meter and choose Zero.

6. Collect magnetic field data as a function of distance.

   a. Start data collection.

   b. Position the magnets so the card is perpendicular to the tip of the Magnetic Field Sensor, 3 cm from the dots that mark the sensor's location (see Figure 1).

   c. Monitor the readings. If necessary, reverse the magnets so the magnetic field values are positive, and then reposition the magnets. If the reading is 5 mT, then increase the distance until the reading is below 5 mT.

   d. When the reading has stabilized, click or tap Keep.

   e. Enter the distance to the magnet. To make later calculations easier, enter the distance in meters (e.g., 3 cm is 0.03 m). Click or tap Keep Point to save this data pair.

7. Collect 10 additional data points.

   a. Taking care not to move the Magnetic Field Sensor or meter stick, move the magnet 0.25 cm (0.0025 m) farther from the sensor.

   b. Click or tap Keep and enter the distance (in meters). Click or tap Keep Point.

   c. After the 11th point, stop data collection. The graph is the magnetic field *vs.* the distance from the magnet. The field should drop off rapidly.

DATA TABLE

Power regression parameter, *a*	
Power regression parameter, *b*	
Power regression equation	

Magnetic moment	
μ (A m^2)	

ANALYSIS

1. A graph of magnetic field *vs.* distance is displayed. Is the data consistent with the equation for the magnetic field of a dipole described in the introduction?

   Compare your data to the inverse-cube model shown below using a power regression curve fit in Graphical Analysis

$$B_{axis} = \frac{\mu_0}{4\pi} \frac{2\mu}{d^3}$$

   a. Click or tap Graph Tools, , and choose Apply Curve Fit.

   b. Select Power as the curve fit and click or tap Apply.

c. A curve is fit to your data and parameters are shown on the graph. Record the parameter values in the data table and use them to write the power regression equation.

d. Export, download, or print the graph.

2. How well does the power regression fit your experimental data? An inverse cube function has b=3. Does your data approximately follow an inverse cube function? From the comparison, does your magnet show the magnetic field pattern of a dipole?

3. Graphical Analysis adjusted *parameter a* so the equation's curve comes close to your data points. Relating the parameter a to the field expression for a magnetic dipole, we see that $a = (\mu_0 2\mu\ 10^3) / (4\pi)$. The factor of 10^3 is present because the magnetic field was measured in mT rather than T. Use your value of a to determine the magnetic moment μ of your magnet, if the power regression fits your experimental data.

EXTENSIONS

1. Find other magnets such as refrigerator magnets, horseshoe magnets, and cow magnets, and see if they also show the magnetic field of a dipole.

2. Measure the dipole moment of just one neodymium magnet, or four stuck together. Is the dipole moment additive when you use two or more magnets attracted together?

3. Show that the units of the magnetic moment are A m^2 (ampere $meter^2$).

4. The units of μ may suggest a relationship of a magnetic moment to an electrical current. A current flowing in a closed loop is a magnetic dipole. A current, I, flowing around a loop of area πr^2 has a magnetic moment $\mu = I\ \pi r^2$. If a single current loop had the same radius as your permanent magnet, what current would be required to create the same magnetic field? (You will be surprised.) Are there currents flowing in loops in the permanent magnet?

Series and Parallel Circuits

Components in an electrical circuit are in *series* when they are connected one after the other, so that the same current flows through both of them. Components are in *parallel* when they are in alternate branches of a circuit. Series and parallel circuits function differently. You may have noticed the differences in electrical circuits you use. When using some types of older decorative holiday light circuits, if one lamp is removed, the whole string of lamps goes off. These lamps are in series. When a light bulb is removed in your home, the other lights stay on. Household wiring is normally in parallel.

You can monitor these circuits using a Current Probe and a Differential Voltage Probe and see how they operate. One goal of this experiment is to study circuits made up of two resistors in series or parallel. You can then use Ohm's law to determine the equivalent resistance of the two resistors.

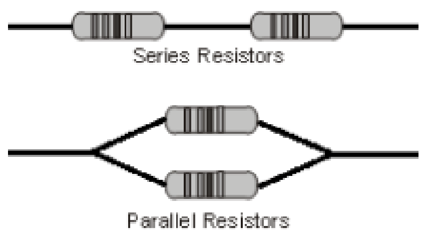

Figure 1

OBJECTIVES

- To study current flow in series and parallel circuits.
- To study potential differences in series and parallel circuits.
- Use Ohm's law to calculate equivalent resistance of series and parallel circuits.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
two Vernier Current Probes
Vernier Differential Voltage Probe
Extech Digital DC Power Supply
connecting wires with clips
Vernier Circuit Board 2 **or**
  two 10 Ω resistors
  two 51 Ω resistors
  two 68 Ω resistors
  switch

PRELIMINARY QUESTIONS

1. Wire three bulbs in series. Turn up the voltage until they all light. Turn down the voltage until the bulbs almost go out. What do you observe? Are all the bulbs the same brightness? Now, remove one bulb from its socket. What happens to the other bulbs?

2. Repeat Preliminary Question 1 for a parallel circuit.

3. Compare your findings for the bulbs in series to those in parallel. What are the differences?

PROCEDURE

1. Connect one of the Current Probes to Channel 1 and the Differential Voltage Probe to Channel 2 of the interface.

2. Open the file "23a Series Parallel Circ" in the *Physics with Vernier* folder. Current and voltage readings will be displayed in a meter.

3. Connect together the two Differential Voltage Probe leads (red and black). Click Zero, and then click OK to zero both sensors. This sets the zero for both probes with no current flowing and with no voltage applied.

4. Set up the equipment.
   a. Connect the series circuit, shown in Figure 2, using 10 Ω resistors for resistor 1 and resistor 2. **Note**: The numbers in the figure refer to the numbered terminals on the Vernier Circuit Board.
   b. Connect the Current and Differential Voltage Probes to the circuit (see Figure 2). **Note**: The red leads from the probes should be toward the positive terminal of the power supply.
   c. Set Switch 1, SW1, located below the battery holder on the Vernier Circuit Board, to External.
   d. Set the power supply to 3.0 V.
   e. To test your circuit, press on Switch 3, SW3, to complete the circuit; hold for several seconds. Both current and voltage readings should increase. If they do not, recheck your circuit.

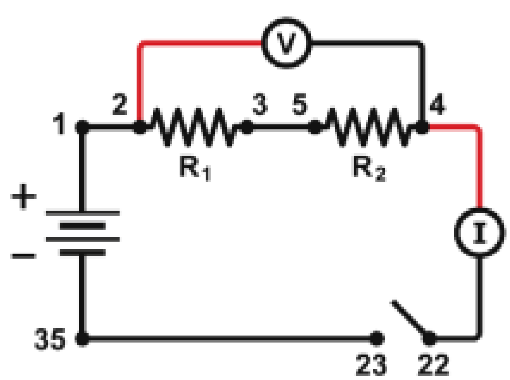

Figure 2

Part I Series circuits

5. For this part of the experiment, take readings from the on-screen meter rather than having the data-collection software collect data. Press on the switch to complete the circuit again and read the current (I) and total voltage (V_{TOT}). Record the values in the data table.

6. Connect the leads of the Differential Voltage Probe across resistor 1. Press on the switch to complete the circuit and read this voltage (V_1). Record this value in the data table.

7. Connect the leads of the Differential Voltage Probe across resistor 2. Press on the switch to complete the circuit and read this voltage (V_2). Record this value in the data table.

8. Repeat Steps 5–7 with a 51 Ω resistor substituted for resistor 2.

9. Repeat Steps 5–7 with 51 Ω resistors for both resistor 1 and resistor 2.

Part II Parallel circuits

10. Connect the parallel circuit shown in Figure 3 using 51 Ω resistors for both resistor 1 and resistor 2. As in the previous circuit, the Differential Voltage Probe is used to measure the voltage across the resistors, but this time you will measure each resistor separately. The Differential Voltage Probe is not shown in the diagram for that reason, but should initially be connected on either side of the parallel portion of the circuit. The red lead of the Voltage Probe and the red terminal of the Current Probe should be toward the + terminal of the power supply. The Current Probe is used to measure the total current in the circuit.

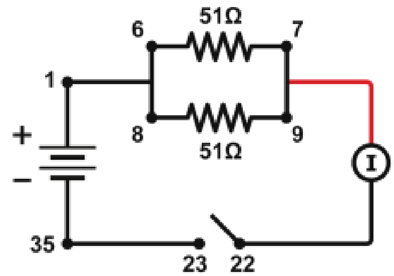

Figure 3

11. As in Part I, take readings from the meter at any time. To test your circuit, briefly press on the switch to complete the circuit. Both current and voltage readings should increase. If they do not, recheck your circuit.

12. Press the switch to complete the circuit again and read the total current (I) and total voltage (V_{TOT}). Record the values in the data table.

13. Connect the leads of the Differential Voltage Probe across resistor 1 only. Press on the switch to complete the circuit and read the voltage (V_1) across resistor 1. Record this value in the data table.

14. Connect the leads of the Differential Voltage Probe across resistor 2 only. Press on the switch to complete the circuit and read the voltage (V_2) across resistor 2. Record this value in the data table.

15. Repeat Steps 12–14 with a 68 Ω resistor substituted for resistor 2.

16. Repeat Steps 12–14 with 68 Ω resistors for both resistor 1 and resistor 2.

Part III Currents in series and parallel circuits

17. For Part III of the experiment, you will use two Current Probes. Disconnect the Differential Voltage Probe and, into the same channel, connect a second Current Probe.

18. Open the file "23b Series Parallel Circ." Two current meters are displayed.

19. Without anything connected to either probe, click Zero, then click OK to zero both sensors. This adjusts the current reading to zero with no current flowing.

20. Connect the series circuit shown in Figure 4 using the 10 Ω resistor and the 51 Ω resistor. The Current Probes will measure the current flowing into and out of the two resistors. The red terminal of each Current Probe should be toward the + terminal of the power supply.

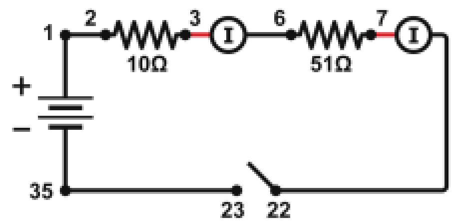

Figure 4

21. For this part of the experiment you will monitor the current through each of two resistors. Note that the two resistors are not the same. What do you expect for the two currents? Will they be the same or different?

22. Press on the switch to complete the circuit, holding for several seconds. The power supply should still be set for 3.0 V. Record the currents in the data table.

23. Connect the parallel circuit as shown in Figure 5 using the 51 Ω resistor and the 68 Ω resistor. The two Current Probes will measure the current through each resistor individually. The red terminal of each Current Probe should be toward the + terminal of the power supply.

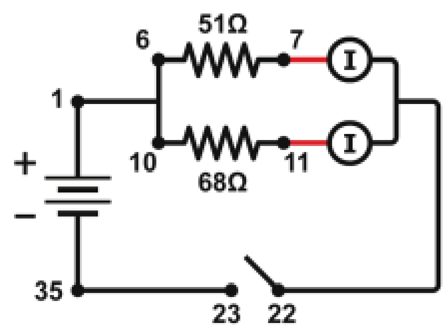

Figure 5

24. Before you make any measurements, predict the currents through the two resistors. Will they be the same or different? Note that the two resistors are not identical in this parallel circuit.

25. Press on the switch to complete the circuit, holding for several seconds. Record the current values in the data table.

DATA TABLE

Part I Series Circuits

	R_1 (Ω)	R_2 (Ω)	I (A)	V_1 (V)	V_2 (V)	R_{eq} (Ω)	V_{TOT} (V)
1	10	10					
2	10	51					
3	51	51					

Part II Parallel circuits

	R_1 (Ω)	R_2 (Ω)	I (A)	V_1 (V)	V_2 (V)	R_{eq} (Ω)	V_{TOT} (V)
1	51	51					
2	51	68					
3	68	68					

Part III Currents

	R_1 (Ω)	R_2 (Ω)	I_1 (A)	I_2 (A)
1	10	51		
2	51	68		

ANALYSIS

1. Examine the results of Part I. What is the relationship between the three voltage readings: V_1, V_2, and V_{TOT}?

2. Using the measurements you made above and your knowledge of Ohm's law, calculate the equivalent resistance (R_{eq}) of the circuit for each of the three series circuits you tested.

3. Study the equivalent resistance readings for the series circuits. Can you come up with a rule for the equivalent resistance (R_{eq}) of a series circuit with two resistors?

4. For each of the three series circuits, compare the experimental results with the resistance calculated using your rule. In evaluating your results, consider the tolerance of each resistor by using the minimum and maximum values in your calculations.

5. Using the measurements you have made above and your knowledge of Ohm's law, calculate the equivalent resistance (R_{eq}) of the circuit for each of the three parallel circuits you tested.

6. Study the equivalent resistance readings for the parallel circuits. Devise a rule for the equivalent resistance of a parallel circuit of two resistors.

7. Examine the results of Part II. What do you notice about the relationship between the three voltage readings V_1, V_2, and V_{TOT} in parallel circuits?

8. What did you discover about the current flow in a series circuit in Part III?

9. What did you discover about the current flow in a parallel circuit in Part III?

10. If the two measured currents in your parallel circuit were not the same, which resistor had the larger current going through it? Why?

EXTENSION

Perform a similar investigation using three resistors in series and in parallel.

Series and Parallel Circuits

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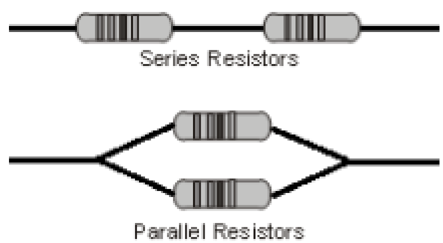


Figure 1

OBJECTIVES

- To study current flow in series and parallel circuits.
- To study potential differences in series and parallel circuits.
- Use Ohm's law to calculate equivalent resistance of series and parallel circuits.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Voltage Probe
two Go Direct Current Probes
Extech Digital DC Power Supply
connecting wires with clips
Vernier Circuit Board 2 **or**
  two 10 Ω resistors
  two 51 Ω resistors
  two 68 Ω resistors
  switch

PRELIMINARY QUESTIONS

1. Wire three bulbs in series. Turn up the voltage until they all light. Turn down the voltage until the bulbs almost go out. What do you observe? Are all the bulbs the same brightness? Now, remove one bulb from its socket. What happens to the other bulbs?
2. Repeat Preliminary Question 1 for a parallel circuit.
3. Compare your findings for the bulbs in series to those in parallel. What are the differences?

PROCEDURE

1. Set up the sensors and data-collection app.
   a. Click or tap View, ⊞, 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. Connect the series circuit, shown in Figure 2, using 10 Ω resistors for resistor 1 and resistor 2. **Note**: The numbers in the figure refer to the numbered terminals on the Vernier Circuit Board.
   b. Connect the Current and Voltage Probes to the circuit (see Figure 2). **Note**: The red leads from the probes should be toward the positive terminal of the power supply.
   c. Set Switch 1, SW1, located below the battery holder on the Vernier Circuit Board, to External.
   d. Set the power supply to 3.0 V.
   e. To test your circuit, press on Switch 3, SW3, to complete the circuit; hold for several seconds. Both current and voltage readings should increase. If they do not, recheck your circuit.

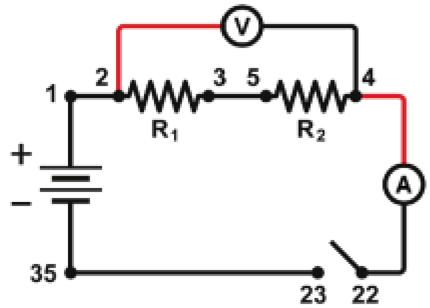


Figure 2

Part I Series circuits

4. Press on the switch to complete the circuit again and read the current (I) and total voltage (V_{TOT}). Record the values in the data table.

5. Connect the leads of the Voltage Probe across resistor 1. Press on the switch to complete the circuit and read this voltage (V_1). Record this value in the data table.

6. Connect the leads of the Voltage Probe across resistor 2. Press on the switch to complete the circuit and read this voltage (V_2). Record this value in the data table.

7. Repeat Steps 4–6 with a 51 Ω resistor substituted for resistor 2.

8. Repeat Steps 4–6 with 51 Ω resistors for both resistor 1 and resistor 2.

Part II Parallel circuits

9. Connect the parallel circuit shown in Figure 3 using 51 Ω resistors for both resistor 1 and resistor 2. As in the previous circuit, the Voltage Probe is used to measure the voltage across the resistors, but this time you will measure each resistor separately. The Voltage Probe is not shown in the diagram for that reason, but should initially be connected on either side of the parallel portion of the circuit. The red lead of the Voltage Probe and the red terminal of the Current Probe should be toward the + terminal of the power supply. The Current Probe is used to measure the total current in the circuit.

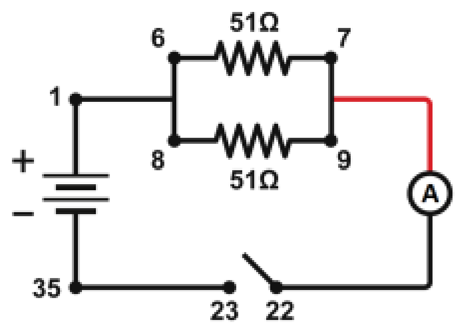


Figure 3

10. To test your circuit, press on the switch to complete the circuit; hold for several seconds. Both current and voltage readings should increase. If they do not, recheck your circuit.

11. Press the switch to complete the circuit again and read the total current (I) and total voltage (V_{TOT}). Record the values in the data table.

12. Connect the leads of the Voltage Probe across resistor 1 only. Press on the switch to complete the circuit and read the voltage (V_1) across resistor 1. Record this value in the data table.

13. Connect the leads of the Voltage Probe across resistor 2 only. Press on the switch to complete the circuit and read the voltage (V_2) across resistor 2. Record this value in the data table.

14. Repeat Steps 11–13 with a 68 Ω resistor substituted for resistor 2.

15. Repeat Steps 11–13 with 68 Ω resistors for both resistor 1 and resistor 2.

Part III Currents in series and parallel circuits

16. For Part III of the experiment, you will use two Current Probes. Disconnect the Voltage Probe and connect a second Current Probe.

17. With no current flowing, zero each Current Probe by clicking or tapping the Current meters and choosing Zero.

18. Connect the series circuit shown in Figure 4 using the 10 Ω resistor and the 51 Ω resistor. The Current Probes will measure the current flowing through the two resistors. The red terminal of each Current Probe should be toward the + terminal of the power supply.

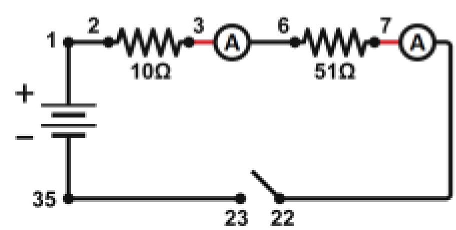


Figure 4

19. For this part of the experiment you will monitor the current through each of two resistors. Note that the two resistors are not the same. What do you expect for the two currents? Will they be the same or different?

20. Press on the switch to complete the circuit, holding for several seconds. The power supply should still be set for 3.0 V. Record the currents in the data table.

21. Connect the parallel circuit as shown in Figure 5 using the 51 Ω resistor and the 68 Ω resistor. The two Current Probes will measure the current through each resistor individually. The red terminal of each Current Probe should be toward the + terminal of the power supply.

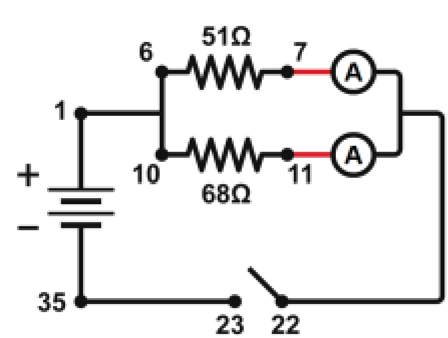


Figure 5

22. Before you make any measurements, predict the currents through the two resistors. Will they be the same or different? Note that the two resistors are not identical in this parallel circuit.

23. Press on the switch to complete the circuit, holding for several seconds. Record the current values in the data table.

DATA TABLE

Part I Series Circuits

	R_1 (Ω)	R_2 (Ω)	I (A)	V_1 (V)	V_2 (V)	R_{eq} (Ω)	V_{TOT} (V)
1	10	10					
2	10	51					
3	51	51					

Part II Parallel circuits

	R_1 (Ω)	R_2 (Ω)	I (A)	V_1 (V)	V_2 (V)	R_{eq} (Ω)	V_{TOT} (V)
1	51	51					
2	51	68					
3	68	68					

Part III Currents

	R_1 (Ω)	R_2 (Ω)	I_1 (A)	I_2 (A)
1	10	51		
2	51	68		

ANALYSIS

1. Examine the results of Part I. What is the relationship between the three voltage readings: V_1, V_2, and V_{TOT}?

2. Using the measurements you made above and your knowledge of Ohm's law, calculate the equivalent resistance (R_{eq}) of the circuit for each of the three series circuits you tested.

3. Study the equivalent resistance readings for the series circuits. Can you come up with a rule for the equivalent resistance (R_{eq}) of a series circuit with two resistors?

4. For each of the three series circuits, compare the experimental results with the resistance calculated using your rule. In evaluating your results, consider the tolerance of each resistor by using the minimum and maximum values in your calculations.

5. Using the measurements you have made above and your knowledge of Ohm's law, calculate the equivalent resistance (R_{eq}) of the circuit for each of the three parallel circuits you tested.

6. Study the equivalent resistance readings for the parallel circuits. Devise a rule for the equivalent resistance of a parallel circuit of two resistors.

7. Examine the results of Part II. What do you notice about the relationship between the three voltage readings V_1, V_2, and V_{TOT} in parallel circuits?

8. What did you discover about the current flow in a series circuit in Part III?

9. What did you discover about the current flow in a parallel circuit in Part III?

10. If the two measured currents in your parallel circuit were not the same, which resistor had the larger current going through it? Why?

EXTENSION

Perform a similar investigation using three resistors in series and in parallel.

Cart on a Ramp (Motion Encoder)

This experiment uses an incline and a low-friction cart. If you give the cart a gentle push up the incline, the cart will roll upward, slow and stop, and then roll back down, speeding up. 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 does the acceleration *vs.* time graph look like? Is the acceleration constant?

In this experiment, you will use a Motion Encoder System to collect position, velocity, and acceleration data for a cart rolling up and down an incline. Analysis of the graphs of this motion will answer these questions.

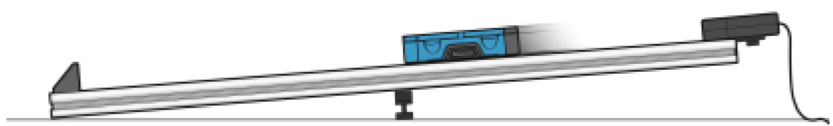


Figure 1

OBJECTIVES

- Collect position, velocity, and acceleration data as a cart rolls freely up and down an incline.
- 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

computer
Vernier computer interface
Logger *Pro*
Motion Encoder Receiver
Vernier Dynamics Track
Adjustable End Stop
Vernier Motion Encoder Cart with plunger

PRELIMINARY QUESTIONS

1. Consider the changes in motion a Dynamics Cart will undergo as it rolls up and down an incline. Make a sketch of your prediction for the position *vs.* time graph. Describe in words what this graph means.

2. Make a sketch of your prediction for the velocity *vs.* time graph. Describe in words what this graph means.

3. Make a sketch of your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

PROCEDURE

Part I

1. Connect the Motion Encoder Receiver to the digital (DIG) port of the interface.

2. Confirm that your Dynamics Track, Adjustable End Stop, and Motion Encoder Receiver are assembled as shown in Figure 1.

3. Open the file “03 Cart on a Ramp” from the *Physics with Vernier* folder.

4. Place the cart on the track near the end stop. Face the transmitter end of the cart toward the receiver at the end of the track. Click ▶ Collect to begin data collection[1]. Wait about a second, then briefly push the cart up the incline, letting it roll freely up nearly to the top, and then back down. Catch the cart as it nears the end stop.

5. Select the position *vs.* time graph by clicking on it and choose Autoscale from the Analyze menu to see all the position data on the graph. Examine the position *vs.* time graph.

6. Answer the Analysis questions for Part I before proceeding to Part II.

Part II

7. Your cart can bounce against the end stop with its plunger. Practice starting the cart so it bounces at least twice during data collection.

8. Collect another set of data showing two or more bounces.

9. Proceed to the Analysis questions for Part II.

ANALYSIS

Part I

1. Either print or sketch the three motion graphs. The graphs you have recorded are fairly complex, and it is important to identify different regions of each graph. Click Examine, , and move the mouse across any graph to answer the following questions. Record your answers directly on the printed or sketched graphs.

[1]Logger *Pro* tip: If a graph is currently selected, you can start data collection by tapping the Space bar.

   a. Identify the region when the cart was being pushed by your hand:
      - 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 the graph.

   b. Identify the region where the cart was rolling freely:
      - Label the region on each graph where the cart was rolling freely and moving up the incline.
      - Label the region on each graph where the cart was rolling freely and moving down the incline.

   c. Determine the position, velocity, and acceleration at specific points:
      - On the velocity *vs.* time graph, decide where the cart had its maximum velocity, just as the cart was released. Mark the spot and record the value on the graph.
      - On the position *vs.* time graph, locate the highest point of the cart on the incline. This point is the closest approach to the Motion Encoder Receiver. Mark the spot and record the value on the graph.
      - What was the velocity of the cart at the top of its motion?
      - What was the acceleration of the cart at the top of its motion?

2. The motion of an object in constant acceleration is modeled by $x = \frac{1}{2} at^2 + v_0t + x_0$, where x is the position, a is the acceleration, t is time, and v_0 is the initial velocity. This is a quadratic equation whose graph is a parabola. If the cart moved with constant acceleration while it was rolling, your graph of position *vs.* time will be parabolic. Fit a quadratic equation to your data.

   a. Click and drag the mouse across the portion of the position *vs.* time graph that is parabolic, highlighting the free-rolling portion.
   b. Click Curve Fit, , select Quadratic fit from the list of models and click Try Fit.
   c. Examine the fit of the curve to your data and click OK to return to the main graph.

   Is the cart's acceleration constant during the free-rolling segment?

3. The graph of velocity *vs.* time is linear if the acceleration is constant. To fit a line to this data, click and drag the mouse across the free rolling region of the motion. Click Linear Fit, . How closely does the slope correspond to the acceleration you found in the previous step?

4. The graph of acceleration *vs.* time should appear approximately constant during the freely-rolling segment. Click and drag the mouse across the free-rolling portion of the motion and click Statistics, . How closely does the mean acceleration value compare to the values of a found in Steps 2 and 3?

Part II

5. Determine the cart's acceleration during the free-rolling segments using the velocity graph. Are they the same?

6. Determine the cart's acceleration during the free-rolling segments using the position graph. Are they the same?

EXTENSIONS

1. Adjust the angle of the incline to change the acceleration and measure the new value. How closely does the coefficient of the t^2 term in the curve fit compare to ½ $g \sin \theta$, where θ is the angle of the track with respect to horizontal? For a trigonometric method for determining θ, see the experiment, "Determining *g* on an Incline," in this book.

2. Compare your results in this experiment with other measurements of *g*. For example, use the experiment, "Picket Fence Free Fall," in this book.

3. Use a free-body diagram to analyze the forces on a rolling cart. Predict the acceleration as a function of incline angle and compare your prediction to your experimental results.

4. Even though the cart has very low friction, the friction is not zero. From your velocity graph, devise a way to measure the difference in acceleration between the roll up and the roll down. Can you use this information to determine the friction force in newtons?

5. Use the modeling feature of Logger *Pro* to superimpose a linear model on the velocity graph. To insert a model, choose Model from the Analyze menu. Select the linear function and click OK. On the Model window, click the slope or intercept label and adjust using the cursor keys or by typing in new values until you get a good fit. Interpret the slope you obtain. Interpret the y-intercept.

Cart on a Ramp (Sensor Cart)

This experiment uses an incline and a low-friction cart. If you give the cart a gentle push up the incline, the cart will roll upward, slow and stop, and then roll back down, speeding up. 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 does the acceleration *vs.* time graph look like? Is the acceleration constant?

In this experiment, you will use a Go Direct Sensor Cart to collect position, velocity, and acceleration data for a cart rolling up and down an incline. Analysis of the graphs of this motion will answer the questions above.

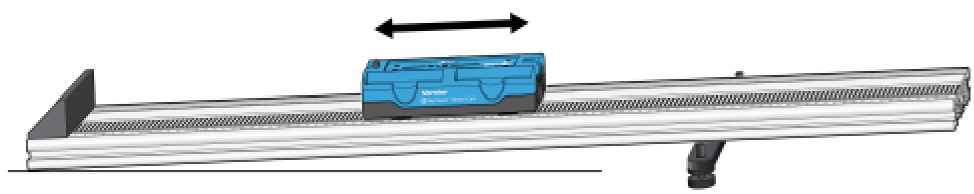


Figure 1

OBJECTIVES

- Collect position, velocity, and acceleration data as a cart rolls freely up and down an incline.
- 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 4 app
Go Direct Sensor Cart
Vernier Dynamics Track
Adjustable End Stop

PRELIMINARY QUESTIONS

1. Consider the changes in motion that a cart will undergo as it rolls up and down an incline. Make a sketch of your prediction for the position *vs.* time graph. Describe in words what this graph means.

2. Make a sketch of your prediction for the velocity *vs.* time graph. Describe in words what this graph means.

3. Make a sketch of your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

PROCEDURE

Part I

1. Launch Graphical Analysis. Connect the Motion Detector to your Chromebook or mobile device.

2. Place the cart on the track near the Adjustable End Stop. Point the **+x** arrow toward the top of the ramp. Click or tap Collect to start data collection. Wait about a second, then briefly push the cart up the incline, letting it roll freely up nearly to the top, and then back down. Catch the cart as it nears the end stop.

3. Examine the position *vs.* time graph. Repeat Step 2 if your position *vs.* time graph does not show an area of smoothly changing position. Check with your instructor if you are not sure whether you need to repeat data collection.

4. Answer the Analysis questions for Part I before proceeding to Part II.

Part II

6. Your cart can bounce against the end stop with its plunger. Practice starting the cart so it bounces at least twice during data collection.

7. Collect another set of data showing two or more bounces. **Note**: The previous data set is automatically saved.

8. Proceed to the Analysis questions for Part II.

ANALYSIS

Part I

1. Export, print, or sketch the three motion graphs. To view the acceleration *vs.* time graph, change the y-axis of either 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 the printed or sketched graphs.

   a. Identify the region when the cart was being pushed by your hand:

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

b. Identify the region where the cart was rolling freely:

- Label the region on each graph where the cart was rolling freely and moving up the incline.
- Label the region on each graph where the cart was rolling freely and moving down the incline.

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

- On the velocity *vs.* time graph, decide where the cart had its maximum velocity, just as the cart was released. Mark the spot and record the value on the graph.
- On the position *vs.* time graph, locate the highest point of the cart on the incline. This point is the closest approach to the Motion Detector. Mark the spot and record the value on the graph.
- What was the velocity of the cart at the top of its motion?
- What was the acceleration of the cart at the top of its motion?

2. The motion of an object in constant acceleration is modeled by the equation $x = ½\,at^2 + v_0t + x_0$, where x is the position, a is the acceleration, t is time, and v_0 is the initial velocity. This is a quadratic equation whose graph is a parabola. If the cart moved with constant acceleration while it was rolling, your graph of position *vs.* time will be parabolic.

   a. Select the data in the parabolic region of the position graph.
   b. Click or tap Graph Tools, , 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 fitted curve (the acceleration).

   Is the cart's acceleration constant during the free-rolling segment?

3. The graph of velocity *vs.* time is linear if the acceleration is constant. Fit a line to the data.

   a. Select the data in the linear region of the velocity graph.
   b. Click or tap Graph Tools, , 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 slope of the fitted line (the acceleration).

   How closely does the slope correspond to the acceleration you found in the previous step?

4. Change the y-axis to Acceleration. The graph of acceleration *vs.* time should appear approximately constant during the freely-rolling segment.

   a. Select the data in the region of the graph that represents when the cart was rolling freely.
   b. Click or tap Graph Tools, , for the acceleration *vs.* time graph and choose View Statistics.

   How closely does the mean acceleration compare to the values of acceleration found in Steps 2 and 3?

Part II

1. Determine the cart's acceleration during the free-rolling segments using the velocity graph. Are they the same?

2. Determine the cart's acceleration during the free-rolling segments using the position graph. Are they the same?

EXTENSIONS

1. Use a free-body diagram to analyze the forces on a rolling cart. Predict the acceleration as a function of incline angle and compare your prediction to your experimental results. For a trigonometric method for determining θ, see the experiment, "Determining g on an Incline," in this book.

2. Even though the cart has very low friction, the friction is not zero. From your velocity graph, devise a way to measure the difference in acceleration between the roll up and the roll down. Can you use this information to determine the friction force in newtons?

Experiment
14

Conservation of Angular Momentum

INTRODUCTION

In your study of linear momentum, you learned that, in the absence of an unbalanced external force, the momentum of a system remains constant. In this experiment, you will examine how the *angular* momentum of a rotating system responds to changes in the moment of inertia, *I*.

OBJECTIVES

In this experiment, you will

- Collect angle *vs.* time and angular velocity *vs.* time data for rotating systems.
- Analyze the θ-t and ω-t graphs both before and after changes in the moment of inertia.
- Determine the effect of changes in the moment of inertia on the angular momentum of the system.

MATERIALS

Vernier data-collection interface	ring stand or vertical support rod
Logger *Pro* or LabQuest App	balance
Vernier Rotary Motion Sensor	metric ruler
Vernier Rotary Motion Accessory Kit	

PROCEDURE

1. Mount the Rotary Motion Sensor to the vertical support rod. Place the 3-step Pulley on the rotating shaft of the sensor so that the largest pulley is on top. Measure the mass and diameter of the aluminum disk with the smaller hole. Mount this disk to the pulley using the longer machine screw sleeve (see Figure 1).

Figure 1

2. Connect the sensor to the data-collection interface and begin the data-collection program. The default data-collections settings are appropriate for this experiment.

3. Spin the aluminum disk so that it is rotating reasonably rapidly, then begin data collection. Note that the angular velocity gradually decreases during the interval in which you collected data. Consider why this occurs. Store this run (Run 1).

4. Obtain the second aluminum disk from the accessory kit; determine its mass and diameter. Position this disk (cork pads down) over the sleeve of the screw holding the first disk to the pulley. Practice dropping the second disk onto the first so as to minimize any torque you might apply to the system (see Figure 2).

Figure 2

5. Begin the first disk rotating rapidly as before and begin collecting data. After a few seconds, drop the second disk onto the rotating disk and observe the change in both the θ-t and ω-t graphs. Store this run (Run 2).

6. Repeat Step 5, but begin with a lower angular velocity than before. Store this run (Run 3).

7. Find the mass of the steel disk. Measure the diameter of both the central hole and the entire disk. Replace the first aluminum disk with the steel disk and hub and tighten the screw as before (see Figure 3).

8. Try to spin the steel disk about as rapidly as you did the aluminum disk in Step 3 and then begin collecting data. Store this run (Run 4).

9. Repeat Step 5, dropping the aluminum disk onto the steel disk after a few seconds. Store this run (Run 5) and save the experiment file in case you need to return to it.

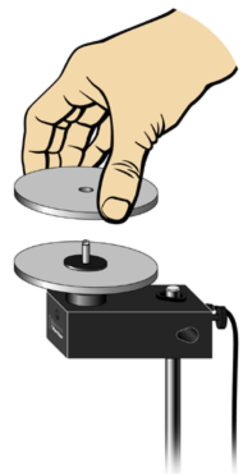


Figure 3

EVALUATION OF DATA

1. Use a text or web resource to find an expression for the moment of inertia for a disk; determine the values of I for your aluminum disks. With its large central hole, the steel disk should be treated as a cylindrical tube. Using the appropriate expression, determine the value of I for the steel disk.

2. Examine the ω-t graph for your runs with the single aluminum disk (Run1) and the steel disk (Run 4). Determine the rate of change of the angular velocity, ω, for each disk as it slowed. Account for this change in terms of any unbalanced forces that may be acting on the system. Explain the difference in the rates of change of ω (aluminum *vs.* steel) in terms of the values you calculated in Step 1.

3. Examine the ω-t graph for Run 2. Determine the rate of change of ω before you dropped the second disk onto the first. Record the angular velocity just before and just after you increased the mass of the system. Determine the time interval (Δt) between these two velocity readings.
   - In Logger *Pro*, drag-select the interval between these two readings. The Δx in the lower left corner gives the value of Δt.
   - In LabQuest App, drag and select the interval between these two readings and use the Delta function under Statistics to perform this task.
4. The angular momentum, L, of a system undergoing rotation is the product of its moment of inertia, I, and the angular velocity, ω.

   $$L = I\omega$$

   Determine the angular momentum of the system before and after you dropped the second aluminum disk onto the first. Calculate the percent difference between these values.
5. Use the initial rate of change in ω and the time interval between your two readings to determine $\Delta\omega$ due to friction alone. What portion of the difference in the angular momentum before and after you increased the mass can be accounted for by frictional losses?
6. Repeat the calculations in Steps 3–5 for your third and fifth runs.

EXTENSION

In this experiment, the moment of inertia of the rotating system was changed by adding mass. In what other way could one change the moment of inertia? Consider an example of how this is done outside the lab. Explain how this change in I produces a change in ω.

Sound Waves and Beats

Sound waves consist of a series of air pressure variations. A Microphone diaphragm records these variations by moving in response to the pressure changes. The diaphragm motion is then converted to an electrical signal. Using a Microphone and an interface, you can explore the properties of common sounds.

The first property you will measure is the *period*, or the time for one complete cycle of repetition. Since period is a time measurement, it is usually written as *T*. The reciprocal of the period (1/*T*) is called the *frequency*, *f*, the number of complete cycles per second. Frequency is measured in hertz (Hz). 1 Hz = 1 s^{-1}.

A second property of sound is the *amplitude*. As the pressure varies, it goes above and below the average pressure in the room. The maximum variation above or below the pressure mid-point is called the amplitude. The amplitude of a sound is closely related to its loudness.

In analyzing your data, you will see how well a sine function model fits the data. The displacement of the particles in the medium carrying a periodic wave can be modeled with a sinusoidal function. Your textbook may have an expression resembling this one:

$$y = \mathrm{A}\sin\left(2\pi f\ t\right)$$

In the case of sound, a longitudinal wave, *y* refers to the change in air pressure that makes up the wave, *A* is the amplitude of the wave, and *f* is the frequency. Time is represented by *t*, and the sine function requires a factor of 2π when evaluated in radians.

When two sound waves overlap, air pressure variations will combine. For sound waves, this combination is additive. We say that sound follows the principle of *linear superposition*. Beats are an example of superposition. Two sounds of nearly the same frequency will create a distinctive variation of sound amplitude, which we call beats.

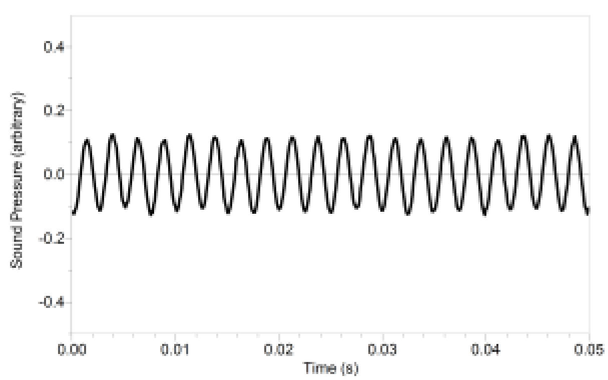


Figure 1

OBJECTIVES

- Measure the frequency and period of sound waves from a keyboard.
- Measure the amplitude of sound waves from a keyboard.
- Observe beats between the sounds of two notes from a keyboard.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Microphone
electronic keyboard

PRELIMINARY QUESTIONS

1. Why are instruments tuned before being played as a group? In what different ways do musicians tune their instruments?

2. Given that sound waves consist of a series of air pressure increases and decreases, what would happen if an air pressure increase from one sound wave was located at the same place and time as a pressure decrease from another of the same amplitude?

3. How is it that we can hear all the instruments played by a group of musicians at once? Are there conditions under which you cannot hear all instruments? Can two sounds add up to create an experience that seems less intense than either sound on its own?

PROCEDURE

Part I Simple Waveforms

1. Connect the Microphone to the computer interface.

2. Set your keyboard to produce a flute sound or pure tone.

3. Open the file "32 Sound Waves" in the *Physics with Vernier* folder. Data are collected for only 0.05 s in order to be able to display the rapid pressure variations of sound waves. The vertical axis corresponds to the variation in air pressure and the units are arbitrary.

4. To center the waveform on zero, it is necessary to zero the Microphone channel. With the room quiet, click Zero to center waveforms on the time axis.

5. Press and hold a key on the keyboard. Hold the Microphone close to the speaker and click Collect. The data should be sinusoidal in form, similar to Figure 1.

6. Note the appearance of the graph. Count and record the number of complete cycles shown after the first peak in your data.

7. Click Examine, . Click and drag the mouse between the first and last peaks of the waveform. Read the time interval Δt, and divide it by the number of cycles to determine the period of the waveform.

8. Calculate the frequency of the note in Hz and record it in your data table.

9. In a similar manner, determine amplitude of the waveform. Click and drag the mouse across the graph from top to bottom for an adjacent peak and trough. Read the difference in y values, shown on the graph as Δy.

10. Calculate the amplitude of the wave by taking half of the difference, Δy. Record the value in your data table.

11. Make a sketch of your graph or print the graph.

12. Save your data by choosing Store Latest Run from the Experiment menu.

13. Fit the function, $y = A * \sin(B*t + C) + D$, to your data. A, B, C, and D are parameters (numbers) that Logger *Pro* reports after a fit. This function is more complicated than the textbook model, but the basic sinusoidal form is the same. Comparing terms, listing the textbook model's terms first, the amplitude A corresponds to the fit term A, and $2\pi f$ corresponds to the parameter B. The time is represented by t, Logger *Pro*'s horizontal axis. The new parameters C and D shift the fitted function left-right and up-down, respectively, and are necessary to obtain a good fit. Only the values of parameters A and B are important to this experiment. In particular, the numeric value of B allows you to find the frequency f using $B = 2\pi f$.
    a. Choose Model from the Analyze menu.
    b. In the dialog box, choose Run 1|Sound Pressure and click OK.
    c. Select "A*sin(B*t +C) + D (Sine)" from the list of equations.
    d. Enter your estimate for the value of A, the amplitude.
    e. Enter your estimate for the value of B (start with $2\pi f$).
    f. Initially use zero for C and D.
    g. Click OK to view the model with your data.
    h. The model and its parameters appear in a box on the graph. Adjust the values until you have a good fit. Then, record the parameters A, B, C, and D in your data table.

14. Hide the run by choosing Hide Data Set from the Data menu and selecting Run 1 to hide. Then, repeat Steps 5–13 for an adjacent key on the keyboard. When repeating Step 13(b), choose Run 2|Sound Pressure. When you are finished analyzing the second frequency, hide the Run 2 data.

15. Answer the Analysis questions for Part I before proceeding to Part II.

Part II Beats

16. Two pure tones with different frequencies sounded at once will create the phenomenon known as beats. Sometimes the waves will reinforce one another and other times they will combine to a reduced intensity. This happens on a regular basis because of the fixed frequency of each tone. To observe beats, simultaneously hold down the two adjacent keys on the keyboard that you used earlier and listen for the combined sound. If the beats are slow enough, you should be able to hear a variation in intensity. When the beats are too rapid to be audible as intensity variations, a single rough-sounding tone is heard. At even greater frequency differences, two separate tones may be heard, as well as various difference tones.

17. Collect data while the two tones are sounding. You should see a time variation of the sound amplitude. When you get a clear waveform, choose Store Latest Run from the Experiment menu. The beat waveform will be stored as Run 3.

18. The pattern will be complex, with a slower variation of amplitude on top of a more rapid variation. Ignoring the more rapid variation and concentrating in the overall pattern, count the number of amplitude maxima after the first maximum and record it in the data table.

19. Click Examine, . As you did before, find the time interval for several complete beats. Divide the difference, Δt, by the number of cycles to determine the period of beats (in seconds). Calculate the *beat frequency* in Hz from the beat period. Record these values in your data table.

20. Proceed to the Analysis questions for Part II.

ANALYSIS

Part I Simple Waveforms

1. Did your model fit the waveform well? In what ways was the model similar to the data and in what ways was it different?

2. Since the model parameter B corresponds to $2\pi f$ (*i.e.*, $f = B/(2\pi)$), use your fitted model to determine the frequency. Enter the value in your data table. Compare this frequency to the frequency calculated earlier. Which would you expect to be more accurate? Why?

3. Compare the parameter A to the amplitude of the waveform.

Part II Beats

4. How is the beat frequency that you measured related to the two individual frequencies? Compare your conclusion with information given in your textbook.

DATA TABLE

Part I Simple Waveforms

Note	Number of cycles	Δt (s)	Period (s)	Calculated frequency (Hz)

Note	Amplitude (V)

Note	Parameter A (V)	Parameter B (s^{-1})	Parameter C	Parameter D (V)	$f = B/2\pi$ (Hz)

Part II Beats

Number of cycles	Δt (s)	Period (s)	Calculated beat frequency (Hz)

EXTENSIONS

1. The beats you observed in Run 3 resulted from the overlap of sound waves from the two notes. How would the data you recorded compare to a simple addition of the waveforms from the notes individually? If the sound waves combined in air by linear addition, then the algebraic sum of the data of the individual waveforms should be similar to data of the beats. The following steps will help you perform the addition:
   a. Show Run 3 only (the waveform of the actual beats).
   b. Choose New Calculated Column from the Data menu. Give the column the name of "Sum."
   c. Click once in the equation field to place the cursor there. Select Choose Specific Column… from the Variables (Columns) menu. Select "Run1|Sound Pressure," then click OK and type the addition symbol "+." Next, select Choose Specific Column… from the Variables (Columns) menu, select "Run 2|Sound Pressure" and click OK. The resulting equation will read "Run 1|Sound Pressure"+ "Run 2|Sound Pressure."
   d. Click Done.
   e. A new column, representing the sum of the two waveforms, will be created in each Data Set.
   f. Click on the y-axis label to show the y-axis selection dialog and choose Sum. Click OK. You now see the mathematical sum of the Runs 1 and 2. Rescale the graph if needed. Now use the y-axis label dialog to display only the actual data of the beats. If you wish to view the sum simultaneously with the collected data, choose "More…" from the y-axis dialog and then select to display both runs. How is the sum similar to the real data? How are they different? Do the graphs support the model of additive sound wave superposition? What if the superposition rule were multiplicative? Would that change the graph?

2. There are commercial products available called *active noise cancellers*, which consist of a set of headphones, microphones, and some electronics. Intended for wearing in noisy environments where the user must still be able to hear (for example, radio communications), the headphones reduce noise far beyond the simple acoustic isolation of the headphones. How might such a product work?

3. The trigonometric identity

$$\sin x + \sin y = 2\sin\left(\frac{x+y}{2}\right)\cdot\cos\left(\frac{x-y}{2}\right)$$

is useful in modeling beats. Show how the beat frequency you measured above can be predicted using two sinusoidal waves of frequency f_1 and f_2, whose pressure variations are described by $\sin(2\pi f_1 t)$ and $\sin(2\pi f_2 t)$.

4. Most of the attention in beats is paid to the overall intensity pattern that we hear. Use the analysis tools to determine the frequency of the variation that lies inside the pattern (the one inside the envelope). How is this frequency related to the individual frequencies that generated the beats?

5. Examine the pattern you get when you play two adjacent notes on a keyboard. How does this change as the two notes played get further and further apart? How does it stay the same?

Impulse and Momentum (Motion Encoder)

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 Motion Encoder Cart will roll along a level track. Its momentum will change as it collides with a hoop spring. 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 is measured by a Dual-Range Force Sensor. The cart velocity throughout the motion is measured with a Motion Encoder. You will then use data-collection software to find the impulse to test the impulse-momentum theorem.

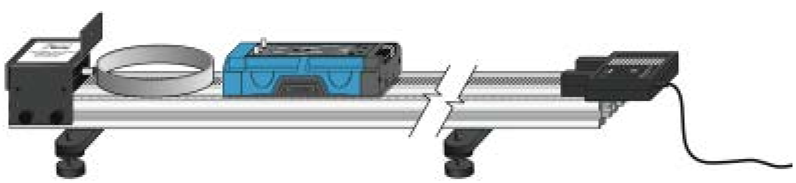


Figure 1

OBJECTIVES

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

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Motion Encoder Receiver
Vernier Dual-Range Force Sensor
Vernier Dynamics Track
Motion Encoder Cart
Vernier Bumper and Launcher Kit

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. Measure the mass of the cart and record the value in the data table.

2. Attach the Motion Encoder Receiver to one end of the Dynamics Track (see Figure 1).

3. Set the range switch on the Dual-Range Force Sensor to 10 N. Replace the hook end of the Dual-Range Force Sensor with the hoop spring bumper. Attach the Dual-Range Force Sensor to the bumper launcher assembly as shown in Figure 2. Then attach the bumper-launcher assembly to the end of the track opposite the Motion Encoder Receiver.

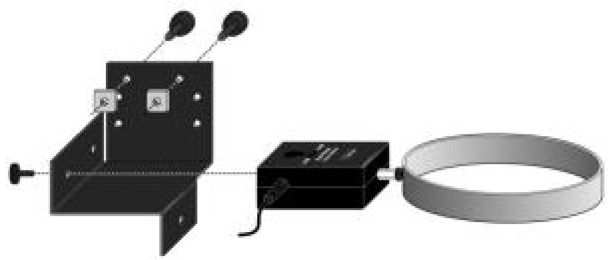


Figure 2 Connect the Dual-Range Force Sensor to the bumper-launcher assembly.
***Note**: Shown inverted from how the sensor and assembly are attached to the track.*

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

5. Connect the Motion Encoder Receiver to a digital (DIG) port of the interface. Connect the Dual-Range Force Sensor to Channel 1 of the interface.

6. Open the file "19 Impulse and Momentum" in the *Physics with Vernier* folder.

7. Remove all force from the Dual-Range Force Sensor. Click Zero, select only the Dual-Range Force Sensor in the list, and click OK to zero the sensor.

Part I Elastic collisions

8. Practice releasing the cart so it rolls toward the hoop spring, bounces gently, and returns to your hand. The Dual-Range Force Sensor must not shift, and the cart must stay on the track.

9. Position the cart so that the front of the cart is approximately 50 cm from the spring. Click Collect; roll the cart so it bounces off the spring.

10. Study your graphs to determine if the run was useful. Inspect the force data. If the peak exceeds 10 N, then the applied force is too large. Roll the cart with a lower initial speed.

11. 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 position *vs.* time graph, find an interval corresponding to a time before the impulse, when the cart was moving at approximately constant speed toward the Dual-Range Force Sensor.
    b. Select this interval and click Linear Fit, . Record the slope (the average velocity during the interval) as the initial velocity in your data table.
    c. In the same manner, choose an interval corresponding to a time after the impulse, when the cart was moving at approximately constant speed away from the Dual-Range Force Sensor.
    d. Select this interval and click Linear Fit, . Record the slope (the average velocity during the interval) as the final velocity in your data table.

12. 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

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

    On the force *vs.* time graph, drag across the impulse, capturing the entire period when the force was non-zero. Find the area under the force *vs.* time graph by clicking Integral, . Record the value of the integral in the impulse column of your data table.

    Method 2 Non-calculus version

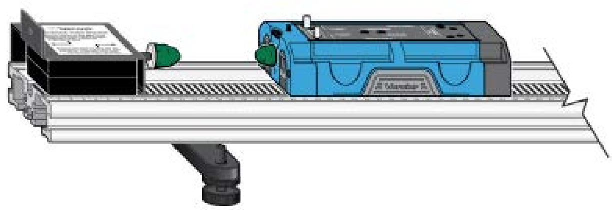
    Calculate the impulse from the average force on your force *vs.* time graph. The impulse is the product of the average (mean) force and the length of time that force was applied, or $\bar{F}\Delta t$.

    a. Click and drag across the impulse, capturing the entire period when the force was non-zero.
    b. Find the average value of the force by clicking Statistics, , and record this value in your data table.
    c. Also read the duration of the time interval, Δt, over which your average force is calculated, which Logger *Pro* reports on the graph. Record this value in your data table.
    d. From the average force and time interval, determine the impulse, $\bar{F}\Delta t$, and record this value in your data table.

13. Repeat Steps 9–12 two more times to collect a total of three trials; record the information in your data table.

Part II Inelastic collisions

14. 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 front of the cart, as shown in Figure 3.



15. Remove all force from the Dual-Range Force Sensor. Click Zero, select Dual-Range Force Sensor from the list, and click OK to zero the Dual-Range Force Sensor.

16. Practice launching the cart with your finger so that when the clay on the front of the cart collides with the clay on the Dual-Range Force Sensor, the cart comes to a stop without bouncing.

17. Position the cart so that the front of the cart is approximately 50 cm from the clay holder on the Bumper and Launcher Kit. Click Collect; roll the cart so that the clay pieces impact one another.

18. Study your graphs to determine if the run was useful. Inspect the force data. If the peak exceeds 10 N, then the applied force is too large. Roll the cart with a lower initial speed.

19. 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 position *vs.* time graph, select an interval corresponding to a time before the impact and and click Linear Fit, . Record the slope as the initial velocity in your data table.
    b. In the same manner, select the interval corresponding to a time after the impact and click Linear Fit, . Record the slope as the final velocity in your data table.
20. Calculate the value of the impulse. Similar to Step 12, use the first method if you have studied calculus and the second if you have not.

    Method 1 Calculus version

    On the force *vs.* time graph, click and drag across the impulse, capturing the entire period when the force was non-zero. Find the area under the force *vs.* time graph by clicking Integral, . Record the value of the integral in the impulse column of your 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 Statistics, , and record this value in your data table.
    b. Also record the length of the time interval, Δt, over which your average force is calculated.
    c. From the average force and time interval, determine the impulse, $\bar{F}\Delta t$, and record this value in your data table.

21. Repeat Steps 17–20 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

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 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.

EXTENSION

The Bumper and Launcher Kit includes two different hoop springs, with one stiffer than the other. Repeat your experiment with the spring you have not yet used. Predict how the results will be similar and how they will be different.

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.

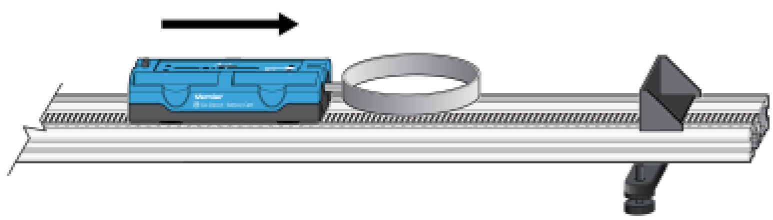


Figure 1

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

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

    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 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 $\overline{F}\Delta t$.

    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, $\overline{F}\Delta t$, 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 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.

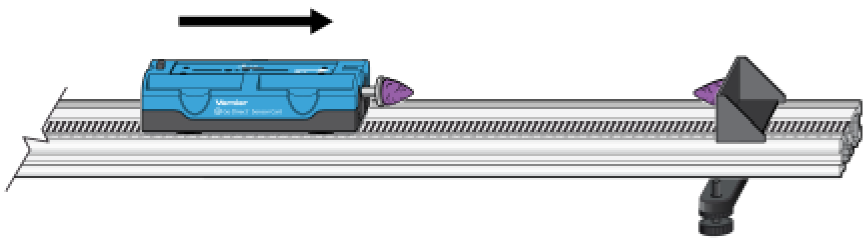


Figure 2

14. 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 spring. Click or tap Collect to start data collection, then roll the cart so that the clay pieces impact one another.

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 Tools, , 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. Click or tap Graph Tools, , 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. Select the impulse, then click or tap graph Tools, , and choose View Integral.
    b. 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, $\overline{F}\Delta t$, 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

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 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.

α, β, and γ

Nuclear radiation can be broadly classified into three categories. These three categories are labeled with the first three letters of the Greek alphabet: α (alpha), β (beta), and γ (gamma). Alpha radiation consists of a stream of fast-moving helium nuclei (two protons and two neutrons). As such, an alpha particle is relatively heavy and carries two positive electrical charges. Beta radiation consists of fast-moving electrons or positrons (an antimatter electron).

A beta particle is much lighter than an alpha and carries one unit of charge. Gamma radiation consists of photons, which are massless and carry no charge. X-rays are also photons, but carry less energy than gammas.

After being emitted from a decaying nucleus, the alpha, beta or gamma radiation may pass through matter, or it may be absorbed by the matter. You will arrange for the three classes of radiation to pass through nothing but a thin layer of air, a sheet of paper, and an aluminum sheet. Will the different types of radiation be absorbed differently by the air, paper and aluminum? The question can be answered by considering which radiation type will interact more strongly with matter, and then tested by experiment.

In this experiment you will use small sources of alpha, beta, and gamma radiation. *Follow all local procedures for handling radioactive materials.*

OBJECTIVES

- Develop a model for the relative absorption of alpha, beta, and gamma radiation by matter.
- Use a radiation counter to measure the absorption of alpha, beta, and gamma radiation by air, paper, and aluminum.
- Analyze count rate data to test for consistency with your model.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Radiation Monitor
paper sheet
polonium-210 0.1µC alpha source
strontium-90 0.1µC beta source
cobalt-60 1µC gamma source
aluminum sheet, about 2 mm thick

PRELIMINARY QUESTIONS

1. Most nuclear radiation carries energy in the range of a few million electron volts, or MeV (1 MeV = 10^6 eV = 1.6×10^{13} J), regardless of its type (alpha, beta, or gamma). This means that more massive particles generally travel more slowly than light particles. Make a preliminary guess as to which radiation type will in general interact most strongly with matter, and therefore would be most strongly absorbed as it passes through matter. Consider electrical charge, mass and speed. Explain your reasons.

2. Which radiation type do you predict would interact, in general, least strongly with matter, and so be less absorbed than others? Why?

3. Which radiation type do you predict would have an intermediate level of interaction with matter? Why?

4. You will be using paper and aluminum sheet metal as absorbers for the radiation. Which material has the greatest areal density (that is, a density measure in mass per unit area, which could be measured in g/cm^2), and so would present more matter to the passing radiation? Which material would have less?

5. Is your Radiation Monitor sensitive to all three types of radiation? How can you tell? Devise a test and carry it out.

PROCEDURE

1. Connect the Radiation Monitor to a DIG port of the computer interface.

2. Prepare the computer for data collection by opening the file "01 Alpha Beta Gamma" from the *Nuclear Radiation w Vernier* folder of Logger *Pro*.

3. To determine the background count rate, move all sources away from the Radiation Monitor. Click Collect to begin collecting data. While it may appear as if data collection did not start, Logger *Pro* is collecting data; it takes 50 s for the number of counts to appear in the meter. When the number of counts is displayed, record the value in your data table.

4. Using no absorber, place the beta source near the monitor screen of your Radiation Monitor, with the underside of the disc facing the monitor screen. **Note**: Place the Radiation Monitor and the source in approximately the same position each time you collect data. When using an absorber, place the absorber between the source and the monitor screen. Each time you collect data, the distance between the Radiation Monitor and the source should be approximately the same.

   Click Collect to begin data collection. Wait for Logger *Pro* to display the number of counts and record the value in your data table.

5. Place a single sheet of paper between the beta source and the monitor, and measure the counts as before. Take care to keep the source in the same position with respect to the Radiation Monitor. Record the count rate in the appropriate place in the data table.

6. In a similar manner, determine and record the counts when the following substances used as an absorber for each of the three sources:
   a. a single sheet of paper
   b. a single sheet of aluminum

DATA TABLE

Counts in 50 s interval			
	No shielding	Paper shield	Aluminum shield
No source (background)			
Alpha source			
Beta source			
Gamma source			

ANALYSIS

1. Compare the no-source, or background, count with the no-absorber counts for the sources. Is the background count number a significant fraction of the counts from the sources? Do you need to consider a correction for the background counts?

2. Inspect your data. Does the count rate appear to follow your initial guesses for the relative absorption of the various types of radiation by matter? Be specific, considering which source should be the most penetrating (least interacting), and which absorber is more difficult to penetrate.

3. X-rays are photons, just like gamma rays. X-rays carry lower energy, however, and so historically received a different name. If you have had an X-ray film picture of your teeth taken by a dentist, the dentist probably placed a lead-lined apron on your chest and lap before making the X-ray. What is the function of the lead apron? Support any assertion you make from your experimental data.

EXTENSIONS

1. If you were presented with a safe, but unknown, radiation source, and assuming that it emitted only one type of radiation, devise a test that would allow you to tentatively identify the type of radiation as primarily alpha, beta, or gamma. Write instructions for another student to follow in performing the test.

2. Your monitor detected some radiation even without a source present. Devise a method to correct for this background radiation. Do the corrected data still agree with your prediction?

The Magnetic Field in a Slinky

A solenoid is made by taking a tube and wrapping it with many turns of wire. A metal Slinky® is the same shape and will serve as a solenoid. When a current passes through the wire, a magnetic field is present inside the solenoid. Solenoids are used in electronic circuits or as electromagnets.

In this lab you will explore factors that affect the magnetic field inside the solenoid and study how the field varies in different parts of the solenoid. By inserting a Magnetic Field Sensor between the coils of the Slinky, you can measure the magnetic field inside the coil. You will also measure μ_0, the permeability constant. The permeability constant is a fundamental constant of physics.

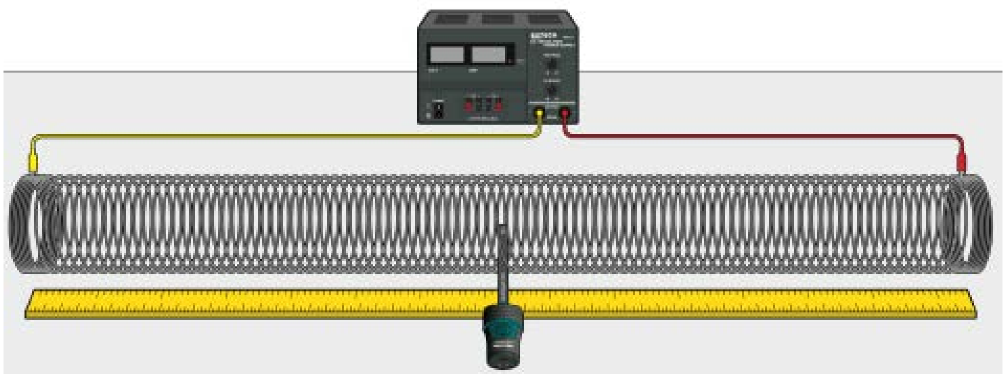


Figure 1

OBJECTIVES

- Determine the relationship between magnetic field and the current in a solenoid.
- Determine the relationship between magnetic field and the number of turns per meter in a solenoid.
- Study how the field varies inside and outside a solenoid.
- Determine the value of μ_0, the permeability constant.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct 3-Axis Magnetic Field
Extech Digital DC Power Supply
metal Slinky
meter stick
masking tape
connecting wires with clips

INITIAL SETUP

1. Set up the sensor.
   a. Launch Graphical Analysis.
   b. Connect the Magnetic Field Sensor to your Chromebook, computer, or mobile device.
   c. Click or tap Sensor Channels.
   d. Enable the Y magnetic field channel and disable the X magnetic field channel.
   e. Click or tap Done.
2. Set up the data-collection mode.
   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   b. Change Event Mode to Selected Events.
   c. Enter **Current** as the Event Name and **A** as the Units.
   d. Click or tap Done.
3. Stretch the Slinky until it is about 1 m long. The spacing between the coils should be 1–2 cm. Use a non-conducting material such as masking tape to hold the Slinky at this length.
4. Set up the circuit and equipment as shown in Figure 1.
5. Turn on the power supply, and adjust it so that the current is 2.0 A.

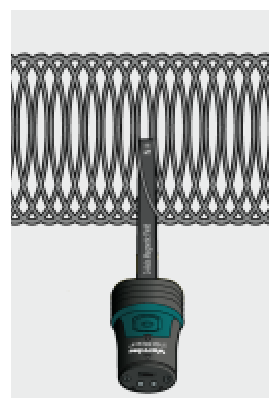


Figure 2

PRELIMINARY QUESTIONS

1. Hold the Magnetic Field Sensor between the turns of the Slinky with the y-axis label at the center of the coil (see Figure 2). Rotate the sensor and determine which direction gives the largest positive magnetic field reading. What direction is the y-axis label on the tip of the sensor pointing?
2. What happens if you rotate the sensor so the y-axis label on the tip points the opposite way? What happens if you rotate the sensor so the y-axis label of the sensor is perpendicular to the axis of the solenoid?
3. Insert the Magnetic Field Sensor through different locations along the Slinky to explore how the field varies along the length. Always orient the sensor to read the maximum magnetic field at that point along the Slinky. How does the magnetic field inside the solenoid seem to vary along its length?
4. Check the magnetic field intensity just outside the solenoid. Is it different from the field inside the solenoid?

PROCEDURE

Part I How is the Magnetic Field in a Solenoid Related to Current?

For the first part of the experiment you will determine the relationship between the magnetic field at the center of a solenoid and the current flowing through the solenoid. Data will be collected in Events with Entry mode. Each time you click or tap Keep during data collection, the sensor reading will be displayed. You will then enter a value and click or tap Keep Point to complete the data point.

1. Turn off the power supply to stop all current in the solenoid.

2. Position the Magnetic Field Sensor between the turns of the Slinky near its center, lengthwise. Rotate the sensor so that the y-axis label points directly down the long axis of the solenoid in the direction that gives the largest positive magnetic field reading. The y-axis label of the sensor should still be at the center of the coil, as shown in Figure 2. This will be the position for all of the magnetic field measurements for the rest of this part.

3. To zero the Magnetic Field Sensor to remove readings due to the Earth's magnetic field, any magnetism in the metal of the Slinky, or the table, click or tap the Y Magnetic Field meter and choose zero.

4. Now you are ready to collect magnetic field data as a function of current.
   a. Turn on the power supply.
   b. Adjust the power supply so that it is set to 0.0 A.
   c. Start data collection.
   d. Hold the sensor still and click or tap Keep. Enter **0.0** as the current and click or tap Keep Point to store the data pair.
   e. Increase the current by 0.5 A. Click or tap Keep and enter **0.5** as the current. Click or tap Keep Point.
   f. Repeat this process until you collect data for 2.0 A, and then stop data collection.
5. Answer the Analysis questions for Part I before proceeding to Part II.

Part II How is the Magnetic Field in a Solenoid Related to the Spacing of the Turns?

For the second part of the experiment, you will determine the relationship between the magnetic field in the center of a coil and the number of turns of wire per meter of the solenoid. You will keep the current constant. Leave the Slinky set up as shown in Figure 1. The sensor will be oriented as it was before, so that it measures the field down the middle of the solenoid. You will change the length of the Slinky from 0.5 to 2.0 m, in order to change the number of turns per meter.

6. Change the event name and the units to create a graph of magnetic field *vs.* turns per meter.
   a. Click or tap Mode to open Data Collection Settings.
   b. Change the Event Name to **turns/m** and the Units to **m**. Leave the rest of the settings as they are.
   c. Click or tap Done.

7. Keep the number of turns the same, but change the length of the slinky to 0.5 m. If you need to, re-count the number of turns, and then calculate the number of turns per meter. Record these values in the data table.

8. With the power supply off and the Magnetic Field Sensor in position, click or tap the Y Magnetic Field meter and choose Zero to zero the sensor and remove readings due to the Earth's magnetic field, any magnetism in the metal of the Slinky, or the table.

9. Collect the first data point.

   a. Turn on the power supply and adjust the power supply so that it is set to 1.5 A.
   b. Start data collection.
   c. Click or tap Keep and hold the sensor still. Enter the number of turns per meter that you calculated, and click or tap Keep Point to store the data pair.

10. Collect additional data.

    a. Change the length of the Slinky to 1.0 m but keep the number of turns the same. As before, re-count the number of turns if necessary, and then calculate the number of turns per meter. Record the values in the data table.
    b. Click or tap Keep and hold the sensor still. Enter the number of turns per meter that you calculated. Click or tap Keep Point.
    c. Repeat this step to collect data for 1.5 m and 2.0 m.
    d. Stop data collection when you have finished with the last point.
    e. Turn off the power supply.

11. Proceed to the Analysis questions for Part II.

ANALYSIS

Part I How is the Magnetic Field in a Solenoid Related to Current?

1. Count the number of turns of the Slinky and measure its length. If you have any unstretched part of the Slinky at the ends, do not count it for either the turns or the length. Calculate the number of turns per meter of the stretched portion. Record the length, turns, and the number of turns per meter in the data table.

2. Inspect the graph of magnetic field, *B*, *vs.* the current, *I*, through the solenoid. How is magnetic field related to the current through the solenoid?

3. If the points on your graph of magnetic field *vs.* current through the coils follow a generally linear path, fit a straight line to the data.

   a. Click or tap Graph Tools, , and choose Apply Curve Fit.
   b. Select Linear as the curve fit, and click or tap Apply. The linear-regression statistics are displayed.
   c. Record the slope and y-intercept of the regression line in the data table, along with their units.
   d. Export, print, or sketch your graph.

4. Inspect the equation of the best-fit line to the field *vs.* current data. What are the units of the slope? What does the slope measure?

Part II How is the Magnetic Field in a Solenoid Related to the Spacing of the Turns?

5. How is magnetic field related to the coil density, *n*, measured in turns/meter of the solenoid?

6. If the points on your graph of magnetic field *vs.* number of turns per meter follow a generally linear path, fit a straight line to the data.

   a. Click or tap Graph Tools, , and choose Apply Curve Fit.
   b. Select Linear as the curve fit, and click or tap Apply. The linear-regression statistics are displayed.
   c. Record the slope and y-intercept of the regression line in the data table, along with their units.
   d. Export, print, or sketch your graph.

7. From Ampere's law, it can be shown that the magnetic field, *B*, inside a long solenoid is

$$B = \mu_0 n I$$

   where μ_o is the permeability constant. Are your results consistent with this equation? Explain.

8. Assuming the equation in the previous question applies for your solenoid, calculate the value of μ_o using your graph of *B vs. n*. You will need to convert the slope to units of T•m from mT•m.

9. Look up the value of μ_o, the permeability constant. Compare it to your experimental value.

10. Was your Slinky positioned along an east-west or north-south axis, or was it on some other axis? Does this have any effect on your readings?

DATA TABLE

Part I

Length of solenoid (m)	
Number of turns	
Coil density (m^{-1})	

Magnetic field *vs.* current	
Slope	
Intercept	

Part II

Number of turns	Length of solenoid (m)	Coil density (m^{-1})

Magnetic field *vs.* coil density	
Slope	
Intercept	

EXTENSIONS

1. Carefully measure the magnetic field at the end of the solenoid. How does it compare to the value at the center of the solenoid? Does the result make sense? Explain your reasoning.

2. Study the magnetic field strength inside and around a toroid, a circular-shaped solenoid.

3. If you have studied calculus, refer to a calculus-based physics text to see how the equation for the field of a solenoid can be derived from Ampere's law.

4. If you look up the permeability constant, you may find it listed in units of henry/meter. Show that these units are the same as tesla-meter/ampere.

5. Take data on the magnetic field intensity *vs.* position along the length of the solenoid. Check the field intensity at several distances along the axis of the Slinky past the end. Note any patterns you see. Plot a graph of magnetic field, *B*, *vs.* distance from center. How does the value at the end of the solenoid compare to that at the center? How does the value change as you move away from the end of the solenoid?

6. Insert a steel or iron rod inside the solenoid and see what effect that has on the field intensity. Be careful that the rod does not short out with the coils of the Slinky.

7. Use the graph obtained in Part I to determine the value of μ_o.