Science with TI-Nspire™ Technology

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This book is a compilation of experiments that have previously appeared in various Vernier lab books. Many thanks to the authors who originally wrote these experiments and the editors who put all of this together.

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Proper safety precautions must be taken to protect teachers and students during experiments described herein. Neither the authors nor the publisher assumes responsibility or liability for the use of material described in this publication. It cannot be assumed that all safety warnings and precautions are included. Teachers must follow local regulations concerning safe handling, use, and disposal of the chemicals associated with the experiments included in this manual.

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Physics

Appendices

* Experiments denoted with an asterisk are appropriate as written for middle school science.

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1	Intro to Data Collection	1														
2	Exploring Magnetism		1													
3	Where IS North?		1													
4	Soil Temperature	3														
5	Watershed Testing	1		1	1	1										
6	Reflection and Absorption of Light	1					1									
7	Dew Point	1														
8	Seasons and Angle of Insolation	1														
9	Acids and Bases			1												
10	Diffusion through Membranes				1											
11	Conducting Solutions				1											
12	Enzyme Action							1								
13	Transpiration							1								
14	Cell Respiration								1							
15	Interdependence of Plants and Animals			1		1										
16	Heart Rate and Physical Fitness									1						
17	Ventilation and Heart Rate									1						
18	Freezing and Melting of Water	1														
19	Boyle's Law: Pressure-Volume Relationship in Gases							1								
20	Evaporation and Intermolecular Attractions	2														
21	Determining the Concentration of a Solution: Beer's Law										1					
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24	Additivity of Heats of Reaction: Hess's Law	1														
25	Acid Rain			1												
26	Graph Matching											1				
27	Ball Toss											1				
28	Newton's Second Law												1	1		
29	Static and Kinetic Friction											1	1			
30	Simple Harmonic Motion											1				
31	Capacitors														1	
32	Sound Waves and Beats															1
33	Speed of Sound															1

Preface

This book contains thirty-three experiments using Vernier probeware with the Texas Instruments TI-Nspire™ handhelds and computer software for collecting, displaying, printing, graphing, and analyzing data. These can comprise a high percentage of the experiments included in any science course. We are convinced of the importance of *hands-on* experiments. Data collection technologies are an integral and indispensable equipment component in a science classroom.

Data-collection technologies not only enable students to experience new experiments with measurements not previously obtainable in the classroom, but they also enhance experiments and demonstrations formerly done with devices such as thermometers, pH strips, and stopwatches. Data-collection technologies can give more accurate measurements, they can allow an experiment to be continuously monitored without close attention, and they can save, display, graph, and analyze data. Temperature probes interfaced with TI-Nspire technology can eliminate student use of mercury thermometers.

Vernier Software & Technology, with its high quality and comparatively inexpensive hardware, supported with well-written, thorough, and easy-to-use software, has made it possible and relatively simple for science teachers to completely integrate data collection with TI-Nspire technology into their classrooms. This book helps in the task.

This book is not intended as a stand-alone laboratory manual. It is intended to supplement the science-teaching materials adopted for use in your school. Experiments in this book can be used unchanged or they can be modified using the word-processing files provided on the accompanying electronic resources. Here are some ways to use the experiments in this book:

- Unchanged. You can photocopy the student sheets, distribute them, and students can do the experiments following the procedures as they are written. Many students will be more comfortable if most of the steps used in data collection and analysis are included in each experiment.
- Slightly modified. The electronic resources accompanying the book are for this purpose. Before producing student copies, you can change the directions to make them better fit your teaching circumstances. See Appendix A.
- Extensively modified. Some teachers will want to decrease the degree of detail in student instructions to allow for more inquiry-driven experimentation.

We hope and expect that experienced science teachers will significantly modify the procedures provided in this book. The *Teacher Information* section that follows each experiment has sample results, answers to questions, directions for preparing solutions, and other helpful hints regarding the planning and implementation of a particular experiment.

For students and teachers that are new to data collection with the TI-Nspire technology, we **strongly** recommend that you start with the first activity, *Introduction to Data Collection*. This activity is designed to introduce students and teachers to the features of the DataQuest application that are used throughout the book. We also recommend reviewing the information in *Appendix B* and *Appendix C* for instructions on the common tasks used when collecting and analyzing data with the Vernier DataQuest™ application.

It is **important** for teachers to read the information presented in the appendices. They include valuable information that can help make you more comfortable with your initial use of the DataQuest application, TI-Nspire technology, and Vernier sensors. Here is a short summary of the information available in each appendix:

- *Appendix A* includes information about the electronic resources that accompany this book.
- *Appendix B* tells you how to use the DataQuest application on a handheld.
- *Appendix C* tells you how to use the DataQuest application on a computer.
- *Appendix D* provides information on Vernier products.
- *Appendix E* provides a list of equipment and supplies used in these experiments.
- *Appendix F* provides safety information.

Introduction to Data Collection on a TI-Nspire Handheld

Data collection is a very important part of science. Meteorologists collect weather data over time to keep a historical record and to help make forecasts. Oceanographers collect data on the salinity (saltiness) of seawater to study changing trends in our Earth's oceans. While data have been collected by hand for thousands of years, the technology to collect data electronically has been around for fewer than 80 years. Only in the last 20 years has this technology been available to schools.

This experiment was designed to introduce you to two of the most common modes of data collection that will be used in this book. Part I will guide you through collecting and analyzing data over time. A Temperature Probe will be used to record the temperature of water for 60 seconds at a rate of one sample every two seconds. In Part II, you will collect data using a mode called Events with Entry. This style of data collection allows you to collect one point of data, then will ask you to enter a corresponding value. In this experiment, the data collected will be the temperature of your hand and the value you enter will be your name.

OBJECTIVES

In this experiment, you will

- Become familiar with TI-Nspire handheld and the DataQuest application.
- Use a Temperature Probe to make measurements.
- Analyze a graph of the data.
- Use this graph to make conclusions about the experiment.
- Determine the response time of a Temperature Probe.

MATERIALS

TI-Nspire handheld	cold tap water
EasyTemp **or** Go!Temp with adapter **or**	hot tap water
Temperature Probe and data-collection interface	ice
two 250 mL beakers	
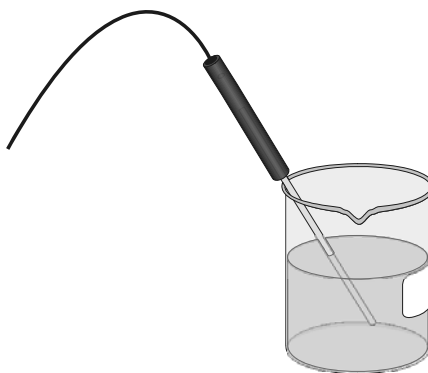
Figure 1

PROCEDURE

Part I Time Graph

1. Place about 100 mL of cold tap water into a 250 mL beaker. Add two or three ice cubes.

2. Set up the handheld for data collection.

    a. Start from a new document.

    To open a new document, press ⌂on *and select **New Document**. You may be prompted to save the current document.*

    b. Connect the Temperature Probe to the data-collection interface. If you are using an EasyTemp or Go!Temp with an adapter, you do not need a data-collection interface.

    c. Connect the interface to the TI-Nspire handheld.

    Connecting an interface or direct-connect USB sensor will automatically launch the DataQuest application in your new document.

3. Set up the data -collection parameters.

    a. Choose New Experiment from the 📷 Experiment menu.

    Press menu *to access the DataQuest menus. Select* 📷 ***Experiment*** *then **New Experiment**.*

    b. Choose Collection Setup from the 📷 Experiment menu.

    Press menu, *select* 📷 ***Experiment*** *then **Collection Setup**.*

    c. Enter **0.5** as the rate (samples/second).

    The default collection rate for a temperature probe is 2 samples per second. To modify this value, press tab *to highlight the **Rate (samples/second)** edit box and type **0.5**. The interval value will automatically update to show 2 seconds between samples.*

    d. Enter **60** as the experiment duration in seconds.

    The default duration for a temperature probe is 180 seconds. To modify this value, press tab *to highlight the **Duration (seconds)** edit box and type **60**. The number of data points collected should show 31.*

    e. Select OK.

    Press tab *until the **OK** option is highlighted and press* enter.

4. Place the Temperature Probe into the cold water and stir briefly. Then position the probe in the cold-water beaker as shown in Figure 1. **Note:** Make sure the beaker will not tip over from the weight of the Temperature Probe.

5. Place about 150 mL of hot water into a second 250 mL beaker.

    Note: In Step 7, you will switch the Temperature Probe from the cold water to the hot water at exactly 10 seconds after you have started data collection.

6. When everything is ready, start data collection. Do not stir or move the water.

    Here are three ways you can start data collection.

    *   *Click the Start Collection button – Use the touchpad or arrow keys to move the cursor over the Start Collection button (⏺) and press* 🔆.
    *   *Use the menus – Press* menu, *select* 📷 ***Experiment*** *then **Start Collection**.*
    *   *Tab to the Start Collection button – Press* tab *until the Start Collection button is in focus (highlighted by a black border) and press* enter.

Note: When data collection begins, the DataQuest Application view will change from Meter View(▨) to Graph View(▰) and the Data Collection button will show the stop icon (▣).

7. When exactly 10 seconds have gone by, quickly move the Temperature Probe to the beaker containing hot water and allow data collection to continue. Do not stir the water or move the Temperature Probe during the remainder of the data-collection period.

8. Data collection will stop automatically after 60 seconds.

   Note: When data collection ends, the data-collection button will again show the start icon (▶) and the graph will autoscale to show all of the data.

9. Remove the Temperature Probe from the beaker and dry it with a paper towel.

10. Determine the elapsed time when the highest temperature was reached.

    a. Examine the data pairs on the displayed graph to find the highest temperature.
       Use the touchpad or arrow keys to move the cursor near a desired point. Press ▨ to select the point. Use the arrow keys to examine other points on the graph.
    b. Record this temperature and the time when it was first reached in the data table.
       The coordinates of the point you are examining will be displayed in the Graph View details box to the left of the graph.
    c. Verify that you found the maximum temperature using statistical analysis. The maximum temperature should match what you found in Step 10b. Did you get the same time both ways?
       To perform a statistics calculation on your data, press menu, select ▰ Analyze then Statistics.

11. Sketch or print copies of the graph as directed by your instructor.

    Note: To print the graph, you must first import the file to a computer running the TI-Nspire computer software. You cannot print the file directly from a TI-Nspire handheld.

12. You can also confirm the time when the highest temperature was reached by viewing the data table directly.

    a. Change to the Table View to view the data lists.
       Here are two ways you change views:

       - *Clicking the Table View tab – Use the touchpad or arrow keys to move the cursor over the Table View tab (▤) and press ▨.*
       - *Using the menus – Press menu, select ▰ View then ▤ Table.*

    b. Find the time when the highest temperature was first reached.
       Here are three ways to scroll through the data table.

       - *Using the table's vertical scroll buttons – Use the touchpad or arrow keys to move the cursor over the table scroll buttons and press ▨.*
       - *Using the table's slider bar – move the cursor over the black portion of the slider, press and hold ▨ or press ctrl followed by ▨, and then use the touchpad or arrow keys to scroll the table. (Press esc to release the slider.)*
       - *Arrow through the table – Use the touchpad or arrow keys to move the cursor over any cell in the table and press ▨ to highlight the table cell. Use the arrow keys to move through the table cells.*

Part II Events with Entry

13. Insert a new problem into your TI-Nspire document and insert a DataQuest Application.

    Inserting a new problem will allow you to retain the data from Part I as you do Part II. To add a new problem, press doc▾ *(* ctrl *)(* ⌂ *) for a clickpad handheld), select* **Insert** *then* **Problem**. *You will notice that a new tab labeled* **2.1** *will be added to your document. To add the DataQuest app to this page, select* ⬚ **Add Vernier DataQuest**.

14. Set up the data-collection parameters.

    a. Choose Collection Mode ► Events with Entry from the 🧪 Experiment menu.
       Press menu, *select* 🧪 **Experiment**, **Collection Mode**, *and then* **Events with Entry**.
    b. Enter **Name** as the Name and leave the Units field blank.
       To add upper case letters, press ⇧shift *followed by the desired letter. If you want all upper case letters, press* ctrl *followed by* ⇧shift *before typing any letters.*
    c. Select OK.
       Note the Keep button (🖫) located to the right of the Start Data Collection button. You will use this button to control when a sensor reading is recorded.

15. Start data collection (▶).

    In Events with Entry mode, starting data collection does not cause a temperature vs. *time graph to be created. In this mode, no temperatures will be collected until you click the Keep button (🖫). After you have started data collection, notice that the Keep button is active.*

16. Measure the hand temperature of the first test subject.

    a. The first test subject should pick up the Temperature Probe and hold its tip in the palm of his or her hand, as shown in Figure 2. Watch the live temperature readout.
       The current sensor reading will be displayed in the details box to the left of the graph.
    b. When the temperature stops rising, click the Keep button (🖫).
       Like in Step 6, there are three ways to activate the Keep option. As you collect data, try the different options to see which you prefer.
    c. You will be prompted to enter the test subject's name. Enter the test subject's name, then select OK. The temperature and name have been saved.

Figure 2

    A data point representing the temperature for this test subject will be added to the graph. Since there is no numerical value associated with the name you typed, the row number associated with this data point is used to locate the point on the independent axis.

17. Cool the Temperature Probe down by placing it in the cold water from Part I. Monitor the temperature on the screen and remove it from the water when the temperature reaches 25°C.

18. Pass the Temperature Probe to the second test subject and repeat Steps 16–17.

    After collecting the second data point, it is recommend that you autoscale the graph. To do this, press menu, *select* **Graph** *then* **Autoscale Now**.

19. Repeat Steps 16–18 until you have tested everyone in your group.

   *Note: If you accidently select Stop Data Collection instead of Keep, restart data collection and choose the option to **Append** the data to the latest data set.*

20. Stop data collection.

   In order to perform any analysis on the data points, you must stop data collection.

21. Record your data in the data table. It may be necessary to add additional rows to your table.

   You can find the data value by examining the data on the graph (see Step 10a) or by viewing the data table (see Step 12).

22. Find the average hand temperature for the subjects you tested by selecting Statistics from the 🎬 Analyze menu.

   *To perform a statistics calculation on your data, press ⌊menu⌋, select 🎬 **Analyze** then **Statistics**.*

23. Sketch or print copies of the graph as directed by your teacher.

DATA

Part I Time Graph

Maximum temperature (°C)	Elapsed time (s)

Part II Events with Entry

Group member number	Group member name	Maximum temperature (°C)
1		
2		
3		
4		
5		
6		
Group average		

QUESTIONS

Part I Time Graph

Note: To get back to your data from Part I, you can do the following:

- *Use the arrow keys – Press* `ctrl` *followed by* ◀(⌨) *to move to the previous page in your TI-Nspire document.*
- *Click on the Page number – Use the touchpad or arrow keys to move the cursor over the* **1.1** *page tab and press* ⌨.

1. Describe the appearance of your graph in Part I.

2. Why is time plotted on the horizontal axis in this experiment?

3. Why is temperature plotted on the vertical axis?

4. Determine the Temperature Probe's response time. To do this, use your data to find how long it took for the Temperature Probe to reach the maximum temperature after moving it from the cold water to the hot water.

5. Explain how you determined your answer to Question 4.

Part II Events with Entry

6. Who had the hottest hand in your group?

7. Who had the coldest hand in your group?

Introduction to Data Collection on a Computer using TI-Nspire Software

Data collection is a very important part of science. Meteorologists collect weather data over time to keep a historical record and to help make forecasts. Oceanographers collect data on the salinity (saltiness) of seawater to study changing trends in our Earth's oceans. While data have been collected by hand for thousands of years, the technology to collect data electronically has been around for fewer than 80 years. Only in the last 20 years has this technology been available to schools.

This experiment was designed to introduce you to two of the most common modes of data collection that will be used in this book. Part I will guide you through collecting and analyzing data over time. A Temperature Probe will be used to record the temperature of water for 60 seconds at a rate of one sample every two seconds. In Part II, you will collect data using a mode called Events with Entry. This style of data collection allows you to collect one point of data, then will ask you to enter a corresponding value. In this experiment, the data collected will be the temperature of your hand and the value you enter will be your name.

OBJECTIVES

In this experiment, you will

- Become familiar with TI-Nspire computer software and the DataQuest application.
- Use a Temperature Probe to make measurements.
- Analyze a graph of the data.
- Use this graph to make conclusions about the experiment.
- Determine the response time of a Temperature Probe.

MATERIALS

Computer with TI-Nspire software	cold tap water
EasyTemp with adapter **or** Go!Temp **or**	hot tap water
Temperature Probe and data-collection interface	ice
two 250 mL beakers	
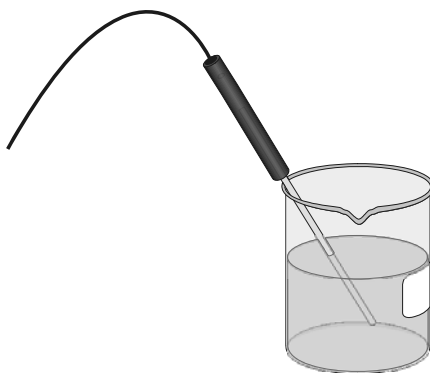
Figure 1

PROCEDURE

Part I Time Graph

1. Place about 100 mL of cold tap water into a 250 mL beaker. Add two or three ice cubes.

2. Set up the handheld for data collection.

    a. Launch the TI-Nspire software on your computer.
    b. Connect the Temperature Probe to the data-collection interface. If you are using an EasyTemp with an adapter or Go!Temp, you do not need a data-collection interface.
    c. Connect the interface to the computer.
        Connecting an interface or direct-connect USB sensor will automatically launch the DataQuest application in your document.

3. Set up the data-collection parameters.

    a. Choose New Experiment from the 🌡 Experiment menu.
        *Menus are accessed from the Document Tools (🔧) section of the Documents Toolbox. Select 🌡 **Experiment** then **New Experiment**.*
    b. Choose Collection Setup from the Experiment menu.
        *From the Document Tools (🔧), select 🌡 **Experiment** then **Collection Setup**.*
    c. Enter **0.5** as the rate (samples/second).
        *The default collection rate for a temperature probe is 2 samples per second. To modify this value, click the **Rate (samples/second)** edit box and type **0.5**. The interval value will automatically update to show 2 seconds between samples.*
    d. Enter **60** as the experiment duration in seconds.
        *The default duration for a temperature probe is 180 seconds. To modify this value, click the **Duration (seconds)** edit box and type **60**. The number of data points collected should show 31.*
    e. Select OK.

4. Place the Temperature Probe into the cold water and stir briefly. Then position the probe in the cold-water beaker as shown in Figure 1. **Note:** Make sure the beaker will not tip over from the weight of the Temperature Probe.

5. Place about 150 mL of hot water into a second 250 mL beaker.

    Note: In Step 7, you will switch the Temperature Probe from the cold water to the hot water at exactly 10 seconds after you have started data collection.

6. When everything is ready, start data collection. Do not stir or move the water.

    *Click the start collection button (▶). **Note:** When data collection begins, the DataQuest Application view will change from Meter View to Graph View and the data-collection button will show the stop icon (⬛).*

7. When exactly 10 seconds have gone by, quickly move the Temperature Probe to the beaker containing hot water and allow data collection to continue. Do not stir the water or move the Temperature Probe during the remainder of the data-collection period.

8. Data collection will stop automatically after 60 seconds.

   Note: When data collection ends, the data-collection button will again show the start icon (⬤) and the graph will autoscale to show all of the data.

9. Remove the Temperature Probe from the beaker and dry it with a paper towel.

10. Determine the elapsed time when the highest temperature was reached.

    a. Examine the data pairs on the displayed graph to find the highest temperature.
       Click on the graph near the point you are interested in. Click on a different point or use the arrow keys to examine other points on the graph.

    b. Record this temperature and the time when it was first reached in the data table.
       The coordinates of the point you are examining will be displayed in the Graph View details box to the left of the graph.

    c. Verify that you found the maximum temperature using statistical analysis. The maximum temperature should match what you found in Step 10b. Did you get the same time both ways?
       *From the Document Tools (⚒), select ⬛ Analyze then **Statistics**. You can also access the menus, right-click (Windows®) or control-click (Macintosh®) on the graph.*

11. Sketch or print copies of the graph as directed by your instructor.

    Select Print from the TI-Nspire file menu.

12. You can also confirm the time when the highest temperature was reached by viewing the data table directly.

    a. Change to the Table View to view the data lists.
       Click the Table View tab (▦) to change views.

    b. Find the time when the highest temperature was first reached.

Part II Events with Entry

13. Insert a new problem into your TI-Nspire document and insert a DataQuest Application.

    *Inserting a new problem will allow you to retain the data from Part I as you do Part II. To add a new problem, select Problem from the TI-Nspire Insert menu (▦). To add the DataQuest app to this page, select ▣ **Add Vernier DataQuest**.*

14. Set up the data-collection parameters.

    a. Choose Collection Mode ► Events with Entry from the Experiment menu.
       *From the Document Tools (⚒), select **Collection Mode** then **Events with Entry**.*

    b. Enter **Name** as the Name and leave the Units field blank.

    c. Select OK.
       Note the Keep button (▣) located to the right of the Start Data Collection button. You will use this button to control when a sensor reading is recorded.

15. Start data collection (⬤).

    In Events with Entry mode, starting data collection does not cause a temperature vs. *time graph to be created. In this mode, no temperatures will be collected until you click the Keep button (▣). After you have started data collection, notice that the Keep button is active.*

16. Measure the hand temperature of the first test subject.

    a. The first test subject should pick up the
       Temperature Probe and hold its tip in the palm of
       his or her hand, as shown in Figure 2. Watch the
       live temperature readout.

       The current sensor reading will be displayed in
       the details box to the left of the graph.

    b. When the temperature stops rising, click the Keep
       button (🖫).

    c. You will be prompted to enter the test subject's
       name. Enter the test subject's name, then select
       OK. The temperature and name have been saved.

       A data point representing the temperature for this
       test subject will be added to the graph. Since
       there is no numerical value associated with the
       name you typed, the row number associated with this data point is used to locate the point
       on the independent axis.
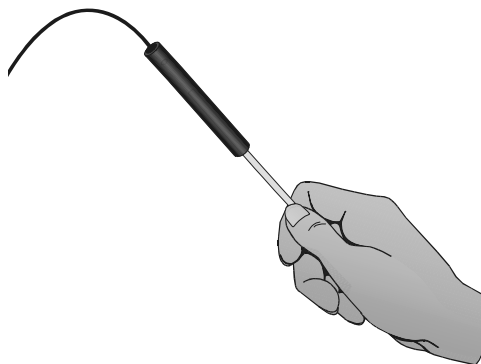
Figure 2

17. Cool the Temperature Probe down by placing it in the cold water from Part I. Monitor the
    temperature on the screen and remove it from the water when the temperature reaches 25°C.

18. Pass the Temperature Probe to the second test subject and repeat Steps 16–17.

    After collecting the second data point, it is recommend that you autoscale the graph. To do
    this, from the Document Tools (✖), select ✓ Graph, Window/Zoom, then Autoscale Now.

19. Repeat Steps 16–18 until you have tested everyone in your group.

    Note: If you accidently select Stop Data Collection instead of Keep, restart data collection
    and choose the option to Append the data to the latest data set.

20. Stop data collection.

    In order to perform any analysis on the data points, you must stop data collection.

21. Record your data in the data table. It may be necessary to add additional rows to your table.

    You can find the data value by examining the data on the graph (see Step 10a) or by viewing
    the data table (see Step 12).

22. Find the average hand temperature for the subjects you tested by selecting Statistics from the
    ▣ Analyze menu.

    From the Document Tools (✖), select ▣ Analyze then Statistics.

23. Sketch or print copies of the graph as directed by your teacher.

DATA

Part I Time Graph

Maximum temperature (°C)	Elapsed time (s)

Part II Events with Entry

Group member number	Group member name	Maximum temperature (°C)
1		
2		
3		
4		
5		
6		
Group average		

QUESTIONS

Part I Time Graph

Note: To get back to your data from Part I, you can do either of the following:

- *Use the TI-Nspire software window scroll bar to change the page view.*
- *Select Page Sorter (⧉) from the TI-Nspire Software Window menu, and click on Problem 1.*

1. Describe the appearance of your graph in Part I.

2. Why is time plotted on the horizontal axis in this experiment?

3. Why is temperature plotted on the vertical axis?

4. Determine the Temperature Probe's response time. To do this, use your data to find how long it took for the Temperature Probe to reach the maximum temperature after moving it from the cold water to the hot water.

5. Explain how you determined your answer to Question 4.

Part II Events with Entry

6. Who had the hottest hand in your group?

7. Who had the coldest hand in your group?

TEACHER INFORMATION

Introduction to Data Collection

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment is intended to be used at the beginning of the school year to introduce you and/or your students to data collection with TI-Nspire technology. It also works well as a review if they have not used the products recently. The procedures in this experiment are more detailed than in the rest of the book. For this reason, it should be done first.

    Note: Hints on how to do each step are included in italics and appear in this lab only.

3. There are two versions of this activity. Experiment 1A is written for the TI-Nspire handheld. Experiment 1B is written for the TI-Nspire computer software.

4. Any of the following temperature probes can be used in this experiment:

Table 1: Temperature Probe Comparison
Stainless Steel Temperature Probe (order code TMP-BTA) • Range: –40°C to 135°C • Connects to TI-Nspire Lab Cradle, Go! Link, or EasyLink
Vernier Go!Temp (order code GO-TEMP) • Range: –20°C to 110°C • Connects directly to a computer USB port • Connects to a TI-Nspire handheld with a USB-MINI adapter
Vernier EasyTemp (order code EZ-TMP) • Range: –20°C to 110°C • Connects directly to a TI-Nspire handheld • Connects to a computer with a MINI-USB adapter

5. If you do not have hot tap water available in your classroom for Part I, water can be heated on a hot plate. A temperature of about 60°C works well.

6. As it is written, this experiment gives the students the option to print graphs of their data. If you prefer to have your students graph "by hand," instruct them to record data from the table at two-second intervals for this purpose.

SAMPLE RESULTS

Part I Time Graph
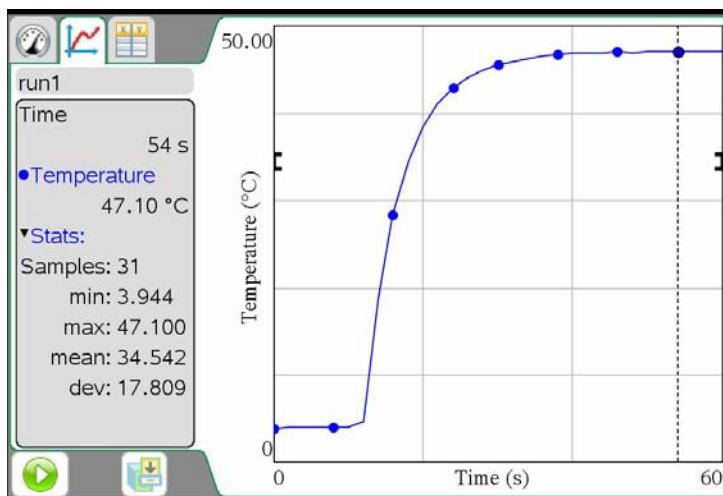
Maximum temperature (°C)	Elapsed time (s)
47.1	54

Part II Events with Entry

Group member number	Group member name	Maximum temperature (°C)
1	Starr C.	35.0
2	Kaden W.	32.5
3	Jeremy N.	33.4
4	Roberto G.	33.7
5	Patrice S.	32.1
6	Tonie L.	31.9
	Group average	33.1

ANSWERS TO QUESTIONS

Part I Time Graph

1. The curve is flat until the 12 second point, then it curves up rapidly. It slowly levels off at the maximum temperature.

2. Time is the independent variable in this experiment. The independent variable is plotted on the horizontal axis.

3. Temperature is the dependent variable in this experiment. The dependent variable is plotted on the vertical axis.

4. Answers will vary. In the example above, the response time is 42 seconds.

5. The response time was calculated by taking the time elapsed when the probe first reached the maximum temperature and subtracting the time the probe was first put into the hot water (12 seconds for this example).

Part II Events with Entry

6. Answers will vary.

7. Answers will vary.

Exploring Magnetism

Magnetism is the force of attraction or repulsion between a magnet and something else. Magnets attract materials made of iron, nickel, or cobalt. Can you think of five things to which a magnet may be attracted? Does it matter which end of the magnet is brought near the object.

All magnets, no matter what their shapes, have two regions called the north and south poles. The north pole of the magnet is the one that points north when the magnet is suspended in the air. When two like poles (i.e. north and north or south and south) are brought near each other, they repel each other. When two unlike poles are brought together they are attracted. The forces of repulsion and attraction are present because of the

Magnetic field of a magnet

magnetic field that completely surrounds the magnet. Magnetic field lines extend out from the north pole into the south pole.
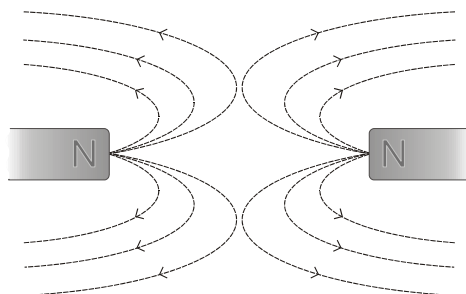
Like poles repel
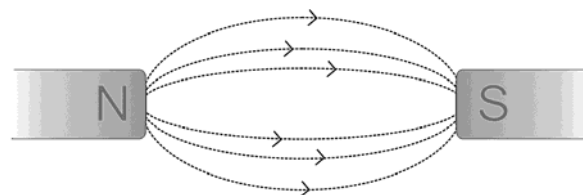
Unlike poles attract

The field lines are more concentrated near the poles of the magnet so the magnetic field is said to be stronger near the poles. The strength of the magnetic field can be measured using a Magnetic Field Sensor. The greater the number of magnetic field lines that pass through the white dot on the sensor, the stronger the field. When the field lines enter the side of the sensor with the white dot, the magnetic field reading is negative. What do you think would happen if the Magnetic Field Sensor were turned around so that the lines passed from the back of the sensor? You will investigate this in Part I of this experiment. In Part II of this experiment you will investigate the relationship between the orientation of the Magnetic Field Sensor and the strength of the magnetic field.
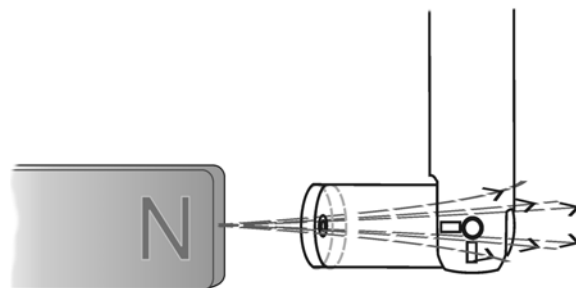
Magnetic field lines through the sensor

OBJECTIVES

In this experiment, you will

- Investigate the response of a Magnetic Field Sensor in the presence of a magnet under various conditions.
- Investigate the relationship between the orientation of the sensor and the strength of the magnetic field.

MATERIALS

TI-Nspire handheld **or**	tape
computer and TI-Nspire software	pointer
data-collection interface	scissors
Vernier Magnetic Field Sensor	paper clips
unmarked bar magnet or cow magnet	small stickers (*optional*)
degree wheel	

PRE-LAB QUESTIONS

1. What happens when you bring a magnet close to some paper clips? Does it matter which end of the magnet is brought near them?

2. What happens when you bring two magnets close to one another? What happens if you turn one of the magnets around?

PROCEDURE

Part I Investigating Bar Magnets

1. Tape the Magnetic Field Sensor to the table with the white dot facing up (see Figure 1). When placing your sensor, avoid things such as electrical wires, computer monitors, or metal brackets as these can interfere with your sensor.

2. Set the switch on the Magnetic Field Sensor to 6.4 mT (low amplification). Connect the Magnetic Field Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

Figure 1

3. Choose New Experiment from the 🔬 Experiment menu. Choose Collection Setup from the 🔬 Experiment menu. Enter **2** as the rate (samples/second) and **10** as the experiment duration in seconds. The number of points collected should be 21. Select OK.

4. Zero the Magnetic Field Sensor. This reduces the effect of the surrounding environment on the magnetic field reading.

   a. Move all magnets far away from the Magnetic Field Sensor.
   b. When the readings on the screen stabilize, choose Set Up Sensors ► Zero from the 🔬 Experiment menu. When the process is complete, the readings for the sensor should be close to zero.
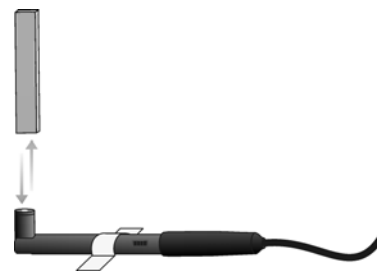
5. Hold the magnet vertically about 20 cm above the Magnetic Field Sensor. One end of the magnet should be lined up with the white dot on the sensor as shown in Figure 1.

6. Start data collection (⏵). Slowly move the magnet toward the Magnetic Field Sensor and then away. You have 10 seconds to complete this motion. Keep track of which end of the magnet you have tested.

7. Sketch and label the resulting graph on the blank graph titled Trial 1 in the Data section.

8. Turn the magnet around so that the other end is facing the white dot on the Magnetic Field Sensor.

9. Click on the Store Latest Data Set button (⊞) to store the first run data. Repeat Steps 6 and 7 but sketch your results in the graph titled Trial 2 in the Data section.

10. Place a sticker (or small piece of tape) on the end of the magnet that produced a positive reading with the Magnetic Field Sensor.

11. Remove the tape from the Magnetic Field Sensor and turn it over so that the white dot faces down. Tape the sensor to the table.

12. Zero the Magnetic Field Sensor in the new position.

    a. Click the Meter View tab (⏲).
    b. Move all magnets far away from the Magnetic Field Sensor.
    c. When the readings on the screen stabilize, choose Set Up Sensors ► Zero from the
       🛠 Experiment menu. When the process is complete, the readings for the sensor should be close to zero.

13. Hold the magnet with the sticker pointing down toward the Magnetic Field Sensor.

14. Start data collection (⏵). Slowly move the magnet toward the Magnetic Field Sensor and then away. You have 10 seconds to complete this motion.

15. Sketch and label the resulting graph on the graph titled Trial 3 in the Data section.

Part II Magnetic Field Sensor Orientation

16. Remove the tape holding the Magnetic Field Sensor to the table.

17. Cut out the degree wheel and pointer supplied by your teacher.

18. Tape the degree wheel to the table with 0° pointing away from you and 90° pointing to your right.

19. Place the bar magnet on 90° with the end of the magnet with the sticker from Part I pointing toward the center of the circle. Tape the magnet to the table.

Figure 2

20. Tape the pointer on top of the white dot of the Magnetic Field Sensor and bend it so that it is perpendicular to the sensor as shown in Figure 2.
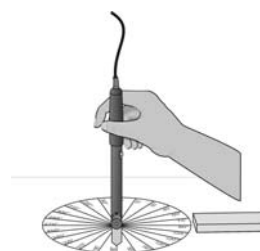
21. Set up Events with Entry data collection.

    a. Insert a new problem into your TI-Nspire Document and insert a DataQuest Application.

    b. Choose Collection Mode ► Events with Entry from the 🎥 Experiment menu.

    c. Enter **Position** as the Name and **deg** as the Units. Select OK.

22. Place the tip of the Magnetic Field Sensor on the center of the degree wheel with the pointer pointing toward 0°. Hold the sensor vertically.

23. Start data collection (▶).

24. Measure the magnetic field at the zero degree position.

    a. When the magnetic field readings stabilize, click the Keep button (📥).

    b. Enter **0** (the position in degrees). Select OK to save this data pair.

25. Rotate the Magnetic Field Sensor so that the pointer points toward 15° and repeat Step 24 entering the current pointer position. Make sure the Magnetic Field Sensor remains vertical.

26. Continue taking a data point every 15° until 360° is reached. When data collection is complete, stop data collection (⏹).

27. To examine the data pairs on the displayed graph, click any data point. Use ► and ◄ to locate the point with the greatest magnetic field intensity. Record the position of the pointer in the Data section.

28. Sketch or print a copy of the graph as directed by your teacher.

DATA

Trial 1

Trial 2

Trial 3

DATA (CONT.)

Part II

Greatest magnetic field intensity position _____°

QUESTIONS

1. What happens when you bring two like poles together? What happens when you bring two unlike poles together?

2. How is it possible that the same end of the magnet can produce both a positive and a negative magnetic field reading?

3. Based on your data from Part II, where (at what angle) was the white dot on the Magnetic Field Sensor pointing when it produced the greatest magnetic field intensity?

4. It is often said that the Earth behaves magnetically like a giant magnet. How could you use a Magnetic Field Sensor to determine which direction is North?

EXTENSION

Measurements of the magnetic field around the Earth show that the Earth behaves magnetically like a giant magnet. It has both a north and south magnetic pole. The magnetic pole in the Northern Hemisphere is the point to which the north end of a compass or suspended bar magnet points.

To show that this is true

    a. Hang an unmarked bar or cow magnet from a piece of string and let it come to rest.
    b. Put a sticker or small piece of tape on the end that points toward north.
    c. Determine whether the end that points north produces a positive or a negative magnetic field reading by repeating Steps 1–8.

1. Does the end that points North give a positive or negative magnetic field reading?

2. Make a sketch of the magnetic field lines around the bar magnet.

Hanging bar magnet

3. If unlike poles attract and the north end of the magnet points toward the magnetic pole in the Northern Hemisphere, what type of pole, north or south, must the magnetic pole in the Northern Hemisphere be?
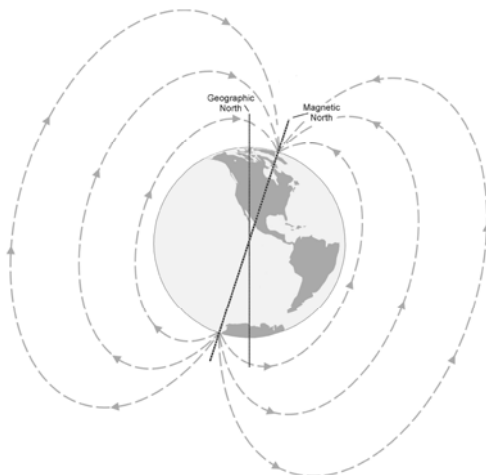
Earth's magnetic field

TEACHER INFORMATION

Exploring Magnetism

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. Demonstrate magnetic field lines by placing a bar magnet on an overhead. Position clear compasses around the magnet and discuss the position of the needles. Another alternative is to provide small compasses for each group. Have them position compasses around the magnet and discuss the position of the needles. Small compasses are available in bags of 10 from Scientifics, www.scientificsonline.com.

3. Another good demonstration is to put some iron filings in a jar with a small mouth. Place a cow magnet in a test tube and place it in the mouth of the jar. Tape the test tube to the mouth of the jar so that no iron filings can escape. Shake the iron filings so that they become aligned along the magnetic field lines. (Be careful not to break the test tube when shaking.) Soda bottle performs or commercially made magnet tubes are available from science equipment suppliers.

4. Make one copy of the degree wheel and pointer for each group.

5. Always store magnets north to south in the packaging in which they came to preserve magnetic field strength. Magnets should never be thrown randomly into a box. Magnets that have lost magnetic field strength due to improper storage, heating, or dropping may not work well for this experiment.

6. Always keep magnets away from computers, monitors, TVs, watches, computer discs, VCRs, audio and video tapes, and credit cards. Storing magnets near compasses may result in permanent damage to the compasses.

7. Readings may fluctuate due to deviation, the influence of the immediate environment upon your sensor, caused by things such as electrical currents, computer monitors, or metal brackets. Try to avoid these influences.

8. Avoid using refrigerator magnet sheets for this experiment. These flexible magnetic sheets have a complex magnetic structure in which the magnetic field lines are U-shaped with most of the magnetic field extending out the back of the magnetic sheet. The resulting magnetic field is a 1–2 mm stripe of alternating north and south poles. An interesting demonstration can be done by passing the Magnetic Field Sensor over the magnetic sheet and comparing the results to those obtained by passing the sensor over a bar magnet.
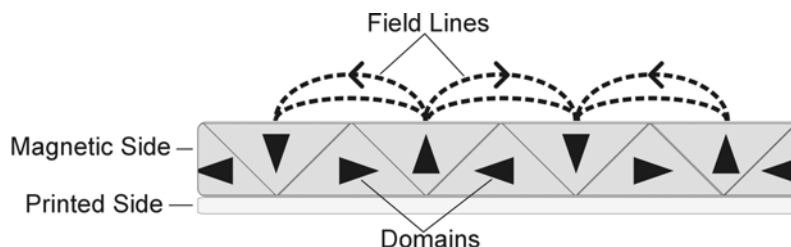
9. If unmarked magnets are not available cover the labels on the magnet with tape.

10. Bar magnets or cow magnets work well for this experiment. Cow magnets are also called Alnico cylindrical magnets.

11. Bar magnets are often mislabeled. Check your magnet for correct labeling by suspending it from a string. The north end of the magnet should align itself with magnetic north.

12. It is important to understand the orientation of the Earth's magnetic field. Many texts liken the magnetic field of Earth to that of a bar magnet with the north end pointing toward a point in the Northern Hemisphere. They label the point to which the north end of the magnet points as magnetic north. Remember, unlike magnetic poles attract. If the north end of a suspended magnet points toward the point labeled magnetic north then that point must be a south magnetic pole. Therefore, the pole labeled magnetic north behaves like a south magnetic pole.

SAMPLE RESULTS

Part I

Results for Trials 1 and 2 may be the opposite of those below depending on the orientation of the magnet.
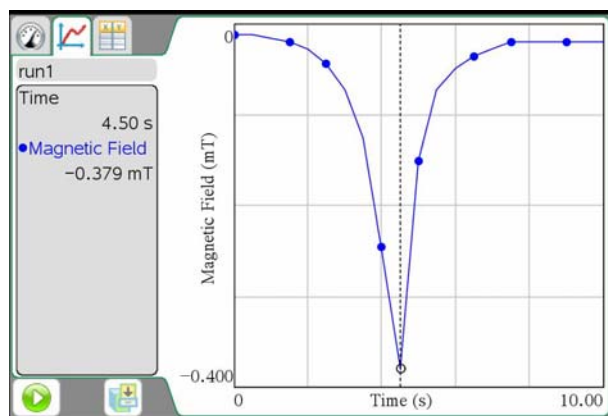
Trial 1
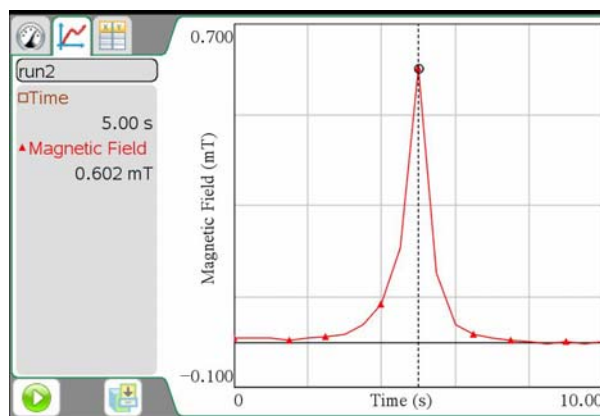
Trial 2
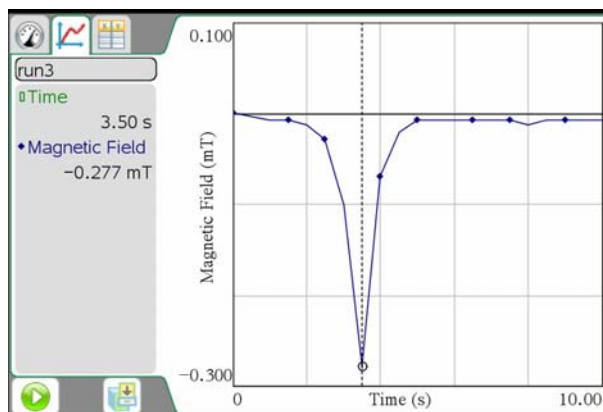
Trial 3

Part II

Greatest magnetic field intensity position $\underline{90^o}$

ANSWERS TO QUESTIONS

1. When two like poles are brought together there is a force of repulsion. When two unlike poles are brought together there is a force of attraction.

2. Magnetic field lines extend out from the north pole into the south pole of a magnet. When the north end of a magnet is brought near the sensor the magnetic field lines enter the front of the white dot on the Magnetic Field Sensor. This produces a negative magnetic field reading. When the sensor is turned around the magnetic field lines enter the back of the sensor and produce a positive magnetic field reading.

3. The white dot points toward 90°, directly at the magnet, when it reads the greatest magnetic field intensity.

4. You could hold the Magnetic Field Sensor vertically and rotate it around until it reads the greatest magnetic field intensity. You could also determine which end of an unmarked magnet has a negative magnetic field reading (making it the north end of the magnet), suspend the magnet from a string, and note in which direction that end of the magnet points.

EXTENSION

1. The end that points toward north gives a negative magnetic field reading.

2.
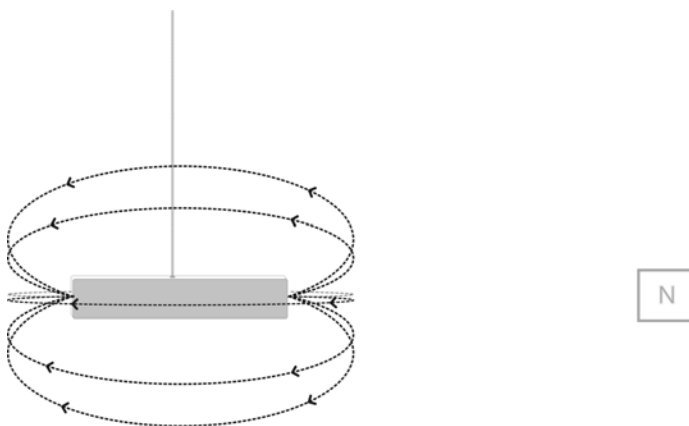
3. The magnetic pole in the Northern Hemisphere behaves like a south magnetic pole.
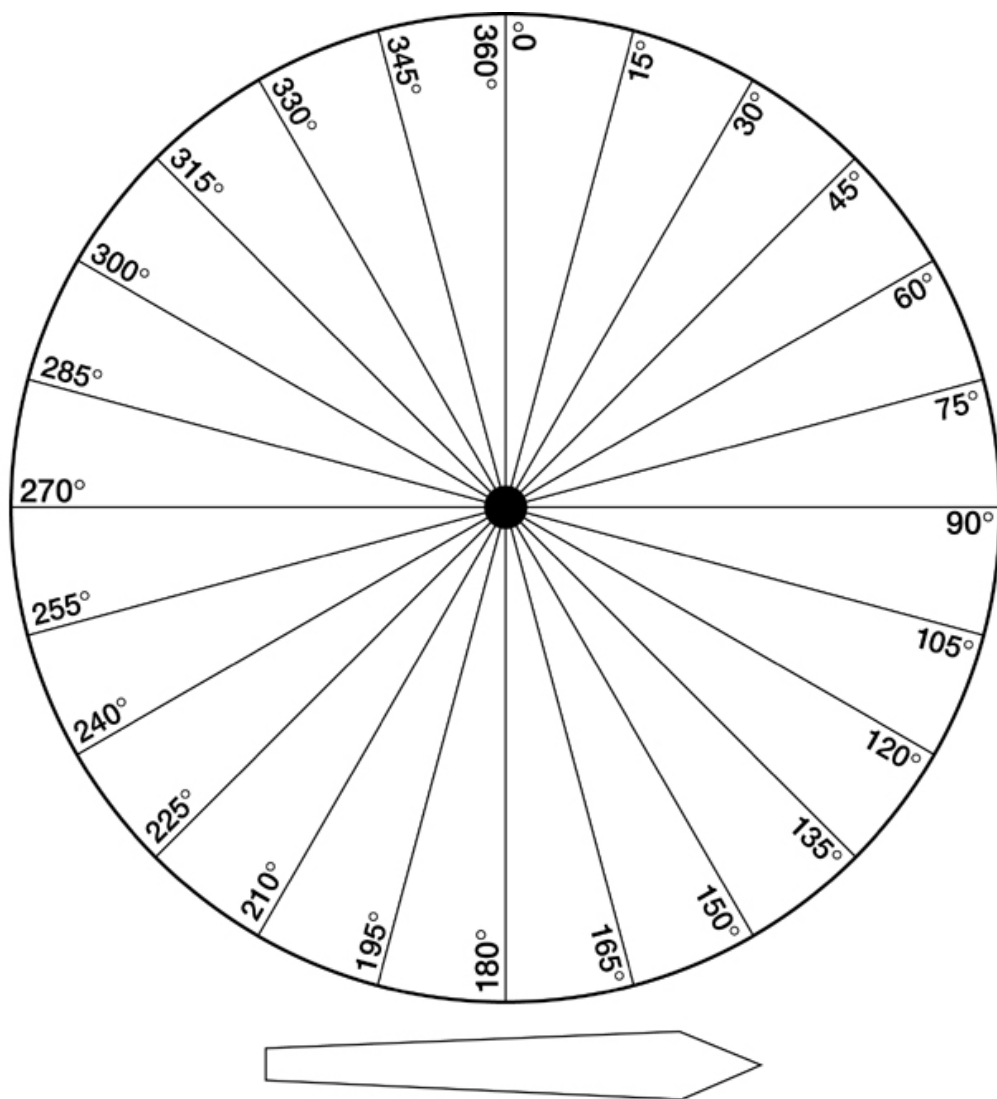
Where IS North?

It depends. Do you mean geographic north or magnetic north? The geographic (true) north pole is the point at 90° N latitude. It is aligned with the rotational axis of the Earth. The Earth is surrounded by a magnetic field with a north and south magnetic pole. The magnetic north pole is the point to which a compass needle points. It is currently in northern Canada, but moves at an average rate of 15 km per year due to complex fluid motion in the outer core of Earth. Depending on your location, the difference between magnetic north and geographic north, called *magnetic declination,* can range from 0° to 30°.

Similar to a bar magnet, the Earth is surrounded by 3-dimensional magnetic field lines. The field lines of the Earth start near the south pole, curve around in space and converge again near the north pole. A compass needle aligns itself along the direction of the magnetic field lines. *Magnetic inclination,* or dip angle, is the angle that the Earth's magnetic field makes with the horizontal plane at a specified location. Magnetic inclination is 0° at the magnetic equator and 90° at each of the magnetic poles.
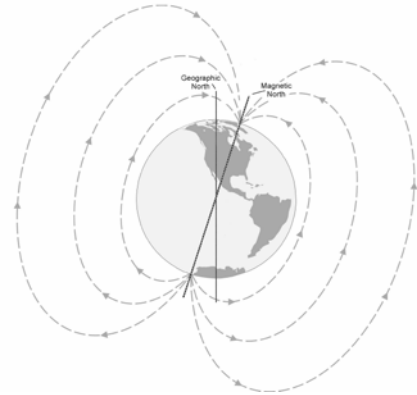
The Earth's magnetic field is used by many animals to determine direction. Every location on Earth has its own unique combination of magnetic field intensity and inclination. The Loggerhead turtle detects magnetic field

Earth's magnetic field

intensity and magnetic inclination and uses this information on its 10 year migration around the Atlantic Ocean. Many birds use both stars and the magnetic field of the Earth to navigate. The birds can detect magnetic inclination. Birds in the northern hemisphere follow a line of decreasing dip angle that guides them on their southerly migration path.

In Part I of this experiment, you will measure the magnetic field of the Earth. You will use this data to determine magnetic north. Knowing the direction of true north, you will calculate the magnetic declination at your location. In Part II you will measure the magnetic inclination of your location.

OBJECTIVES

In this experiment, you will

- Use a Magnetic Field Sensor to measure the magnetic field of the Earth.
- Calculate magnetic declination for your location.
- Measure the magnetic inclination of your location.

MATERIALS

TI-Nspire handheld **or**	ruler
computer and TI-Nspire software	degree wheel
data-collection interface	pointer
Vernier Magnetic Field Sensor	tape
protractor	

PROCEDURE

Part I Finding Magnetic North

1. Tape the pointer on top of the white dot of the Magnetic Field Sensor and bend it so that it is perpendicular to the sensor as shown in Figure 1.

2. Set the switch on the Magnetic Field Sensor to 0.3 mT (high amplification). Connect the Magnetic Field Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the 🖳 Experiment menu. Choose Collection Mode ► Events with Entry from the 🖳 Experiment menu. Enter **Position** as the Name and **deg** as the Units. Select OK.

Figure 1

4. Place the tip of the Magnetic Field Sensor on the center of the degree wheel with the pointer pointing toward 0°. Hold the sensor vertically. When placing your sensor, avoid things such as electrical wires, computer monitors, or metal brackets as these can interfere with your sensor.

5. Start data collection (▶).

6. Measure the magnetic field at the zero degree position.

    a. When the magnetic field readings stabilize, click the Keep button (📇).
    b. Enter **0** (the position in degrees). Select OK to save this data pair.

7. Rotate the Magnetic Field Sensor so that the pointer points toward 15° and repeat Step 6 entering the current pointer position. Continue to repeat Step 6 until 360° is reached.

8. When you have reached 360°, stop data collection (⬛).

9. To examine the data pairs on the displayed graph, click any data point. Use ► and ◄ to locate the point with the greatest magnetic field intensity. Record the corresponding direction in the data table. This location is magnetic north.

10. Sketch or print a copy of the graph as directed by your teacher.
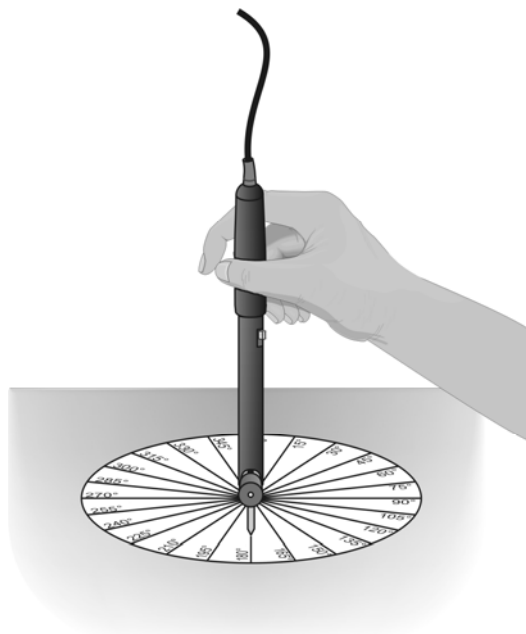
Part II Magnetic Inclination (Dip Angle)

11. Click the Meter View tab (📷).

12. Place the tip of the Magnetic Field Sensor at the center of the degree wheel with the pointer pointing toward magnetic north. Make sure the sensor is held vertically.

13. Slowly tilt the sensor toward and away from the direction of magnetic north. Monitor the magnetic field intensity on the screen. Continue to adjust the tilt until a maximum reading is displayed. Hold the sensor in that position. See Figure 2.

14. Use a protractor to measure the angle between vertical and the Magnetic Field Sensor. This is the magnetic inclination for your location. Record this value in the data table.
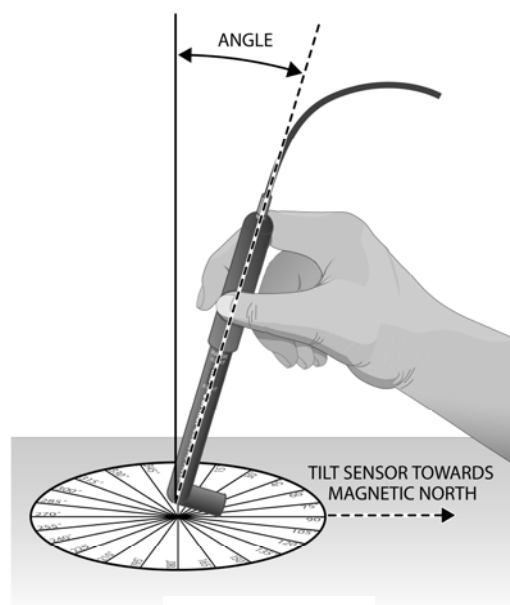
Figure 2

DATA

Magnetic north direction (°)	
Magnetic inclination (°)	

QUESTIONS

1. The difference between the measured magnetic north and true north is called magnetic declination. What is the magnetic declination for your location? What modifications would be needed on a compass in your location to keep you on course when following a map?

2. How does the measured magnetic inclination compare with the accepted magnetic inclination for your location?

3. Scientists have found that the magnetic field of the Earth is continually changing. What would be the implications of a big change?

EXTENSIONS

1. Compare the magnetic declinations of various locations on your continent and discuss the adjustments needed on a compass at each location to stay on course.

2. Research current theories on why the magnetic north pole moves.

TEACHER INFORMATION

Where IS North?

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. Make one copy of the degree wheel and pointer for each student group. Tape the circle to each group's work space with 0° aligned with true north. True north can be located using a GPS or blue prints for your school. If these are not available, you can determine true north by using a compass to find magnetic north, then correct for the magnetic declination. If you don't know the magnetic declination at your location, it can be calculated at several locations on the Internet, including www.ngdc.noaa.gov/geomag/.

3. The Magnetic Field Sensor needs to remain vertical the entire time during Part I. Students should be careful to keep the sensor centered on the dot.

4. Readings may fluctuate due to deviation, the influence of the immediate environment upon your sensor, caused by things such as electrical currents, computer monitors, or metal brackets. Try to avoid these influences.

5. A paper protractor cut in half makes it easy to measure the magnetic inclination.

6. The magnetic inclination can also be calculated using the length of the Magnetic Field Sensor and the distance from the top of the sensor to the table instead of measuring the angle directly.

7. The Magnetic Field Sensor does not need to be zeroed at any time during this experiment since you are looking for a peak reading location rather than the actual magnetic field intensity.

SAMPLE RESULTS
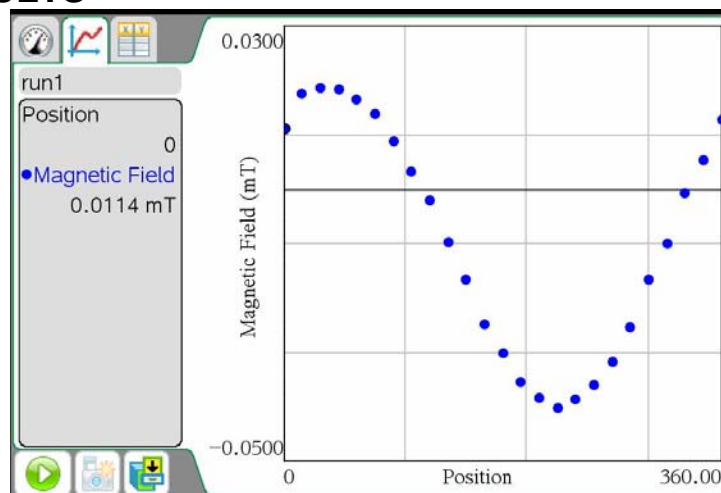
Magnetic north direction (°)	30°
Magnetic inclination (°)	67°

ANSWERS TO QUESTIONS

1. Answers will vary. If the declination in your area is to the right of true north (0° on the degree wheel) it is an east declination. Magnetic north is pulling the compass too far to the east. To stay on course you would need to subtract the declination from the magnetic reading. If the declination in your area is to the left of true north it is a west declination. To stay on course you need to add the declination to the magnetic reading.

2. Answers will vary.

3. Answers will vary but may include navigation systems not working properly and migrating animals straying off course, among others.
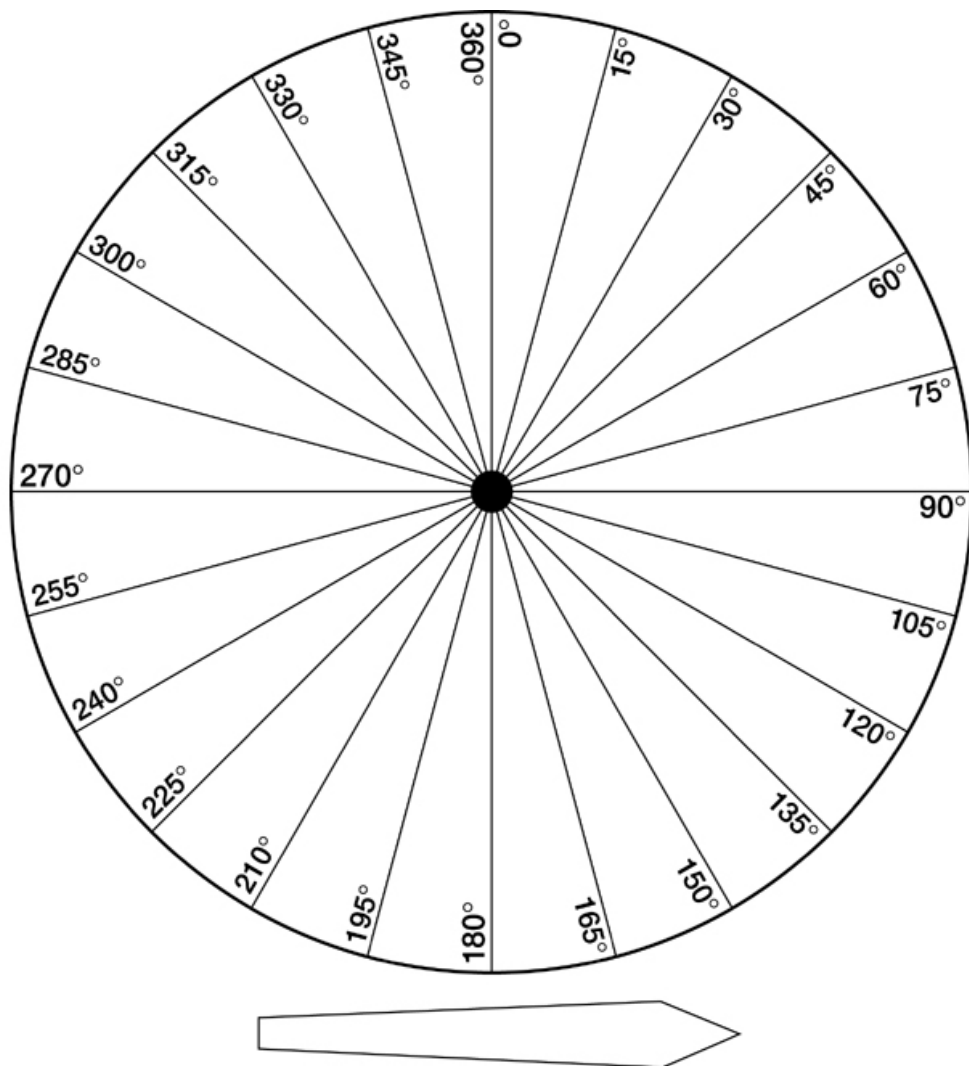
Soil Temperature

How do flowers and other plants know when to start growing in the spring? How do farmers know when it is safe to plant their crops? Soil temperature plays an important role in both of these decisions. Each spring, soil is heated from above by warmer air and by solar radiation. Once the soil reaches a certain temperature, it is time to plant and grow.

Soil temperature changes more slowly than the air temperature, so there is always a lag time between the extremes of air temperatures and soil temperatures. Because of daily temperature fluctuations, the soil could be cooler than the air in the daytime and warmer than the air in the nighttime.

Soil temperatures also change with depth. The deeper the soil, the more constant the temperature will be. Because of this, when referring to soil temperatures, the depth at which the measurements were taken is also important. Figure 1 shows the average soil temperatures across the United States at a depth of 4 inches. This is the depth used by the U.S. Department of Agriculture (USDA) and the National Oceanographic and Atmospheric Administration (NOAA) in their *Weekly Weather and Crop Bulletin*. This particular figure shows data from April 2002. If you look carefully, you can see the isotherms indicating the regions where various crops such as wheat and corn can develop.
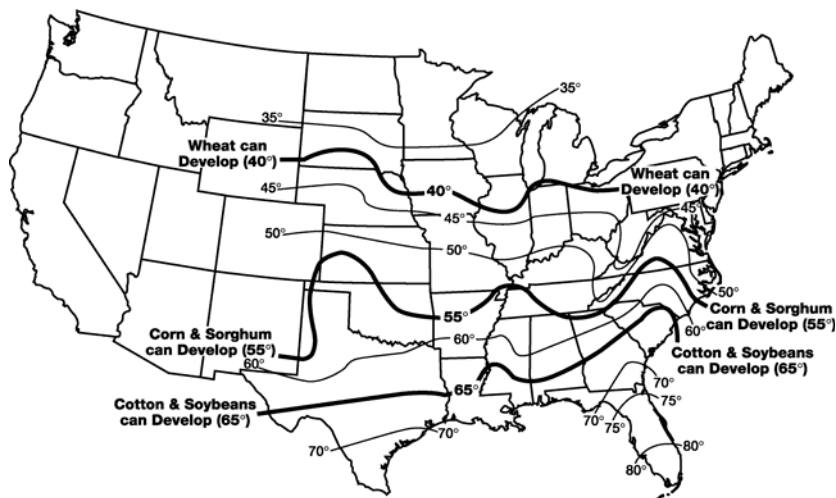
Figure 1: Soil temperatures at a depth of four inches.

In this experiment, you will use Temperature Probes to monitor the soil temperature at three different depths. A lamp and a bowl of ice will be used to simulate day and night over a two-day period. You will observe how soil temperatures vary at different depths and the timing of these variations.

OBJECTIVES

In this experiment, you will

- Simulate temperature changes over a two-day period.
- Use Temperature Probes to measure the temperature of soils at different depths.
- Explain your results.

MATERIALS

TI-Nspire handheld **or**
   computer and TI-Nspire software
data-collection interface
3 Temperature Probes
tape
plastic milk jug containing soil

bowl
lamp
ruler
ice
watch with a second hand

PROCEDURE

1. Connect the three Temperature Probes to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

2. Choose New Experiment from the 🔬 Experiment menu. Choose Collection Setup from the 🔬 Experiment menu. Using the pull down menu, change the sample Rate (samples/second) to Interval (seconds/sample). Enter **30** as the time between samples in seconds and **2400** as the experiment length in seconds (40 minutes). **Note:** the number of points should be 81. Choose the Data Marker option and select OK.

3. A plastic milk jug has already been prepared with soil. On one side, you should find three small holes, at 1 cm, 3 cm, and 7 cm below the soil surface.

   a. Insert Probe 1 (the Probe in Channel 1) into the hole that is 1 cm below the soil surface. Push the probe in far enough so that the tip of the probe is in the center of the jug.
   b. Insert Probe 2 the same distance into the hole that is 3 cm below the soil surface.
   c. Insert Probe 3 the same distance into the hole that is 7 cm below the soil surface.

4. The Temperature Probes must be parallel to the tabletop during data collection. Secure them in this position by taping them to a ruler, as shown in Figure 2.

Figure 2

5. Position the lamp so that the bulb is between 5 and 10 cm from the soil surface. Do not turn it on yet. Once it is in position, move it slightly off to the side to make room for the bowl of ice to be placed on the soil. Later, when you are instructed to turn on the lamp, move it back over the soil.

6. Fill the bowl with ice.

7. When everything is ready, place the bowl of ice on the surface of the soil as shown in Figure 3, and start data collection (▶). Immediately record the time displayed on your watch.
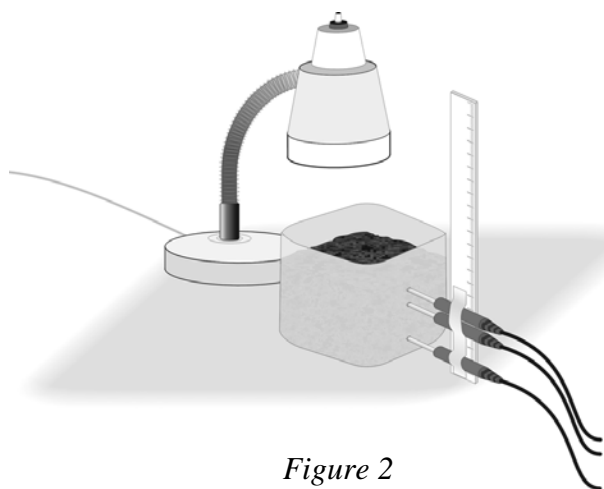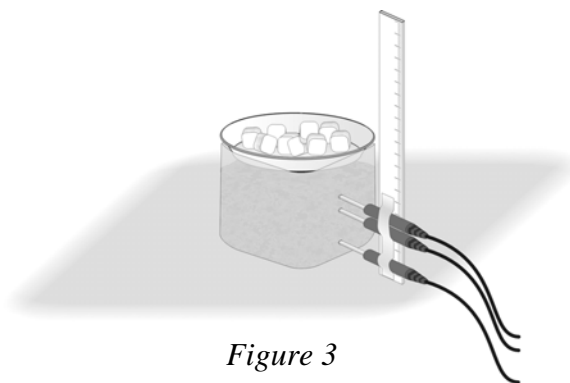
Figure 3

8. Once every five minutes, you will need to make a change to the setup. These changes will simulate the temperature changes over a two-day period. Calculate the times that will be displayed on your watch when you will be making changes. Record these times in the table below. Watch the time displayed on your watch and use the chart below to make your changes. When you make a change, click the Add Data Marker button (🖫) to mark when you made the change.

Time (minutes)	Time on Watch	Change to Setup	Time of Day (simulated)
0		Place bowl of ice on soil	Nighttime
5		Remove ice and position lamp above soil (do not turn lamp on)	Morning
10		Turn on lamp	Daytime
15		Turn off lamp and move it aside	Evening
20		Place bowl of ice on soil	Nighttime
25		Remove ice and position lamp above soil (do not turn lamp on)	Morning
30		Turn on lamp	Daytime
35		Turn off lamp and move it aside	Evening
40		Data collection will stop	

9. Data collection will stop after 40 minutes.

10. Label the marked points.

   a. The Data Marked points will be highlighted in the graph with a large point icon. There will be one point on each of the temperature graphs for each time you marked. Double-click on one of the marked points at 5 minutes (300 s), and label it **Morning**, then select OK. This will label all of the points marked at 5 minutes.
   b. Repeat Step 10a for one of the marked points at 10 minutes (600 s). Label this point **Daytime**.
   c. Repeat Step 10b for the other marked points labeling them as described in the Time of Day column in the table above.
   d. The point label is displayed in the Graph View Details box to the right of the graph.

11. Analyze your data to determine the temperature changes.

   a. After data collection is complete, choose Statistics ► Run 1.Temperature from the 🟦 Analyze menu. The statistics for Probe 1 will be displayed.
   b. Record the minimum and maximum temperatures.
   c. Repeat this process, choosing Run 1.Temperature2 and Run 1.Temperature3, to the get the statistics for Probes 2 and 3.
   d. Subtract to find the change in temperature for each sensor and record the results.

12. Print or sketch your graph according to your instructor's directions.

DATA

	1 cm depth	3 cm depth	7 cm depth
Maximum temperature (°C)			
Minimum temperature (°C)			
Change in temperature (°C)			

QUESTIONS

1. Study your graph. Describe the shapes of the three lines. Refer to the lines as the 1 cm line, the 3 cm line, and the 7 cm line, indicating their depth beneath the soil surface.

2. Propose an explanation for why the three lines have different shapes.

3. Study the timing of the temperature changes.

   a. Did the rising and falling temperatures reach their peaks and valleys at the same time?
   b. How long after the light was turned off did the 1 cm line reach its first temperature peak?
   c. How long after the 1 cm line reached its first peak did the 3 cm line reach its first peak?

4. Propose an explanation for your answers to Question 3.

EXTENSIONS

1. Move the experiment outside and measure temperatures over longer periods of time. Describe how the results compare to the simulated exercise in class.

2. Explain how a blanket of snow could actually protect plants in the soil from freezing.

Soil Temperature

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment calls for three Temperature Probes. This may mean that you will need to combine the students into larger groups or have some of the groups perform the experiment one day and the rest of the class perform it the next.

3. This experiment is not intended for use with Easy or Go! Products since data from three sensors must be collected at the same time. While you can use three different handhelds, each with their own sensor or multiple Go! Products on the same computer, to collect the data, a single, multi-channel interface is preferred.

4. The soil container should be made up ahead of time. Make one per group.
   a. Cut the top off of a plastic milk jug so that it is 14 cm high.
   b. Fill the jug with soil 10 cm deep.
   c. Using an awl (or a tough ball-point pen), poke three holes in the side of the jug. The holes should be large enough for the Temperature Probe to easily fit and lined up vertically at 1, 3, and 7 cm below the surface of the soil.
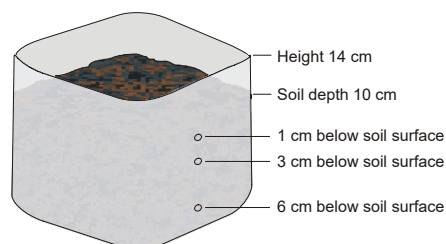
5. A 100 W or 150 W bulb works well for this lab. Compact fluorescent and LED bulbs should not be used for this lab.

6. To make it easier for the students to tell which sensor is which, you can have them rename the sensors. To do this, choose Column Options from the ▦ Data menu then select the desired column name. (The sample data was created using this method.)

SAMPLE RESULTS
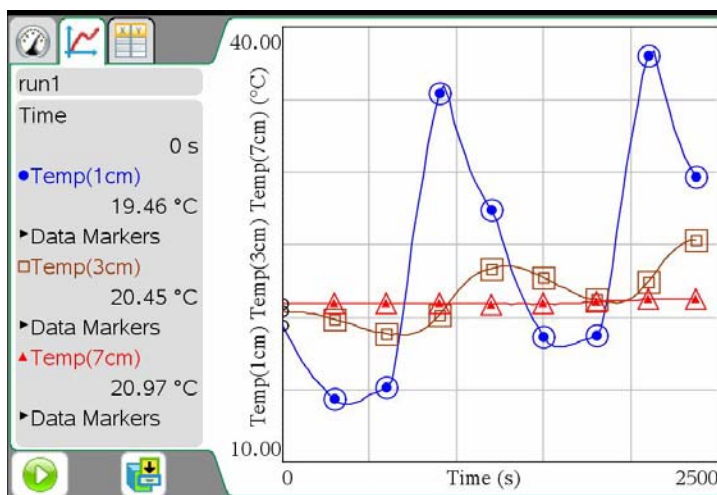
	1 cm depth	3 cm depth	7 cm depth
Maximum temperature (°C)	38.33	25.39	21.31
Minimum temperature (°C)	13.99	18.82	20.89
Change in temperature (°C)	24.34	6.57	0.42

ANSWERS TO QUESTIONS

1. The 1 cm line went up in temperature when the light was turned on and went down when the ice was applied. Of the three, it had the largest temperature swings. The 3 cm line also went up and down in temperature, but there was a time lag and it had smaller temperature swings. The 7 cm line stayed fairly flat.

2. The closer to the surface the measurement was taken, the larger the temperature swing. This is because the change in temperature was always applied from the top. Therefore, the soil closest to the top is most affected.

3. a. No, the temperature peaks and valleys occurred at different times.
   b. Answers will vary. For the sample data, the first peak in the 1 cm line came 0.5 minutes after the light was turned off.
   c. Answers will vary. For the sample data, the lag time between 1 cm and 3 cm was approximately 5.5 minutes.

4. As the soil is warmed by the lamp or cooled by the ice, that change in temperature takes time to move through the soil. The heat from the lamp may only take a short time to reach 1 cm into the soil, but it will take several minutes to reach the soil to the 3 cm line.

Watershed Testing

There are many reasons for determining water quality. You may want to compare the water quality upstream and downstream to locate a possible source of pollutants along a river or stream. Another reason may be to track the water quality of a watershed over time by making measurements periodically. When comparing the quality of a watershed at different times, it is important that measurements be taken from the same location and at the same time of day.

In 1970, the National Sanitation Foundation, in cooperation with 142 state and local environmental specialists and educators, devised a standard index for measuring water quality. This index, known as the Water Quality Index, or *WQI*, consists of nine tests to determine water quality. These nine tests are; temperature, pH, turbidity, total solids, dissolved oxygen, biochemical oxygen demand, phosphates, nitrate, and fecal coliform. A graph for each of the nine tests indicates the water quality value (or Q-value) corresponding to the data obtained. Once the Q-value for a test has been determined, it is multiplied by a weighting factor. Each of the tests is weighted based on its relative importance to a stream's overall quality. The resulting values for all nine tests are totaled and used to gauge the stream's health (excellent, good, medium, poor, or very poor).

While the WQI can be a useful tool, it is best used in light of historical data. Not all streams are the same, and without historical data, it is difficult to determine if a stream is truly at risk. For example, a stream may earn a very low WQI value and appear to be in poor health. By looking at historical data, however, you may find that samples were collected just after a heavy rain with an overflow from the local city sewer system and do not accurately reflect the stream's overall health.

For the purpose of this exercise, you will perform only four of the WQI tests: dissolved oxygen, water temperature, pH, and total dissolved solids. A modified version of the WQI for these four tests, will allow you to determine the general quality of the stream or lake you are sampling.

OBJECTIVES

In this experiment, you will

- Use a Temperature Probe, Dissolved Oxygen Probe, Conductivity Probe, and a pH Sensor to make on-site measurements.
- Calculate the water quality based on your findings.

MATERIALS

TI-Nspire handheld **or**	Vernier Temperature Probe
computer and TI-Nspire software	4 water sampling bottles
data-collection interface	large plastic cup or beaker
Vernier Dissolved Oxygen Probe	D.O. calibration bottle
Vernier pH Sensor	distilled water
Vernier Conductivity Probe	tap water

PRE-LAB PROCEDURE

1. Connect the temperature probe to your interface. Connect the interface to the TI-Nspire handheld or laptop computer. Monitor the temperature probe reading. When the reading is stable, record the room temperature value. This value is used in Step 7h.

2. Set up the data-collection mode.

   a. Choose New Experiment from the 🎛 Experiment menu.
   b. Choose Collection Mode ► Events with Entry from the 🎛 Experiment menu.
   c. Enter **Sensor** as the Name and leave the Units blank. Select OK.

3. Take a sample temperature reading.

   a. Obtain a sample of tap water and place the temperature probe in the water.
   b. Start data collection (▶).
   c. Monitor the readings displayed on the screen. When the reading is stable, click the Keep button (💾) and enter **Temp** as the sensor.
   d. Stop data collection (⏹).

4. Prepare the Dissolved Oxygen Probe for use.

   a. Remove the protective cap.
   b. Unscrew the membrane cap from the tip of the probe.
   c. Using a pipet, fill the membrane cap with 1 mL of DO Electrode Filling Solution.
   d. Carefully thread the membrane cap back onto the electrode.
   e. Place the probe into a 250 mL beaker containing distilled water.

| Remove membrane cap | Add electrode filling solution | Replace membrane cap |
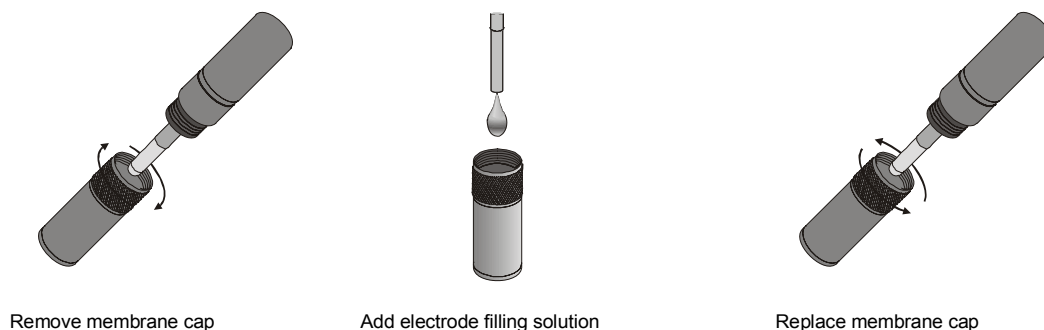
Figure 1

5. Disconnect the temperature probe and connect the Dissolved Oxygen Probe to the data collection interface.

6. It is necessary to warm up the Dissolved Oxygen Probe for 10 minutes before taking readings. With the probe still in the distilled water beaker, wait 10 minutes while the probe warms up. The probe must stay connected at all times to keep it warmed up. (Note: If you are using the TI-Nspire Lab Cradle, the meter will display the sensor values in light gray until the sensor has warmed up. At that time, the sensor values will display in black.)

7. Calibrate the Dissolved Oxygen Probe.

   • If your instructor directs you to perform a new calibration, continue with this step to calibrate your sensor. Otherwise, proceed directly to Step 8.

Zero-Oxygen Calibration Point

a. Choose Set Up Sensors ► Calibrate ► Two Point from the 🌡 Experiment menu.

b. Remove the probe from the water bath and place the tip of the probe into the Sodium Sulfite Calibration Solution. **Important:** No air bubbles can be trapped below the tip of the probe or the probe will sense an inaccurate dissolved oxygen level. If the voltage does not rapidly decrease, tap the side of the bottle with the probe to dislodge the bubble. The readings should be in the 0.2 to 0.6 V range.

c. Enter **0** as the first reference value.

d. When the voltage stabilizes (~1 minute), select OK.

Insert probe at an angle Submerge probe tip 1-2 cm

Figure 2

Saturated DO Calibration Point

e. Rinse the probe with distilled water and gently blot dry.

f. Unscrew the lid of the calibration bottle provided with the probe. Slide the lid and the grommet about 1/2 inch onto the probe body.

Insert probe into hole in grommet

Screw lid and probe back onto bottle

1 cm of water in bottom

Figure 3

g. Add water to the bottle to a depth of about 1 cm (1/4 inch) and screw the bottle into the cap, as shown. **Important:** Do not touch the membrane or get it wet during this step.

h. Enter the correct saturated dissolved-oxygen value (in mg/L) from Table 9 using the current barometric pressure and air temperature values (for example, at 18 °C and atmospheric pressure of 690 mmHg enter **8.66**). If you do not have the current barometric pressure, use Table 10 to estimate the barometric pressure at your altitude.

i. Keep the probe in this position for about a minute. The readings should be above 2.0 V. When the voltage reading stabilizes, select OK.

j. If directed by your instructor, record the values for K0 and K1. Select the Save Calibration with Document option, and then select OK.

8. Take a sample DO reading.

a. Start data collection (▶) and select the **Append** option.

b. Monitor the readings displayed on the screen. When the reading is stable, click the Keep button (🔲) and enter **DO** as the sensor.

    c. Stop data collection (⬛).

    d. Prepare the Dissolved Oxygen probe for transport by filling the calibration bottle half full with water. Secure the Dissolved Oxygen Probe far enough down in the bottle that the membrane is completely covered by water. Screw the calibration bottle lid completely onto the bottle so that no water will leak out.

9.   Set up the pH sensor and take a sample reading.

    a.   Disconnect the Dissolved Oxygen Sensor and connect the pH sensor to the data collection interface.

    b.   Start data collection (▶) and select the **Append** option.

    c.   Remove the pH sensor from it storage bottle and place it in your sample of tap water.

    d.   Monitor the readings displayed on the screen. When the reading is relatively stable, click the Keep button (📇) and enter **pH** as the sensor.

    e.   Stop data collection (⬛).

    f.   Return the pH sensor to its storage bottle.

10.   Set up the Conductivity Probe and take a sample reading.

    a. Set the switch on the Conductivity Probe box to 0–2000 µS/cm.

    b. Disconnect the pH sensor and connect the Conductivity probe to the data-collection interface.

    c. If the Conductivity Probe is reading in a unit other than mg/L, change units to mg/L by choosing Set Up Sensors ► Change Units ► Conductivity ► mg/L from the 🧪 Experiment menu.

    d. Start data collection (▶) and select the **Append** option.

    e. Place the Conductivity probe in your sample of tap water.

    f. Monitor the readings displayed on the screen. When the reading is relatively stable, click the Keep button (📇) and enter **Cond** as the sensor.

    g. Stop data collection (⬛).

11.   Final Preparations for the field

    a. Click the Table View tab (▦). Record your readings for tap water in Table 1.

    b. Click the Store Latest Run button (▦) to save your tap water data and prepare for data collection in the field.

    c. Double click on the run1 heading in the table and change the name to Tap Water.

    d. Double click on the run2 heading in the table and change the name to Site 1.

    e. Save the file to retain the calibration settings.

    f. Mark the sensors you used in this set up. It is important that you use the same sensors for all of your measurements.

PROCEDURE

You will measure dissolved oxygen concentration, water temperature, pH, and total dissolved solid (TDS) concentration at four different sites.

12.   Open the file saved in Step 11. Be sure the data-collection interface is connected to the handheld or laptop computer. Connect the Dissolved Oxygen probe to your interface. This will start the 10 minute warm up of the sensor.

13. Choose a desirable location to perform your measurements. It is best to take your samples as far from the shore edge as is safe. Your site should be representative of the whole watershed.

14. Rinse the sampling bottle a few times with stream water. Place the sample bottle below the surface, allowing water to flow into the opening for two to three minutes. Fill the sampling bottle so it is completely full and then stopper the bottle under water. This should minimize the amount of atmospheric oxygen that gets dissolved in the water prior to making measurements. Label the sample bottle Site 1.

15. Measure the dissolved oxygen of your water sample. Perform the following steps to prepare the Dissolved Oxygen Probe.

    Important: Prior to each use, the Dissolved Oxygen Probe must warm up for a period of 10 minutes. If the probe is not warmed up properly, inaccurate readings will result. If using the TI-Nspire Lab Cradle, the values for this sensor will display in black only after the sensor has warmed up.

    a. Start data collection (⏵).
    b. Remove the Dissolved Oxygen Probe from its storage bottle. Place the probe into the water and gently swirl to allow water to move past the probe's tip.
    c. Monitor the readings displayed on the screen. When the reading is stable, click the Keep button (💾) and enter **DO** as the sensor.
    d. Stop data collection (⏹).
    e. Remove the probe from the water, rinse it with distilled water, and place it back into the storage bottle.

16. Measure the temperature of your water sample.

    a. Disconnect the Dissolved Oxygen Probe and connect the Temperature Probe.
    b. Start data collection (⏵) and select the **Append** option.
    c. Place the Temperature Probe into the water sample.
    d. Monitor the temperature reading. When the reading has stabilized, click the Keep button (💾) and enter **Temp** as the sensor. Remove the probe from the water.
    e. Stop data collection (⏹).

17. Measure the pH of your water sample.

    a. Disconnect the Temperature Probe and connect the pH Sensor.
    b. Start data collection (⏵) and select the **Append** option.
    c. Remove the pH Sensor from its storage bottle. Place the sensor into the sample.
    d. Monitor the pH reading displayed on the screen. When the reading has stabilized, click the Keep button (💾) and enter **pH** as the sensor. Remove the sensor from the water, rinse the probe with distilled water, and place it back into the storage bottle.
    e. Stop data collection (⏹).

18. Measure the TDS of your water sample.

    a. Disconnect the pH Sensor and connect the Conductivity Probe.
    b. Start data collection (⏵) and select the **Append** option.
    c. Place the tip of the Conductivity Probe into the water sample. The hole near the tip of the probe should be submerged completely.

    d. Monitor the TDS reading. When the reading has stabilized, click the Keep button (🔲) and enter **Cond** as the sensor. Remove the probe from the water and rinse it with distilled water.

    e. Stop data collection (🔲).

19. Click the Store Latest Run button (🔲) to save the data for Site 1. Disconnect the Conductivity probe and connect the Dissolved Oxygen probe. This will start the 10 minute warm up period required for the Dissolved Oxygen probe.

20. Repeat Steps 13–19 at a location 6 meters from Site 1. This second location will be designated Site 2.

21. Repeat Steps 13–19 at a location 1.6 km (1 mile) from Site 1. This third location will be designated Site 3.

22. Repeat Steps 13–18 at a location 6 m from Site 3. This fourth location will be designated Site 4. Note: it is not necessary to store the latest data set after collecting the Site 4 data.

23. Click the Table View tab (🔲). If desired, double click on the site name and use the notes field to record the location of the sites.

24. Record the data in Table 1.

25. Save the file to ensure data will not be lost.

DATA

Room Temperature (°C)   _____

Table 1				
Location	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Total dissolved solids (mg/L)
Tap Water				
Site 1				
Site 2				
Average Sites 1 & 2				
Site 3				
Site 4				
Average Sites 3 & 4				

Temperature Difference: _____

Table 2 - DO (% Saturated)			
	Average Dissolved Oxygen (mg/L)	DO in saturated water	% Saturated
Sites 1 & 2			
Sites 3 & 4			

Table 3 – use with Sites 1 & 2			
Test	Q-Value	Weight	Total Q-value
DO		0.38	
pH		0.24	
TDS		0.16	
Temperature		0.22	

Overall Quality: _____

Table 4 – use with Sites 3 & 4			
Test	Q-Value	Weight	Total Q-value
DO		0.38	
pH		0.24	
TDS		0.16	
Temperature		0.22	

Overall quality: _____

PROCESSING THE DATA

1. Calculate the averages for measurements at sites that are 6 meters apart (sites 1 & 2 and sites 3 & 4) record the results in Table 1.

2. Subtract the two average temperatures from the sites. Record the result as the temperature difference in the blank below Table 1. This value will be used in Step 5.

3. Determine the % saturation of dissolved oxygen:

   a. Copy the value of the average dissolved oxygen from Table 1 to Table 2.
   b. Obtain the barometric pressure, in mm Hg. If you do not have the current barometric pressure, use Table 10 to estimate the barometric pressure at your altitude.
   c. Note the average water temperature at each site.
   d. Using the pressure and temperature values, look up the level of dissolved oxygen for air-saturated water (in mg/L) using Table 9. Record the results in Table 2.

e. Determine the % saturation using the formula:

$$\% \text{ saturation} = \frac{\text{measured D.O. level}}{\text{saturated D.O. level}} \times 100$$

f. Record the % saturation of dissolved oxygen in Table 2.

4. Using Tables 5 – 7, determine the water quality value (Q value) for each of the following measurements: dissolved oxygen, pH, and TDS. You may need to interpolate to obtain the correct Q values. Record your result in Table 3 for Sites 1 & 2 and in Table 4 for Sites 3 & 4.

5. Using Table 8 and the value you calculated in Processing the Data Step 2, determine the water quality value (Q value) for the temperature difference measurement. You may need to interpolate to obtain the correct Q values. Record your result in Table 3 for Sites 1 & 2 and in Table 4 for Sites 3 & 4. The temperature Q-value will be the same in both tables.

6. Multiply each Q-value by the weighting factor listed in Tables 3 and 4. Record the total Q-value in each Table.

7. Determine the overall water quality of your stream by adding the four total Q-values in Table 3 for Sites 1 & 2 and in Table 4 for Sites 3 & 4. Record the result in the line next to the label "Overall Quality." The closer this value is to 100, the better the water quality of the stream at this site.

Note: This quality index is not a complete one—this value uses only four measurements. For a more complete water quality determination, you should measure fecal coliform counts, biological oxygen demand, phosphate and nitrate levels, and turbidity. It is also very valuable to do a "critter count"—that is, examine the macroinvertebrates in the stream.

QUESTIONS

1. Using your measurements, what is the quality of the watershed? Explain.

2. How do you account for each of the measurements? For example, if the pH of the downstream site is very low, and you took measurements above and below an auto repair station, perhaps battery acid leaked into the stream.

   DO:

   pH:

   TDS:

   Temperature:

3. How did measurements between the two sites 1 mile apart compare? How might you account for any differences?

4. Compare the measurements you obtained with those from previous months or years. Has the water quality improved, remained about the same, or declined? Explain.

5. Why would you expect the DO in a pond to be less than in a rapidly moving stream? If applicable, did your measurements confirm this assumption? Explain.

6. What could be done to improve the quality of the watershed?

WATER QUALITY VALUE TABLES

Table 5 Dissolved oxygen (DO) test results	
DO (% saturation)	Q Value
0	0
10	5
20	12
30	20
40	30
50	45
60	57
70	75
80	85
90	95
100	100
110	95
120	90
130	85
140	80

Table 6 pH test results	
pH	Q Value
2.0	0
2.5	1
3.0	3
3.5	5
4.0	8
4.5	15
5.0	25
5.5	40
6.0	54
6.5	75
7.0	88
7.5	95
8.0	85
8.5	65
9.0	48
9.5	30
10.0	20
10.5	12
11.0	8
11.5	4
12.0	2

Table 7 Total dissolved solids (TDS) test results	
TDS (mg/L)	Q Value
0	80
50	90
100	85
150	78
200	72
250	65
300	60
350	52
400	46
450	40
500	30

Table 8 Temperature test results	
ΔTemp (°C)	Q Value
0	95
5	75
10	45
15	30
20	20
25	15
30	10

DISSOLVED OXYGEN CALIBRATION TABLES

	770 mm	760 mm	750 mm	740 mm	730 mm	720 mm	710 mm	700 mm	690 mm	680 mm	670 mm	660 mm
						Table 9: 100% Dissolved Oxygen Capacity (mg/L)						
0°C	14.76	14.57	14.38	14.19	13.99	13.80	13.61	13.42	13.23	13.04	12.84	12.65
1°C	14.38	14.19	14.00	13.82	13.63	13.44	13.26	13.07	12.88	12.70	12.51	12.32
2°C	14.01	13.82	13.64	13.46	13.28	13.10	12.92	12.73	12.55	12.37	12.19	12.01
3°C	13.65	13.47	13.29	13.12	12.94	12.76	12.59	12.41	12.23	12.05	11.88	11.70
4°C	13.31	13.13	12.96	12.79	12.61	12.44	12.27	12.10	11.92	11.75	11.58	11.40
5°C	12.97	12.81	12.64	12.47	12.30	12.13	11.96	11.80	11.63	11.46	11.29	11.12
6°C	12.66	12.49	12.33	12.16	12.00	11.83	11.67	11.51	11.34	11.18	11.01	10.85
7°C	12.35	12.19	12.03	11.87	11.71	11.55	11.39	11.23	11.07	10.91	10.75	10.59
8°C	12.05	11.90	11.74	11.58	11.43	11.27	11.11	10.96	10.80	10.65	10.49	10.33
9°C	11.77	11.62	11.46	11.31	11.16	11.01	10.85	10.70	10.55	10.39	10.24	10.09
10°C	11.50	11.35	11.20	11.05	10.90	10.75	10.60	10.45	10.30	10.15	10.00	9.86
11°C	11.24	11.09	10.94	10.80	10.65	10.51	10.36	10.21	10.07	9.92	9.78	9.63
12°C	10.98	10.84	10.70	10.56	10.41	10.27	10.13	9.99	9.84	9.70	9.56	9.41
13°C	10.74	10.60	10.46	10.32	10.18	10.04	9.90	9.77	9.63	9.49	9.35	9.21
14°C	10.51	10.37	10.24	10.10	9.96	9.83	9.69	9.55	9.42	9.28	9.14	9.01
15°C	10.29	10.15	10.02	9.88	9.75	9.62	9.48	9.35	9.22	9.08	8.95	8.82
16°C	10.07	9.94	9.81	9.68	9.55	9.42	9.29	9.15	9.02	8.89	8.76	8.63
17°C	9.86	9.74	9.61	9.48	9.35	9.22	9.10	8.97	8.84	8.71	8.58	8.45
18°C	9.67	9.54	9.41	9.29	9.16	9.04	8.91	8.79	8.66	8.54	8.41	8.28
19°C	9.47	9.35	9.23	9.11	8.98	8.86	8.74	8.61	8.49	8.37	8.24	8.12
20°C	9.29	9.17	9.05	8.93	8.81	8.69	8.57	8.45	8.33	8.20	8.08	7.96
21°C	9.11	9.00	8.88	8.76	8.64	8.52	8.40	8.28	8.17	8.05	7.93	7.81
22°C	8.94	8.83	8.71	8.59	8.48	8.36	8.25	8.13	8.01	7.90	7.78	7.67
23°C	8.78	8.66	8.55	8.44	8.32	8.21	8.09	7.98	7.87	7.75	7.64	7.52
24°C	8.62	8.51	8.40	8.28	8.17	8.06	7.95	7.84	7.72	7.61	7.50	7.39
25°C	8.47	8.36	8.25	8.14	8.03	7.92	7.81	7.70	7.59	7.48	7.37	7.26
26°C	8.32	8.21	8.10	7.99	7.89	7.78	7.67	7.56	7.45	7.35	7.24	7.13
27°C	8.17	8.07	7.96	7.86	7.75	7.64	7.54	7.43	7.33	7.22	7.11	7.01
28°C	8.04	7.93	7.83	7.72	7.62	7.51	7.41	7.30	7.20	7.10	6.99	6.89
29°C	7.90	7.80	7.69	7.59	7.49	7.39	7.28	7.18	7.08	6.98	6.87	6.77
30°C	7.77	7.67	7.57	7.47	7.36	7.26	7.16	7.06	6.96	6.86	6.76	6.66

Table 10: Approximate Barometric Pressure at Different Elevations					
Elevation (m)	Pressure (mm Hg)	Elevation (m)	Pressure (mm Hg)	Elevation (m)	Pressure (mm Hg)
0	760	800	693	1600	628
100	748	900	685	1700	620
200	741	1000	676	1800	612
300	733	1100	669	1900	604
400	725	1200	661	2000	596
500	717	1300	652	2100	588
600	709	1400	643	2200	580
700	701	1500	636	2300	571

TEACHER INFORMATION

Watershed Testing

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See Appendix A for more information.

2. This lab can be done by monitoring the Meter View readings and recording the values instead of using Events with Entry data collection.

3. To make data collection more efficient, you may choose to have each group collect data for only one sensor and then share the data.

4. In order for the Dissolved Oxygen Probe to warm up and stay polarized, **power to the sensor must be continuous**. Go! Link or EasyLink, with a computer, and the TI-Nspire Lab Cradle deliver continuous power once the data-collection software is started. However, EasyLink or Go!Link with a handheld will lose power when the TI handheld goes to sleep (APD™). If power to the sensor is disrupted, the sensor must be warmed up for 10 minutes again before calibrating or taking readings. To avoid having to warm up the sensor again, students must press a button on the handheld every few minutes to keep it awake.

5. When using a TI-Nspire handheld with an EasyLink or Go!Link interface, we recommend that the handhelds power standby feature be set to 30 minutes. To set this feature, select Settings ►Handheld Setup from the TI-Nspire home screen. Change the Power Standby feature to 30 minutes. You may want to set this back after completing this experiment.

6. The Dissolved Oxygen Probe must be calibrated the day of use. Follow the pre-lab procedure to prepare and calibrate the Dissolved Oxygen Probe. To save time, you may wish to calibrate the probe and record the calibration values. The students can then skip the pre-lab procedure and they will have the calibration values available for manual entry in case the values stored in the program are lost. We strongly recommend that your students store the calibration values to the document after calibrating the probe the first time.

7. To ensure the most accurate measurements of pH in water quality experiments, the pH System should be calibrated prior to use. For instructions on calibration, refer to the sensor documentation, and *Appendix B* or *C*.

8. When transporting the Dissolved Oxygen Probe to the field site, you should store it in the plastic calibration bottle filled with distilled water. This plastic bottle is shipped with the Dissolved Oxygen Probe. It is important that the students understand the fragile nature of the electrode membrane and proper handling procedures. When setting up the Dissolved Oxygen Probe, be sure to remove the blue plastic cap from the end of the probe. The cap is made of a soft plastic material and easily slides off the probe end.

9. A glass-stoppered water sampling bottle is recommended for collecting samples. Filling this bottle to the brim, followed by stoppering, will prevent additional oxygen from dissolving after water is collected.

10. Two sites 1.6 km (1 mile) apart should be selected for comparison. Have students take samples at two points for each site. Each of the sample points should be approximately 6 m (20 feet) apart.

11. To determine the D.O. concentration for a solution saturated with dissolved oxygen, refer to Table 9 and Table 10. **Important:** Be sure to bring a copy of these tables on the day you collect and test water samples! Use Table 10 to estimate barometric pressure using your approximate elevation above sea level. Temperature and barometric pressure values can then be used in Table 9 to determine the saturated level of dissolved oxygen, in mg/L. Use this formula to calculate % saturation of dissolved oxygen:

$$\% \text{ saturation} = \frac{\text{measured D.O. level}}{\text{saturated D.O. level}} \times 100$$

12. To ensure the most accurate measurements of TDS in water quality experiments, the conductivity probe should be calibrated prior to use. For instructions on calibration, refer to the sensor documentation and *Appendix B* or *C*.

13. When measuring total dissolved solids, you may wish to have students use the 0–200 µS/cm (equal to 100 mg/L TDS) range to improve accuracy. This should only be done if TDS levels are below 100 mg/L.

14. A more complete water quality index can be obtained by measuring fecal coliform counts; biological oxygen demand, phosphate and nitrate levels, and turbidity. It is also very valuable to do a "critter count"—that is, examine the macroinvertebrates in the stream.

   For more information on the Water Quality Index, you may be interested in the Vernier book, *Water Quality with Vernier*.

SAMPLE RESULTS

Table 1				
Location	Dissolved oxygen (mg/L)	pH	Total dissolved solids (mg/L)	Temperature (°C)
Sites 1 & 2 average	10.2	7.4	88.4	11.0
Sites 3 & 4 average	8.1	7.4	94.0	8.0

Table 2 - DO (% Saturated)			
	Dissolved oxygen (mg/L)	DO in saturated water	% saturated
Sites 1 & 2	10.2	11.1	91.9
Sites 3 & 4	8.1	11.9	68.0

Table 3 - Sites 1 & 2			
Test	Q-value	Weight	Total Q-value
DO	97	0.38	36.9
pH	95	0.24	22.8
TDS	84	0.16	13.4
Temperature	85	0.22	18.7

Overall Quality: 91.8

Table 4 – Sites 3 & 4			
Test	Q-value	Weight	Total Q-value
DO	70	0.38	26.6
pH	95	0.24	22.8
TDS	83	0.16	13.3
Temperature	85	0.22	18.7

Overall quality: 81.4

ANSWERS TO QUESTIONS

1. The water quality indices for the above sites are 91.8 and 81.4. These are very high indices, considering that they were obtained in an urban Seattle watershed. The first site was from a small, rapidly moving stream (~3.4 m^3/s), and the second from a pond 1.6 km upstream. Other measurements corroborated these measurements—the water quality was very high.

2. Answers will vary.

3. Answers will vary. The two sites compared equally except for the DO value. Since water at the second site was hardly moving, it had less dissolved oxygen than in rapidly moving, highly aerated water.

4. Answers will vary.

5. Water in rapidly moving stream is aerated as it flows through riffles, and may have more dissolved oxygen than in slowly moving water.

6. Answers will vary.

Reflection and Absorption of Light

Would you feel cooler wearing a light or dark-colored shirt on a hot, sunny day? The color and texture of an object influences how much radiant energy from the sun it will absorb or reflect. Every color reflects a certain amount of light while absorbing the rest as heat energy. The amount of reflected light is called the color's *light reflectance value.* Dark colors with low light reflectance values tend to reflect little light while absorbing lots of heat energy, whereas light colors with high reflectance values reflect a lot of light and absorb little energy. People in warm, sunny climates are more likely to purchase light-colored cars since they don't heat up as quickly as dark-colored ones. Many house paints come with a predetermined light reflectance value to guide consumers when making color choices for their homes. Since the Earth's surface is made of many colors and textures, it is heated unevenly. Snow, ice, and clouds reflect a lot of energy back into space while green forests and vegetated lands absorb energy.

In this experiment, you will investigate the relationship between the percent reflectivity of various colors and the temperature change due to energy absorption. You will measure the amount of light reflected from paper of various colors using a Light Sensor and calculate percent reflectivity. You will also measure the temperature change of the air under the paper due to energy absorption by the paper using a Temperature Probe.

OBJECTIVES

In this experiment, you will

- Use a Light Sensor to measure the amount of reflected light.
- Calculate percent reflectivity of various colored paper.
- Use a Temperature Probe to measure the energy absorbed from light.

MATERIALS

TI-Nspire handheld **or**	white paper
computer and TI-Nspire software	black paper
data-collection interface	2 other pieces of colored paper
Light Sensor	ring stand
Temperature Probe	2 utility clamps
4 cm piece of drinking straw	tape
lamp and 150 W clear bulb	ruler
aluminum foil	

Figure 1

PROCEDURE

1. Prepare the sensors for data collection.

   a. Tape the straw to the table surface as shown in Figure 1.
   b. Insert a Temperature Probe into the straw as far as it will go. Check to make sure the end of the Temperature Probe is not touching the tabletop.
   c. Place the piece of white paper over the Temperature Probe.
   d. Use a utility clamp and ring stand to fasten a Light Sensor 5 cm above the paper as shown in Figure 2. Set the Light Sensor switch to the 0–6000 lux position.
   e. Use the other utility clamp to fasten the lamp and bulb to the ring stand 10 cm above the paper.
   f. The classroom lights should be on.

Figure 2

2. Connect the Light Sensor and Temperature Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the Experiment menu. Choose Collection Setup from the Experiment menu. Enter **0.1** as the rate (samples/second) and **600** as the experiment duration (seconds). The number of points collected should be 61. Select OK.

4. Switch on the light bulb and immediately start data collection (). When data collection is complete, turn off the light bulb.

5. Determine and record the mean light reflection value and the minimum and maximum temperature readings.

   a. Choose Statistics ► Illumination from the Analyze menu. Record the mean light reflection value in your data table (to the nearest whole lux). The lux is the SI unit for light illumination.
   b. Choose Statistics ► Temperature from the Analyze menu. Record the minimum and maximum temperature readings (round to the nearest 0.1°C).

6. Click the Store Latest Data Set button () to save the first run data. Replace the white paper with the black paper. Repeat Steps 4–5 for black paper.

7. Click the Store Latest Data Set button () to save the second run data. Replace the black paper with aluminum foil. Repeat Steps 4–5 for aluminum foil.

8. If time allows, collect data for two additional colors of paper. Be sure to store the latest data set () before collecting new data.
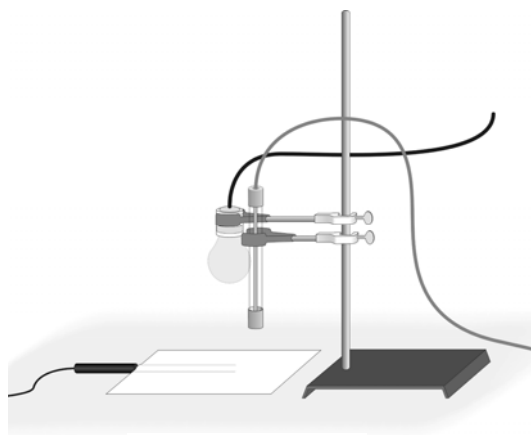
DATA

Color	White	Black	Aluminum	_____	_____
Starting temperature (°C)					
Final temperature (°C)					
Change in temperature (°C)					
Reflection value (lux)					
Percent reflectivity	%	%	100%	%	%

PROCESSING THE DATA

1. Subtract to find the change in temperature for each color paper. Record your values in the data table.

2. Calculate the percent reflectivity of each color paper using the relationship:

$$\% \text{ Reflectivity } = \frac{\text{reflection value for paper}}{\text{reflection value for aluminum}} \times 100$$

Record your values in the data table.

QUESTIONS

1. Which color paper had the largest temperature increase?

2. Which color paper had the smallest temperature increase?

3. Solar collectors can be used to absorb the sun's radiation and change it to heat. What color would work best for solar collectors? Explain.

4. Which color paper has the highest reflectivity?

5. Which color paper has the lowest reflectivity?

6. What relationship do you see between percent reflectivity and temperature change?

7. What types of surfaces might give a planet a high reflectivity? Explain.

8. Does the planet Earth have high reflectivity? Why or why not?

EXTENSIONS

1. Design an experiment to test the reflectivity of sand, soil, water, and other materials. Perform the experiment you designed.

2. Design an experiment to test the effect of texture on reflectivity. Perform the experiment you designed.

TEACHER INFORMATION

Reflection and Absorption of Light

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment is not intended for use with Easy or Go! Products since data from two sensors must be collected at the same time. While you can use two different handhelds, each with their own sensor or multiple Go! Products on the same computer, to collect the data, a single, multi-channel interface is preferred.

3. The straw is used to keep the temperature probe from moving around during the length of the experiment.

4. Heavy construction paper works well in this experiment. Try to obtain pieces with the same texture and thickness. Rectangular 10 cm ⅹ 20 cm pieces work well.

5. If you are using a TI Light Probe (order code TILT-BTA) for data collection, the sensor will measure Light Level rather than Illumination.

6. Remind your students not to touch a hot bulb.

7. To make it easier for the students to tell which run is which, you can have them rename the runs. To do this, from the table, double click on the run name and type in the color of the paper.

8. Be sure that the aluminum foil does not get wrinkled as the reflectance value will be greatly diminished. If the foil does get wrinkled, replace it.

9. Do not use compact florescent or led lights for this experiment.

SAMPLE RESULTS

Color	White	Black	Aluminum	Purple	Yellow
Starting temperature (^{o}C)	23.7	23.9 23.2	25.2 24.1		
Final temperature (^{o}C)	30.0	36.6 28.0	31.0 30.1		
Change in temperature (^{o}C)	6.3	12.7	4.8	5.8	6
Reflection value (lux)	1778	372	2579	1012	1539
Percent reflectivity	68.9%	14.4%	100%	39.2%	59.7%
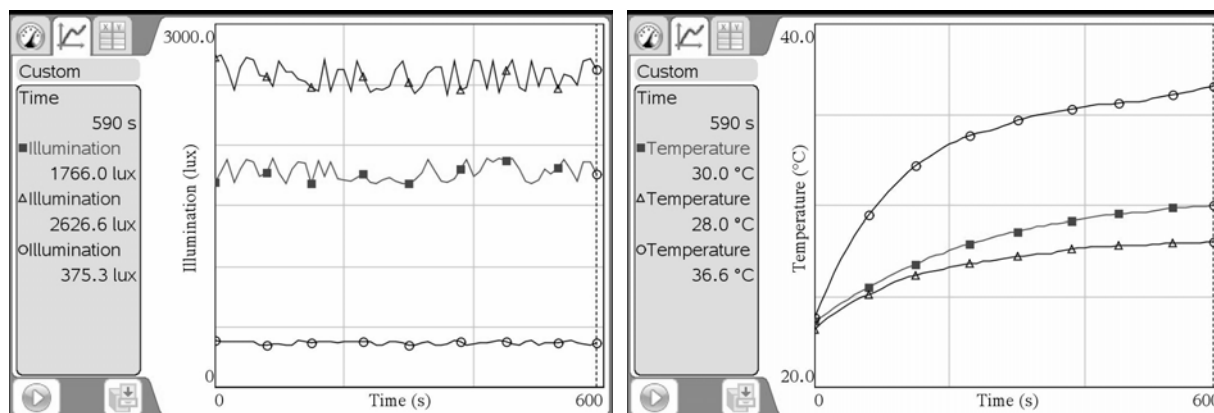
*Reflection values and temperature changes for
white paper (■), black paper (○), and aluminum foil (△).*

ANSWERS TO QUESTIONS

1. Black paper had the largest temperature increase.

2. White paper had the smallest temperature increase.

3. Black would work best for a solar collector since it absorbs radiant energy best.

4. White paper has the highest reflectivity.

5. Black paper has the lowest reflectivity.

6. The lower the reflectivity, the greater the temperature change.

7. Snow, ice, sand, clouds, and water would be expected to give a planet high reflectivity.

8. Planet Earth has high reflectivity because much of it is covered by snow, ice, sand, clouds, and water. The results of this experiment suggest that dark-colored parts of the Earth, such as forests and green cropland, would have lower reflectivity.

ACKNOWLEDGEMENT

We wish to thank Don Volz and Sandy Sapatka for their help in developing and testing this experiment.

Dew Point Temperature

On hot summer days, you may notice water droplets forming on the outside of a glass of ice water. It is commonly said that the glass is "sweating." Since the glass cannot actually sweat, the liquid on the glass must come from the air outside the glass. This liquid forms by the condensation of water vapor that is near the surface of the glass. The air next to the cold glass has been cooled to the *dew point* or *dew point temperature*. The dew point temperature is the temperature to which air would have to be cooled to become saturated. Once the air is saturated, the water vapor condenses to form a liquid. The same process occurs when dew forms on the lawn.

In this experiment, you will use a temperature probe to make two investigations. In the first, you will measure the temperature of air next to a can of ice water to see if it is colder than room temperature. In the second investigation, you will determine the dew point temperature of the air in the classroom. You will do this by slowly adding ice to water and watching for condensation to form on the outside of the container. Throughout this process, you will continuously record the temperature of the water. When condensation first forms on the container, the temperature of the water is the dew point temperature.

OBJECTIVES

In this experiment, you will

- Compare room temperature to the temperature of air next to a can of ice water.
- Record the temperature of water while ice is slowly added.
- Observe the formation of condensation.
- Determine the dew point temperature.

MATERIALS

TI-Nspire handheld **or**	plastic spoon
computer and TI-Nspire software	ice cubes and ice chips
EasyTemp **or** Go!Temp **or**	ring stand
Temperature Probe and data-collection interface	utility clamp
room temperature water	paper towels

PRE-LAB QUESTIONS

1. To determine the dew point temperature, you will slowly add small pieces of ice to room temperature water. After each piece is added, you will wait for the ice to melt. Throughout this process, you will graph the temperature of the water. Draw a rough sketch of what the temperature *vs.* time graph will look like while the ice melts.

2. In the experiment, you will continue to collect temperature data after the small pieces of ice have melted. Draw a rough sketch of what the temperature *vs.* time graph will look like after the ice has melted.
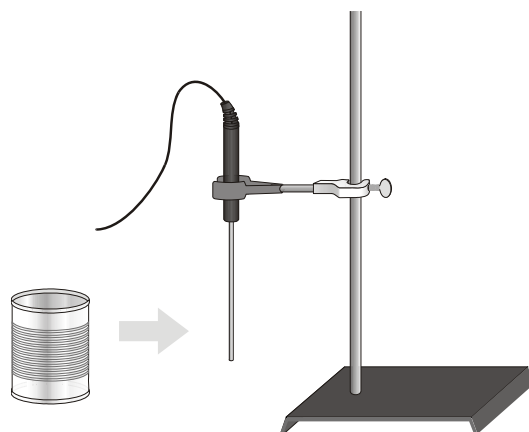
Figure 1

PROCEDURE

Part I Measure the Temperature of the Air Next to a Can of Ice Water

1. Use a utility clamp to suspend the Temperature Probe on a ring stand as shown in Figure 1. The end of the Temperature Probe should be about 1 cm above the tabletop.

2. Connect the Temperature Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using an EasyTemp or Go!Temp, you do not need a data-collection interface.)

3. Choose New Experiment from the Experiment menu. Choose Collection Setup from the Experiment menu. Enter **1** as the rate (samples/second) and **900** as the experiment duration in seconds. The number of points collected should be 901. Choose the Data Marker option and select OK.

4. Read the room temperature displayed on the screen. Record it in the data table.

5. Place 5 or 6 ice cubes in the metal can, fill it with water, and place it away from the Temperature Probe.

6. Start data collection (). Wait 30 seconds and then place the can about 1 mm from the tip of the Temperature Probe. Do not touch the probe to the can.

7. Watch the outside of the can. When condensation forms on the can, click the Add Data Marker button () to mark the dew point temperature. Stop data collection ().

8. A graph of temperature *vs*. time will be displayed. The temperature you marked with the Data Marker will be highlighted in the graph with a large point icon. Double-click on this point, label it **Dew Point**, and then select OK. The point label is displayed in the Graph View Details box. Record the dew point temperature in the data table.

9. Print or sketch copies of the graph as directed by your instructor.

10. Empty the can and dry the outside.
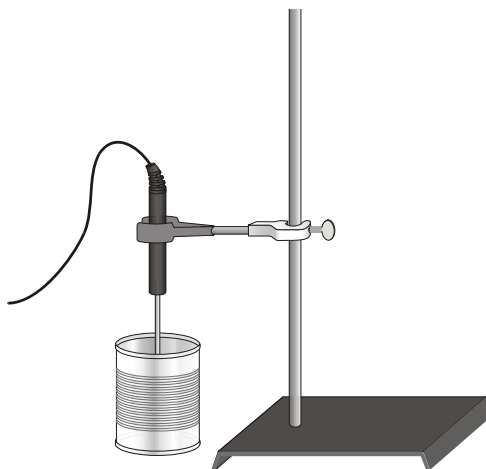
Figure 2

Part II Determine the Dew Point Temperature

11. Fill the dry can half full with room temperature water.

12. Lower the Temperature Probe into the water (to about 1 cm from the bottom) as shown in Figure 2. Click the Store Latest Data Set button (▣) to save the first run data.

13. Click the Meter View tab (▣). Monitor the temperature of the water. Once the temperature is stable, go to Step 14.

14. Start data collection (▶). Wait about 30 seconds and then add a spoonful of ice chips to the water. Stir the water while the ice melts. After the ice has melted, continue to stir the water for about 10 seconds.

15. Add another spoonful of ice chips and again stir the water until it melts. Again wait about 10 seconds after the ice has melted. Observe the can to see if water has condensed on the outside.

16. Repeat Step 15 until you observe condensation. When condensation forms on the can, click the Add Data Marker button (▣) to identify the dew point temperature. Stop data collection (▣).

17. A graph of temperature *vs.* time will be displayed. The temperature you marked with the Data Marker will be highlighted in the graph with a large point icon. Click on this point, label it **Dew Point**, and then select OK. Record the dew point temperature in the data table.

18. Print or sketch copies of the graphs as directed by your instructor.

DATA

Part I	
Room temperature (°C)	
Air temperature close to the can of ice water (°C)	

Part II	
Dew point temperature (°C)	

QUESTIONS

1. Compare the room temperature to the temperature of the air next to the can of ice water. How much colder was this air than room temperature?

2. Compare the room temperature, the temperature of the air next to the can, and the dew point temperature.

EXTENSIONS

1. Repeat Part II of this experiment four more times and determine the average dew point temperature.

2. Collect results from other lab groups and determine the average dew point temperature.

3. Repeat the experiment outside and compare the dew point temperature of the outside air to that of the inside air. Explain any differences.

TEACHER INFORMATION

Dew Point Temperature

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment is relatively easy to perform. The key is to carefully watch for the formation of condensation on the can. The initial condensation will be extremely small water droplets. The surface of the can will actually look dull instead of shiny.

3. A shiny, metal soup can works well for this lab. Be sure to remove any sharp edges on the can.

4. In Part 1 use enough ice cubes to produce an ice bath.

5. In Part 2 use crushed ice instead of whole ice cubes. The crushed ice allows the students to slowly add the ice and allow each addition to melt. This process provides time for the condensation to form.

SAMPLE RESULTS
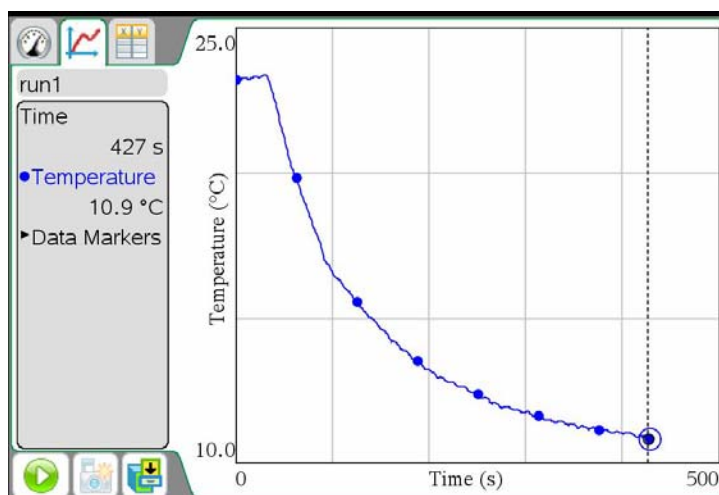
Typical graph for Part 1

Part 1	
Room temperature (°C)	23.4
Air temperature close to the can of ice water (°C)	10.9
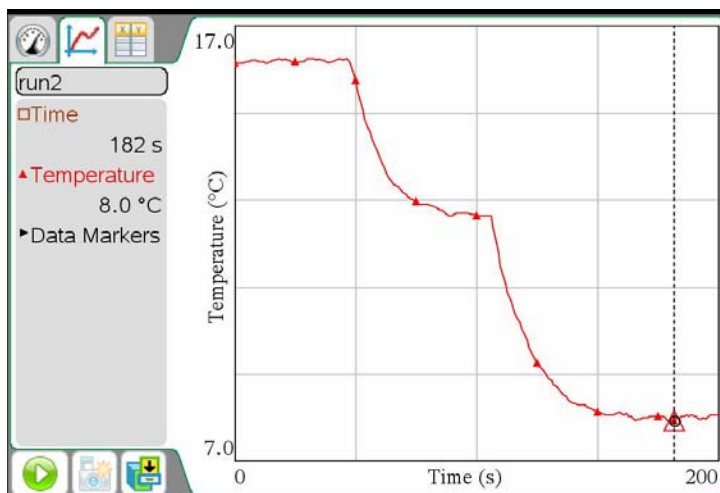
Typical graph for Part 2

Part 2	
Dew point temperature (°C)	8.0

ANSWERS TO QUESTIONS

1. Answers will vary. See the Sample Results.

2. Answers will vary. See the Sample Results.

Seasons and Angle of Insolation

Have you ever wondered why temperatures are cooler in the winter and warmer in the summer? This happens because the Earth's axis is tilted. The Earth remains tilted as it revolves around the sun. Because of this tilt, different locations on the Earth receive different amounts of solar radiation at different times of the year. The amount of solar radiation received by the Earth or another planet is called *insolation*. The *angle of insolation* is the angle at which the sun's rays strike a particular location on Earth. When the north end of the Earth's axis points toward the sun, the Northern Hemisphere experiences summer. At the same time, the south end of the axis points away from the sun and the Southern Hemisphere experiences winter.
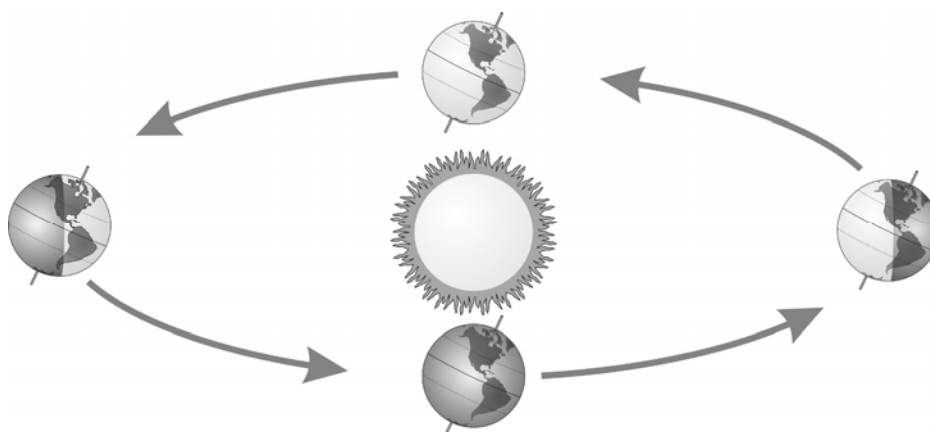
Figure 1

In this experiment you will investigate the relationship between angle of insolation and temperature change due to energy absorption from a simulated sun—a light bulb.

OBJECTIVES

In this experiment, you will

- Use a Temperature Probe to monitor simulated warming of your city by the sun in the winter.
- Use a Temperature Probe monitor simulated warming of your city by the sun in the summer.
- Measure the angle of insolation.
- Determine the relationship between temperature change and angle of insolation.

MATERIALS

TI-Nspire handheld **or**	lamp with clear 150 watt bulb
computer and TI-Nspire software	tape
EasyTemp **or** Go!Temp **or**	ruler
Temperature Probe and data-collection interface	two 20 cm lengths of string
ring stand	protractor
globe of the Earth	utility clamp
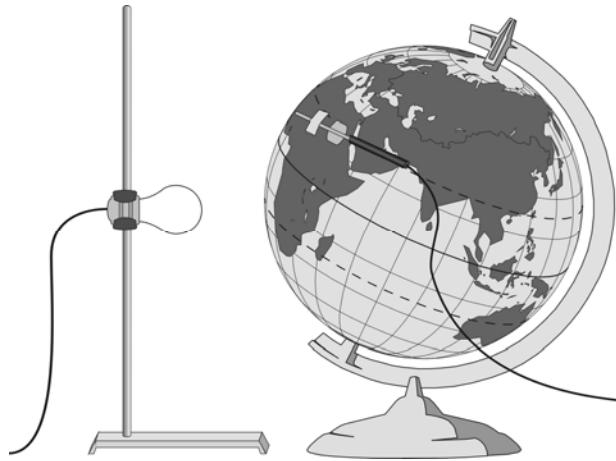
Figure 2

PROCEDURE

1. Set up the light bulb (simulated sun).

   a. Fasten the lamp to a ring stand as shown in Figure 2.
   b. Stand the ring stand and lamp to the left side of your work area.
   c. Position the globe with the North Pole tilted away from the lamp as shown in Figure 2. Position the bulb at approximately the same height as the Tropic of Capricorn. **Note:** The sun is directly over the Tropic of Capricorn on December 21, the first day of winter.

2. Attach the Temperature Probe to the globe.

   a. Find your city or location on the globe.
   b. Tape the Temperature Probe to the globe with the tip of the probe at your location. Tape the probe parallel to the equator. Place the tape about 1 cm from the tip of the probe
   c. Fold a piece of paper and wedge it under the Temperature Probe to keep it in contact with the surface of the globe as shown in Figure 3.

Figure

3. Position the globe for winter (in the Northern Hemisphere) data collection.

   a. Turn the globe to position the North Pole (still tilting away from the lamp), your location, and the bulb in a straight line. Tape the globe in this position so that it does not rotate.
   b. Measure the vertical distance from the Tropic of Capricorn to the table. Position the bulb so that its center is the same height from the table.
   c. Obtain a piece of string 20 cm long.
   d. Use the string to position your location on the globe 20 cm from the center of the end of the bulb.
   e. Do not turn on the lamp until directed in Step 7.
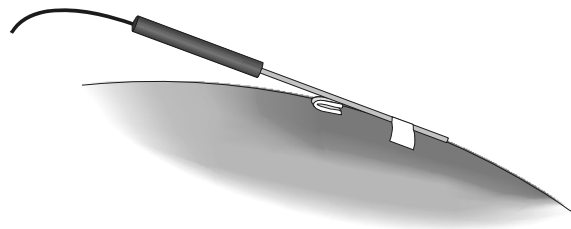
4. Measure the angle of insolation.

   a. Tape the 20 cm string from your location on the globe to the center of the end of the bulb.
   b. Tape another piece of string from the Tropic of Capricorn to the center of the end of the bulb. This string should be taut and parallel to the table. Use only as much of the string as needed.
   c. Use a protractor to measure the angle between the strings. Record the angle in the data table.
   d. Remove the tape and string from the bulb and globe.

5. Connect the Temperature Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using an EasyTemp or Go!Temp, you do not need a data-collection interface.)

6. Choose New Experiment from the 📽 Experiment menu. Choose Collection Setup from the 📽 Experiment menu. Enter **0.1** as rate (samples/second) and **300** as the experiment duration in seconds. The number of points collected should be 31. Select OK.

7. Collect winter data.

   a. Record the temperature displayed on the screen, then start data collection (▶).
   b. After the first temperature reading has been taken, turn on the lamp.
   c. When data collection stops after 5 minutes, turn the lamp off.
   Caution: Do not touch the bulb. It will be very hot.

8. Determine and record the minimum and maximum temperatures.

   a. Choose Statistics from the 📊 Analyze menu.
   b. Record the minimum and maximum temperature readings (round to the nearest 0.1°C).

9. Click the Store Latest Data Set button (🖳) to store the data.

10. Position the globe for summer data collection.

    a. Rotate the entire globe setup so that North Pole is tilted toward the lamp. **Note:** This represents the position of the Northern Hemisphere on June 21, the first day of summer.
    b. Turn the globe to position the North Pole, your location, and the bulb in a straight line.
    c. Use the string to position your location on the globe 20 cm from the bulb.
    d. Do not turn on the lamp until directed in Step 12.

11. Measure the angle of insolation.

    a. Tape the 20 cm string from your location on the globe to the center of the end of the bulb.
       Caution: The bulb can be very hot. Allow the bulb to cool before touching it.
    b. Tape another piece of string from the Tropic of Cancer to the center of the end of the bulb. This string should be taut and parallel to the table.
    c. Use a protractor to measure the angle between the strings. Record the angle.
    d. Remove the tape and string from the bulb and globe.

12. Collect summer data.

    a. Click the Meter View tab (📷) and let the globe and probe cool to the temperature that you recorded in Step 7. Then start data collection (▶).
    b. After the first temperature reading has been taken, turn on the lamp.

  c. When data collection stops after 5 minutes, turn the lamp off.

13. Determine and record the minimum and maximum temperatures.

  a. Choose Statistics from the ![icon] Analyze menu.
  b. Record the minimum and maximum temperature readings (round to the nearest 0.1°C).

14. To display a graph of both runs, click **run2** and select All.

15. Sketch or print copies of the graph as directed by your instructor.

DATA

Beginning temperature (°C)		

	Winter	Summer
Maximum temperature (°C)		
Minimum temperature (°C)		
Temperature change (°C)		
Angle of Insolation (°)		

PROCESSING THE DATA

In the space provided in the data table, subtract to find the temperature change for each season.

QUESTIONS

1. How does the temperature change for summer compare to the temperature change for winter?

2. During which season is the sunlight more direct? Explain.

3. What would happen to the temperature changes if the Earth were tilted more than 23.5 degrees?

4. What relationship is there between angle of insolation and temperature change?

5. Draw a picture showing the setup you would use to measure the change in temperature in the Southern Hemisphere during their winter.

6. What other factors affect the weather in a region?

EXTENSIONS

1. Repeat the experiment for other locations in the Northern and Southern Hemispheres.

2. Compare the temperature changes at various latitudes and determine the relationship between latitude and temperature change.

TEACHER INFORMATION

Seasons and Angle of Insolation

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. If you use globes with adjustable tilt, make sure the tilt is 23.5 degrees.

3. You may wish to use a fan to cool the globe and probe between runs.

4. It is important that the tip of the Temperature Probe be in contact with the globe surface during data collection. Scotch® Magic™ Tape seems to stick best to the globe. If tape will not hold the Temperature Probe in place, it is possible to hold the probe in place with your hand or clamp stand.

5. A Surface Temperature Sensor (order code STS-BTA) works very well for this experiment and is easier to tape to the globe than a Stainless Steel Temperature Probe.

6. A paper protractor cut in half makes it easier to read the angle of insolation than using a big protractor.

7. Longer data-collection durations can be used, if desired.

8. A 100 W clear bulb may be used, but temperature changes will be smaller. Compact florescent and LED bulbs should not be used for this lab.

SAMPLE RESULTS

Beginning temperature (°C)	23.4

	Winter	Summer
Maximum temperature (°C)	23.6	24.7
Minimum temperature (°C)	23.3	23.2
Temperature change (°C)	0.3	1.5
Angle of Insolation (°)	50	17

ANSWERS TO QUESTIONS

1. The temperature change for summer is larger than that for winter.

2. In the Northern Hemisphere, the sunlight is more direct in the summer because the Earth is tipped toward the sun. A greater amount of solar radiation is directed at a smaller area.

3. If the Earth were tilted at a greater angle, summers would be warmer and winters would be cooler.

4. The smaller the angle of insolation, the greater the temperature change.

5.
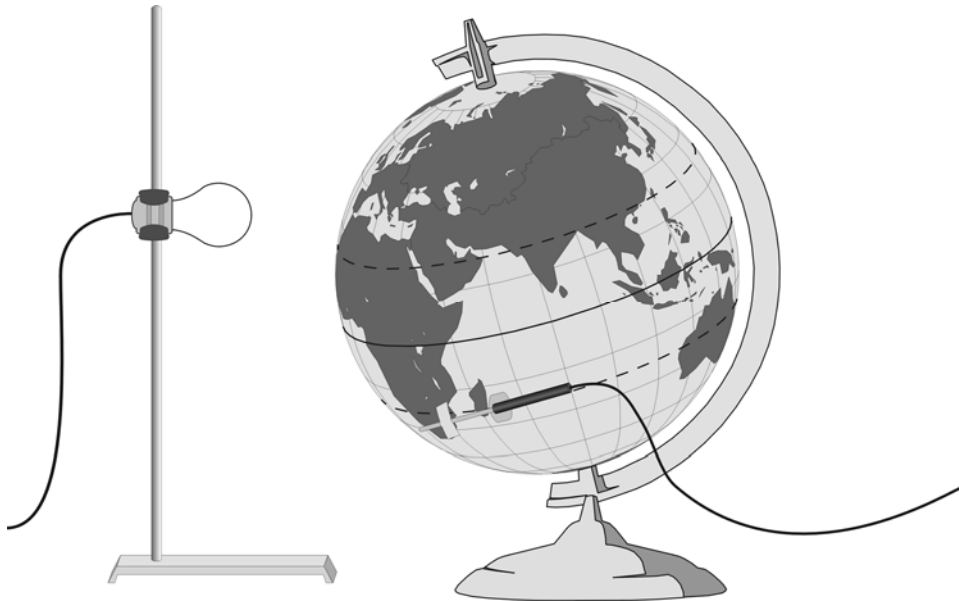
6. Other factors that affect weather in an area include proximity to water, movement of air masses, and geographic features.

ACKNOWLEDGEMENT

Acids and Bases

Organisms are often very sensitive to the effect of acids and bases in their environment. They need to maintain a stable internal pH in order to survive—even in the event of environmental changes. Many naturally occurring biological, geological, and man-made chemicals are capable of stabilizing the environment's pH. This may allow organisms to better survive in diverse environments found throughout the earth. Using the pH Sensor, each lab group will measure the effect of an acid and a base in water. Each group will also test the effect of an acid and a base on a biological material assigned to them. All groups will share their data at the end of the class.

OBJECTIVES

In this experiment, you will

- Add an acid to a material and note the extent to which it resists changes in pH.
- Add a base to a material and note the extent to which it resists changes in pH.
- Work with classmates to compare the ability of different materials to resist changes in pH.
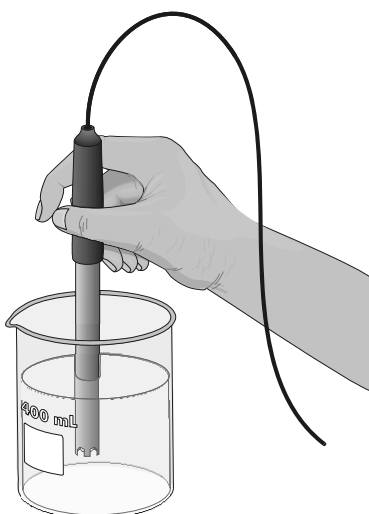
Figure 1

MATERIALS

TI-Nspire handheld **or**
  computer and TI-Nspire software
data-collection interface
Vernier pH Sensor
250 mL beaker
50 mL graduated cylinder
50 mL beaker
0.10 M HCl (acid) with dropper
0.10 M NaOH (base) with dropper
rinse bottle with distilled water
graph paper

goggles
lab apron
Various non-biological materials, such
  as an antacid, buffer, carbonated water
  or soda, salt, or Alka-Seltzer® solution
Various simple biological materials,
  such as egg white, vitamin C, or
  gelatin solution
Various biological organisms (or parts of
  an organism), such as yeast, potato,
  orange juice, or a plant leaf solution

PROCEDURE

1. Obtain and wear goggles.

2. Before each use of the pH Sensor, you need to rinse the tip of the sensor thoroughly with distilled water. To do this, hold the pH Sensor above a rinse beaker and use the rinse bottle to thoroughly rinse the sensor tip.

   Important: Do not let the pH Sensor dry out. Keep it in a 250 mL beaker with about 100 mL of *tap water* when not in use. The tip of the sensor is made of glass—it is fragile. Handle with care!

3. Connect the pH Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

4. Choose New Experiment from the Experiment menu. Choose Collection Mode ► Events with Entry from the Experiment menu. Enter **Drops** as the Name and leave the Units field blank. Select OK.

Testing the effect of acid on water

5. Label a 50 mL beaker *acidic*. Place 20 mL of distilled water in the beaker.

6. Rinse the pH Sensor thoroughly with distilled water, then place it into the beaker to be tested. Be sure the tip of the probe is totally submerged in the water.

7. Start data collection (). Monitor the pH readings displayed to the right of the graph. When the readings are stable, click the Keep button ().

8. Enter **0** as the number of drops you have added. Select OK to store the first data pair for this experiment.

9. Add 5 drops of acid to the beaker. Stir the solution thoroughly after addition.
   CAUTION: *Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with your skin. Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.*

10. When the readings are stable, click the Keep button (). Enter the total number of drops of acid added to the water in the beaker and select OK.

11. Repeat Steps 9–10 adding 5 drops each time until a total of 30 drops has been added.

12. Stop data collection ().

13. Click the Table View tab () and record the pH values in Table 1.

14. Rinse the pH Sensor thoroughly and place the sensor into the beaker of tap water.

Testing the effect of base on water

15. Label a 50 mL beaker *basic*. Place 20 mL of distilled water in the beaker. Click the Graph View tab (), click the Store Latest Data Set button (), and repeat Steps 6–14 substituting base for acid.

Testing the effect of acid on other materials

16. Clean the 50 mL beaker labeled *acidic*. Place 20 mL of test solution, obtained from your teacher, in the beaker. Click the Graph View tab (📈), click the Store Latest Data Set button (📇), and repeat Steps 6–14 using acid.

Testing the effect of base on other materials

17. Clean the 50 mL beaker labeled *basic*. Place 20 mL of test solution, obtained from your teacher, in the beaker. Click the Graph View tab (📈), click the Store Latest Data Set button (📇), and repeat Steps 6–14 substituting base for acid.

18. If time permits, repeat Steps 16–17 for as many materials as you can.

19. Share your data with the rest of the class. Obtain the pH values of any materials you did not test from your classmates. These values should be listed on the board. Record these values in Table 1.

DATA

Table 1									
		pH, after adding this many drops							
Material tested	Add	0	5	10	15 20 25 30			ΔpH	Buffer range
	acid								
	base								
	acid								
	base								
	acid								
	base								
	acid								
	base								
	acid								
	base								
	acid								
	base								
	acid								
	base								
	acid								
	base								
	acid								
	base								

PROCESSING THE DATA

1. Make a series of graphs of the data in Table 1. Construct the graphs using these guidelines:

   - The horizontal axis has Volume scaled from 0 to 30 drops.
   - The vertical axis has pH scaled from 0 to 12.
   - The acid and base data you obtained for water should be included in every graph.
   - Construct one graph for each material tested in Table 1. The graph should include the acid data and the base data.

2. Calculate the pH change, ΔpH, for each material and record in Table 1. The change in pH can be found using the equation

$$\Delta pH = pH \text{ at 30 drops} - pH \text{ at 0 drops}$$

3. Determine the buffering ability of each substance listed in Table 1. Subtract the Δ*pH* of acid from the Δ*pH* of base for each substance. Record in the Buffer Range column of Table 1.

4. In Table 2, make a list of each material tested by the teams in your class. Place the most acidic material at the top of the list and the most basic material at the bottom of the list. Use the pH at 0 drops of acid or base. This value represents the natural pH of the material.

Table 2		
Material	Initial pH	Rank
		most acidic
		2
		3
		4
		5
		6
		7
		8
		least acidic

5. Put the materials tested into the following three categories:

Biological organisms (tissues or cells)	Biological chemicals	Non-biological chemicals

6. List each material tested with its buffer value in Table 3. Order the materials from worst buffering ability (largest buffer range) to best buffering ability (smallest buffer range).

Table 3		
Material	Buffer Range	Rank
		greatest change
		2
		3
		4
		5
		6
		7
		8
		least change

QUESTIONS

1. How should the pH of a material in the *Acidic* beaker compare to that in the *Basic* beaker before any acid or base is added? Why?

2. Referring to Question 1, do your data support your hypothesis? If not, what might cause the differences?

3. Generally, what was the effect of adding HCl to each solution? Was this true for every solution? Why do you think this happened the way it did?

4. Generally, what was the effect of adding NaOH to each solution? Was this true for every solution? Why do you think this happened the way it did?

5. Compare the various graphs of each substance. Why was it beneficial to include the plot of water in acid and water in base with every experiment?

6. Which class of materials (biological organisms, biological chemicals, or non-biological chemicals) reacted most dramatically to the addition of acid or base? How does this relate to their complexity?

7. Which of the materials tested is the best buffer? The poorest buffer?

EXTENSION

1. Bring in common materials from home to test. How do you think they will respond? How did their response compare to your predictions?

TEACHER INFORMATION

Acids and Bases

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. To prepare the 0.1 M NaOH solution, use 4.0 g of solid NaOH pellets per 1 L of solution. **HAZARD ALERT:** Corrosive solid; skin burns are possible; much heat evolves when added to water; very dangerous to eyes; wear face and eye protection when using this substance. Wear gloves. Hazard Code: B—Hazardous.

    To prepare the 0.1 M HCl solution, use 8.6 mL of concentrated acid per 1 L of solution. **HAZARD ALERT:** Highly toxic by ingestion or inhalation; severely corrosive to skin and eyes. Hazard Code: A—Extremely hazardous.

    The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual, 2000*, (800) 452-1261, www.flinnsci.com. See *Appendix F* for more information.

3. Try to make a 1% solution of the materials to test. It is not too critical to be exact. Add ~10 grams of material for each liter of solution.

4. Have the students help design the list of materials to use. Try to use the same number of chemicals in each of the three classes of materials—biological organisms or tissues, biological chemicals, and non-biological chemicals.

    Good organisms or tissues to use might include blended liver, plant leaves, potato roots, yeast, fruit juices (from real fruit—not those <10% varieties!) or Euglena (if you culture them). Try to avoid oily materials—they will be difficult to clean off the probe.

    Good chemicals include starch, enzymes, gelatin, vitamin Bs or C, casein, egg white, or other simple, non-oily biochemicals.

    Good non-biological materials include a mix of buffers with non-buffers. Buffers might include soda water, Alka-Seltzer, phosphate buffer, Tums, etc. An interesting combination is aspirin and Bufferin. Good non-buffers include table salt and nitrogen fertilizer. It is fun to include rocks—try marble (calcium carbonate—a buffer in acid) and quartz.

5. It is not necessary to calibrate your pH sensors, the stored calibration will work fine for this experiment.

6. Vernier Software & Technology sells a pH buffer package for preparing buffer solutions with pH values of 4, 7, and 10 (order code PHB). Simply add the capsule contents to 100 mL of distilled water. You can also prepare pH buffers using the following recipes:

    *   pH 4.00: Add 2.0 mL of 0.1 M HCl to 1 L of 0.1 M potassium hydrogen phthalate.
    *   pH 7.00: Add 582 mL of 0.1 M NaOH to 1 L of 0.1 M potassium dihydrogen phosphate.
    *   pH 10.00: Add 214 mL of 0.1 M NaOH to 1 L of 0.05 M sodium bicarbonate.

SAMPLE RESULTS

Table 1									
		pH, after adding this many drops							
Material Tested	Add	0	5	10	15	20	25	30	ΔpH	Total buffer range
Tap water	Acid	6.46	5.07	3.20	2.92	2.74	2.61	2.54	-3.92	8.82
	Base	5.67	9.59	9.97	10.21	10.37	10.46	10.57	4.90	
Aspirin	Acid	2.71	2.65	2.62	2.58	2.55	2.51	2.48	-0.23	0.38
	Base	2.76	2.76	2.79	2.82	2.85	2.88	2.91	0.15	
Vitamin B2	Acid	4.72	4.25	3.48	2.95	2.74	2.63	2.54	-2.18	5.89
	Base	6.56	8.64	9.45	9.85	10.08	10.19	10.27	3.71	
Vitamin C	Acid	2.84	2.71	2.65	2.59	2.56	2.52	2.48	-0.36	0.49
	Base	2.52	2.53	2.55	2.56	2.58	2.61	2.65	0.13	
Soda water	Acid	3.76	3.34	3.08	2.87	2.74	2.63	2.55	-1.21	2.13
	Base	3.52	3.73	3.94	4.14	4.26	4.36	4.44	0.92	
Cornstarch	acid	4.87	3.30	3.02	2.87	2.76	2.67	2.60	-2.27	7.29
	base	5.84	9.54	10.21	10.47	10.64	10.78	10.86	5.02	
Salt water	acid	4.13	3.06	2.75	2.63	2.53	2.46	2.40	-1.73	8.49
	base	4.72	10.35	10.85	11.07	11.23	11.37	11.48	6.76	
Yeast	acid	4.91	4.87	4.81	4.77	4.72	4.68	4.64	-0.27	0.43
	base	4.86	4.86	4.89	4.92	4.95	4.99	5.02	0.16	
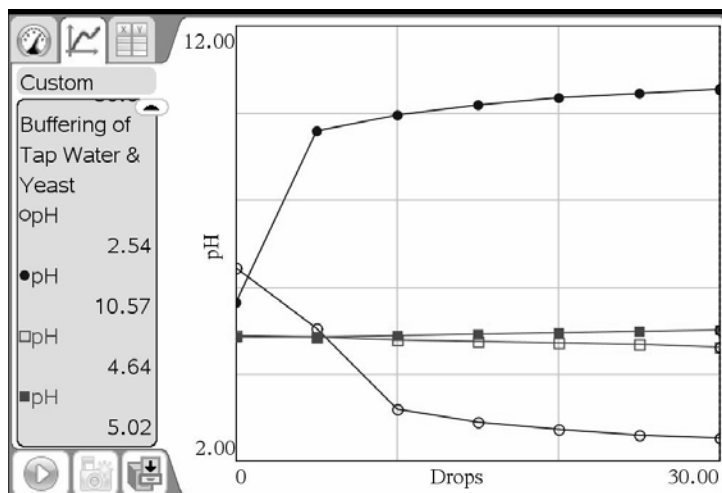
Data for tap water (acid - ○ and base - ●) and Yeast (acid - □ and base - ■). Notice that Tap water has virtually no buffering while yeast shows significant buffering.
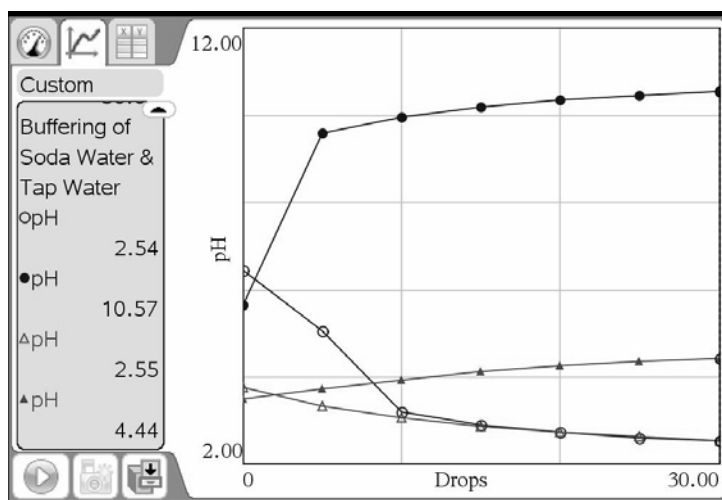
Data for tap water (acid - ○ and base - ●) and soda water (acid - △ and base - ▲).

Classification of Materials		
Organisms or tissues	Biological chemicals	Non-biological chemicals
Yeast	Aspirin	Soda Water
	Starch	Tap Water
	Vitamin B2	Salt Water
	Vitamin C	

Table 2				Table 3		
Material	Initial pH	Rank		Material	Total Buffer Range	Rank
Aspirin	2.71	most acidic		Tap Water	8.82	Greatest change
Vitamin C	2.84	2		Salt Water	8.49	2
Soda Water	3.76	3		Cornstarch	7.29	3
Salt Water	4.13	4		Vitamin B2	5.89	4
Vitamin B2	4.72	5		Soda Water	2.13	5
Cornstarch	4.87	6		Vitamin C	0.49	6
Yeast	4.91	7		Yeast	0.43	7
Tap Water	6.46	least acidic		Aspirin	0.38	Least change

ANSWERS TO QUESTIONS

1. The values should be the same, since the same solution is in each beaker.

2. The actual results may vary. Possible reasons include:

    - The beakers were not cleaned equally well by the cooperative groups.
    - The probes differed slightly in their response.

3. The effect HCl had on each solution was to decrease its pH. Not all materials responded equally, and several did not respond much at all. These were better buffers.

4. The effect NaOH had on each solution was to increase its pH. Not all materials responded equally, and several did not respond much at all. These were better buffers.

5. Tap water acted as a control. The similarities and differences among the graphs can be noted more easily when each is compared to a single substance, such as water.

6. Non-biological chemicals, such as water and salt, reacted most dramatically to the addition of acid or base. Biologically complex materials and non-biological buffers resisted pH changes most. The non-biological materials were most divergent in their behavior. This is especially true if any of the graphs have a different scaling than the others.

    The order in which material reacted most dramatically to the addition of acid or base is: tap water, salt water, cornstarch, vitamin B2, soda water, vitamin C, yeast and aspirin. The ranking by complexity is similar—water (tap and salt) is the simplest material, followed by a carbohydrate. The soda water has a natural buffer, the bicarbonate ion. Yeast is cellular material, thus more complex than any of the above. Finally, aspirin is a simple chemical with great buffering capacity.

    As a general rule, simple chemicals may or may not be good buffers, depending upon their make-up. Complex biological materials are almost always better buffers than simple ones, since there are usually a greater number of chemicals in cellular matter that serve as buffers.

7. Answers may vary. See Table 1 for sample values. Of these data, aspirin is the best buffer and water is the poorest buffer.

Diffusion through Membranes

Diffusion is a process that allows ions or molecules to move from where they are more concentrated to where they are less concentrated. This process accounts for the movement of many small molecules across a cell membrane. Diffusion allows cells to acquire food and exchange waste products. Oxygen, for instance, might diffuse in pond water for use by fish and other aquatic animals. When animals use oxygen, more oxygen will diffuse to replace it from the neighboring environment. Waste products released by aquatic animals are diluted by diffusion and dispersed throughout the pond.

It is important to consider how the rate of diffusion of particles may be affected or altered.

- Diffusion may be affected by how steep the concentration gradient is. The direction that a diffusing molecule or ion might travel is random. While the particles are diffusing, is there a net movement from where they are concentrated to where they are less concentrated?

- Diffusion may be affected by other different, neighboring particles. For instance, if oxygen diffuses towards a single-celled pond organism at a certain rate, will that rate be altered by the presence of another type of molecule? Would the presence of other molecules block or enhance the diffusion of a molecule? Would the molecule's rate be independent of particles that do not alter the concentration gradient?

One way to measure the rate of diffusion of ions is to monitor their concentration in solution over a period of time. Since ions are electrically charged, water solutions containing ions will conduct electricity. A Conductivity Probe measures the concentration of ions in a solution, but not the concentration of electrically neutral molecules. Salts, such as sodium chloride, produce ions when they dissolve in water. If you place a salt solution inside a selectively permeable membrane such as dialysis tubing, the salt ions can diffuse out of the tubing and into the surrounding water.

OBJECTIVES

In this experiment, you will

- Use a Conductivity Probe to measure the ionic concentration of various solutions.
- Study the effect of temperature on diffusion.
- Study the effect of concentration gradients on the rate of diffusion.
- Determine if the diffusion rate for a molecule is affected by the presence of a second molecule.

MATERIALS

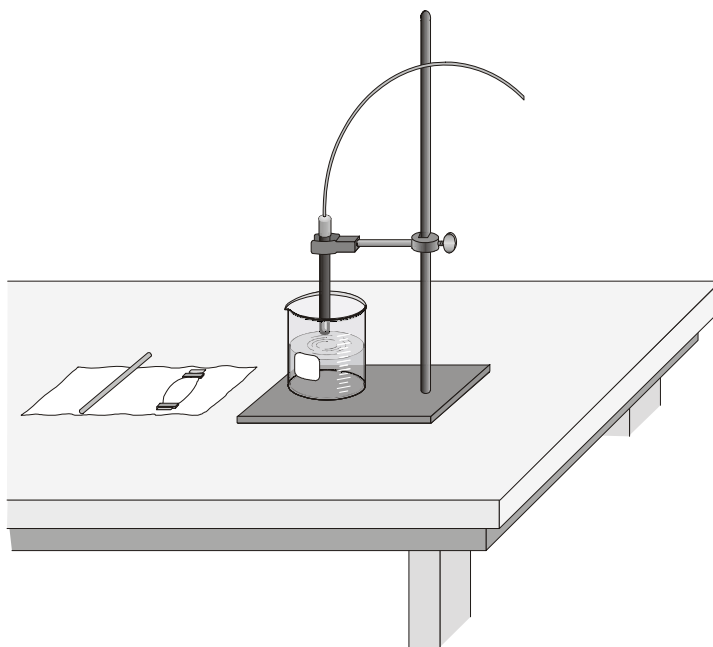|	
TI-Nspire handheld **or**	ring stand and utility clamp
computer and TI-Nspire software	dialysis tubing, 2.5 cm × 12 cm
data-collection interface	dropper pipet or Beral pipet
Vernier Conductivity Probe	scissors
three 18 × 150 mm test tubes with rack	stirring rod
1%, 5%, and 10% salt water	5% sucrose (table sugar) solution
400 mL beaker	dental floss or clamp

Figure 1

PROCEDURE

1. Obtain and wear goggles.

2. Set up the utility clamp and ring stand as shown in Figure 1.

3. Set the Conductivity Probe to the 0–2000 µS/cm range. Connect the Conductivity Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

4. Choose New Experiment from the ![icon] Experiment menu. Choose Collection Setup from the ![icon] Experiment menu. Enter **0.2** as the rate (samples/second) and **60** as the experiment duration in seconds. The number of points collected should be 13. Select OK.

Part I Concentration gradients

5. Test whether different concentration gradients affect the rate of diffusion. To do this, three solutions of differing salt concentrations (1%, 5%, and 10%) will be placed in distilled water. Each salt solution will be placed in a dialysis tube and allowed to diffuse into the surrounding water. When salt diffuses, the conductivity of the water in the beaker will increase.

6. In Table 1, predict what you believe will happen in this set of experiments. How will the rate of diffusion change when a 10% salt solution is placed in contact with pure water compared to when a 1% salt solution is placed in contact with pure water?

7. Prepare the dialysis tubing. Obtain a wet dialysis tube and a dialysis tube clamp or a short length of dental floss. Using the clamp or floss, tie one end of the tube closed about 1 cm from the end, as in shown Figure 2.

8. Place a 1% salt solution into a section of dialysis tubing.

    a. Obtain about 15 mL of a 1% salt water solution in a test tube.

    b. Using a funnel or Beral pipet, transfer about 10 mL of the 1% salt water into the dialysis tube, as in Figure 2. **Note:** To open the tube, you may need to rub the tubing between your fingers.

    c. Tie off the top of the dialysis tube with a clamp or a new length of dental floss. Try not to allow any air into the dialysis tube. The tube should be very firm after it is tied or clamped. Trim off any excess dental floss extending more than 1 cm from either knot.

    d. Wash the outside of the tubing with tap water thoroughly, so that there is no salt water adhering to the tubing.

Figure 2

9. Place 300 mL of distilled or deionized water into a 400 mL beaker. Secure the Conductivity Probe with the utility clamp in the water filled beaker as shown in Figure 1.

10. Place the dialysis tube into the water. Be sure the tubing is submerged completely under the water. **Important:** Position the Conductivity Probe and dialysis tubing the same distance apart in each trial.

11. After stirring the solution for 15 seconds, start data collection (⯈). Stir the solution slowly and continuously throughout the one-minute data collection period.

12. Data collection will stop after 60 seconds. Analyze the graph to determine the rate of diffusion for the curve of conductivity *vs.* time:

    a. Examine the graph and identify the most linear region and select the data points in the most linear region.

    b. Choose Curve Fit ▶ Linear from the ☒ Analyze menu.

    c. Record the slope, *m*, as the rate of diffusion in (μS/cm/s) in Table 2.

13. Remove one of the clamps. If the dialysis tubing is tied off with floss, use a pair of scissors and carefully cut one of the dental floss knots and discard the floss. If you accidentally make a cut in the tubing, replace it.

14. Empty all of the liquid out of the dialysis tube. Squeeze the excess liquid out with your fingers.

15. Rinse the Conductivity Probe with distilled water.

16. Click the Store Latest Data Set button (▤) to save data from the first run. Obtain 15 mL of a 5% salt solution in a test tube. Repeat Steps 8–15, substituting this 5% salt solution for the 1% solution.

17. Click the Store Latest Data Set button (▤) to save data from the second run. Obtain 15 mL of a 10% salt solution in a test tube. Repeat Steps 8–15, substituting this 10% salt solution for the 1% solution.
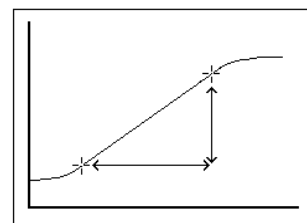
18. Graph all three runs of conductivity data on a single graph.

   a. Click **run3** and select All. All three runs will now be displayed on the same graph.
   b. Examine the graph closely and make a conclusion. Record your conclusion in Table 1.

19. (optional) Print a copy of your graph as directed by your instructor.

Part II Effect of other molecules

In this set of experiments you will measure the rate of diffusion of salt while it is in the presence of a non-conducting molecule. Since sugar does not form ions in solution, it should not conduct electricity. Therefore, sugar will be added to the water to determine whether it interferes with the diffusion of salt.

20. In Table 1, predict what you believe will happen in this set of experiments. Will the non-conducting sugar in the water block or reduce the rate of diffusion of salt? Explain your prediction.

Test to determine if water or a sugar solution conducts electricity.

21. Place about 100 mL of distilled or deionized water in a clean 400 mL beaker.

22. Test the conductivity of the water by placing a clean Conductivity Probe into it.

23. Click the Meter View tab (⏱). Record the conductivity value in Table 3.

24. Obtain 300 mL of a 5% sugar solution in a clean 400 mL beaker.

25. Test the conductivity of the 5% sugar solution by placing a clean Conductivity Probe into the beaker. Record the conductivity value in Table 3.

Test if 5% sugar interferes with the diffusion of a 5% salt solution.

26. Click the Store Latest Data Set button (📇). Repeat Steps 7–15 with the following changes:

   a. Substitute a 5% salt solution for the 1% solution in Step 8.
   b. Use 300 mL of 5% sugar water, prepared in Step 24, in place of the water in Step 9.
   c. In Step 12c, record the slope, *m*, as the rate of diffusion in (μS/cm/s) in Table 4.

27. Graph the two 5% salt solution runs, one in water and one in a sugar solution, on a single graph.

   a. Click **run4** and select the More option. Select run2 and run4, then select OK. Both runs will be displayed on the same graph.
   b. Examine the graph closely and make a conclusion. Record your conclusion in Table 1.

DATA

Table 1		
	Prediction	Conclusion
Part I		
Part II		

Part I

Table 2 – Summary of Data	
Salt concentration (%)	Rate of diffusion (μS/cm/s)
1	
5	
10	

Part II

Table 3	
Solution	Conductivity (μS/cm)
Distilled water	
Sugar water	

Table 4 – Summary of Data	
Solution	Rate of diffusion (μS/cm/s)
5% salt	
5% salt / 5% sugar	

QUESTIONS

1. What conclusion can you draw from the data in Table 2?

2. How did your conclusion compare to your prediction for Part I? Can you account for any differences?

3. If the rates in any of the three experiments varied in Part I, calculate how much faster each rate was compared to that for the 1% salt solution. For instance, if the rate of the 1% solution was 1 μS/cm/s and the rate of the 10% solution was 5 μS/cm/s, then the rate of diffusion for the 10% solution would be (5/1) five times the rate of the 1% salt solution.

4. Compare the conductivity of pure water with a sugar solution. How do you account for this?

5. What conclusion can you draw from the data in Tables 3 and 4?

EXTENSIONS

1. Make a plot of the rate of diffusion *vs.* the salt concentration. Using your plot, estimate the rate of diffusion of a 3% salt solution.

2. If the results of the experiments in Part I can be extrapolated to diffusion in living systems, how would a single-celled organism respond in an oxygen rich pond compared to an oxygen-poor pond? Explain.

3. If waste products of an aquatic single-celled organism were released into a pond, how would that affect the organism's ability to obtain oxygen from the pond water? Explain how your data from Part II supports your answer.

4. Design an experiment to determine the effect of temperature on the diffusion of salt. Perform the experiment you designed.

5. Ectotherms are organisms whose body temperatures vary with the surrounding environment. On the basis of your data from Extension Question 4, how do you expect the oxygen consumption of ectotherms to vary as the temperature varies? Explain.

Diffusion through Membranes

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. If the water in your area is very soft, you may want to use tap water instead of distilled water. Test to see if the conductivity of the tap water is less than about 50 mg/L salt.

3. Provide each group with pre-cut, hydrated dialysis tubing. The tubing must be soaked in water for at least ten minutes prior to use. The tubing should be soft and flexible.

4. Use dialysis tubing clamps if at all possible, as this will speed things up greatly. If desired, use dental floss or string to tie off the dialysis tubing. The floss works exceptionally well. You may want to show students how to tie off the dialysis tubes.

5. Have students check their dialysis tubes for leakage. This should be done before each experiment. Leaky tubes should be replaced.

6. Any sugar may be used in Part II. Table sugar is inexpensive and readily available.

7. To prepare 5% sugar solution, add 50 grams of sugar to make one liter of solution (300 mL per group is needed).

8. To prepare 1% salt solution, add 10 grams of NaCl to make one liter of solution (15 mL per group is needed).

9. To prepare 5% salt solution, add 50 grams of NaCl to make one liter of solution (30 mL per group is needed as they will use the 5% salt solution twice).

10. To prepare 10% salt solution, add 100 grams of NaCl to make one liter of solution (15 mL per group is needed).

11. The 0–2000μS/cm range works well for this experiment. The ionic concentration is approximately proportional to the conductivity of the solution.

SAMPLE RESULTS

Part I
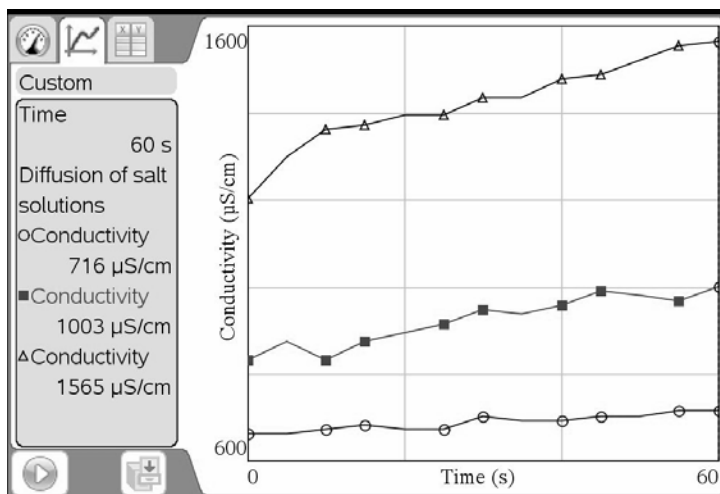
Typical graph for Part I –1% salt (○), 5% salt (■) and 10% salt (△).

Table 2	
Salt concentration (%)	Rate of diffusion (µS/cm/s)
1	0.9
5	2.8
10	4.5

Part II
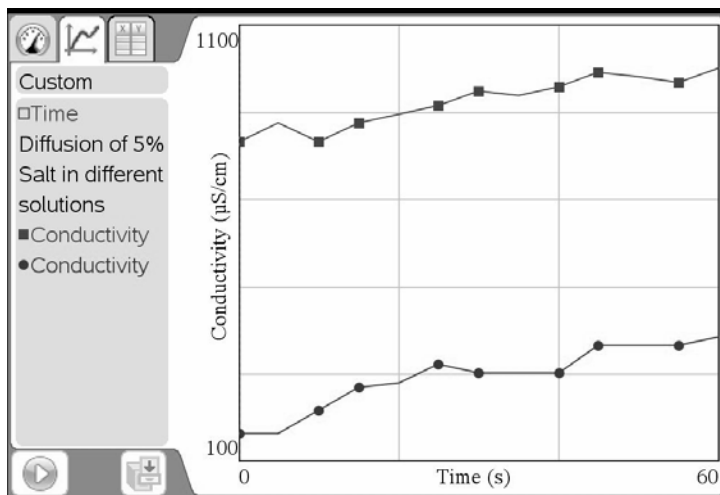
Typical graph for Part II–5% salt solution diffused into distilled water (■) and 5% sugar solution (●).

Table 3	
Solution	Conductivity (µS/cm)
Distilled water	34
Sugar water	36

| Table 4: Summary of Data	
Solution	Rate of diffusion (µS/cm/s)
5% salt	2.8
5% salt / 5% sugar	2.8

ANSWERS TO QUESTIONS

1. Rate of diffusion should increase with increasing salt concentration.

2. The rate of diffusion should increase as the concentration gradient becomes steeper. The rate of the 10% salt solution should be the greatest and the rate of the 1% salt solution should be the lowest of the three.

3. The rate of the 10% salt solution should be approximately ten times that of the 1% solution, while the rate of the 5% salt solution should be five times that of the 1% solution.

4. The conductivity should be the same, as neither will conduct appreciably. Neither molecule is electrically charged.

5. Student answers will vary. The rates of diffusion should be the same.

ANSWERS TO EXTENSIONS

1. Based on the sample data, this value is about 1.8 µS/cm/s.

2. Based on the results from the experiment in part 1, the concentration gradient between the organism and the external environment would be the determinant in the amount of oxygen diffusing across its membrane. The organism would tend to migrate to a position in the pond where the dissolved oxygen concentration was in line with its requirements for oxygen and other essential metabolic needs.

3. In considering the results of part 2 and basing these on how a single celled organism would respond to its own waste, an oxygen concentration gradient will still exist favoring the movement of oxygen into the organism. As the concentration of oxygen in the external environment surrounding the organism declines due to the release of waste, diffusion of dissolved oxygen into the organism too will decline.

4. Answers will vary.

5. Since dissolved oxygen is more plentiful or at a greater concentration at lower liquid temperatures, ectotherms would be more active at lower temperatures.

Conducting Solutions

In this experiment, you will study the electrical conductivity of water and various water solutions. A solution can contain molecules, ions, or both. Some substances, such as sucrose ($C_{12}H_{22}O_{11}$) and glucose ($C_6H_{12}O_6$), dissolve to give a solution containing mostly molecules. An equation representing the dissolving of sucrose (table sugar) in water is:

$$C_{12}H_{22}O_{11}(s) \longleftrightarrow C_{12}H_{22}O_{11}(aq)$$
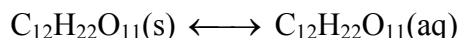
where (s) refers to a solid substance and (aq) refers to a substance dissolved in water. Other substances, such as calcium chloride ($CaCl_2$), dissolve in water to produce a solution containing mostly ions. An equation is:

$$CaCl_2(s) \longleftrightarrow Ca^{2+}(aq) + 2\ Cl^-(aq)$$
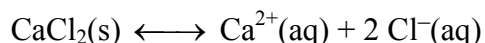
Calcium ions are necessary for muscle contraction, mitochondrial activity, bone formation, and many other metabolic processes. Organisms may obtain minerals such as calcium from their water supply, since ions dissolve in water.

You will determine conductivity of the solutions using a Vernier Conductivity Probe. In this experiment microsiemens per centimeter, μS/cm, is the unit of conductivity.

OBJECTIVES

In this experiment, you will

- Write equations for the dissolving of substances in water.
- Use a Conductivity Probe to test the electrical conductivity of solutions.
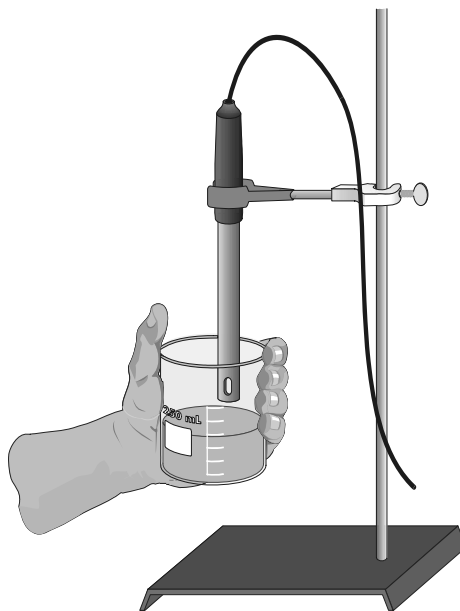- Determine whether molecules or ions are responsible for electrical conductivity of solutions.

Figure 1

MATERIALS

TI-Nspire handheld **or**
  computer and TI-Nspire software
data-collection interface
Vernier Conductivity Probe
sodium chloride, NaCl, solution
calcium chloride, CaCl₂, solution
aluminum chloride, AlCl₃, solution
ring stand

utility clamp
ethanol, C_2H_6O, solution
sucrose, $C_{12}H_{22}O_{11}$, solution
glucose, $C_6H_{12}O_6$, solution
stream or lake water
ocean water (optional)
various foods in solution
distilled water

PRE-LAB QUESTIONS

Many of the materials you will be using today are found in common household items. A list of common names or uses can be found below:

Sodium chloride, NaCl	Common household salt
Calcium chloride, $CaCl_2$	Used to pickle cucumbers, or to help concrete cure in cold weather
Acetic acid, CH_3COOH	Vinegar
Ethanol, C_2H_6O	Found in gasoline or in alcoholic beverages. Usually obtained from yeast fermentation
Fructose, $C_6H_{12}O_6$	Fruit sugar
Sucrose, $C_{12}H_{22}O_{11}$	Table sugar, beet or cane sugar
Glucose, $C_6H_{12}O_6$	Corn or blood sugar

1. An equation representing the dissolving of sucrose in water is:

$$C_{12}H_{22}O_{11}(s) \longleftrightarrow C_{12}H_{22}O_{11}(aq)$$
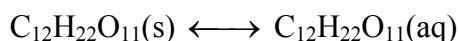
   Like solid sucrose, the substances glucose, $C_6H_{12}O_6(s)$, and ethanol, $C_2H_6O(l)$, dissolve in water to yield solutions containing mostly molecules. Write equations showing the dissolving of these two substances in water in Table 1.

2. An equation showing the dissolving of CaCl₂ in water is:

$$CaCl_2(s) \longleftrightarrow Ca^{2+}(aq) + 2\ Cl^-(aq)$$
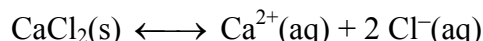
   Like CaCl₂, the substances NaCl and AlCl₃ dissolve in water to give solutions containing mostly ions. Write equations in Table 2 showing these two substances dissolving in water.

PROCEDURE

1. Obtain and wear goggles. Secure the Conductivity Probe with the ring stand and utility clamp, as shown in Figure 1.

2. Set the selector switch on the side of the Conductivity Probe to the 0–20000 µS/cm range. Connect the Conductivity Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Set up Events with Entry data collection.

   a. Choose New Experiment from the 🎛 Experiment menu.
   b. Choose Collection Mode ► Events with Entry from the 🎛 Experiment menu.
   c. Enter **Chemical** as the Name and leave the Units field blank.
   d. Select the Average over 10 s option. This will collect 10 seconds of data and report the average reading.
   e. Select OK.

4. Start data collection (▶).

5. Measure the conductivity of each solution listed in the data table. You can do the tests in any sequence.

   a. Place the Conductivity Probe into a small sample of the test solution. The hole near the probe end must be completely submerged in the solution.
   b. Once the conductivity reading has stabilized, click the Keep button (🖫). A countdown dialog will show the 10 second data collection.
   c. Enter the name of the solution tested, and select OK.
   d. To avoid contaminating the solutions, rinse the probe with distilled water after each test. Blot the outside of the probe end dry with a tissue or paper towel. It is not necessary to dry the *inside* of the hole near the probe end.

6. Repeat Step 5 for all of your solutions.

7. Stop data collection (⬛).

8. Click the Table View tab (▦) to switch to Table View. Enter your results in Table 3

DATA

Table 1	
$C_6H_{12}O_6(s)$	$C_2H_6O(l)$

Table 2	
$NaCl(s)$	$AlCl_3(s)$

DATA (CONT.)

Table 3		
Solution	Material	Conductivity (μS/cm)
1	Distilled water	
2	Sodium chloride, NaCl	
3	Calcium chloride, $CaCl_2$	
4	Aluminum chloride, $AlCl_3$	
5	Ethanol, C_2H_6O	
6	Sucrose, $C_{12}H_{22}O_{11}$	
7	Glucose, $C_6H_{12}O_6$	
8	Tap water	
9	Stream water	
10	Ocean water	
11		
12		

QUESTIONS

1. Which solutions conduct electricity best, those containing mostly ions or those containing mostly molecules?

2. Does distilled water conduct electricity well? Explain.

3. Does tap water conduct electricity? Account for this observation.

4. Consider the conductivity readings for the NaCl, $CaCl_2$, and $AlCl_3$ solutions. What trend do you observe? Account for this trend.

5. How does the conductivity of ocean water compare to pond or stream water? How can you account for this?

6. Which foods in solution conducted electricity well? How can you account for this?

7. Suggest three other substances whose water solutions would conduct electricity well. Explain how you decided on your choices.

EXTENSION

1. Test your predictions for Question 7 above. Click the Store Latest Data Set button (⬚) before starting data collection.

TEACHER INFORMATION

Conducting Solutions

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. Two or more sets of the solutions can be made available in small beakers or jars.

3. The solutions can be prepared (using distilled water) as follows:

   0.05 M NaCl (2.93 g/liter)   0.05 M sucrose (17.1 g/liter)
   0.05 M AlC1$_3$ (6.7 g/liter)   0.05 M CaCl$_2$ (5.55 g/liter)
   0.05 M ethanol (2.3 g or 2.9 mL/liter)   0.05 M glucose (9.0 g/liter)

4. A variety of food suspensions may be used. Both plant and animal foods might be considered.

5. To prepare food suspensions, cut the food into small pieces and blend for 5 to 10 seconds, or until finely chopped. Strain the food through cheesecloth and collect the resulting filtrate for testing. This way, students will be testing the resulting dilute solution that will contain varying amounts of ions and molecules. Avoid foods that are high in oil or fat content, as they may leave residues on the electrodes of the Conductivity Probe (see the probe user's guide that was shipped with the probe for further information).

6. Several sources of water can be tested, including stream, tap, ocean, and lake water. Students may want to bring samples in from home to test.

7. The calibration that is stored within the data-collection software will work fine for a comparison of different solutions. For more accurate conductivity readings, you (or your students) can do a 2-point calibration for each Conductivity Probe using air (0 conductivity value) and the calibration solution that came with the Conductivity Probe (1000 µS/cm value).

8. If you make measurements of ocean water, you will need to dilute samples to 1/4 of their original concentration by adding 100 mL of the salt-water sample to 300 mL of distilled water. This diluted sample can then be measured using the Conductivity Probe at the high-range setting. Multiply the conductivity reading by 4 to obtain the actual conductivity.

SAMPLE RESULTS

| Table 1		
Solution	Material	Conductivity (µS/cm)
1	Distilled water	0
2	Sodium chloride, NaCl	5214
3	Calcium chloride, $CaCl_2$	9362
4	Aluminum chloride, $AlCl_3$	11707
5	Ethanol, C_2H_6O	0
6	Sucrose, $C_{12}H_{22}O_{11}$	0
7	Glucose, $C_6H_{12}O_6$	0
8	Tap water	varies (20 – 1000)

ANSWERS TO QUESTIONS

1. The solutions containing mostly ions conduct best.

2. Distilled water does not conduct well because it contains few ions.

3. Tap water does conduct electricity. It contains Ca^{2+}, Mg^{2+}, Fe^{3+}, CO_3^{-2}, HCO_3^{-}, and other ions that dissolve into water as it flows through and over soil and rocks.

4. The conductivity increases from NaCl through $AlC1_3$ because of the increasing number of ions. A formula unit of NaCl contributes two ions, $CaCl_2$ three ions, and $AlCl_3$ four total ions.

5. Ocean water conducts much more than pond water. It has many more ions in it than pond water.

6. Answers may vary.

7. Any soluble ionic solid, and some soluble molecular substances, will give a conducting solution. Some common ionic solids that give conducting solutions include

   - The "no-salt" substitute, potassium chloride (KCl).
   - Salt peter, sodium nitrate ($NaNO_3$).
   - Ammonium chloride (NH_4Cl).
   - Epsom salts, magnesium sulfate ($MgSO_4$).
   - Drano®, sodium hydroxide (NaOH).
   - Muriatic acid, hydrochloric acid (HCl), is an example of a conducting solution made by dissolving a molecular substance.

Enzyme Action:
Testing Catalase Activity

Many organisms can decompose hydrogen peroxide (H_2O_2) enzymatically. Enzymes are globular proteins, responsible for most of the chemical activities of living organisms. They act as *catalysts,* substances that speed up chemical reactions without being destroyed or altered during the process. Enzymes are extremely efficient and may be used over and over again. One enzyme may catalyze thousands of reactions every second. Both the temperature and the pH at which enzymes function are extremely important. Most organisms have a preferred temperature range in which they survive, and their enzymes most likely function best within that temperature range. If the environment of the enzyme is too acidic or too basic, the enzyme may irreversibly *denature*, or unravel, until it no longer has the shape necessary for proper functioning.

H_2O_2 is toxic to most living organisms. Many organisms are capable of enzymatically destroying the H_2O_2 before it can do much damage. H_2O_2 can be converted to oxygen and water, as follows:

$$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$$
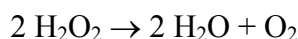
Although this reaction occurs spontaneously, the enzyme catalase increases the rate considerably. Catalase is found in most living organisms. A great deal can be learned about enzymes by studying the rates of enzyme-catalyzed reactions.

In this experiment, you will measure the rate of enzyme activity under various conditions, such as different enzyme concentrations, pH values, and temperatures. It is possible to measure the pressure of oxygen gas formed as H_2O_2 is destroyed. If a plot is made, it may appear similar to the graph shown.
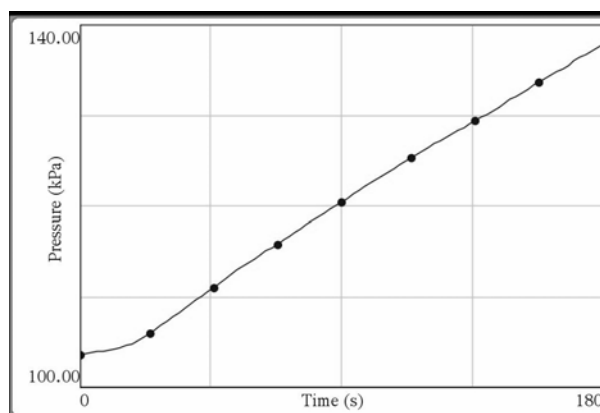
At the start of the reaction, there is no product, and the pressure is the same as the atmospheric pressure. After a short time, oxygen accumulates at a rather constant rate. The slope of the curve at this initial time is constant and is called the *initial rate*. As the peroxide is destroyed, less of it is available to react and the O_2 is produced at lower rates. When no more peroxide is left, O_2 is no longer produced.
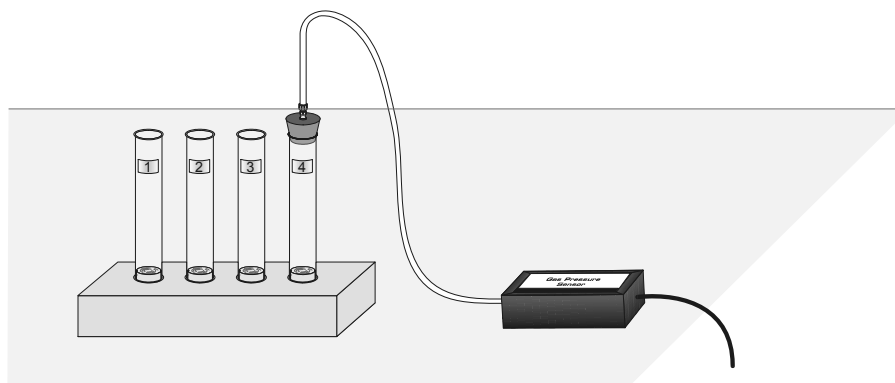
Figure 1

OBJECTIVES

In this experiment you will

- Use a Gas Pressure Sensor to measure the production of oxygen gas as hydrogen peroxide is destroyed by the enzyme catalase or peroxidase at various enzyme concentrations.
- Measure and compare the initial rates of reaction for this enzyme when different concentrations of enzyme react with H_2O_2.
- Measure the production of oxygen gas as hydrogen peroxide is destroyed by the enzyme catalase or peroxidase at various temperatures.
- Measure and compare the initial rates of reaction for the enzyme at each temperature.
- Measure the production of oxygen gas as hydrogen peroxide is destroyed by the enzyme catalase or peroxidase at various pH values.
- Measure and compare the initial rates of reaction for the enzyme at each pH value.

MATERIALS

TI-Nspire handheld **or**	600 mL beaker
computer and TI-Nspire software	enzyme suspension
data-collection interface	four 18 × 150 mm test tubes
Vernier Gas Pressure Sensor	ice
rubber-stopper assembly	pH buffers
10 mL graduated cylinder	test tube rack
250 mL beaker of water	thermometer
3% H_2O_2	four dropper pipettes

PROCEDURE

1. Obtain and wear goggles.

2. Connect the plastic tubing to the valve on the Gas Pressure Sensor.

3. Connect the Gas Pressure Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

4. Choose New Experiment from the ⚏ Experiment menu. Choose Collection Setup from the ⚏ Experiment menu. Enter **0.5** as the rate (samples/second) and **180** as the experiment duration in seconds. The number of points collected should be 91. Select OK.

Part I Testing the Effect of Enzyme Concentration

5. Place four test tubes in a rack and label them 1, 2, 3, and 4.

6. Add 3 mL of 3.0% H_2O_2 and 3 mL of water to each test tube.

7. Use a clean dropper pipette to add 1 drop of enzyme suspension to test tube 1. **Note:** Be sure not to let the enzyme fall against the side of the test tube.

8. Stopper the test tube and gently swirl to thoroughly mix the contents. The reaction should begin. The next step should be completed as rapidly as possible.

9. Connect the free-end of the plastic tubing to the connector in the rubber stopper as shown in Figure 2. Start data collection (⏺).

10. Monitor the pressure readings displayed on the screen. If the pressure exceeds 130 kPa, the pressure inside the tube will be too great and the rubber stopper is likely to pop off. Disconnect the plastic tubing from the Gas Pressure Sensor if the pressure exceeds 130 kPa.

11. When data collection has finished, an auto-scaled graph of pressure *vs*. time will be displayed. Disconnect the plastic tubing connector from the rubber stopper. Remove the rubber stopper from the test tube and discard the contents in a waste beaker.

12. Click any data point and use ▶ and ◀ to examine the data pairs on the displayed graph.

Figure 2

13. Determine the rate of enzyme activity for the curve of pressure *vs*. time. To help make comparisons between experimental runs, choose your data points at the same time values.

   a. Examine the graph and identify the most linear region.
   b. Select the linear region of the data.
   c. Choose Curve Fit ▶Linear from the 📊 Analyze menu. The linear-regression statistics for these two data columns are displayed for the equation in the form

$$y = mx + b$$

   d. Enter the slope, *m*, as the reaction rate in Table 1.

14. Find the rate of enzyme activity for test tubes 2, 3, and 4.

   a. Click the Store Latest Data Set button (📇) to save the first run. Add 2 drops of the enzyme solution to test tube 2. Repeat Steps 8–13.
   b. Click the Store Latest Data Set button (📇) to save the second run. Add 3 drops of the enzyme solution to test tube 3. Repeat Steps 8–13.
   c. Click the Store Latest Data Set button (📇) to save the third run. Add 4 drops of the enzyme solution to test tube 4. Repeat Steps 8–13.

15. Graph all four runs of data on a single graph.

   a. Click **run4**, and select All. All four runs will now be displayed on the same graph axes.
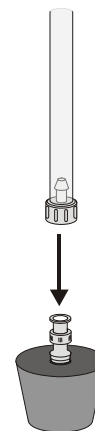   b. Use the displayed graph and the data in Table 1 to answer the questions for Part I.

Part II Testing the Effect of Temperature

16. Insert a new **problem** in the document. Insert a new DataQuest App into problem 2. Choose Collection Setup from the ⚙ Experiment menu. Enter **0.5** as the rate (samples/second) and **180** as the experiment duration in seconds. The number of points collected should be 91. Select OK.

17. Place four clean test tubes in a rack and label them T 0–5, T 20–25, T 30–35, and T 50–55.

18. Add 3 mL of 3.0% H_2O_2 and 3 mL of water to each test tube.

19. Measure the enzyme activity at 0–5°C.

   a. Prepare a water bath at a temperature in the range of 0–5°C by placing ice and water in a 600 mL beaker. Using a thermometer check that the temperature remains in this range throughout this test. See Figure 3.
   b. Place test tube T 0–5 in the cold water bath for 5 minutes so that it reaches a temperature in the 0–5°C range. Record the actual temperature of the test-tube contents in Table 2.
   c. Add 2 drops of the enzyme solution to test tube T 0–5. Repeat Steps 8–13, except this time record the reaction rate in Table 2.

   Figure 3

20. Measure the enzyme activity at 30–35°C.

   a. Prepare a water bath at a temperature in the range of 30–35°C by placing warm water in a 600 mL beaker. Using a thermometer, check that the temperature remains in this range throughout this test.
   b. Place test tube T 30–35 in the warm water bath for 5 minutes so that it reaches a temperature in the 30–35°C range. Record the actual temperature of the test-tube contents in the blank in Table 2.
   c. Add 2 drops of the enzyme solution to test tube T 30–35.
   d. Click the Store Latest Data Set button (🖳) to save the first run. Repeat Steps 8–13, again recording the reaction rate in Table 2.

21. Measure the enzyme activity at 50–55°C.

   a. Prepare a water bath at a temperature in the range of 50–55°C by placing hot water in a 600 mL beaker (hot tap water will probably work fine). Check that the temperature remains in this range throughout this test.
   b. Place test tube T 50–55 in the warm water bath until the temperature of the mixture reaches a temperature in the 50–55°C range. Record the actual temperature of the test-tube contents in the blank in Table 2.
   c. Add 2 drops of the enzyme solution to test tube T 50–55.
   d. Click the Store Latest Data Set button (🖳) to save the second run. Repeat Steps 8–13, again recording the reaction rate in Table 2.

22. Measure the enzyme activity at 20–25°C (room temperature).

   a. Record the temperature of test tube T 20–25 in Table 2.
   b. In the tube labeled T 20–25, add 2 drops of the enzyme solution.
   c. Click the Store Latest Data Set button (🖳) to save the third run. Repeat Steps 8–13, again recording the reaction rate in Table 2.

23. Graph all four runs of data on a single graph.

    a. Click **run4**, and select All. All four runs will now be displayed on the same graph axes.
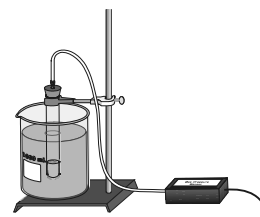   b. Use the displayed graph and the data in Table 2 to answer the questions for Part II.

Part III Testing the Effect of pH

24. Insert a new **problem** in the document. Insert a new DataQuest App into problem 3. Choose New Experiment from the ⚗ Experiment menu. Choose Collection Setup from the ⚗ Experiment menu. Enter **0.5** as the rate (samples/second) and **180** as the experiment duration in seconds. The number of points collected should be 91. Select OK.

25. Place three clean test tubes in a rack and label them pH 4, pH 7, and pH 10.

26. Add 3 mL of 3% H_2O_2 and 3 mL of the appropriate pH buffer to each labeled test tube label.

27. In the tube labeled pH 4, add 2 drops of the enzyme solution. Repeat Steps 8–13, except this time record the reaction rate in Table 3.

28. Click the Store Latest Data Set button (▣) to save the first run. In the tube labeled pH 7, add 2 drops of the enzyme solution. Repeat Steps 8–13, again recording the reaction rate in Table 3.

29. Click the Store Latest Data Set button (▣) to save the second run. In the tube labeled pH 10, add 2 drops of the enzyme solution. Repeat Steps 8–13, again recording the reaction rate in Table 3.

30. Graph all three runs of data on a single graph.

    a. Click **run3** and select All. All three runs will now be displayed on the same graph axes.
    b. Use the displayed graph and the data in Table 3 to answer the questions for Part III.

DATA

Table 1		
Label	Rate (kPa/s)	Reaction Rate (kPa/min)
1 drop		
2 drops		
3 drops		
4 drops		

DATA (CONT.)

Table 2			
Label	Actual Temperature (°C)	Rate (kPa/s)	Reaction Rate (kPa/min)
0–5°C			
20–25°C			
30–35°C			
50–55°C			

Table 3		
Label	Rate (kPa/s)	Reaction Rate (kPa/min)
pH 4		
pH 7		
pH 10		

PROCESSING THE DATA

1. Convert your reaction rates from kPa/s to kPa/min. Record the rates in the appropriate tables.

2. Create summary graphs for the data in each part.

   a. Insert a new problem in the document, then Insert a new DataQuest App into problem 4. Click on the Table View tab (⊞) to view the Table.

   b. Double click on the *X* column to access the column options. Enter **Test Tube** for the column name. Change the Display Precision to 0 decimal places. Select OK.

   c. Double click on the *Y* column to access the column options. Enter **Rate** for the column name. Enter **kPa/min** as the units. Select OK.

   d. Using the data from Table 1, enter the values in the DataQuest Table. Use the number of drops in the Test Tube column.

   e. Choose New Data Set from the ⊞ Data menu. Using the data from Table 2, enter the values in the DataQuest Table. Use the actual temperature in the Test Tube column.

   f. Choose New Data Set from the ⊞ Data menu. Using the data from Table 3, enter the values in the DataQuest Table. Use the pH value in the Test Tube column.

   g. For each data set, double click the data set name and change the name to something more meaningful (for example, change run1 to Concentration).

   h. Click on the Graph View tab (📈) to view the summary graphs. To view the different summary graphs, click on the run indicator and select the desired run.

QUESTIONS

Part I Effect of Enzyme Concentration

1. How does changing the concentration of enzyme affect the rate of decomposition of H_2O_2?

2. What do you think will happen to the rate of reaction if the concentration of enzyme is increased to five drops? Predict what the rate would be for 5 drops.

Part II Effect of Temperature

3. At what temperature is the rate of enzyme activity the highest? Lowest? Explain.

4. How does changing the temperature affect the rate of enzyme activity? Does this follow a pattern you anticipated?

5. Why might the enzyme activity decrease at very high temperatures?

Part III Effect of pH

6. At what pH is the rate of enzyme activity the highest? Lowest?

7. How does changing the pH affect the rate of enzyme activity? Does this follow a pattern you anticipated?

EXTENSIONS

1. Different organisms often live in very different habitats. Design a series of experiments to investigate how different types of organisms might affect the rate of enzyme activity. Consider testing a plant, an animal, and a protist.

2. Presumably, at higher concentrations of H_2O_2, there is a greater chance that an enzyme molecule might collide with H_2O_2. If so, the concentration of H_2O_2 might alter the rate of oxygen production. Design a series of experiments to investigate how differing concentrations of the substrate hydrogen peroxide might affect the rate of enzyme activity.

3. Design an experiment to determine the effect of boiling catalase on the reaction rate.

4. Explain how environmental factors affect the rate of enzyme-catalyzed reactions.

Enzyme Action:
Testing Catalase Activity

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment may take a single group several lab periods to complete. A good breaking point is after the completion of Part I, when students have tested the effect of different enzyme concentrations. Alternatively, if time is limited, different groups can be assigned one of the three tests and the data can be shared.

3. Your hot tap water may be in the range of 50–55°C for the hot-water bath. If not, you may want to supply pre-warmed temperature baths for Step 21, where students need to maintain very warm water. Warn students not to touch the hot water.

4. Many different organisms may be used as a source of catalase in this experiment. If enzymes from an animal, a protist, and a plant are used by different teams in the same class, it will be possible to compare the similarities and differences among those organisms. Often beef liver, beef blood, or living yeast are used.

5. To prepare the yeast solution, dissolve 7 g (1 package) of dried yeast per 100 mL of 2% glucose solution. Incubate the suspension in 37–40°C water for at least 10 minutes to activate the yeast. Test the experiment before the students begin. The yeast may need to be diluted if the reaction occurs too rapidly. The reaction in Step 14, with 3 mL of 3% hydrogen peroxide, 3 mL of water, and 2 drops of suspension should produce a pressure of 130 kPa in 40 to 60 seconds.

6. To prepare a 2% sugar solution, add 20 grams of sugar to make one liter of solution (100 mL per group is needed).

7. To prepare a liver suspension, homogenize 0.5 to 1.5 g of beef liver in 100 mL of cold water. You will need to test the suspension before use, as its activity varies greatly depending on its freshness. Dilute the suspension until the reaction in Step 14, with 3 mL of 3% hydrogen peroxide, 3 mL of water, and 2 drops of suspension produces a pressure of 130 kPa in 40 to 60 seconds. The color of the suspension will be a faint pink. Keep the suspension on ice until used in an experiment.

8. You can purchase 3% H_2O_2 from any supermarket. If refrigerated, bring it to room temperature before starting the experiment.

9. Emphasize to your students the importance of providing an airtight fit with all plastic-tubing connections and when closing valves or twisting the stopper into a test tube.

10. The accessory items used in this experiment are the #1 single hole stopper fitted with a tapered valve connector and the section of plastic tubing fitted with Luer-lock connectors.
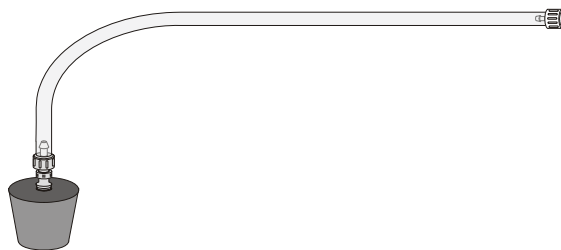
11. The length of plastic tubing connecting the rubber stopper assemblies to each gas pressure sensor must be the same for all groups. It is best to keep the length of tubing reasonably small to keep the volume of gas in the test tube low. **Note:** If pressure changes during data collection are too small, you may need to decrease the total gas volume in the system. Shortening the length of tubing used will help to decrease the volume.

12. Vernier Software & Technology sells a pH buffer package for preparing buffer solutions with pH values of 4, 7, and 10 (order code PHB). Simply add the capsule contents to 100 mL of distilled water.

13. You can also prepare pH buffers using the following recipes:

   • pH 4: Add 2.0 mL of 0.1 M HCl to 1000 mL of 0.1 M potassium hydrogen phthalate.
   • pH 7: Add 582 mL of 0.1 M NaOH to 1000 mL of 0.1 M potassium dihydrogen phosphate.
   • pH 10: Add 214 mL of 0.1 M NaOH to 1000 mL of 0.05 M sodium bicarbonate.

14. You may need to let students know that at pH values above 10, enzymes will become denatured and the rate of activity will drop. If you have pH buffers higher than 10, have students perform an experimental run using them.

SAMPLE RESULTS

Label	Reaction Rate (kPa/min)
1 drop	12.06
2 drops	14.27
3 drops	24.72
4 drops	25.74

Actual Temperature (°C)	Reaction Rate (kPa/min)
3 °C	4.73
22 °C	14.31
31 °C	25.02
51 °C	9.84

Label	Reaction Rate (kPa/min)
pH 4	11.16
pH 7	22.86
pH 10	48.60
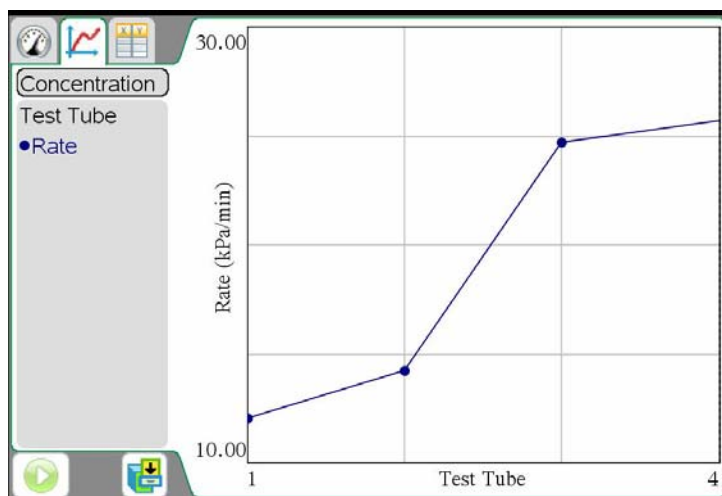
The effect of enzyme concentration on the rate of activity.
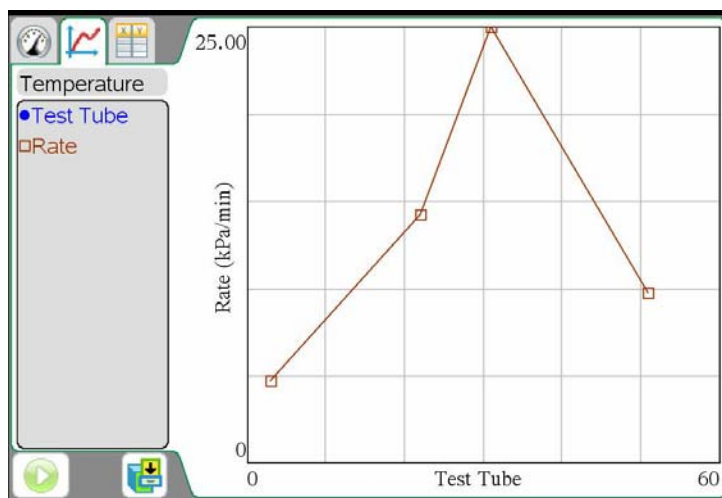
The effect of temperature on the rate of enzyme activity
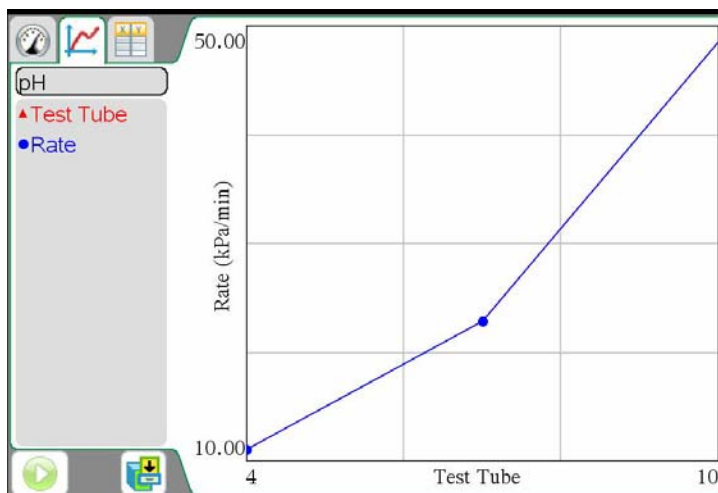
The effect of pH on the rate of enzyme activity

ANSWERS TO QUESTIONS

1. The rate should be highest when the concentration of enzyme is highest. With higher concentration of enzyme, there is a greater chance of an effective collision between the enzyme and H_2O_2 molecule.

2. Roughly, the rate doubles when the concentration of enzyme doubles. Since the data are somewhat linear, the rate is proportional to the concentration. At a concentration of 5 drops, the rate in the above experiment should be about 30.89 kPa/min.

3. The temperature at which the rate of enzyme activity is the highest should be close to 30°C. The lowest rate of enzyme activity should be at 50°C.

4. The rate increases as the temperature increases, until the temperature reaches about 50°C. Above this temperature, the rate decreases.

5. At high temperatures, enzymes lose activity as they are denatured.

6. Student answers may vary. Activity is usually highest at pH 10 and lowest at pH 4.

7. Student answers may vary. Usually, the enzyme activity increases from pH 4 to 10. At low pH values, the protein may denature or change its structure. This may affect the enzyme's ability to recognize a substrate or it may alter its polarity within a cell.

Transpiration

Water is transported in plants, from the roots to the leaves, following a decreasing water potential gradient. *Transpiration*, or loss of water from the leaves, helps to create a lower osmotic potential in the leaf. The resulting transpirational pull is responsible for the movement of water from the xylem to the mesophyll cells into the air spaces in the leaves. The rate of evaporation of water from the air spaces of the leaf to the outside air depends on the water potential gradient between the leaf and the outside air.

Various environmental factors, including those conditions which directly influence the opening and closing of the stomata, will affect a plant's transpiration rate. This experiment will measure transpiration rates under different conditions of light, humidity, temperature, and air movement. The data will be collected by measuring pressure changes as the plant takes up water into the stem.

OBJECTIVES

In this experiment, you will

- Observe how transpiration relates to the overall process of water transport in plants.
- Use a handheld interface and a Gas Pressure Sensor to measure the rate of transpiration.
- Determine the effect of light intensity, humidity, wind, and temperature on the rate of transpiration of a plant cutting.
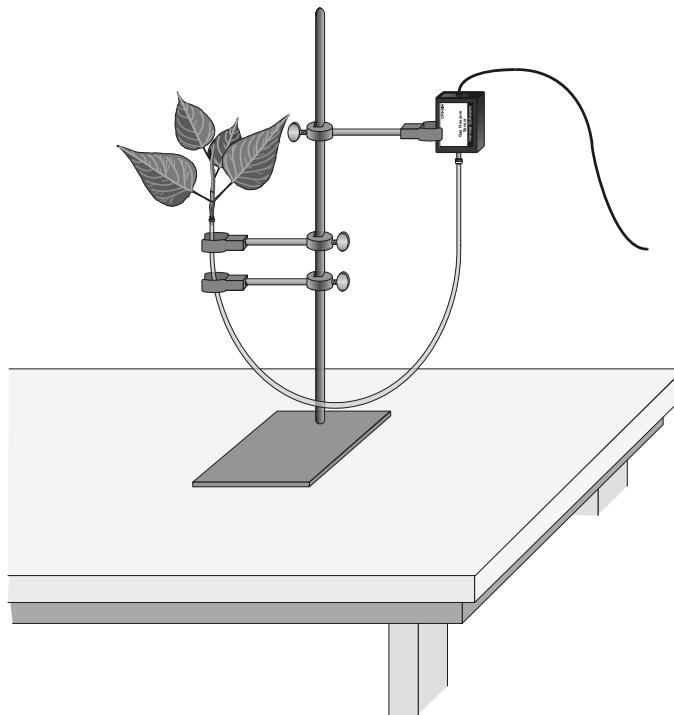

Figure 1

MATERIALS

TI-Nspire handheld **or**
   computer and TI-Nspire software
data-collection interface
Vernier Gas Pressure Sensor
utility clamps
ring stand
plant cuttings
plastic tubing clamps
dropper or Beral pipette
razor blade or scalpel

100 watt light source
metric ruler
masking tape
plastic gallon size bag with twist tie
heater, small electric
fan with slow speed
aerosol spray container or plant mister
plastic syringe
graph paper

PROCEDURE

1. Position the ring stand, utility clamps, and Gas Pressure Sensor as shown in Figure 1.

2. Prepare the plastic tubing.

   a. Connect the plastic syringe to one end of a 36–42 cm piece of plastic tubing.
   b. Place the other end of the tubing into water and use the syringe to draw water up into the tubing until it is full. Tap the tubing to expel any air bubbles that form inside the tube.
   c. Slip a plastic tubing clamp onto the tubing as shown in Figure 2.
   d. Bend the tubing into a U shape with both ends up. Remove the syringe, leaving the tubing full of water.

Figure 2

3. Select a plant which has a stem roughly the same diameter as the opening of the plastic tubing. Using a scalpel or razor blade, carefully cut the plant one inch above the soil. Place the plant under water against a hard surface and make a new cut at a 45° angle near the base of the stem.

4. Connect the plant to the tubing.

   a. The plastic tubing has a white plastic connector at one end that allows you to connect it to the valve on the Gas Pressure Sensor. Raise the end of the tubing with the connector until you see water beginning to drip out of the other end.
   b. Carefully push the cut stem of the plant down into the end of the tubing where the water is dripping out. Be careful not to allow any air bubbles to form between the cut portion of the stem and the water in the tube.
   c. Push the plant down as far as it will go without damaging the plant. At least one centimeter of the plant stem should fit into the tubing. If the stem is too large for the tubing, cut the stem at a higher point where it is smaller.
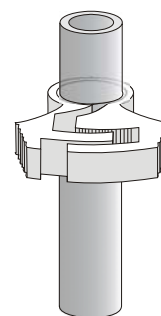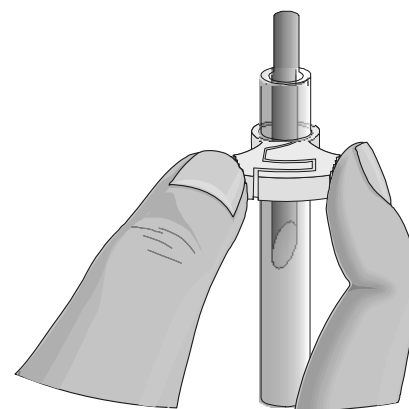   d. Squeeze the tubing clamp shut as tight as possible as shown in Figure 3.

Figure 3

5. When the tubing clamp is shut tight, invert your plant cutting to check for any leaks. If water does leak out, turn the plant right-side up and try tightening the clamp further.

    Important: Be sure the tubing is filled completely with water. The water column must be flush with the stem. There should be no air visible at the base of the stem. If water moves down the tube away from the stem after it has been inserted, check for a leak in the system.

6. Connect the plastic tubing to the sensor valve. **Caution**: Do not allow water to enter the valve of the Gas Pressure Sensor.

7. Secure the plant in an upright position with the utility clamps as shown in Figure 1. It should be positioned so that the cut stem is about 8 cm below the water level at the other end of the tubing, as shown in Figure 1.

8. Place a mark on the tube at the starting water level to allow you to refill the tube to the proper level when you repeat data collection.

9. Place your plant setup in an area where the wind, humidity, and temperature are reasonably constant. This will be your control setup.

10. Allow the system 5 minutes to adjust to the environment. While the system is adjusting, continue with this procedure to complete setting up the sensor and data-collection parameters.

11. Connect the Gas Pressure Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

12. Choose New Experiment from the 🔬 Experiment menu. Choose Collection Setup from the 🔬 Experiment menu. Enter **0.25** as the rate in samples per second and **900** as the experiment duration in seconds (15 minutes). The number of points collected should be 226. Select OK.

13. Check the base of the plant stem in the water tube to make sure that no air bubbles or air pockets have formed that will prevent the plant from taking up water. If an air pocket has formed, refit the plant in the tubing before initiating data collection in Step 14.

14. After the plant has equilibrated for 5 minutes, start data collection (▶). Data will be collected for 900 seconds. If necessary, you can stop data collection early (◼).

15. When data collection has stopped, perform a linear regression to calculate the rate of transpiration.

    a. Examine the graph and identify the most linear region.
    b. Select the linear region of the data.
    c. Choose Curve Fit ▶ Linear from the 📊 Analyze menu. The linear-regression statistics for these two data columns are displayed for the equation in the form

    $$y = mx + b$$

    where *x* is time, *y* is pressure, *m* is the slope, and *b* is the y-intercept.
    d. Enter the absolute value of the slope, *m*, as the rate of transpiration in Table 1.

16. Design an experiment to simulate *one* of the following environmental conditions, as assigned by your teacher:

    - the effect of light intensity
    - the effect of the wind blowing on the plant
    - the effect of humidity
    - the effect of temperature
    - the effect of another self-identified environmental variable

    Be sure to address the following questions in your design:

    - What is the essential question being addressed?
    - What assumptions are made about the system being measured?
    - Can those assumptions be easily verified?
    - Will the measurements provide the necessary data to answer the question under study?

17. After checking your procedure with your teacher, obtain the materials needed for the experiment and perform the tests. Be sure to store the latest data set (📇) before each new trial. Record your values in Table 1.

18. Identify the environmental condition you tested in the blank provided in Table 1.

PROCESSING THE DATA

1. Determine the surface area of all the leaves on your plant cutting by the following method:

    a. Cut all the leaves (not stems) off your plant and determine their mass using a balance.
    b. Estimate the total leaf surface area in cm^2 for your plant by cutting out a section of leaf 5 cm x 5 cm.
    c. Determine the mass for this leaf section and divide by 25 cm^2 to find the mass of l cm^2 of leaf.
    d. Divide the total mass of the leaves by the mass of l cm^2 to find the total leaf surface area.
    e. Record the calculated surface area in Table 1.

2. Divide the slope by the surface area for each test and record in the *rate/area* column of Table 1. These rate values should be expressed as $kPa/s/cm^2$.

3. Subtract the control (rate/area) value from the experimental value. Record this adjusted rate in the last column of Table 1.

4. Record the adjusted rate for your experimental test on the board to share with the class. Record the class results in Table 2 for each of the environmental conditions tested. If a condition was tested by more than one group, take the average of the values and record in Table 2.

5. Make a bar graph that shows the effect of different environmental conditions on the transpiration of water in plant cuttings. Using the data in Table 2 plot the adjusted rate for each test on the y-axis and the test label on the x-axis.

    a. Insert a new problem in the document, then Insert a new DataQuest App into the problem. Click on the Table View tab (▦) to view the Table.

b. Double click on the *X* column to access the column options. Enter **Test** for the column name. Change the Display Precision to 0 decimal places. Select OK.

c. Double click on the *Y* column to access the column options. Enter **Rate** for the column name. Enter **kPa/s/cm^2** as the units. Select OK.

d. Insert a Data and Statistics application into the problem.

e. Move the cursor over the Click to Add Variable label in the lower center of the screen and access the contextual menu. (/b on a handheld or right-click on a computer.)

f. Choose the Add X Variable with Summary List option.

g. Choose run1.Test as the X List and run1.Rate as the Summary List, then Select OK.

DATA

Table 1				
Test	Slope (kPa/s)	Surface area (cm^2)	Rate/area (kPa/s/cm^2)	Adjusted rate (kPa/s/cm^2)
Experimental _____				
Control				

Table 2 - Class Data	
Test	Adjusted rate (kPa/s/cm^2)
Light	
Humidity	
Wind	
Temperature	

QUESTIONS

1. How was the rate of transpiration affected in each of the experimental situations as compared to the control?

2. Which variable resulted in the greatest rate of water loss? Explain why this factor might increase water loss when compared to the others.

3. What adaptations enable plants to increase or decrease water loss? How might each affect transpiration?

EXTENSIONS

1. Using a compound microscope, identify the vascular tissues of a plant stem. Describe the function of each tissue type identified.

    a. Obtain a section of stem from the plant you used during the transpiration experiment.
    b. Using a nut-and-bolt microtome, carefully cut 6 cross sections of the plant stem. The cross sections should be cut as thin as possible.
    c. Place each of the cross sections in a dish or cup of 50% ethanol solution for 5 minutes.
    d. Remove the cross sections from the alcohol and place them in a dish containing toludine blue O stain for 5 minutes.
    e. Rinse the cross sections with distilled water and mount them on a microscope slide with a drop of 50% glycerin. Place a cover slip on the slide and examine the cross sections using a compound microscope.
    f. On a separate sheet of paper, make a drawing of the cross sections. Identify and label the cell and tissue types described by your teacher.

2. Test cuttings from a variety of different plant species. How does each compare?

3. Count the number of stoma/cm^2 for each of the plants in Extension 1. How does this relate to the plant's ability to transpire water?

4. Design an experiment to test for the variables in Question 3.

TEACHER INFORMATION

Transpiration

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. You should leave water out overnight in a beaker or cup to allow any excess dissolved air to escape. This will ensure that no air bubbles form in the tube at the cut end of the stem. If air bubbles form, it may be necessary to restart your experiment. If bubbles do form, remove the plant and tubing from the two utility clamps and allow the plant to hang towards the ground with the other end of the tubing pointing up. Carefully tap on the sides of the tubing to loosen any bubbles—they will float to the water's surface at the other end. Once all bubbles are removed, check the plant's seal at the tube. Secure your plant in the tubing and restart the data collection.

3. There is not always an immediate change in the transpiration rate. Allow the plant to spend a few extra minutes under a particular condition before initiating data collection. This will give the plant the necessary time to adjust. When the transpiration rate changes drastically, the stomata will close, decreasing the transpiration rate. If the length of data collection is extended, you will be able to see on the graph when the stomata have closed and the rate slows down.

4. Many plants work well for this experiment. Plants that have been used include tomato, strawberry, bean, geranium, cyclamen, and even honeysuckle. For best results, we recommend using plants with numerous leaves. Tomato plants work very well and have been used to collect the sample data for this activity. One possible extension of this experiment would be to have the students use different plant species under similar conditions and evaluate how different plants have adapted to prevent water loss.

5. The thick-wall plastic tubing that comes with the Gas Pressure Sensor is well suited for this lab. The inner diameter of the tubing is 3 mm and may be too small for some plant specimens. Science supply companies carry thick-wall plastic tubing, with a larger inner diameter, that will work well on larger plant stems. They also sell tubing connectors that will allow you to connect the larger tubing to the tubing provided with the Gas Pressure Sensor.

6. Emphasize to your students the importance of providing an airtight fit with all plastic-tubing connections.

7. The plastic tubing clamps (order code PTC) used in the student procedure may be purchased in packages of 100 from Vernier Software & Technology.

SAMPLE RESULTS

| Test	Adjusted rate $(kPa/s/cm^2)$
Control	-4.0×10^{-5}
Light	-9.4×10^{-5}
Humidity	$-.87 \times 10^{-5}$
Wind	$-.27 \times 10^{-5}$
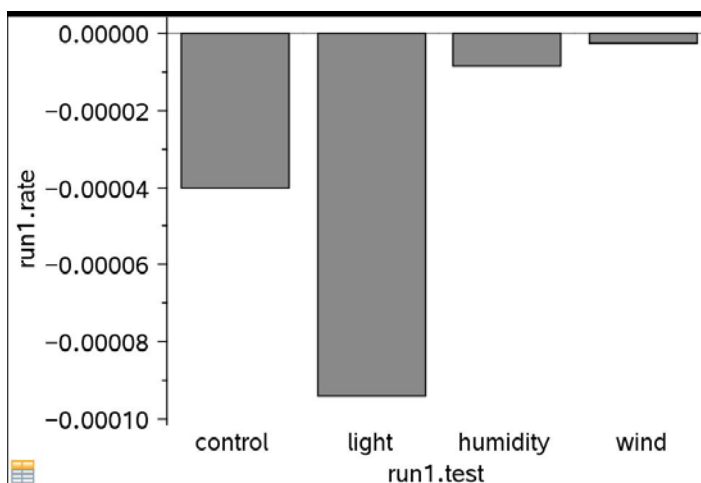
ANSWERS TO QUESTIONS

1. It is typically predicted that the light and wind will increase the rate of transpiration. This may not be apparent until after correction for surface area differences. Sometimes the wind, if too strong, may cause the leaves to droop or fold up, and in this case they may transpire less. Stomates may close to counter the dehydration. If this happens, discuss the nature of science experimentation, e.g., the expected may not always be the result. Usually, after correction for surface area, the high humidity plant will transpire less than a control. A student may question whether the light increased the temperature of the leaf. If the light was too close to the plant, temperature may indeed be a variable without a control.

2. Answers will vary—usually the light will produce the greatest rate of water loss. High light intensity increases water loss due to increased photosynthesis. Wind removes water vapor from the surface of the leaf more rapidly. It may increase the evaporation rate by increasing the gradient between water in the leaf air spaces and water vapor in the air.

3. Plants can increase or decrease water loss by

    *   closing the stomata during water stress.
    *   reducing the number of stomata.
    *   waxy cuticles.
    *   fleshy, thick leaves.
    *   hairy surfaces.
    *   reducing the overall leaf surface area.

Cell Respiration

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

$$C_6H_{12}O_6 + 6\ O_2(g) \longleftrightarrow 6\ H_2O + 6\ CO_2(g) + energy$$
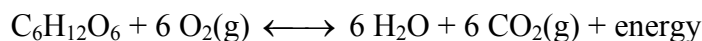
All organisms, including plants and animals, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. It is known that pea seeds undergo cell respiration during germination. Do pea seeds undergo cell respiration before germination? Using your collected data, you will be able to answer this question concerning respiration and non-germinated peas.

Using the CO_2 Gas Sensor, you will monitor the carbon dioxide produced by pea seeds during cell respiration. Both germinated and non-germinated peas will be tested. Additionally, cell respiration of germinated peas at two different temperatures will be tested.

OBJECTIVES

In this experiment, you will

- Use a CO_2 Gas Sensor to measure concentrations of carbon dioxide during cell respiration.
- Study the effect of temperature on cell respiration rate.
- Determine whether germinating peas and non-germinating peas respire.
- Compare the rates of cell respiration in germinating and non-germinating peas.
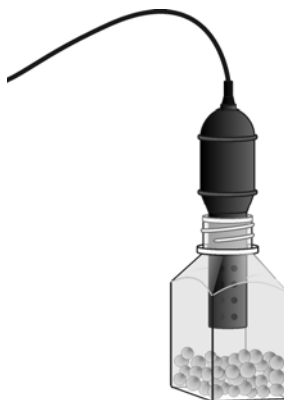
Figure 1

MATERIALS

TI-Nspire handheld **or**	250 mL respiration chamber
computer and TI-Nspire software	25 germinated pea seeds
data-collection interface	25 non-germinated pea seeds
Vernier CO_2 Gas Sensor	ice cubes
100 mL beaker	thermometer

PROCEDURE

1. If your CO_2 Gas Sensor has a switch, set it to the Low (0–10,000 ppm) setting. Connect the sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

2. Choose New Experiment from the ⚙ Experiment menu. Choose Collection Setup from the ⚙ Experiment menu. Enter **300** as the experiment duration in seconds. The number of points collected should be 76. Select OK.

3. Measure the room temperature using a thermometer and record the temperature in Table 1.

4. Obtain 25 germinated pea seeds and blot them dry between two pieces of paper towel.

5. Place the germinated peas into the respiration chamber.

6. Place the shaft of the CO_2 Gas Sensor in the opening of the respiration chamber.

7. Wait one minute, then start data collection (▶). Data will be collected for 300 seconds.

8. When data collection has finished, a graph of carbon dioxide gas *vs.* time will be displayed.

9. Remove the CO_2 Gas Sensor from the respiration chamber. Place the peas in a 100 mL beaker filled with cold water and an ice cube. The cold water will prepare the peas for part II of the experiment.

10. Use a notebook or notepad to fan air across the openings in the probe shaft of the CO_2 Gas Sensor for 1 minute.

11. Fill the respiration chamber with water and then empty it. Thoroughly dry the inside of the respiration chamber with a paper towel.

12. Determine the rate of respiration.

    a. Examine the graph and identify the most linear region and select the data points in the most linear region.
    b. Choose Curve Fit ▶Linear from the ⬛ Analyze menu.
    c. Record the slope, *m*, as the rate of respiration in ppm/s in Table 2.

13. Click the Store Latest Data Set button (⊞) to save the first run data. Repeat Steps 5–12 substituting the germinated peas with non-germinated pea seeds. In Step 9 place the non-germinated peas on a paper towel and not in the ice bath.

Part II Germinated peas, cool temperatures

14. Remove the germinated pea seeds from the cold water and blot them dry between two paper towels.

15. Click the Store Latest Data Set button (⊞) to save the second run data. Repeat Steps 5–12 using the cold peas.

16. Graph all three runs of data on a single graph.

    a. Click **run3** and select All. All three runs will now be displayed on the same graph axes.

    b. Use the displayed graph and Tables 1 and 2 to answer the questions below.

DATA

Table 1	
Room Temperature (°C)	

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

QUESTIONS

1. Do you have evidence that cell respiration occurred in peas? Explain.

2. What is the effect of germination on the rate of cell respiration in peas?

3. What is the effect of temperature on the rate of cell respiration in peas?

4. Why do germinated peas undergo cell respiration?

EXTENSIONS

1. Compare the respiration rate among various types of seeds.

2. Compare the respiration rate among seeds that have germinated for different time periods, such as 1, 3, and 5 days.

3. Compare the respiration rate among various types of small animals, such as insects or earthworms.

TEACHER INFORMATION

Cell Respiration

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. Allow the seeds to germinate for three days prior to the experiment. Prior to the first day, soak them in water overnight. On subsequent days, roll them in a moist paper towel and place the towel in a paper bag. Place the bag in a warm, dark place. Check each day to be sure the towels remain very moist. If time is short, the peas can be used after they have soaked overnight. For best results, allow them to germinate for the full three days.

3. The CO_2 Gas Sensor has a 90 second warm-up period. Any data collected during this warm up will not be accurate. When using the TI-Nspire Lab Cradle, the text in the CO_2 sensor meter will be displayed in light gray until the sensor has warmed up. At that time, the meter text will be displayed in black.

4. Heavy condensation buildup in the respiration chamber can interfere with readings from the CO_2 Gas Sensor. This can be a source of error if the peas are very wet when placed in the respiration chamber. Before placing the peas in the respiration chamber, blot them dry with a paper towel.

5. The CO_2 Gas Sensor relies on the diffusion of gases into the probe shaft. Students should allow a couple of minutes between trials so that gases from the previous trial will have exited the probe shaft. Alternatively, the students can use a firm object such as a book or notepad to fan air through the probe shaft. This method is used in Step 10 of the student procedure.

6. The morning of the experiment fill a 1 L beaker with ice and water so that students will have cold water. Students will also need access to ice.

7. When doing this experiment with a TI-Nspire handheld, your batteries will drain quickly. This is especially true when using an EasyLink or Go!Link interface. Be sure your handheld has fresh or fully charged batteries.

8. The older-style CO_2 sensor cannot be used with an EasyLink or Go!Link interface. To use this probe, you must use a multi-channel sensor interface.

9. The stopper included with the older-style CO_2 Gas Sensor is slit to allow easy application and removal from the probe. When students are placing the probe in the respiration chamber, they should gently twist the stopper into the chamber opening. Warn the students not to twist the probe shaft or they may damage the sensing unit.

SAMPLE RESULTS
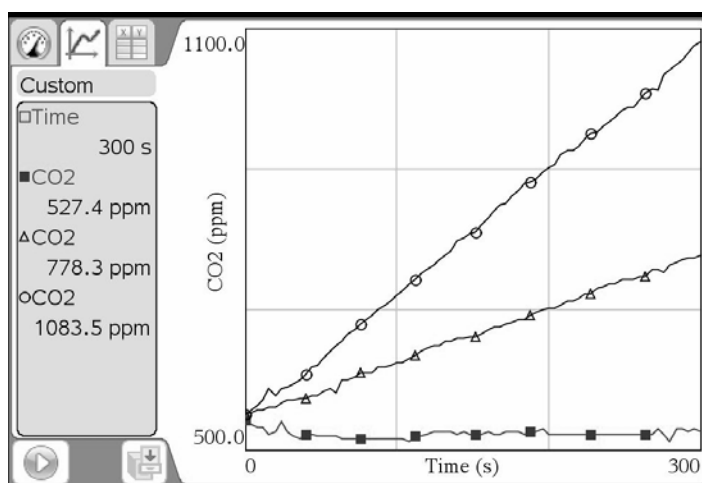
*CO$_2$ respired by germinating – room temperature (○),
non-germinating (■), and germinating – cool temperature peas (△).*

| Table 1	
Room Temperature (°C)	22.4

Table 2	
Peas	Rate respiration (ppm/s)
Germinating, room temperature	1.78
Non-germinating, room temperature	0.02
Germinating, cool temperature	0.78

ANSWERS TO QUESTIONS

1. Yes, the carbon dioxide concentration *vs.* time graph clearly indicates that carbon dioxide is being produced at a steady rate when germinating peas are in the respiration chamber.

2. Germination greatly accelerates the rate of cellular respiration. This reflects a higher rate of metabolic activity in germinating seeds. In most experiments, non-germinating seeds do not seem to be respiring. Occasionally, however, some respiration is detectable.

3. Warm temperatures increase the rate of respiration. This reflects a higher rate of metabolic activity in warm germinating seeds than in cool seeds.

4. It is necessary for germinating seeds to undergo cellular respiration in order to acquire the energy they need for growth and development. Unlike their mature relatives, seeds do not yet have the necessary photosynthetic abilities needed to produce their own energy sources.

Interdependence of Plants and Animals

Plants and animals share many of the same chemicals throughout their lives. In most ecosystems, oxygen, carbon dioxide, water, food, and nutrients are exchanged between plants and animals. In this lab, you will determine the relationships between two organisms—a plant (elodea) and an animal (a snail).
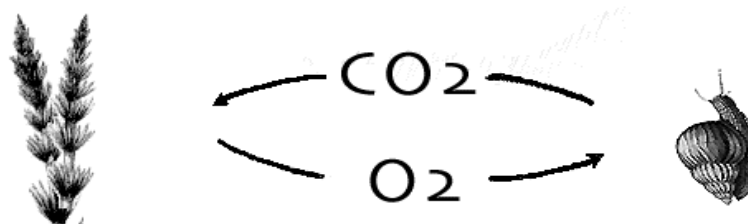
You will determine how oxygen and carbon dioxide are exchanged among elodea plants, snails, and the water in which both exist.

To perform the necessary tests, you will need to determine the presence of carbon dioxide. An easy way to do this is to monitor the pH of the pond water. If carbon dioxide dissolves in water, it forms carbonic acid, H_2CO_3, and the pH decreases. If carbon dioxide is removed from pond water, the amount of carbonic acid goes down and the pH increases. A pH Sensor can be used to monitor the pH and determine whether carbon dioxide is released into the pond water or is removed from the water. Dissolved oxygen (DO) can be monitored with the aid of a Dissolved Oxygen Probe. Increases or decreases in the amount of dissolved oxygen can be rapidly assessed with the Dissolved Oxygen Probe.

OBJECTIVES

In this experiment, you will

- Use a Dissolved Oxygen Probe to measure the dissolved oxygen in water.
- Use a pH Sensor to measure the pH of water.
- Use pH measurements to make inferences about the amount of CO_2 dissolved in water.
- Determine whether snails consume or produce oxygen and CO_2 in water.
- Determine whether plants consume or produce oxygen and CO_2 in the light.
- Determine whether plants consume or produce oxygen and CO_2 in the dark.

MATERIALS

TI-Nspire handheld **or**	two test tube racks
computer and TI-Nspire software	distilled wash water
data-collection interface	aluminum foil
Vernier Dissolved Oxygen Probe	Parafilm
Vernier pH Sensor	pond snails
250 mL beaker	pond water
eight 25 x 150 mm screw top test tubes	sprigs of elodea

PRE-LAB PROCEDURE

Important: Prior to each use, the Dissolved Oxygen Probe must warm up for a period of 10 minutes as described below. If the probe is not warmed up properly, inaccurate readings will result. Perform the following steps to prepare the Dissolved Oxygen Probe.

1. Prepare the Dissolved Oxygen Probe for use.

   a. Remove the protective cap.
   b. Unscrew the membrane cap from the tip of the probe.
   c. Using a pipet, fill the membrane cap with 1 mL of DO Electrode Filling Solution.
   d. Carefully thread the membrane cap back onto the electrode.
   e. Place the probe into a 250 mL beaker containing distilled water.

Remove membrane cap   Add electrode filling solution   Replace membrane cap
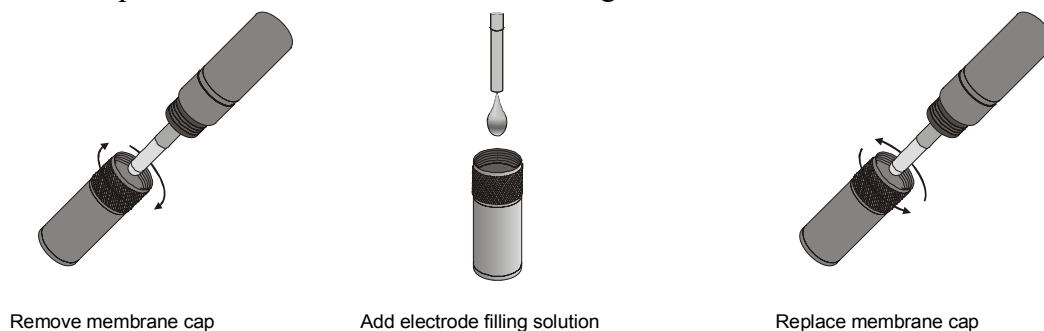
Figure 1

2. Connect the pH Sensor and the Dissolved Oxygen Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the 🖳 Experiment menu. For this experiment, you will monitor the sensor meter and record the data by hand. You will not electronically store the data.

4. It is necessary to warm up the Dissolved Oxygen Probe for 10 minutes before taking readings. With the probe still in the distilled water beaker, wait 10 minutes while the probe warms up. The probe must stay connected at all times to keep it warmed up. If disconnected for a period longer than 5 minutes, it will be necessary to repeat this step. (Note: If you are using the TI-Nspire Lab Cradle, the meter will display the sensor values in light gray until the sensor has warmed up. At that time, the sensor values will display in black.)

5. Calibrate the Dissolved Oxygen Probe.

   • If your instructor directs you to use the stored calibration, proceed directly to Step 6.
   • If your instructor directs you to manually enter the calibration values, choose Set Up Sensors ► Calibrate ► Dissolved Oxygen ► Manual Entry from the 🖳 Experiment menu. Enter the values for K0 and K1. Select OK. Proceed directly to Step 6.
   • If your instructor directs you to perform a new calibration, continue with this step to calibrate your sensor.

Zero-Oxygen Calibration Point

a. Set Up Sensors ► Calibrate ► Dissolved Oxygen ► Two Point from the Experiment menu.

b. Remove the probe from the water bath and place the tip of the probe into the Sodium Sulfite Calibration Solution. **Important:** No air bubbles can be trapped below the tip of the probe or the probe will sense an inaccurate dissolved oxygen level. If the voltage does not rapidly decrease, tap the side of the bottle with the probe to dislodge the bubble. The readings should be in the 0.2 to 0.6 V range.

c. Enter **0** as the first reference value.

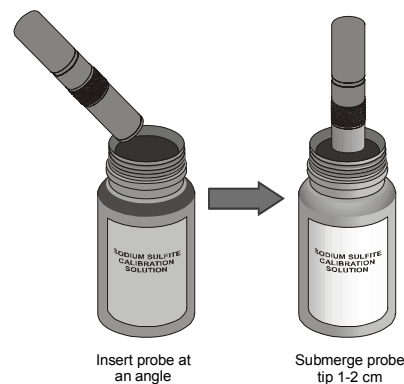d. When the voltage stabilizes (~1 minute), select OK.

Figure 2

Saturated DO Calibration Point

e. Rinse the probe with distilled water and gently blot dry.

f. Unscrew the lid of the calibration bottle provided with the probe. Slide the lid and the grommet about 1/2 inch onto the probe body.
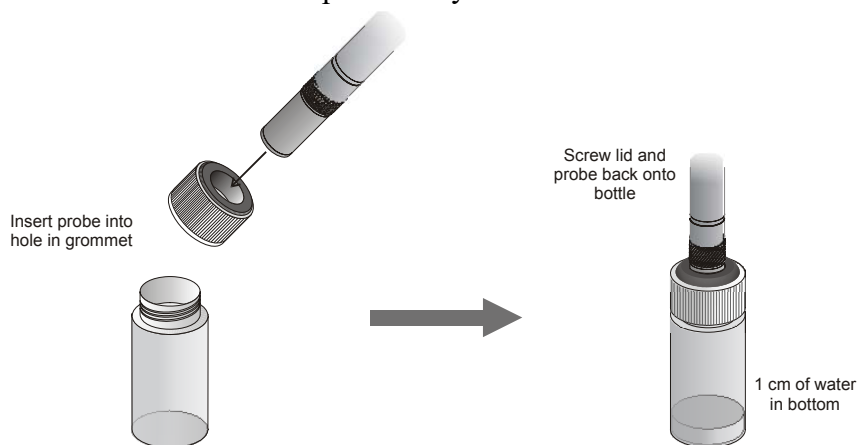
Figure 3

g. Add water to the bottle to a depth of about 1/4 inch and screw the bottle into the cap, as shown. **Important:** Do not touch the membrane or get it wet during this step.

h. Enter the correct saturated dissolved-oxygen value (in mg/L) from Table 3 (for example, at 18 °C and atmospheric pressure of 690 mmHg enter **8.66**) using the current barometric pressure and air temperature values. If you do not have the current air pressure, use Table 4 to estimate the air pressure at your altitude.

i. Keep the probe in this position for about a minute. The readings should be above 2.0 V. When the voltage reading stabilizes, select OK.

j. If directed by your instructor, record the values for K0 and K1. Select the Save Calibration with Document option, and then select OK.

PROCEDURE

6. Obtain and label eight test tubes 1–8.

7. Set test tubes 1–4 in one test tube rack and test tubes 5–8 in a second test tube rack.

8. Fill each tube with pond water.

9. Place one snail each in test tubes 2, 4, 6, and 8.

10. Place one sprig of elodea in test tubes 3, 4, 7, and 8. Each set of four tubes should appear similar to those in Figure 4.
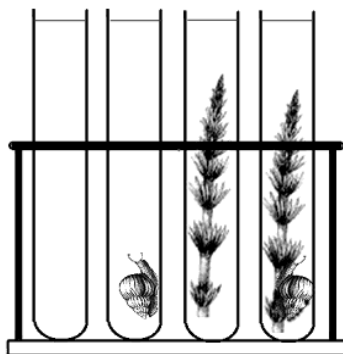

Figure 4

11. Wrap test tubes 5–8 in aluminum foil to make each light tight.

12. Remove the pH Sensor from the storage bottle. Rinse the sensor thoroughly with distilled water. Place the pH Sensor into test tube 1 and gently swirl to allow water to move past the sensor's tip. When the reading stabilizes, record the pH value in Table 1.

13. Repeat Step 12 for each of the other seven test tubes.

14. When all of the pH readings have been taken, rinse the pH Sensor and return it to the pH storage bottle.

15. Place the Dissolved Oxygen Probe into test tube 1 so that it is submerged half the depth of the water. Gently and continuously move the probe up and down a distance of about 1 cm in the tube. This allows water to move past the probe's tip. **Note:** Do not agitate the water, or oxygen from the atmosphere will mix into the water and cause erroneous readings.

16. When the dissolved oxygen reading stabilizes (~30 seconds), record its value in Table 1.

17. Repeat Steps 15–16 for each of the other seven test tubes.

18. When all of the dissolved oxygen readings have been taken, rinse the Dissolved Oxygen Probe and return it to the distilled water beaker.

19. Completely fill each test tube with pond water and tighten the cap onto the tube. Do not allow any air bubbles to remain in any of the test tubes. Unscrew each cap slightly, so that they just barely open. Wrap each tube with Parafilm so that they do not leak water. The Parafilm will expand, if necessary, to accommodate any pressure build-up in a tube. No oxygen or carbon dioxide should enter or leave a tube.

20. Place test tubes 1–8 near the light source, as directed by your instructor.

21. Predict how the pH and dissolved oxygen will change in each tube. Write a short statement that explains your reasoning. Be specific about the roles of both the snail and elodea. Be prepared to discuss your reasoning in class on Day 2.

Day 2

22. Repeat Steps 1–5 to set up the pH Sensor and Dissolved Oxygen Probe.

23. Repeat Steps 12–18 to take pH and DO readings for each of the test tubes.

24. Now, the elodea will use the environment established by the snail and the snail will use the environment established by the elodea. Remove the snail from test tube 2 and the elodea from test tube 3. Place the snail in test tube 3 and the elodea in test tube 2. **Note:** Try not to aerate the water during the transfer.

25. Remove the snail from test tube 6 and the elodea from test tube 7. Place the snail in test tube 7 and the elodea in test tube 6.

26. Measure the pH and DO of test tubes 1–3 and test tubes 5–7. Record the results in Table 2. These values should be similar to those measured before the transfer. If not, the water may have been mixed too vigorously with the atmospheric air.

27. Completely fill test tubes 1–3 and test tubes 5–7 with water and tighten the cap onto each tube, as in Step 19. Wrap each slightly opened test tube with Parafilm. Place test tubes 1–3 and test tubes 5–7 near the light source, as in Step 19.

28. Return the snails and elodea from test tubes 4 and 8, as directed by your instructor. Clean and return the test tubes.

Day 3

29. Repeat Steps 1–5 to set up the pH Sensor and Dissolved Oxygen Probe.

30. Repeat Steps 12–18 for test tubes 1–3 and 5–7. Record the results in Table 2.

31. Return the snails and elodea as directed by your instructor. Clean and return the test tubes.

DATA

Table 1						
Test Tube	pH Day 1	pH Day 2	ΔpH	DO Day 1	DO Day 2	ΔDO
1						
2						
3						
4						
5						
6						
7						
8						

Table 2						
Test Tube	pH Day 2	pH Day 3	ΔpH	DO Day 2	DO Day 3	ΔDO
1						
2						
3						
5						
6						
7						

PROCESSING THE DATA

1. Calculate the change in pH for Tables 1–2. Record your results in Tables 1–2.

2. Calculate the change in dissolved oxygen for Tables 1–2. Record your results in Tables 1–2.

QUESTIONS

1. Consider the snails. Comparing the readings from day 1 to day 2, answer the following:

   a. Do snails produce or consume CO_2 when in the light?

   b. Do snails produce or consume oxygen when in the light?

   c. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?

   d. Do snails produce or consume CO_2 when in the dark?

   e. Do snails produce or consume oxygen when in the dark?

   f. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?

2. Consider the elodea. Comparing the readings from day 1 to day 2, answer the following:

   a. Do elodea produce or consume CO_2 when in the light?
   b. Do elodea produce or consume oxygen when in the light?
   c. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?
   d. Do elodea produce or consume CO_2 when in the dark?
   e. Do elodea produce or consume oxygen when in the dark?
   f. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?

3. Consider the elodea placed in the snail's water on days 2–3. Comparing the readings from day 2 to day 3, answer the following:

   a. Do elodea produce or consume CO_2 when in the light?
   b. Do elodea produce or consume oxygen when in the light?
   c. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?
   d. Do elodea produce or consume CO_2 when in the dark?
   e. Do elodea produce or consume oxygen when in the dark?
   f. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?

4. Consider the snail placed in the elodea's water on days 2–3. Comparing the readings from day 2 to day 3, answer the following:

   a. Do snails produce or consume CO_2 when in the light?
   b. Do snails produce or consume oxygen when in the light?
   c. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?
   d. Do snails produce or consume CO_2 when in the dark?
   e. Do snails produce or consume oxygen when in the dark?
   f. Which test tubes allow you to answer this? Which test tube is the experimental test tube? Which test tube is the control test tube?

5. Summarize the relationship between snails and plants in a pond. Explain your reasoning.

6. Interpret the results of Test Tube 4 and Test Tube 8. Compare your findings to the results obtained from Table 2.

7. How do your conclusions compare to your predictions in Step 21?

CALIBRATION TABLES

	770 mm	**760 mm**	**750 mm**	**740 mm**	**730 mm**	**720 mm**	**710 mm**	**700 mm**	**690 mm**	**680 mm**	**670 mm**	**660 mm**
Table 3: 100% Dissolved Oxygen Capacity (mg/L)												
0°C	14.76	14.57	14.38	14.19	13.99	13.80	13.61	13.42	13.23	13.04	12.84	12.65
1°C	14.38	14.19	14.00	13.82	13.63	13.44	13.26	13.07	12.88	12.70	12.51	12.32
2°C	14.01	13.82	13.64	13.46	13.28	13.10	12.92	12.73	12.55	12.37	12.19	12.01
3°C	13.65	13.47	13.29	13.12	12.94	12.76	12.59	12.41	12.23	12.05	11.88	11.70
4°C	13.31	13.13	12.96	12.79	12.61	12.44	12.27	12.10	11.92	11.75	11.58	11.40
5°C	12.97	12.81	12.64	12.47	12.30	12.13	11.96	11.80	11.63	11.46	11.29	11.12
6°C	12.66	12.49	12.33	12.16	12.00	11.83	11.67	11.51	11.34	11.18	11.01	10.85
7°C	12.35	12.19	12.03	11.87	11.71	11.55	11.39	11.23	11.07	10.91	10.75	10.59
8°C	12.05	11.90	11.74	11.58	11.43	11.27	11.11	10.96	10.80	10.65	10.49	10.33
9°C	11.77	11.62	11.46	11.31	11.16	11.01	10.85	10.70	10.55	10.39	10.24	10.09
10°C	11.50	11.35	11.20	11.05	10.90	10.75	10.60	10.45	10.30	10.15	10.00	9.86
11°C	11.24	11.09	10.94	10.80	10.65	10.51	10.36	10.21	10.07	9.92	9.78	9.63
12°C	10.98	10.84	10.70	10.56	10.41	10.27	10.13	9.99	9.84	9.70	9.56	9.41
13°C	10.74	10.60	10.46	10.32	10.18	10.04	9.90	9.77	9.63	9.49	9.35	9.21
14°C	10.51	10.37	10.24	10.10	9.96	9.83	9.69	9.55	9.42	9.28	9.14	9.01
15°C	10.29	10.15	10.02	9.88	9.75	9.62	9.48	9.35	9.22	9.08	8.95	8.82
16°C	10.07	9.94	9.81	9.68	9.55	9.42	9.29	9.15	9.02	8.89	8.76	8.63
17°C	9.86	9.74	9.61	9.48	9.35	9.22	9.10	8.97	8.84	8.71	8.58	8.45
18°C	9.67	9.54	9.41	9.29	9.16	9.04	8.91	8.79	8.66	8.54	8.41	8.28
19°C	9.47	9.35	9.23	9.11	8.98	8.86	8.74	8.61	8.49	8.37	8.24	8.12
20°C	9.29	9.17	9.05	8.93	8.81	8.69	8.57	8.45	8.33	8.20	8.08	7.96
21°C	9.11	9.00	8.88	8.76	8.64	8.52	8.40	8.28	8.17	8.05	7.93	7.81
22°C	8.94	8.83	8.71	8.59	8.48	8.36	8.25	8.13	8.01	7.90	7.78	7.67
23°C	8.78	8.66	8.55	8.44	8.32	8.21	8.09	7.98	7.87	7.75	7.64	7.52
24°C	8.62	8.51	8.40	8.28	8.17	8.06	7.95	7.84	7.72	7.61	7.50	7.39
25°C	8.47	8.36	8.25	8.14	8.03	7.92	7.81	7.70	7.59	7.48	7.37	7.26
26°C	8.32	8.21	8.10	7.99	7.89	7.78	7.67	7.56	7.45	7.35	7.24	7.13
27°C	8.17	8.07	7.96	7.86	7.75	7.64	7.54	7.43	7.33	7.22	7.11	7.01
28°C	8.04	7.93	7.83	7.72	7.62	7.51	7.41	7.30	7.20	7.10	6.99	6.89
29°C	7.90	7.80	7.69	7.59	7.49	7.39	7.28	7.18	7.08	6.98	6.87	6.77
30°C	7.77	7.67	7.57	7.47	7.36	7.26	7.16	7.06	6.96	6.86	6.76	6.66

Table 4: Approximate Barometric Pressure at Different Elevations					
Elevation (m)	**Pressure (mm Hg)**	**Elevation (m)**	**Pressure (mm Hg)**	**Elevation (m)**	**Pressure (mm Hg)**
0	760	800	693	1600	628
100	748	900	685	1700	620
200	741	1000	676	1800	612
300	733	1100	669	1900	604
400	725	1200	661	2000	596
500	717	1300	652	2100	588
600	709	1400	643	2200	580
700	701	1500	636	2300	571

Interdependence of Plants and Animals

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. The Dissolved Oxygen Probe must be calibrated the first day of use. Follow the pre-lab procedure to prepare and calibrate the Dissolved Oxygen Probe. To save time, you may wish to store the calibration values on paper. The students can then skip the pre-lab procedure. They will have the calibration values available for manual entry in case the values stored in the program are lost.

3. In order for the Dissolved Oxygen Probe to warm up and stay polarized, power to the sensor must be continuous. Go! Link or EasyLink, with a computer, and the TI-Nspire Lab Cradle deliver continuous power once the data-collection software is started. However, EasyLink or Go!Link with a handheld will lose power when the TI handheld goes to sleep (APD™). If power to the sensor is disrupted, the sensor must be warmed up for 10 minutes before calibrating or taking readings. To avoid having to warm up the sensor again, students must press a button on the handheld every few minutes to keep it awake.

4. When using a TI-Nspire handheld with an EasyLink or Go!Link interface, we recommend that the handhelds power standby feature be set to 30 minutes. To set this feature, select Settings ►Handheld Setup from the TI-Nspire home screen. Change the Power Standby feature to 30 minutes. You may want to set this back after completing this experiment.

5. As a time-saving measure, instruct the students at the end of class to leave the data-collection program running. This will keep power going to the probes. When the next group of students comes in, they can begin at Step 5 of the procedure. They can skip Steps 1–5 because the initial group of students has completed all of the setup. Have the last group of students for the day shut everything off and put things away.

6. The pond water should be adjusted to pH 7 before class begins. Use 0.1 M NaOH or 0.1 M HCl to adjust the pH. Be sure the elodea are fresh and healthy.

7. Florescent lamps should be used as a source of light. They should be on for the entire 24 hour period, set a few inches from the tubes. If the tubes are water tight, as they should be, test tube racks are not necessary. Students can place them horizontally on a table and the light can be lowered until it is just above the tubes.

8. Wrap the test tubes thoroughly in aluminum foil if they require darkness, or place them in a darkened part of the room. If there are not a sufficient number of test tube racks for these, place the set of four wrapped tubes in a small beaker.

9. Between classes, store the Dissolved Oxygen Probes in a beaker of distilled water. At the end of the day, be sure to empty out the electrode filling solution in the Dissolved Oxygen Probe and rinse the inside of the membrane cap with distilled water.

10. If you have a pH System, but do not have a Dissolved Oxygen Probe, the experiment may be modified to indirectly investigate carbon dioxide levels using only the pH System.

11. When taking dissolved oxygen readings, the students should allow ample time for the readings to stabilize. In some instances this can take 60 seconds.

12. Each student team should use the same set of equipment to make measurements each day.

13. When setting up the Dissolved Oxygen Probe, be sure to remove the blue plastic cap from the end of the probe. The cap is made of a soft plastic material and easily slides off the probe end.

14. Elodea canadensis is a good alternative for those who live in any area to which it is illegal to ship Elodea. Other aquatic plants may work equally well.

ANSWERS TO QUESTIONS

1. Consider the snails.
    a. Snails produce CO_2 when in the light. The pH decreased, meaning the acidity increased. Higher acidity means more CO_2 is dissolved. A snail was the only organism present to produce the CO_2.
    b. Snails consume O_2 when in the light. The DO decreased, so less O_2 is dissolved. A snail was the only organism present to consume the O_2.
    c. Experimental Test Tube: 2. Control Test Tube: 1.
    d. Snails produce CO_2 when in the dark. The pH decreased, so the acidity increased. Higher acidity means more CO_2 is dissolved. A snail was the only organism present to produce the CO_2.
    e. Snails consume O_2 in the dark. The DO decreased, so less O_2 is dissolved. A snail was the only organism present to consume the O_2.
    f. Experimental Test Tube: 6. Control Test Tube: 5.

2. Consider the Elodea.
    a. Elodea consume CO_2 when in the light. The pH increased, so the acidity decreased. Lower acidity means less CO_2 is dissolved. Elodea was the only organism present to consume the CO_2.
    b. Elodea produce O_2 when in the light. The DO increased, so more O_2 is dissolved. Elodea were the only organism present to make the O_2.
    c. Experimental Test Tube: 3. Control Test Tube: 1.
    d. Elodea produce CO_2 in the dark. The pH decreased, so the acidity increased. Higher acidity means more CO_2 is dissolved. Elodea were the only organism present to produce the CO_2.
    e. Elodea consume O_2 in the dark. The DO decreased, so less O_2 is dissolved. Elodea was the only organism present to consume the O_2.
    f. Experimental Test Tube: 7. Control Test Tube: 5.

3. Consider the elodea placed in the snail's water on days 2–3.
    a. Elodea consumes the CO_2 that snails release when in the light. CO_2 increased when a snail was alone in the pond water, yet it decreased when elodea replaced the snail. Some of the CO_2 used by the plant must have come from the snail. The increase in pH was greater for elodea in Tube 2 of Table 2 than in Tube 3, Table 1, so more CO_2 was consumed from water the snail was in.

  b. Elodea produces O_2 when in the light, as above. The DO increased, so more O_2 is dissolved.

  c. Experimental Test Tube: 2. Control Test Tube: 1.

  d. The pH change in Test Tube 6 from Day 2 to Day 3 was negative. This indicates that the plant did not remove the CO_2; rather, it was added as the plant respired. Elodea did not consume CO_2 in the dark, and did not use the CO_2 from the snail.

  e. Elodea consumed O_2 when in the dark. The DO decreased, so the plant respired when in the dark.

  f. Experimental Test Tube: 6. Control Test Tube: 5.

4. Consider the snail placed in the elodea's water on days 2–3.

  a. The snail did release CO_2 in the light, as during Day 1 – Day 2. The pH decreased, so the acidity increased. Higher acidity means more CO_2 is dissolved.

  b. Snails consume O_2 that elodea produce in the light. 2b (above) shows that plants make O_2 in the light. The DO change in Test Tube 3 from Day 2 to Day 3 was negative. This indicated that the snail removed the O_2 made by elodea.

  c. Experimental Test Tube: 3. Control Test Tube: 1.

  d. The snail did release CO_2 in the dark, as the pH decreased.

  e. The snail did consume O_2 while in the dark, as the DO decreased.

  f. Experimental Test Tube: 7. Control Test Tube: 5.

5. Here is a summary of the relationship between snails and plants in a pond:

  • Snails can produce CO_2 in both light and dark conditions.

  • Elodea produce CO_2 in the dark, but consume CO_2 when illuminated with light.

  • In the light, elodea can use the CO_2 that snails produce.

  • In the dark, elodea cannot use the CO_2 that snails produce.

  • Snails can consume O_2 in both light and dark conditions.

  • Elodea produce O_2 in the light, but consume O_2 when in the dark.

  • In the light, snails can use the O_2 elodea produce.

  • In the dark, elodea do not produce O_2, so snails cannot use it.

6. Answers may vary. The answer depends upon the rate of photosynthesis vs. the rate of respiration in Test Tube 4.

  • If the rate of respiration by the snail and plant was greater than the rate of photosynthesis, 3a and 3b might be answered differently. The pH would remain low and the amount of DO would also be low.

  • If the rate of respiration by the snail and plant was less than the rate of photosynthesis, 4a and 4b might be answered differently. The pH difference would be higher, indicating a removal of CO_2. The amount of dissolved oxygen would also be high. This might mask the respiration by both plant and animal.

7. Answers may vary.

Heart Rate and Physical Fitness

The circulatory system is responsible for the internal transport of many vital substances in humans, including oxygen, carbon dioxide, and nutrients. The components of the circulatory system include the heart, blood vessels, and blood. Heartbeats result from electrical stimulation of the heart cells by the *pacemaker,* located in the heart's inner wall of the right atrium. Although the electrical activity of the pacemaker originates from within the heart, the rhythmic sequence of impulses produced by the pacemaker is influenced by nerves outside the heart. Many things might affect heart rate, including the physical fitness of the individual, the presence of drugs such as caffeine or nicotine in the blood, and the age of the person.

As a rule, the maximum heart rate of all individuals of the same age and sex is about the same. However, the time it takes individuals to reach that maximum level while exercising varies greatly. Since physically fit people can deliver a greater volume of blood in a single cardiac cycle than unfit individuals, they can usually sustain a greater work level before reaching the maximum heart rate. Physically fit people not only have less of an increase in their heart rate during exercise, their heart rate recovers to the resting rate more rapidly than unfit people.

In this experiment, you will evaluate your physical fitness. An arbitrary rating system will be used to "score" fitness during a variety of situations. Tests will be made while in a resting position, in a prone position, as well as during and after physical exercise.

Important: Do not attempt this experiment if physical exertion will aggravate a health problem. Inform your instructor of any possible health problems that might be affected if you participate in this exercise.

OBJECTIVES

In this experiment, you will

- Determine the effect of body position on heart rates.
- Determine the effect of exercise on heart rates.
- Determine your fitness level.
- Correlate the fitness level of individuals with factors such as smoking, the amount of daily exercise, and other factors identified by students.

MATERIALS

TI-Nspire handheld **or**
  computer and TI-Nspire software
data-collection interface
Vernier Hand-Grip Heart Rate Monitor **or**
  Vernier Exercise Heart Rate Monitor

stepping stool, 45 cm (18 inches) high
dropper bottle with saline solution
  (only for use with the Exercise HRM)
stopwatch or clock with second hand

PROCEDURE

Each person in a lab group will take turns being the subject and the tester. When it is your turn to be the subject, your partner will be responsible for recording the data on your lab sheet.

1. Connect the receiver module of the Heart Rate Monitor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

2. Set up data collection.

   a. Choose New Experiment from the ⚙ Experiment menu. Choose Collection Setup from the ⚙ Experiment menu. Enter **15** as the experiment duration in seconds. Choose the Strip Chart option and select OK.
   b. Click on the Graph View tab (📈) to view the graph. Choose Y-axis Columns ▶ Signal from the 📈 Graph menu.
   c. Press Ctrl+D to display the Sensor Console at the bottom of the page.

3. Set up the Heart Rate Monitor. Follow the directions for your type of Heart Rate Monitor.

   Using a Hand-Grip Heart Rate Monitor

   a. Grasp the handles of the Hand-Grip Heart Rate Monitor. Place the fingertips of each hand on the reference areas of the handles (see Figure 1).
   b. The left hand grip and the receiver are both marked with an alignment arrow. When collecting data, be sure that the arrow labels on each of these devices are in alignment (see Figure 2) and that they are not too far apart. The reception range of the plug-in receiver is 80–100 cm, or 3 feet.
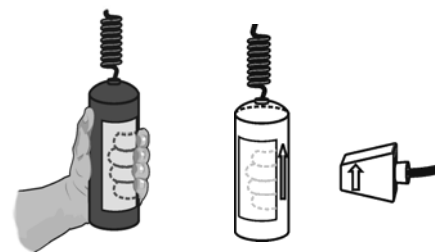
Figure 1   *Figure 2*

   Using an Exercise Heart Rate Monitor

   a. If you have an older sensor that does not auto-ID, manually set up the sensor.
   b. Depending upon your size, select a small- or large-size elastic strap. Secure one of the plastic ends of the elastic strap to the transmitter belt. It is important that the strap provide a snug fit of the transmitter belt.
   c. Wet each of the electrodes (the two textured oval areas on the underside of the transmitter belt) with 3 drops of saline solution.
   d. Secure the transmitter belt against the skin directly over the base of the rib cage (see Figure 3). The POLAR logo on the front of the belt should be centered. Adjust the elastic strap to ensure a tight fit.

chest belt
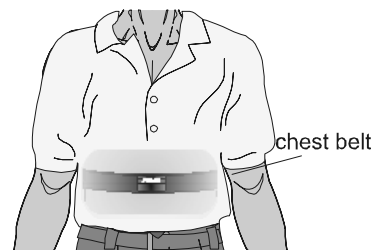
Figure 3

   e. Take the receiver module of the Heart Rate Monitor in your right hand. Remember that the receiver must be within 80 cm of the transmitter in the Heart Rate Monitor belt.

4. Start data collection. Determine that the sensor is functioning correctly. The readings should be consistent and within the normal range of the individual, usually between 55 and 80 beats per minute. When you have determined that the equipment is operating properly, stop data collection and proceed to Step 5.

5. Collect data.

   a. Start data collection ( ).

   b. Instruct the subject to stand upright for 2 minutes.

   c. When the 2 minutes have passed, record the subject's Standing Heart Rate in Table 1.

   d. Instruct the subject to recline on a clean surface or table for 2 minutes.

   e. When the 2 minutes have passed, record the subject's Reclining Heart Rate in Table 1.

   f. Instruct the subject to quickly stand up and remain standing still.

   g. Record the subject's peak heart rate observed after standing as the Reclining to Standing Heart Rate in Table 1.

   h. Instruct the subject to rest for 2 minutes.

   i. After the rest period, record the subject's heart rate as the Pre-exercise Heart Rate in Table 1.

   j. Instruct the subject to begin the Step Test as describe below.

   Step Test

- Place the right foot on the top step of the stool.

- Place the left foot completely on the top step of the stool next to the right foot.

- Place the right foot back on the floor.

- Place the left foot completely on the floor next to the right foot.

- This stepping cycle should take 3 seconds to complete.

- Repeat until the test subject completes 5 steps.

   k. When five steps have been completed, record the heart rate as the After 5 Steps Heart Rate in Table 1. Quickly move to the next step.

   l. Instruct the subject to stop. They should remain standing and relatively still.

   m. With a stopwatch or clock, begin timing to determine the subject's recovery time. Monitor the heart rate readings and stop timing when the readings return to the pre-exercise heart rate value recorded in Step 5i. Record the recovery time in Table 1.

   n. Stop data collection ( ).

6. Repeat Step 5 with a new test subject until everyone in your group has been tested.

DATA

Table 1		
Condition	Rate or time	Points
Standing heart rate	beats/min	
Reclining heart rate	beats/min	
Reclining to standing	beats/min	
Heart rate increase after standing	beats/min	
Pre-exercise heart rate	beats/min	
After 5 steps	beats/min	
Recovery time	seconds	
Endurance	beats/min	
	Total points:	

PROCESSING THE DATA

1. Locate your Standing Heart Rate in Table 2 and record the corresponding fitness point value in Table 1.

Table 2: Standing			
Beats/min	Points	Beats/min	Points
60–70	12	101–110	8
71–80	11	111–120	7
81–90	10	121–130	6
91–100	9	131–140	4

2. Locate your Reclining Heart Rate in Table 3 and record the corresponding fitness point value in Table 1.

Table 3: Reclining			
Beats/min	Points	Beats/min	Points
50–60	12	81–90	8
61–70	11	91–100	6
71–80	10	101–110	4

3. Subtract your Reclining Heart Rate from your Reclining to Standing Heart Rate to find your Heart Rate Increase after Standing. Record this value in Table 1

4. Locate the row corresponding to your Reclining Heart Rate in Table 4 and use your heart rate increase value to determine the proper fitness points. Record the corresponding fitness point value in Table 1.

Table 4: Reclining to Standing					
Reclining heart rate	Heart rate increase after standing				
	0–10	11–17	18–24	25–33	34+
50–60	12	11	10	8	6
61–70	12	10	8	6	4
71–80	11	9	6	4	2
81–90	10	8	4	2	0
91–100	8	6	2	0	0
101–110	6	4	0	0	0

5. Locate your recovery time in Table 5 and record the corresponding fitness point value in Table 1. If your recovery time is greater than 120 seconds, record a value of 6 points.

Table 5: Recovery	
Time (s)	Points
0–30	14
31–60	12
61–90	10
91–120	8

6. Subtract your Pre-exercise Heart Rate from your After 5 Steps Heart Rate. Record this heart rate increase in the endurance row of Table 1.

7. Locate the row corresponding to the Pre-exercise Heart Rate in Table 6 and use the heart rate increase value to determine the proper fitness points. In Table 1, record the fitness points.

Table 6: Endurance					
Pre-exercise heart rate	Heart rate increase after exercise				
	0–10	11–20	21–30	31–40	41+
60–70	12	12	10	8	6
71–80	12	10	8	6	4
81–90	12	10	7	4	2
91–100	10	8	6	2	0
101–110	8	6	4	1	0
111–120	8	4	2	1	0
121–130	6	2	1	0	0
131+	5	1	0	0	0

8. Total all the fitness points recorded in Table 1. Determine your personal fitness level using the scale below. Mark your fitness level in Table 1 and on the scale below.

Low Fitness   **Average Fitness**   **Exceptional Fitness**

20   30   40   50   60
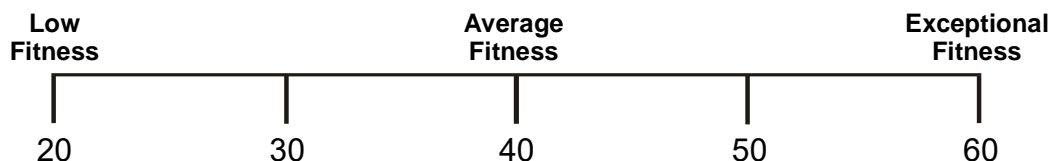
QUESTIONS

1. How did your heart rate change after moving from a standing position to a reclining position? Is this what you expected? How do you account for this?

2. How did your heart rate change after moving from a reclining position back to a standing position? Is this what you expected? How do you account for this?

3. Predict what your heart rate might be if you had exercised for twice the length of time that you actually did. Explain.

4. How does your maximum heart rate compare to other students in your group? Is this what you expected? How do you account for this?

5. Why would athletes need to work longer and harder before their heart rates were at the maximum value?

6. How do you evaluate your physical fitness? Do you agree with the rating obtained from this experiment? Explain.

7. Current research indicates that most heart attacks occur as people get out of bed after sleep. Account for this observation.

EXTENSIONS

1. Using a sphygmomanometer or a Vernier Blood Pressure Sensor, learn how to measure blood pressure. Compare a person's blood pressure when reclining, to that of the same person immediately after standing from a reclined position. Relate the change in blood pressure to the heart rate values measured when going from reclining to standing.

2. Design an anonymous survey to be taken by each member of your class. In the survey, ask questions that you think might influence the test results. Examples might include:
    *   Did you have more than 6 hours of sleep last night?
    *   Do you regularly drink caffeinated beverages?
    *   Gender?
    *   Age?

3. Try to determine whether any of the variables from your survey show a statistical link to fitness. You may want to use a statistical T-Test to determine whether a relationship between the variable and physical fitness is due to chance.

Heart Rate
and Physical Fitness

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment works equally well with either a Hand-Grip Heart Rate Monitor or an Exercise Heart Rate Monitor.

3. The receiver module of either type of Heart Rate Monitors will receive signals from the closest transmitter source. To avoid confusion or erroneous readings, have the test subjects from different lab teams stay at least 2 m apart.

4. Computer monitors can be a source of electrical interference. Keep the receiver module of the Heart Rate Monitor as far as possible from any computer monitors in the class.

5. It is possible to alter your heart rate by simply decreasing your respiratory rate and relaxing. Encourage students to stay alert and to breathe normally.

6. The Exercise Heart Rate Monitor includes a transmitter belt, receiver module, large elastic strap, and small elastic strap.

7. It is important to have good contact between the transmitter belt and the test subject when using the Exercise Heart Rate Monitor. It is very important that the belt fit snugly, but not too tight. Both electrodes should be wet with either saline solution or contact lens solution. A 5% salt solution works well and can be prepared by adding 5 g of NaCl per 100 mL of solution. Typical symptoms of inadequate contact with the electrodes are a noisy signal with erroneous peaks, missing heart beat readings, or a flat-line display. If the students receive a flat reading with no heart rate detected, have them move the transmitter and the receiver closer together. The range of the transmitter in the chest belt is 80 cm.

8. Data is not stored by the software for this experiment, requiring them to record the heart rate values as they are being collected. Students will monitor the strip chart graph of the heart rate signal to ensure the sensor is registering the signal. The students will monitor the heart rate values from the sensor console.

9. You must start data collection for the rate meter to show values.

10. If a larger meter is desired, rather than launching the sensor console, you can adjust the page layout to show two instances of the DataQuest app, split horizontally. One app can show the graph of the signal, while the second app can show the meter. If using this configuration, it is recommended that you hide the details boxes (select Hide Details from the Options menu) in both DataQuest applications.

SAMPLE RESULTS

Sample data from two students are listed below. The first student was a 17 year old male and the second was a 16 year old female.

Condition	Rate, Student 1 (beats/min) or time	Points	Rate, Student 2 (beats/min) or time	Points
Standing heart rate	73	11	93	9
Reclining heart rate	54	12	69	11
Reclining to standing	69	11	84	8
Pre-exercise heart rate	72		93	
After 5 steps	87		116	
Recovery rate	57 s	12	98 s	10
Endurance	14	10	23	2
Total		56		40

Table 1: Sample Student Data

ANSWERS TO QUESTIONS

1. The heart rate generally lowers when a student moves from a standing position to a reclining position. The forces of gravity do not have to be overcome for blood to flow while in a reclining position.

2. The heart rate generally increases when a student moves from a reclining position to a standing position. The forces of gravity do have to be overcome while in a standing position.

3. The heart rate generally increases when a student exercises twice as long. It will not increase to twice the rate, however, because the heart will adjust to the new stress and increase the blood flow to meet the body's needs. The blood flow is proportional to the heart rate. When the blood flow is appropriate, the heart rate will no longer continue increasing.

4. Answers will vary. Factors such as weight, regular exercise, health, etc., may play a part in determining the maximum heart rate of a student.

5. An athlete's heart is more efficient at moving blood through the body. Each contraction of an athlete's heart moves a greater volume of blood than an average individual. More blood per contraction means more oxygen for the body's cells. Because of this athletes must work harder to increase their heart rate to its maximum values.

6. Answers will vary.

7. The heart rate increases significantly when an individual moves from a reclining position to a standing position. The force of gravity on the blood makes the heart work harder, as in Question 2. This increased stress might provoke a heart attack in susceptible people.

Ventilation and Heart Rate

In this experiment, you will investigate the effect of altering the levels of oxygen and carbon dioxide on the rate at which the heart beats. Two different methods of ventilation will be used to investigate this phenomenon. The first method, *hyperventilation*, is when the breathing rate of an organism is greater than what is necessary for proper exchange of oxygen and carbon dioxide. This will be achieved by a period of rapid breathing by the test subject. The second method, *hypoventilation*, occurs when there is a decrease in ventilation without a decrease in oxygen consumption or carbon dioxide production by the body. True hypoventilation is usually the result of a disease. The test subject will simulate this condition by holding his or her breath for a period of time. Heart rate will be monitored using a Heart Rate Monitor.

OBJECTIVES

In this experiment, you will

- Monitor the heart rate of the test subject using a Heart Rate Monitor.
- Evaluate the effects of hyperventilation and hypoventilation on heart rate.

MATERIALS

TI-Nspire handheld **or**
   computer and TI-Nspire software
data-collection interface
Vernier Hand-Grip Heart Rate Monitor **or**
   Vernier Exercise Heart Rate Monitor

dropper bottle with saline solution
   (only for use with the Exercise HRM)

PROCEDURE

Each person in a lab group will take turns being the subject and the tester. When it is your turn to be the subject, your partner will be responsible for recording the data on your lab sheet.

1. Connect the receiver module of the Heart Rate Monitor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

2. Choose New Experiment from the 📟 Experiment menu. Choose Collection Setup from the 📟 Experiment menu. Choose the Data Marker option and select OK.

3. Set up the Heart Rate Monitor. Follow the directions for your type of Heart Rate Monitor.

    Using a Hand-Grip Heart Rate Monitor

    a. Grasp the handles of the Hand-Grip Heart Rate Monitor. Place the fingertips of each hand on the reference areas of the handles (see Figure 1).

    b. The left hand grip and the receiver are both marked with an alignment arrow. When collecting data, be sure that the arrow labels on each of these devices are in alignment (see Figure 2) and that they are not too far apart. The reception range of the plug-in receiver is 80–100 cm, or 3 feet.
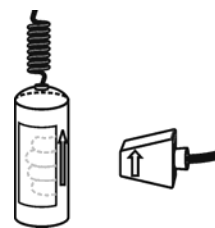
Figure 1   *Figure 2*

Using an Exercise Heart Rate Monitor

a. Depending upon your size, select a small- or large-size elastic strap. Secure one of the plastic ends of the elastic strap to the transmitter belt. It is important that the strap provide a snug fit of the transmitter belt.

b. Wet each of the electrodes (the two textured oval areas on the underside of the transmitter belt) with 3 drops of saline solution.

c. Secure the transmitter belt against the skin directly over the base of the rib cage (see Figure 3). The POLAR logo on the front of the belt should be centered. Adjust the elastic strap to ensure a tight fit.

d. Take the receiver module of the Heart Rate Monitor in your right hand. Remember that the receiver must be within 80 cm of the transmitter in the Heart Rate Monitor belt.

chest belt

Figure 3

4. Start data collection (▶). Determine that the sensor is functioning correctly. The readings should be consistent and within the normal range of the individual, usually between 55 and 80 beats per minute. When you have determined that the equipment is operating properly, stop data collection (■) and proceed to Step 5.
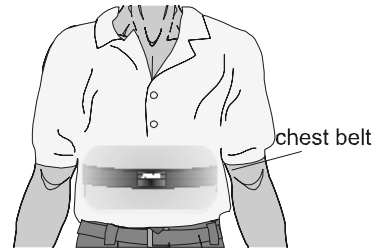
Part I Hyperventilation

5. Collect data while the subject hyperventilates.

a. Instruct the subject to sit still in a chair and breathe normally.
b. Start data collection (▶).
c. After collecting data for 30 seconds, click the Add Data Marker button (📑) and have the subject make rapid shallow breaths for the next 30 seconds.
d. After 30 seconds of hyperventilation, click the Add Data Marker button (📑) and have the subject breathe normally until data collection stops.

6. Labeling the marked data points.

a. After data collect is complete. Double click on the point marked in Step 5c. Label this point **Start**.
b. Double click on the point marked in Step 5d. Label this point as **Stop**.

7. Click any data point and use ► and ◄ to examine the data pairs on the displayed graph. The coordinates of the points are displayed in the Graph View details box. Record the heart rate data in Table 1 for every 10 second interval.

Part II Hypoventilation (simulated)

8. Click the Store Latest Data Set button (📥) to save the hyperventilation data.

9. Collect data while the subject hypoventilates.

a. Instruct the subject to sit still in a chair and breathe normally.
b. Start data collection (▶).
c. After collecting data for 30 seconds, click the Add Data Marker button (📑) and have the subject take a large breath and hold it as long as possible. *Note: the subject should not hold his or her breath longer than 60 seconds.*
d. When the subject releases their breath, click the Add Data Marker button (📑). The subject should breathe normally until data collection stops.

10. Labeling the marked data points.

    a. After data collect is complete. Double click on the point marked in Step 9c. Label this point **Hold**.

    b. Double click on the point marked in Step 9d. Label this point as **Release**.

11. Examine the data and record the heart rate data in Table 1 for every 10 second interval.

12. Click **run2** and select All. Both runs will now be displayed on the same graph axes.

13. (optional) Print a graph of heart rate *vs.* time (with two curves displayed). Label each curve as "hyperventilation" or "hypoventilation".

DATA

Time (s)	10	20 30	40 50	60 70	80 90				100	110	120
Hyperventilation											
Hypoventilation											

QUESTIONS

1. What happens to the heart rate during hyperventilation?

2. How long did it take the subject's heart rate to respond to hyperventilation?

3. What happens to the heart rate during hypoventilation?

4. How long did it take the subject's heart rate to respond to hypoventilation?

5. List several factors that you think may have caused the test subject's heart rate to change in each of the trials.

6. What happens to the oxygen levels in your lungs during hyperventilation? Carbon dioxide levels?

7. In what way would the change in heart rate that corresponds with holding your breath be advantageous in other types of organisms? What organisms might commonly exhibit such an adaptation?

TEACHER INFORMATION

Ventilation and Heart Rate

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment works equally well with either a Hand-Grip Heart Rate Monitor or an Exercise Heart Rate Monitor.

3. It is important to have good contact between the transmitter belt and the test subject when using the Exercise Heart Rate Monitor. It is very important that the belt fit snugly, but not too tight. Both electrodes should be wet with either saline solution or contact lens solution. A 5% salt solution works well and can be prepared by adding 5 g of NaCl per 100 mL of solution. Typical symptoms of inadequate contact with the electrodes are a noisy signal with erroneous peaks, missing heart beat readings, or a flat-line display. If the students receive a flat reading with no heart rate detected, have them move the transmitter and the receiver closer together. The range of the transmitter in the chest belt is 80 cm.

4. Computer monitors can be a source of electrical interference. Keep the receiver module of the Exercise Heart Rate Monitor as far as possible from any computer monitors in the class.

5. The receiver module of either type of Heart Rate Monitors will receive signals from the closest transmitter source. To avoid confusion or erroneous readings, have the test subjects from different lab teams stay at least 2 m apart.

6. It is possible to alter your heart rate by simply decreasing your respiratory rate and relaxing. Encourage students to stay alert and breathe normally.

7. Anyone prone to dizziness, nausea, or headaches should not be selected as the test subject.

8. You can have your students create graphs of the data recorded in the data table by doing the following:

   a. Insert a new **problem** in your TI-Nspire document and launch the DataQuest App.
   b. Click on the Table View tab (▦) to view the table.
   c. Double-click on the x-column to open the column options.
   d. Change the Name to **Time** and enter **s** as the units.
   e. Select the Generate Values option. Enter **10** for the Start value, **120** as the end value, and **10** as the increment. Select OK to generate the values.
   f. Double-click on the y-column.
   g. Change the Name to **Heart Rate** and enter **BPM** as the units. Select OK.
   h. Double-click the run name and enter **HyperVent** as the Data Set name. Select OK.
   i. Enter the data in the table.
   j. Select New Data Set from the ▦ Data menu.
   k. Repeat Steps c – i. Be sure to use **HypoVent** as the data set name.
   l. Click on the Graph View tab (📈) to view the graph.

SAMPLE RESULTS

Table 1									
Time (s)	10	20 30 40 50 60 70 80 90					100	110	120
Hyperventilation	77	75 71 77 80 82 86 88 89 88 80 73							
Hypoventilation	72	73 76 78 74 64 63 66 69 76 77 82							
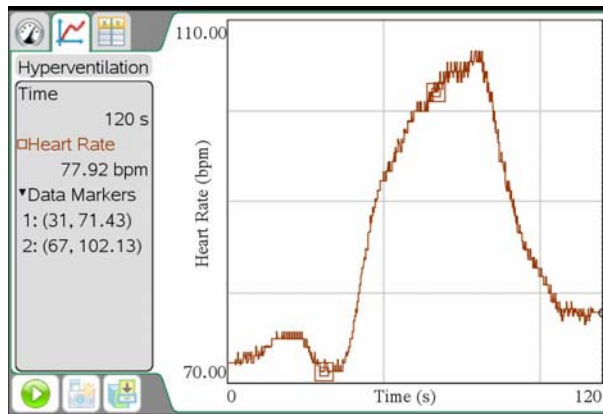
Typical graph for hyperventilation   *Typical graph for hypoventilation*
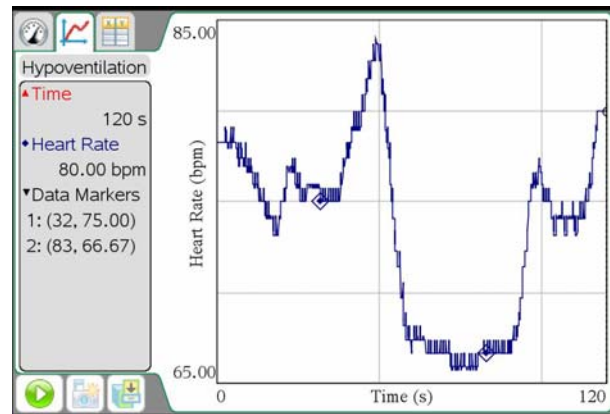
ANSWERS TO QUESTIONS

1. Heart rate will increase during hyperventilation.

2. This would be the time between the marked start of hyperventilation and the time the heart rate begins to rise. For the sample data, this was approximately 2–5 seconds.

3. Heart rate will decrease during hypoventilation.

4. This would be the time between the marked start of holding your breath and the time the heart rate begins to decrease. For the sample data, this was approximately 18 seconds.

5. Answers will vary. Factors that may be listed are blood carbon dioxide concentrations, blood oxygen concentrations, blood pressure, body temperature, and hormones.

6. Hyperventilation results in an increase of oxygen levels in the alveoli of the lungs and a decrease in carbon dioxide levels. The opposite results during hypoventilation.

7. When heart rate decreases, so does the rate at which carbon dioxide levels increase in the lungs. By slowing the increase of carbon dioxide in the lungs, an organism could hold its breath for a longer period of time. Aquatic mammals are a good example of organisms that use such an adaptation. This allows whales to stay under water for as long as one hour. A seal's heart rate can change from 150 beats per minute to 10 beats per minute when it dives underneath the water to search for food.

Freezing and Melting of Water

Freezing temperature, the temperature at which a substance turns from liquid to solid, and melting temperature, the temperature at which a substance turns from a solid to a liquid, are characteristic physical properties. In this experiment, the cooling and warming behavior of a familiar substance, water, will be investigated. By examining graphs of the data, the freezing and melting temperatures of water will be determined and compared.

OBJECTIVES

In this experiment, you will

- Collect temperature data during the freezing and melting of water.
- Analyze graphs to determine the freezing and melting temperatures of water.
- Determine the relationship between the freezing and melting temperatures of water.
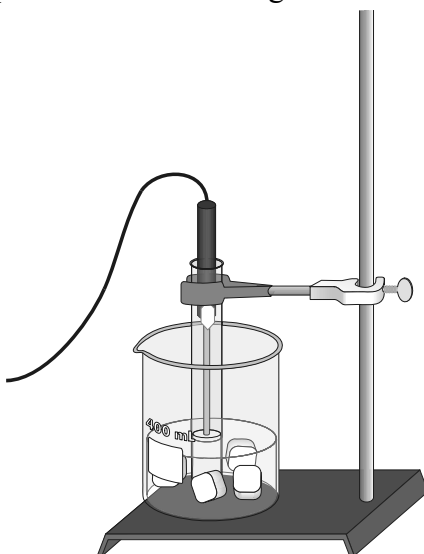
Figure 1

MATERIALS

TI-Nspire handheld **or**	400 mL beaker
computer and TI-Nspire software	10 mL graduated cylinder
EasyTemp **or** Go!Temp **or**	test tube (25 x 150 mm)
Temperature Probe and data-collection interface	salt
ring stand with utility clamp	ice
stirring rod	water

PROCEDURE

Part I Freezing

1. Put about 100 mL of water and 6 ice cubes into a 400 mL beaker.

2. Put 5 mL of water into a test tube and use a utility clamp to fasten the test tube to a ring stand. The test tube should be situated above the water bath. Place the Temperature Probe into the water inside the test tube.

3. Connect the Temperature Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using an EasyTemp or Go!Temp, you do not need a data-collection interface.)

4. Choose New Experiment from the ⚙ Experiment menu. Choose Collection Setup from the ⚙ Experiment menu. Enter **0.2** as the rate (samples/second) and **900** as the experiment duration in seconds (15 minutes). The number of points collected should be 181. Select OK.

5. When everything is ready, start data collection (▶). Lower the test tube into the ice-water bath.

6. Soon after lowering the test tube, add 5 spoons of salt to the beaker and stir with a stirring rod. Continue to stir the ice-water bath throughout the remainder of Part I.

7. Slightly, but continuously, move the Temperature Probe during the first 10 minutes of Part I. Be careful to keep the probe in, and not above, the ice as it forms. When 10 minutes have gone by, stop moving the probe and allow it to freeze into the ice. Add more ice cubes to the beaker as the original ice cubes get smaller.

8. Data collection will stop after 900 seconds. Keep the test tube *submerged* in the ice-water bath until Step 11.

9. Analyze the flat part of the graph to determine the freezing temperature of water.

    a. Identify the flat portion of the graph that represents freezing. Select the data in the flat portion of the graph.
    b. Choose Statistics from the 📈 Analyze menu.
    c. Record the mean (average) temperature. This is your value for the freezing temperature of water.

Part II Melting

10. Click the Store Latest Data Set button (📇) to store data from the first run.

11. Start data collection (▶), then raise the test tube and fasten it in a position above the ice-water bath. Do not move the Temperature Probe during Part II.

12. Dispose of the ice water as directed by your teacher. Obtain 250 mL of warm tap water in the beaker. When 12 minutes have passed, lower the test tube and its contents into this warm-water bath.

13. Data collection will stop after 900 seconds. Analyze the flat part of the graph to determine the melting temperature of water.

   a. Identify a flat portion of the graph that represents melting. Select a region of data in the flat potion of the graph.
   b. Choose Statistics from the ![icon] Analyze menu.
   c. Record the mean (average) temperature. This is your value for the melting temperature of ice.

14. A good way to compare the freezing and melting curves is to view both sets of data on one graph. Click **run2** and select All. Both runs will now be displayed on the same graph. Sketch or print this graph.

DATA

Freezing temperature of water (°C)	
Melting temperature of ice (°C)	

QUESTIONS

1. What happened to the water temperature during freezing? During melting?

2. According to your data and graph, what is the freezing temperature of water? The melting temperature? Express your answers to the nearest 0.1°C.

3. How does the freezing temperature of water compare to the melting temperature of ice?

4. Tell if the *kinetic energy* of the water in the test tube increases, decreases, or remains the same in each of these time segments during the experiment when:

   a. the temperature is changing before and after the water reaches its freezing point in Part I.
   b. the temperature remains constant in Part I.
   c. the temperature is changing before and after the ice reaches its melting point in Part II.
   d. the temperature remains constant in Part II.

5. In those parts of Question 4 in which there was no kinetic energy change, tell if *potential energy* increased or decreased.

TEACHER INFORMATION

Freezing and Melting of Water

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This entire experiment requires a full 45–50 minute period.

3. The freezing and melting temperatures of water should be within 0°C ± 0.2°C using sensors.

4. Test tubes size 20 × 150 mm work well. Sizes 25 × 150 mm and 18 × 150 mm work, too.

5. A water sample size of 5 mL works well. Larger samples will take more time than is recommended in this procedure.

6. As shown in the first graph in the Sample Results, many of the samples will supercool. Stirring will bring the super-cooled water to the melting temperature plateau.

SAMPLE RESULTS
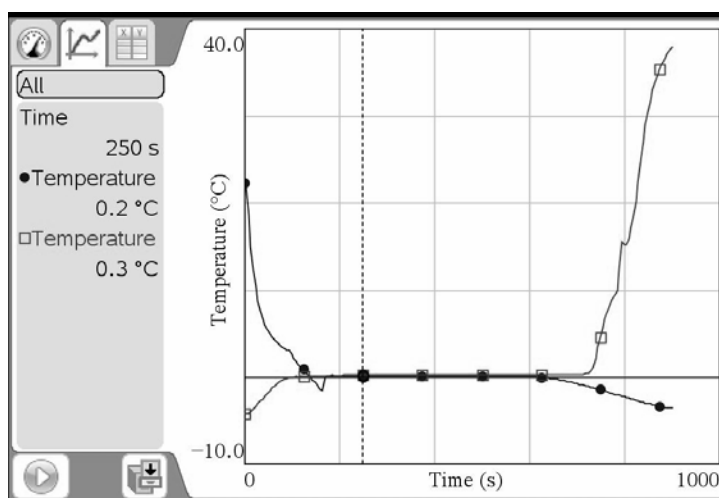
Typical graph for freezing (●) and melting (□) of water.

Freezing temperature of water (°C)	0.02°C
Melting temperature of water (°C)	0.03°C

ANSWERS TO QUESTIONS

1. The water temperature stayed constant near 0°C during freezing and melting.

2. The expected value is 0°C for both the freezing and melting temperatures, but answers may vary slightly.

3. The freezing temperature of water and melting temperature of ice are about the same.

4. a. Average kinetic energy decreases with the temperature decrease at the beginning and end of Part I.
    b. Since there is no temperature change during freezing, average kinetic energy remains constant.
    c. Average kinetic energy increases with the temperature increase at the beginning and end of Part II.
    d. Since there is no temperature change during melting, average kinetic energy is constant.

5. Potential energy decreased during freezing. Potential energy increased during melting.

Boyle's Law: Pressure-Volume Relationship in Gases

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

OBJECTIVES

In this experiment, you will

- Use a Gas Pressure Sensor and a gas syringe to measure the pressure of an air sample at several different volumes.
- Determine the relationship between pressure and volume of the gas.
- Describe the relationship between gas pressure and volume in a mathematical equation.
- Use the results to predict the pressure at other volumes.
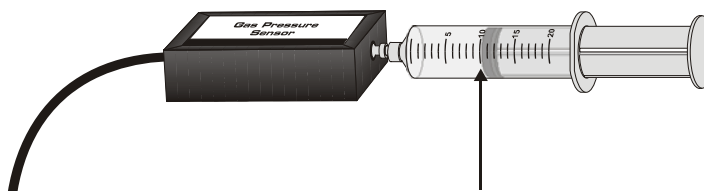
Figure 1

MATERIALS

TI-Nspire handheld **or** computer and TI-Nspire software data-collection interface	Vernier Gas Pressure Sensor 20 mL gas syringe

PROCEDURE

1. Prepare the Gas Pressure Sensor and an air sample for data collection.

   a. With the 20 mL syringe disconnected from the Gas Pressure Sensor, move the piston of the syringe until the front edge of the inside black ring (indicated by the arrow in Figure 1) is positioned at the 10.0 mL mark.

   b. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.

2. Connect the Gas Pressure Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the 🔬 Experiment menu. Choose Collection Mode ► Events with Entry from the 🔬 Experiment menu. Enter **Volume** as the Name and **mL** as the Units. Select OK.

4. To obtain the best data possible, you will need to correct the volume readings from the syringe. Look at the syringe; its scale reports its own internal volume. However, that volume is not the total volume of trapped air in your system since there is a little bit of space inside the pressure sensor.

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

5. You are now ready to collect pressure and volume data. It is easiest if one person works with the gas syringe and another person enters volumes.

   a. Start data collection (▶).
   b. Move the piston so the front edge of the inside black ring (see Figure 2) is positioned at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value displayed on the screen stabilizes.
   c. Click the Keep button (📷) and enter **5.8**, the gas volume (in mL). Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Select OK to store this pressure-volume data pair.
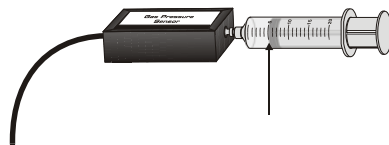
Figure 2

   d. Continue this procedure using syringe volumes of 7.0, 9.0, 11.0, 13.0, 15.0, 17.0, and 19.0 mL. After collecting the second data point, autoscale the graph by choosing Autoscale Now from the 📈 Graph menu.
   e. Stop data collection (⏹).

6. When data collection is complete, a graph of pressure *vs.* volume will be displayed. Click Table View (▦). Record the pressure and volume data values in Table 1.

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

   a. Click the Graph View tab (📈).
   b. Choose Curve Fit ► Power from the 📈 Analyze menu. The curve fit statistics for these two data columns are displayed for the equation in the form

   $$y = ax^b$$

   where *x* is volume, *y* is pressure, *a* is a proportionality constant, and *b* is the exponent of *x* (volume) in this equation. **Note:** The relationship between pressure and volume can be determined from the value and sign of the exponent, *b*.
   c. If you have correctly determined the mathematical relationship, the regression line should very nearly *fit* the points on the graph (that is, pass through or near the plotted points).

8. (optional) If directed by your instructor, proceed directly to the Extension.

DATA

Table 1		
Volume (mL)	Pressure (kPa)	Constant, k (P/V or P•V)

Table 2: Values based on Power Fit	
Volume (mL)	Pressure (kPa)
5.0	
10.0	
15.0	
20.0	

PROCESSING THE DATA

1. With the Power Fit curve still displayed, choose Interpolate from the ▣ Analyze menu. Move the cursor along the regression line until the volume value is 5.0 mL. Record the values in table 2.

2. Continue moving the cursor along the line to find the predicted pressure values for volumes of 10.0, 15.0 and 20.0 mL. Record these values in Table 2.

3. Determine if the relationship between pressure and volume is inverse or direct by finding the proportionality constant, *k*, from the data. The value for *k* will be constant for all values of *P* and *V*. If this relationship is direct, *k* = *P/V*. If it is inverse, *k* = *P·V*.

    a. Choose New Calculated Column from the ▦ Data menu.
    b. Enter **P over V** as the Name, **P/V** as the Short Name, and **kPa/mL** as the Units.
    c. Enter **Pressure/Volume** as the Expression. **Note:** The terms "Pressure" and "Volume" must exactly match the names of these columns. If you are unsure how it was entered, the available column names can be found below the Expression entry box.
    d. Select OK.
    e. Repeat steps a-d for pressure times volume. Enter **P times V** as the Name, **P*V** as the Short Name and **kPa*mL** as the units. Enter **Pressure*Volume** as the Expression.
    f. In the column provided in Table 1, enter the values for *k* from either *P/V* or *P·V*. Choose the calculation for *k* that shows *k* to be relatively constant.

QUESTIONS

1. What does your data show happens to the pressure when the volume is *doubled* from 5 mL to 10 mL?

2. What does your data show happens to the pressure if the volume is *halved* from 20 mL to 10 mL*?*

3. What does your data show happens to the pressure if the volume is *tripled* from 5.0 mL to 15.0 mL?

4. From your answers to the first three questions *and* the shape of the curve in the plot of pressure *vs.* volume, do you think the relationship between the pressure and volume of a confined gas is direct or inverse? Explain your answer.

5. Based on your data, what would you expect the pressure to be if the volume of the syringe was increased to 40.0 mL? Explain or show work to support your answer.

6. Based on your data, what would you expect the pressure to be if the volume of the syringe was decreased to 2.5 mL? Explain or show work to support your answer.

7. What experimental factors are assumed to be constant in this experiment?

8. Based on your work for Step 3 in Processing the Data, is the relationship between pressure and volume direct or inverse? Explain your answer.

9. How *constant* were the values for *k* you recorded in Table 1?

10. Using *P, V*, and *k*, write an equation representing Boyle's law. Write a verbal statement that correctly expresses Boyle's law.

EXTENSION

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure *vs. reciprocal of volume* (1/volume) may also be plotted.

   a. Choose New Calculated Column from the 📊 Data menu.
   b. Enter **ReciprocalVol** as the Name, **1/V** as the Short Name, and **1/mL** as the Units.
   c. Enter **1/Volume** as the Expression. **Note:** The term "Volume" must be entered exactly as it was entered when you set up data collection. If you are unsure how it was entered, the available column names can be found below the Expression entry box.
   d. Select OK.

2. Set up the graph of pressure *vs.* reciprocal of volume

   a. Choose Select X-axis Column ► ReciprocalVol from the 📈 Graph menu. Ensure that pressure is plotted on the y-axis and that reciprocal of volume is on the x-axis.
   b. Choose Window Settings from the 📈 Graph menu.
   c. Enter **0** as the values for X Min and Y Min.
   d. Select OK.

3. Follow this procedure to calculate regression statistics and to plot a best-fit regression line on your graph of pressure *vs.* reciprocal of volume:

   a. Choose Curve Fit ► Linear from the 📈 Analyze menu. The linear-regression statistics for these two data columns are displayed in the form:

   $$y = mx + b$$

   where x is 1/volume, y is pressure, m is a proportionality constant, and b is the y-intercept.
   b. If the relationship between P and V is an inverse relationship, the graph of pressure *vs.* reciprocal of volume should be direct; that is, the curve should be linear and pass through (or near) the origin. Examine your graph to see if this is true for your data.

TEACHER INFORMATION

Boyle's Law: Pressure-Volume Relationship in Gases

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment is written for the Gas Pressure Sensor. The default calibration for this experiment has units of kPa (kilopascals). You can use other units (mm Hg, atm, or psi) by changing them in the data-collection software.

3. In order to save time, you may prefer to do Step 1 of the student procedure prior to the start of class.

4. As explained in the student procedures, this experiment is written to compensate for the small volume air a chamber inside the Gas Pressure Sensor. The volume of this space is about 0.8 mL. This means that when students enter a volume of 5.0 mL (as read on the syringe), the volume is really about 5.8 mL. To compensate for this error, the students are instructed add 0.8 mL to each of the volumes they enter. By doing this, they will get better results for the value of the exponent, *b*, in Step 6b.

5. Question 8 in the Processing the Data section asks the students to calculate a proportionality constant, *k*, using the equation, $k = P \cdot V$. Your students can do this manually, or you could have them create a calculated column using DataQuest.

SAMPLE RESULTS

Table 1		
Volume (mL)	Pressure (kPa)	Constant, *k* (kPa·mL)
5.8	189.69	1100
7.8	141.75	1105
9.8	113.20	1109
11.8	93.28	1100
13.8	80.22	1107
15.8	69.80	1102
17.8	61.97	1103
19.8	55.87	1106

Table 2 – Values based on Power Fit	
Volume (mL)	Pressure (kPa)
5.0	220.61
10.0	110.24
15.0	73.5
20.0	55.26
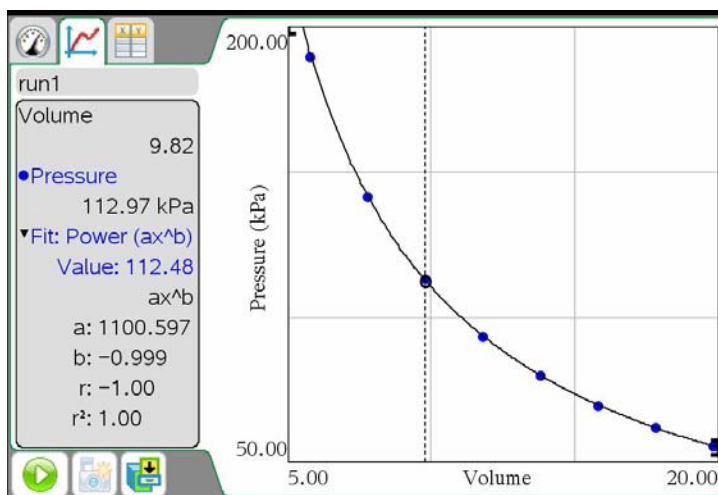
Typical graph of Pressure vs. *Volume shown with a power fit.*

ANSWERS TO QUESTIONS

1. When the volume was doubled, the pressure was halved (pressure went from 220.61 kPa to 110.24 kPa).

2. When the volume was halved, the pressure doubled (pressure went from 55.26 kPa to 110.24 kPa).

3. The pressure is reduced by a factor of 1/3 (pressure went from 220.61 kPa to 73.5 kPa).

4. From the data, the relationship appears to be inverse. When pressure data increases, volume data seems to decrease proportionally. The shape of the pressure-volume plot appears to be a simple inverse relationship.

5. If the volume is increased to 40.0 mL, one would expect the pressure to be 1/2 of what it was at 20.0 mL. This would be a pressure of approximately 27 kPa.

6. If the volume were reduced to 2.5 mL, one would expect the pressure to be double what it was at 5.0 mL. This would be a pressure of approximately 440 kPa.

7. The temperature and the number of molecules in the gas sample are assumed to be constant.

8. The correct formula for an inverse relationship is: $k = P \cdot V$. For k values, see the third column of the sample results (1104 kPa·mL is the average value for the constant, k).

9. Values were quite constant, with a very small deviation.

10. The equation representing Boyle's law is: $k = P \cdot V$. The pressure of a confined gas varies inversely with the volume of the gas if the temperature of the sample remains constant.

EXTENSION
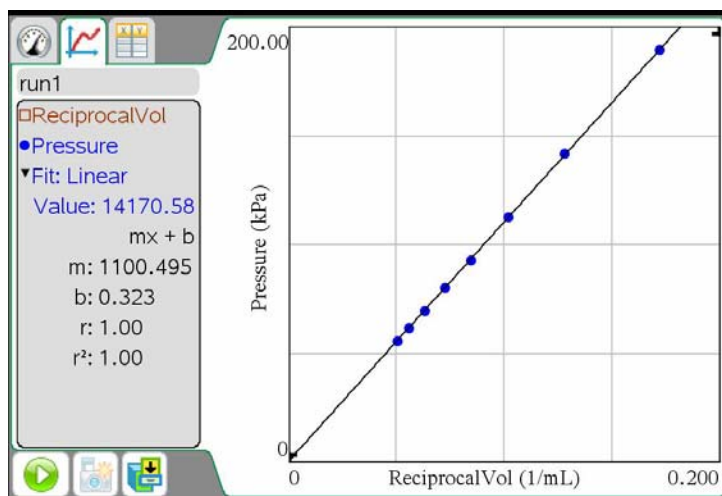
Typical graph of Pressure vs. *the Reciprocal of Volume shown with a linear fit.*

Evaporation and
Intermolecular Attractions

In this experiment, Temperature Probes are placed in various liquids. Evaporation occurs when the probe is removed from the liquid's container. This evaporation is an endothermic process that results in a temperature decrease. The magnitude of a temperature decrease is, like viscosity and boiling temperature, related to the strength of intermolecular forces of attraction. In this experiment, you will study temperature changes caused by the evaporation of several liquids and relate the temperature changes to the strength of intermolecular forces of attraction. You will use the results to predict, and then measure, the temperature change for several other liquids.

You will encounter two types of organic compounds in this experiment—alkanes and alcohols. The two alkanes are pentane, C_5H_{12}, and hexane, C_6H_{14}. In addition to carbon and hydrogen atoms, alcohols also contain the -OH functional group. Methanol, CH_3OH, and ethanol, C_2H_5OH, are two of the alcohols that we will use in this experiment. You will examine the molecular structure of alkanes and alcohols for the presence and relative strength of two intermolecular forces—hydrogen bonding and dispersion forces.

OBJECTIVES

In this experiment, you will

- Study temperature changes caused by the evaporation of several liquids.
- Relate the temperature changes to the strength of intermolecular forces of attraction.
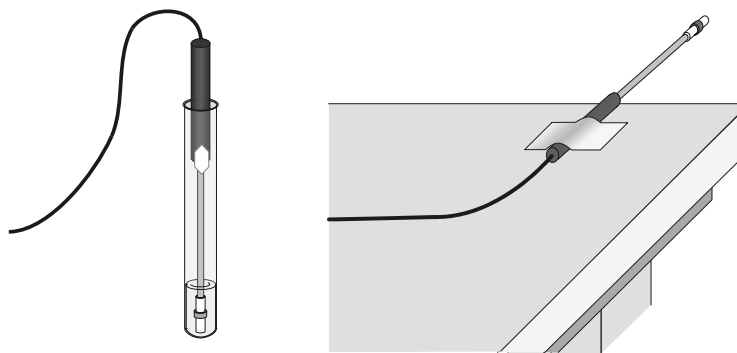
Figure 1

MATERIALS

TI-Nspire handheld **or**	methanol (methyl alcohol)
computer and TI-Nspire software	ethanol (ethyl alcohol)
data-collection interface	1-propanol
2 Temperature Probes	1-butanol
6 pieces of filter paper (2.5 cm ✕ 2.5 cm)	n-pentane
2 small rubber bands	n-hexane
masking tape	

PRE-LAB QUESTIONS

Prior to doing the experiment, complete the Pre-Lab table. The name and formula are given for each compound. Draw a structural formula for a molecule of each compound. Then determine the molecular weight of each of the molecules. Dispersion forces exist between any two molecules, and generally increase as the molecular weight of the molecule increases. Next, examine each molecule for the presence of hydrogen bonding. Before hydrogen bonding can occur, a hydrogen atom must be bonded directly to an N, O, or F atom within the molecule. Tell whether or not each molecule has hydrogen-bonding capability.

Substance	Formula	Structural formulas	Molecular weight	Hydrogen bond (yes or no)
ethanol	C_2H_5OH			
1-propanol	C_3H_7OH			
1-butanol	C_4H_9OH			
n-pentane	C_5H_{12}			
methanol	CH_3OH			
n-hexane	C_6H_{14}			

PROCEDURE

1. Obtain and wear goggles! **CAUTION:** The compounds used in this experiment are flammable and poisonous. Avoid inhaling their vapors. Avoid contacting them with your skin or clothing. Be sure there are no open flames in the lab during this experiment. Notify your teacher immediately if an accident occurs.

2. Connect the Temperature Probes to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the ⚙ Experiment menu. Choose Collection Setup from the ⚙ Experiment menu. Enter **240** as the experiment duration in seconds (4 minutes). The number of points collected should be 481. Select OK.

4. Wrap Probe 1 and Probe 2 with square pieces of filter paper secured by small rubber bands as shown in Figure 1. Roll the filter paper around the probe tip in the shape of a cylinder. **Hint:** First slip the rubber band on the probe, wrap the paper around the probe, and then finally slip the rubber band over the paper. The paper should be even with the probe end.

5. Stand Probe 1 in the ethanol container and Probe 2 in the 1-propanol container. Make sure the containers do not tip over.

6. Prepare 2 pieces of masking tape, each about 10 cm long, to be used to tape the probes in position during Step 7.

7. After the probes have been in the liquids for at least 30 seconds, start data collection (⏵). A live graph of temperature vs. time for both Probe 1 and Probe 2 is being plotted on the screen. Live readings are also displayed. Monitor the temperature for 15 seconds to establish the initial temperature of each liquid. Then simultaneously remove the probes from the liquids and tape them so the probe tips extend 5 cm over the edge of the table top as shown in Figure 1. **Note:** avoid moving near the sensors as air movement can affect your results.

8. Data collection will stop after 240 seconds. Click any data point and use ► and ◄ to examine the data pairs on the displayed graph. Based on your data, determine the maximum temperature, t_1, and minimum temperature, t_2 for both probes. Record t_1 and t_2 for each probe in the data table.

9. For each liquid, subtract the minimum temperature from the maximum temperature to determine Δt, the temperature change during evaporation.

10. Based on the Δt values you obtained for these two substances, plus information in the Pre-Lab exercise, *predict* the size of the Δt value for 1-butanol. Compare its hydrogen-bonding capability and molecular weight to those of ethanol and 1-propanol. Record your predicted Δt, then explain how you arrived at this answer in the space provided. Do the same for n-pentane. It is not important that you predict the exact Δt value; simply estimate a logical value that is higher, lower, or between the previous Δt values.

11. Test your prediction in Step 10. Click on the Store Latest Data Set button (⊞). Repeat Steps 5–9 using 1-butanol with Probe 1 and n-pentane with Probe 2.

12. Based on the Δt values you have obtained for all four substances, plus information in the Pre-Lab exercise, predict the Δt values for methanol and n-hexane. Compare the hydrogen-bonding capability and molecular weight of methanol and n-hexane to those of the previous four liquids. Record your predicted Δt, then explain how you arrived at this answer in the space provided.

13. Test your prediction in Step 12. Click on the Store Latest Data Set button (⊞). Repeat Steps 5–9, using methanol with Probe 1 and n-hexane with Probe 2.

DATA

Substance	t_1 (°C)	t_2 (°C)	$\Delta t\ (t_1 - t_2)$ (°C)
ethanol			
1-propanol			
1-butanol			
n-pentane			
methanol			
n-hexane			

Predicted Δt (°C)	Explanation

PROCESSING THE DATA

Plot a graph of Δt values of the four alcohols versus their respective molecular weights. Plot molecular weight on the horizontal axis and Δt on the vertical axis.

    a. Insert a new problem in the document, then Insert a new DataQuest App into problem 2. Click on the Table View tab (▦) to view the Table.

    b. Double click on the *X* column to access the column options. Enter **Molecular Weight** for the Name, **Weight** for the short name, and **amu** for the units. Change the Display Precision to 0 decimal places. Select OK.

    c. Double click on the *Y* column to access the column options. Enter **ΔT** for the column name. Enter **°C** as the units. Select OK.

    d. Using the data recorded in the tables, enter the values in the DataQuest Table.

    e. Click on the Graph View tab (☒) to view the graph.

QUESTIONS

1. Two of the liquids, n-pentane and 1-butanol, had nearly the same molecular weights, but significantly different Δt values. Explain the difference in Δt values of these substances, based on their intermolecular forces.

2. Which of the alcohols studied has the strongest intermolecular forces of attraction? The weakest intermolecular forces? Explain using the results of this experiment.

3. Which of the alkanes studied has the stronger intermolecular forces of attraction? The weaker intermolecular forces? Explain using the results of this experiment.

TEACHER INFORMATION

Evaporation and Intermolecular Attractions

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment, as written, is not intended for use with Easy or Go! products since data from two sensors must be collected at the same time. A single, multi-channel interface is preferred.

3. If you are using Easy or Go! products, or if you have a limited number of temperature probes, you can do this experiment with only a single sensor, testing a single alcohol with each run. Similarly, you can use more than two temperature probes if you have a multi-channel interface.

4. We recommend wrapping the probes with paper as described in the procedure. Wrapped probes provide more uniform liquid amounts, and generally greater Δt values, than bare probes. Chromatography paper, filter paper, and various other paper types work well.

5. Snug-fitting rubber bands can be made by cutting short sections from a small rubber hose. Surgical tubing works well. Orthodontist's rubber bands are also a good size.

6. Other liquids can be substituted. Although it has a somewhat larger Δt, 2-propanol can be substituted for 1-propanol. Some petroleum ethers have a high percentage of hexane and can be used in its place. Other alkanes of relatively high purity, such as n-heptane or n-octane can be used. Water, with a Δt value of about 5°C, emphasizes the effect of hydrogen bonding on a low-molecular weight liquid. However, students might have difficulty comparing its hydrogen bonding capability with that of the alcohols used.

7. Sets of the liquids can be supplied in 13×100 mm test tubes stationed in stable test-tube racks. This method uses very small amounts of the liquids. Alternatively, the liquids can be supplied in sets of small bottles kept for future use. Adjust the level of the liquids in the containers so it will be above the top edge of the filter paper.

8. Because several of these liquids are highly volatile, keep the room well-ventilated. Cap the test tubes or bottles at times when the experiment is not being performed. The experiment should not be performed near any open flames.

9. Other properties, besides Δt values, vary with molecular size and consequent size of intermolecular forces of attraction. Viscosity increases noticeably from methanol through 1-butanol. The boiling temperatures of methanol, ethanol, 1-propanol, and 1-butanol are 65°C, 78°C, 97°C, and 117°C, respectively.

10. **HAZARD ALERTS:**

    n-Hexane: Flammable liquid: dangerous fire risk; may be irritating to respiratory tract. Hazard Code: B—Hazardous.

    Methanol: Flammable; dangerous fire risk; toxic by ingestion (ingestion may cause blindness). Hazard Code: B—Hazardous.

Ethanol: Dangerous fire risk; flammable; addition of denaturant makes the product poisonous—it cannot be made non-poisonous; store in a dedicated flammables cabinet or safety cans. If a flammables cabinet or safety cans are not available, store in a Flinn *Saf-Stor®* Can. Hazard Code: C—Somewhat hazardous.

n-Pentane: Flammable liquid; narcotic in high concentrations. Hazard Code: B—Hazardous.

1-Propanol: Flammable liquid; dangerous fire risk; harmful to eyes and respiratory tract. Hazard Code: B—Hazardous.

1-Butanol: Moderate fire risk; toxic on prolonged inhalation; eye irritant; absorbed by skin. Hazard Code: B—Hazardous.

The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual*, 1-800-452-1261, www.flinnsci.com. See *Appendix F* for more information.

11. Piping which can be purchased at a yard goods or sewing store can serve as an appropriate sleeve for the temperature probe. You have to cut it pieces and remove the "rope".

ANSWERS TO PRE-LAB QUESTIONS

Substance	Formula	Structural Formulas	Molecular Weight	Hydrogen Bond (Yes or No)
ethanol	C_2H_5OH	H H | | H–C–C–O–H | | H H	46	yes
1-propanol	C_3H_7OH	H H H | | | H–C–C–C–O–H | | | H H H	60	yes
1-butanol	C_4H_9OH	H H H H | | | | H–C–C–C–C–O–H | | | | H H H H	74	yes
n-pentane	C_5H_{12}	H H H H H | | | | | H–C–C–C–C–C–H | | | | | H H H H H	72	no
methanol	CH_3OH	H | H–C–O–H | H	32	yes

n-hexane	C₆H₁₄	H H H H H H │ │ │ │ │ │ H–C–C–C–C–C–C–H │ │ │ │ │ │ H H H H H H	86	no

SAMPLE RESULTS

Substance	t_1 (°C)	t_2 (°C)	Δt (t_1–t_2) (°C)
ethanol	21.0	8.5	12.5
1-propanol	21.1	14.3	6.8
1-butanol	21.5	17.4	4.1
n-pentane	21.3	-0.6	21.9
Methanol	21.0	1.3	19.7
n-hexane	22.8	6.7	16.1

Predicted Δt (°C)	Explanation
varies (< 4.9°C)	It has a higher molecular wt. than 1-propanol (both have H-bonds).
varies (> 8.3°C)	It has a higher molecular wt. than either, but no H-bonding.
varies (> 8.3°C)	It has a lower molecular wt. than ethanol (both have H-bonds).
varies (< 16.1°C)	It has a higher molecular wt. than n-pentane; also no H-bonding.
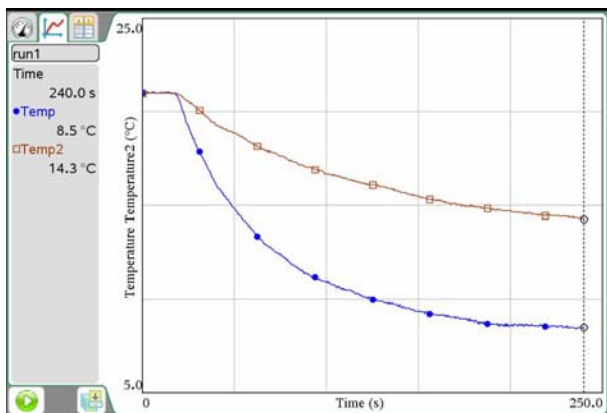
Evaporation of ethanol (●)
and 1-propanol (□).
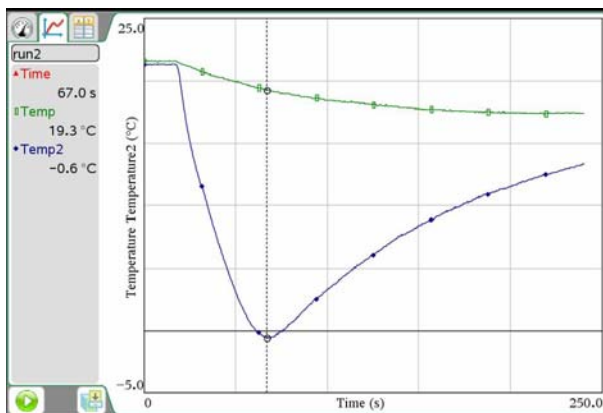
Evaporation of 1-butanol (▯)
and n-pentane (♦)
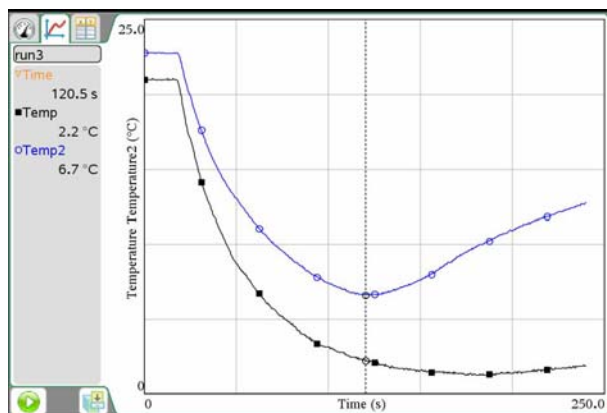
*Evaporation of methanol (■)
and n-hexane (○).*
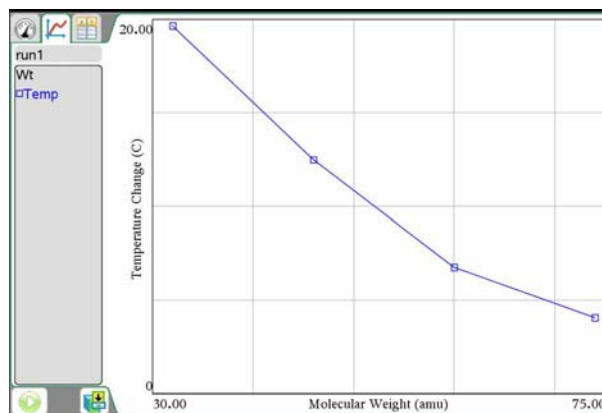
Temperature change vs.
alcohol molecular weight.

ANSWERS TO QUESTIONS

1. Even though n-pentane and 1-butanol have molecular weights of 72 and 74, respectively, 1-butanol has a much smaller Δt due to the presence of hydrogen bonding between its molecules. This results in a stronger attraction, and a slower rate of evaporation.

2. The 1-butanol has the strongest attractions between its molecules. Methanol has the weakest attractions. The 1-butanol has the largest molecules and resulting strongest dispersion forces. This gives it the lowest evaporation rate and the smallest Δt.

3. The n-hexane has the stronger attractions between its molecules. The n-pentane has the weaker attractions. The n-hexane has the larger molecules and the resulting stronger dispersion forces. This gives it a lower evaporation rate and the smallest Δt.

Determining the Concentration of a Solution: Beer's Law

The primary objective of this experiment is to determine the concentration of an unknown nickel (II) sulfate solution. You will be using a Colorimeter. The wavelength of light used should be one that is absorbed by the solution. The $NiSO_4$ solution used in this experiment has a deep green color, so you will use the red LED on your Colorimeter. The light striking the detector is reported as *absorbance* or *percent transmittance*. A higher concentration of the colored solution absorbs more light (and transmits less) than a solution of lower concentration.

You will prepare five nickel sulfate solutions of known concentration (standard solutions). Each is transferred to a small, rectangular cuvette that is placed into the Colorimeter. The amount of light that penetrates the solution and strikes the photocell is used to compute the absorbance of each solution. When a graph of absorbance *vs*. concentration is plotted for the standard solutions, a direct relationship should result, as shown in Figure 1. The direct relationship between absorbance and concentration for a solution is known as Beer's law.
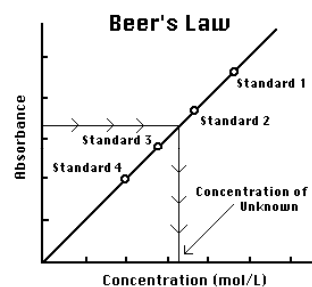
Figure 1

You will determine the concentration of an *unknown* $NiSO_4$ solution by measuring its absorbance. By locating the absorbance of the unknown on the vertical axis of the graph, the corresponding concentration can be found on the horizontal axis (follow the arrows in Figure 1). The concentration of the unknown can also be found using the slope of the Beer's law curve.

OBJECTIVES

In this experiment, you will

- Prepare $NiSO_4$ standard solution.
- Measure the absorbance value of each standard solution.
- Find the relationship between absorbance and concentration of a solution.
- Determine the concentration of an unknown $NiSO_4$ solution.

MATERIALS

TI-Nspire handheld **or**	two 10 mL pipets (or graduated cylinders)
computer and TI-Nspire software	two 100 mL beakers
data-collection interface	pipet or pipet bulb
Vernier Colorimeter	distilled water
one cuvette	test tube rack
five 25 x 150 mm test tubes	stirring rod
30 mL of 0.40 M $NiSO_4$	tissues (preferably lint-free)
5 mL of $NiSO_4$ unknown solution	

PROCEDURE

1. Obtain and wear goggles. **CAUTION:** *Be careful not to ingest any NiSO₄ solution or spill any on your skin. Inform your teacher immediately in the event of an accident*.

2. Add about 30 mL of 0.40 M $NiSO_4$ stock solution to a 100 mL beaker. Add about 30 mL of distilled water to another 100 mL beaker.

3. Label four clean, dry, test tubes 1–4 (the fifth solution is the beaker of 0.40 M $NiSO_4$). Pipet 2, 4, 6, and 8 mL of 0.40 M $NiSO_4$ solution into Test Tubes 1–4, respectively. With a second pipet, deliver 8, 6, 4, and 2 mL of distilled water into Test Tubes 1–4, respectively. *Thoroughly* mix each solution with a stirring rod. Clean and dry the stirring rod between stirrings. Keep the remaining 0.40 M $NiSO_4$ in the 100 mL beaker to use in the fifth trial. Volumes and concentrations for the trials are summarized below:

Trial number	0.40 M NiSO₄ (mL)	Distilled H₂O (mL)	Concentration (M)
1	2	8	0.08
2	4	6	0.16
3	6	4	0.24
4	8	2	0.32
5	~10 0		0.40

4. Prepare a *blank* by filling an empty cuvette 3/4 full with distilled water. To correctly use a cuvette, remember:

    *   All cuvettes should be wiped clean and dry on the outside with a tissue.
    *   Handle cuvettes only by the top edge of the ribbed sides.
    *   All solutions should be free of bubbles.
    *   Always position the cuvette so the light passes through the clear sides.

5. Connect the Colorimeter to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

6. Set up the data-collection mode and change the scale options for the graph.

    a. Choose New Experiment from the 🖫 Experiment menu. Choose Collection Mode ▶ Events with Entry from the 🖫 Experiment menu. Enter **Concentration** as the Name and **mol/L** as the Units. Select OK.
    b. Choose Autoscale Settings from the 🖩 Options menu. Select Autoscale from Zero as the After Collection setting. Select OK.

7. Calibrate the Colorimeter.

    a. Place the blank in the cuvette slot of the Colorimeter and close the lid.
    b. Press the < or > buttons on the Colorimeter to set the wavelength to 635 nm (Red). Then calibrate by pressing the CAL button on the Colorimeter. When the LED stops flashing, the calibration is complete.

8. You are now ready to collect absorbance-concentration data for the five standard solutions.

   a. Start data collection (▶).

   b. Empty the water from the cuvette. Using the solution in Test Tube 1, rinse the cuvette twice with ~1 mL amounts and then fill it 3/4 full. Wipe the outside with a tissue and place it in the Colorimeter. Close the lid.

   c. When the value displayed on the screen has stabilized, click the Keep button (⬛) and enter **0.080** as the concentration in mol/L. Select OK. The absorbance and concentration values have now been saved for the first solution.

   d. Discard the cuvette contents as directed by your instructor. Using the solution in Test Tube 2, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Place the cuvette in the Colorimeter and close the lid. Wait for the value displayed on the screen to stabilize and click the Keep button (⬛). Enter **0.16** as the concentration in mol/L. Select OK.

   e. Repeat the procedure for Test Tube 3 (0.24 M) and Test Tube 4 (0.32 M), as well as the stock 0.40 M $NiSO_4$. **Note:** Wait until Step 10 to test the unknown.

   f. Stop data collection (⬛).

   g. Click the Table View tab (⊞) to display the data table. Record the absorbance and concentration data values in your data table.

9. Display a graph of absorbance *vs.* concentration with a linear regression curve.

   a. Click the Graph View tab (✐).

   b. Choose Curve Fit ► Linear from the ✐ Analyze menu. The linear-regression statistics for these two data columns are displayed for the equation in the form

$$y = mx + b$$

   where *x* is concentration, *y* is absorbance, *m* is the slope, and *b* is the y-intercept.

   c. Record your fit equation in your data table.

   Note: One indicator of the quality of your data is the size of *b*. It is a very small value if the regression line passes through or near the origin. The correlation coefficient, *r*, indicates how closely the data points match up with (or *fit*) the regression line. A value of 1.00 indicates a nearly perfect fit. The graph should indicate a direct relationship between absorbance and concentration, a relationship known as Beer's law. The regression line should closely fit the five data points *and* pass through (or near) the origin of the graph.

10. Determine the absorbance value of the unknown $NiSO_4$ solution.

    a. Click the Meter View tab (◉).

    b. Obtain about 5 mL of the *unknown* $NiSO_4$ in another clean, dry, test tube. Record the number of the unknown in your data table.

    c. Rinse the cuvette twice with the unknown solution and fill it about 3/4 full. Wipe the outside of the cuvette and place it into the device.

    d. Monitor the absorbance value. When this value has stabilized, record it in your data table.

11. Discard the solutions as directed by your instructor.

DATA

Trial	Concentration (mol/L)	Absorbance
1	0.080	
2	0.16	
3	0.24	
4	0.32	
5	0.40	
6	Unknown number ____	

Linear Fit Equation: y = mx + b	
Concentration of unknown (mol/L)	

PROCESSING THE DATA

1. To determine the concentration of the unknown $NiSO_4$ solution, interpolate along the regression line to convert the absorbance value of the unknown to concentration.

   a. Click the Graph View tab (🖉).
   b. Choose Interpolate from the 🖉 Analyze menu.
   c. Click on any point on the regression curve. Use ► and ◄ to find the Linear Fit value that is closest to the absorbance reading you obtained in Step 10. The corresponding $NiSO_4$ concentration, in mol/L, will be displayed.
   d. Record the concentration value in your data table.

2. (optional) Print a graph of absorbance *vs.* concentration, with a regression line and interpolated unknown concentration displayed.

TEACHER INFORMATION

Determining the Concentration of a Solution: Beer's Law

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. The light source for the nickel (II) sulfate solution is the red LED (635 nm). Since the $NiSO_4$ is green in color, the nearly monochromatic red light is readily absorbed by the solution.

3. The 0.40 M $NiSO_4$ solution can be prepared by using 10.51 g of $NiSO_4•6H_2O$ per 100 mL. **HAZARD ALERT:** Toxic; avoid dispersing this substance; dispense with care; Nickel dust is a *possible carcinogen*. Hazard Code: B—Hazardous.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual,* (800) 452-1261, www.flinnsci.com.

4. Solutions of $Ni(NO_3)_2$ also work well, and can be prepared by using 11.63 g of solid $Ni(NO_3)_2•6H_2O$ per 100 mL of solution.

5. Unknowns can be prepared by doing dilutions starting with the 0.40 M $NiSO_4$ stock solution. For example, to prepare a 0.22 M unknown, use 55 mL of the standard plus 45 mL of water:
$$(55 \text{ mL} / 100 \text{ mL})(.40 \text{ M}) = 0.22 \text{ M}$$

6. This experiment works well using solutions of green food coloring. A solution with an absorbance similar to 0.40 M $NiSO_4$ can be prepared by dissolving 8–9 drops of green Schilling Food Coloring in 1 liter of distilled water. Check to see that the absorbance of this stock solution falls in the range of 0.40 to 0.80. Assign this solution a concentration of 100%. Students will follow the same procedure to dilute the stock solution to 80%, 60%, 40%, and 20%. Make the solutions fresh as they can discolor over time.

7. The cuvette must be from 55% to 100% full in order to get a valid absorbance reading. If students fill the cuvette 3/4 full, as described in the procedure, they should easily be in this range. To avoid spilling solution into the cuvette slot, remind students not to fill the cuvette.

8. Since there is some variation in the amount of light absorbed by the cuvette if it is rotated 180°, you should use a water-proof marker to make a reference mark on the top edge of one of the clear sides of all cuvettes. Students are reminded in the procedure to align this mark with the white reference mark at the top of the cuvette slot on the Colorimeter.

9. The use of a single cuvette in the procedure is to eliminate errors introduced by slight variations in the absorbance of different plastic cuvettes. If one cuvette is used throughout the experiment by a student group, this variable is eliminated. The two rinses done prior to adding a new solution can be accomplished very quickly.

10. There are two models of Vernier Colorimeters. The first model (rectangular shape) has three wavelength settings, and the newest model (a rounded shape) has four wavelength settings. The 635 nm wavelength of either model is used in this experiment. The newer model is an auto-ID sensor and supports automatic calibration (pressing the CAL button on the Colorimeter with a blank cuvette in the slot). If you have an older model Colorimeter, see www.vernier.com/til/1665.html for calibration information.

11. This experiment gives you a good opportunity to discuss the relationship between percent transmittance and absorbance. At the end of the experiment, students can click the Absorbance vertical-axis label of the graph, and choose Transmittance. The graph should now be transmittance *vs.* concentration. You can also discuss the mathematical relationship between absorbance and percent transmittance, as represented by either of these formulas:

$$A = \log(100/\%T) \text{ or } A = 2 - \log\%T$$

SAMPLE RESULTS
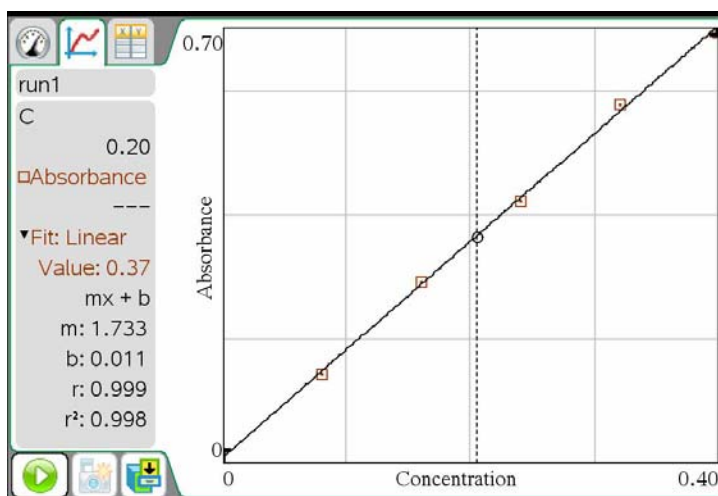
Absorbance vs. concentration for NiSO$_4$
with interpolation of the unknown displayed

Trial	Concentration (mol / L)	Absorbance
1	0.080	0.14
2	0.16	0.29
3	0.24	0.42
4	0.32	0.58
5	0.40	0.69
6	Unknown number 1	0.37

Linear Fit Equation:	Absorbance = 1.733*Concentration + 0.011	
Concentration of the unknown	0.20	mol/L

Properties of Solutions:
Electrolytes and Non-Electrolytes

In this experiment, you will discover some properties of strong electrolytes, weak electrolytes, and non-electrolytes by observing the behavior of these substances in aqueous solutions. You will determine these properties using a Conductivity Probe. When the probe is placed in a solution that contains ions, and thus has the ability to conduct electricity, an electrical circuit is completed across the electrodes that are located on either side of the hole near the bottom of the probe body (see Figure 1). This results in a conductivity value that can be read by a data-collection interface. The unit of conductivity used in this experiment is the microsiemens per centimeter, or µS/cm.
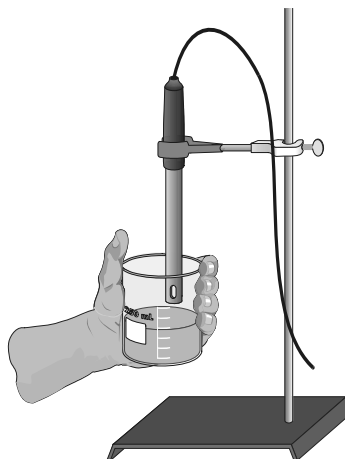
Figure 1

The size of the conductivity value depends on the ability of the aqueous solution to conduct electricity. Strong electrolytes produce large numbers of ions, which results in high conductivity values. Weak electrolytes result in low conductivity, and non-electrolytes should result in no conductivity. In this experiment, you will observe several factors that determine whether or not a solution conducts, and if so, the relative magnitude of the conductivity. Thus, this simple experiment allows you to learn a great deal about different compounds and their resulting solutions.

In each part of the experiment, you will be observing a different property of electrolytes. Keep in mind that you will be encountering three types of compounds and aqueous solutions:

Ionic Compounds

These are usually strong electrolytes and can be expected to 100% dissociate in aqueous solution.

Example: $NaNO_3(s) \longrightarrow Na^+(aq) + NO_3^-(aq)$
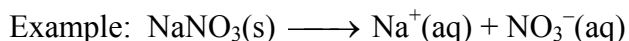
Molecular Compounds

These are usually non-electrolytes. They do not dissociate to form ions. Resulting solutions do not conduct electricity.

Example: $CH_3OH(l) \longrightarrow CH_3OH(aq)$
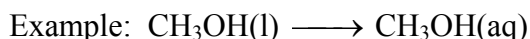
Molecular Acids

These are molecules that can partially or wholly dissociate, depending on their strength.

Example: Strong electrolyte $H_2SO_4 \longrightarrow H^+(aq) + HSO_4^-(aq)$ (100% dissociation)

Example: Weak electrolyte $HF \longleftrightarrow H^+(aq) + F^-(aq)$ (<100% dissociation)

OBJECTIVES

In this experiment, you will

- Write equations for the dissociation of compounds in water.
- Use a Conductivity Probe to measure the conductivity of solutions.
- Determine which molecules or ions are responsible for conductivity of solutions.
- Investigate the conductivity of solutions resulting from compounds that dissociate to produce different numbers of ions.

MATERIALS

TI-Nspire handheld **or**	H_2O (distilled)
computer and TI-Nspire software	0.05 M NaCl
data-collection interface	0.05 M $CaCl_2$
Vernier Conductivity Probe	0.05 M $AlCl_3$
ring stand	0.05 M $HC_2H_3O_2$
utility clamp	0.05 M H_3PO_4
250 mL beaker	0.05 M H_3BO_3
wash bottle and distilled water	0.05 M HCl
tissues	0.05 M CH_3OH (methanol)
H_2O (tap)	0.05 M $C_2H_6O_2$ (ethylene glycol)

PROCEDURE

1. Obtain and wear goggles! **CAUTION:** Handle the solutions in this experiment with care. Do not allow them to contact your skin. Notify your teacher in the event of an accident.

2. Assemble the Conductivity Probe, utility clamp, and ring stand as shown in Figure 1. Be sure the probe is clean and dry before beginning the experiment.

3. Set the selector switch on the side of the Conductivity Probe to the 0–20000 μS/cm range. Connect the Conductivity Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

4. Set up the data-collection mode.

   a. Choose New Experiment from the Experiment menu.
   b. Choose Collection Mode ► Events with Entry from the Experiment menu. Enter **Compound** as the Name and leave the Units field blank.
   c. Select the Average over 10 s option, then Select OK.

5. Obtain the Group A solution containers. The solutions are: $CaCl_2$, NaCl, and $AlCl_3$.

6. Measure the conductivity of each of the solutions.

   a. Start data collection (▶).

   b. Carefully raise each vial and its contents up around the Conductivity Probe until the hole near the probe end is completely submerged in the solution being tested. **Important:** Since the two electrodes are positioned on either side of the hole, this part of the probe must be completely submerged.

   c. Briefly swirl the vial contents. Monitor the conductivity reading displayed on the screen for 6–8 seconds. Click the Keep button (📷), wait for the collection to complete, and enter the name of the solution, for example CaCl2. Select OK to store the data.

   d. Before testing the next solution, clean the electrodes by surrounding them with a 250 mL beaker and rinse them with distilled water from a wash bottle. Blot the outside of the probe end dry using a tissue. It is *not* necessary to dry the *inside* of the hole near the probe end.

   e. Test the remaining solutions in the group by repeating Steps 6b – d.

   f. Stop data collection (⬤).

7. Click the Store Latest Data Set button (📷) to store the data from the Group A solutions. Obtain the four Group B solution containers. These include $HC_2H_3O_2$, HCl, H_3PO_4, and H_3BO_3. Repeat the Step 6 procedure.

8. Click the Store Latest Data Set button (📷) to store the data from the Group B solutions. Obtain the five Group C solutions or liquids. These include distilled H_2O, tap H_2O, CH_3OH, and $C_2H_6O_2$. Repeat the Step 6 procedure.

9. Click the Table View tab (📷) to display the data table. Record the conductivity data in the data table.

DATA

Solution	Conductivity (µS/cm)
A – $CaCl_2$	
A – $AlCl_3$	
A – $NaCl$	
B – $HC_2H_3O_2$	
B – HCl	
B – H_3PO_4	
B – H_3BO_3	
C – $H_2O_{distilled}$	
C – H_2O_{tap}	
C – CH_3OH	
C – $C_2H_6O_2$	

QUESTIONS

1. Based on your conductivity values, do the Group A compounds appear to be molecular, ionic, or molecular acids? Would you expect them to partially dissociate, completely dissociate, or not dissociate at all?

2. Why do the Group A compounds, each with the same concentration (0.05 M), have such large differences in conductivity values? **Hint:** Write an equation for the dissociation of each. Explain.

3. In Group B, do all four compounds appear to be molecular, ionic, or molecular acids? Classify each as a strong or weak electrolyte, and arrange them from the strongest to the weakest, based on conductivity values.

4. Write an equation for the dissociation of each of the compounds in Group B. Use $\longrightarrow$ for strong; $\longleftrightarrow$ for weak.

5. For H_3PO_4 and H_3BO_3, does the subscript "3" of hydrogen in these two formulas seem to result in additional ions in solution as it did in Group A? Explain.

6. In Group C, do all four compounds appear to be molecular, ionic, or molecular acids? Based on this answer, would you expect them to dissociate?

7. How do you explain the relatively high conductivity of tap water compared to a low or zero conductivity for distilled water?

Properties of Solutions:
Electrolytes and Non-Electrolytes

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. We suggest that you set up the Conductivity Probes before the experiment. Set the selection switch on the amplifier box of the probe to the 0–20000 µS/cm range.

3. Fewer sets of Groups A, B, and C can be prepared if students are advised that they need not start with Group A. Add solutions to 100 mL beakers or small vials to a depth that easily allows the hole near the Conductivity Probe tip to be completely submerged (the graphite electrodes of the probe are located on either side of this hole).

4. Preparation of solutions (prepare all solutions in distilled water):

   0.050 M $CaCl_2$ (5.55 g of solid calcium chloride, $CaCl_2$, per 1 L solution) Hazard Code: D—Relatively non-hazardous. Alternatively, 7.35 g $CaCl_2 \cdot 2H_2O$, per 1 L solution. **HAZARD ALERT:** Toxic by ingestion. Hazard Code: D—Relatively non-hazardous.

   0.050 M NaCl (2.93 g of solid sodium chloride, NaCl, per 1 L solution) **HAZARD ALERT:** Moderately toxic. Hazard Code: D—Relatively non-hazardous.

   0.050 M $AlCl_3$ (12.05 g of solid aluminum chloride, $AlCl_3 \cdot 6H_2O$, per 1 L solution)—preferred. Hazard Code: D—Relatively non-hazardous. Alternatively, 6.67 g anhydrous $AlCl_3$ per liter of solution. **HAZARD ALERT:** Reacts very violently with water; toxic by inhalation and ingestion; strong skin irritant. Hazard Code: A—Extremely hazardous.

   0.050 M HCl (4.2 mL of concentrated hydrochloric acid, HCl, per 1 L solution) **HAZARD ALERT:** Highly toxic by ingestion or inhalation; severely corrosive to skin and eyes. Hazard Code: A—Extremely hazardous.

   0.050 M $HC_2H_3O_2$ (2.9 mL of concentrated acetic acid, $HC_2H_3O_2$, per 1 L solution) **HAZARD ALERT:** Corrosive to skin and tissue; moderate fire risk (flash point: 39°C); moderately toxic by ingestion and inhalation. Hazard Code: A—Extremely hazardous.

   0.050 M H_3PO_4 (3.4 mL of concentrated phosphoric acid, H_3PO_4, per 1 L solution) **HAZARD ALERT:** Skin and eye irritant; moderately toxic by ingestion and inhalation; corrosive; burns tissue. Hazard Code: A—Extremely hazardous.

   0.050 M H_3BO_3 (3.09 g of solid boric acid, H_3BO_3, per 1 L solution) **HAZARD ALERT:** Moderately toxic by ingestion; irritant to skin in dry form. Hazard Code: C—Somewhat hazardous.

   0.050 M CH_3OH (1.60 g (2.1 mL) methanol per 1 L solution) **HAZARD ALERT:** Flammable; dangerous fire risk; toxic by ingestion (ingestion may cause blindness). Hazard Code: B—Hazardous.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual*, (800) 452-1261, www.flinnsci.com. See *Appendix F* for more information.

5. Conductivity readings are normally reported in microsiemens per centimeter, or μS/cm. This SI derived unit has replaced the conductivity unit, micromho/cm.

6. Students are instructed to rinse the probe with distilled water between samples. They are told to blot the probe tip dry—however, the directions also remind them that they do *not* need to blot dry the inside of the hole containing the graphite electrodes. It is cumbersome to do so, and leaving a drop or two of distilled water does not significantly dilute the next sample.

7. Using the stored calibration, measured conductivity values for H_3BO_3, CH_3OH, or distilled water will be in the range of 0 to 30 μS/cm. If a two-point calibration is performed, students will get readings closer to 0 μS/cm. These four samples will usually have a small conductivity value due to dissolved carbon dioxide, which forms aqueous ions according to the equation:

$$CO_2(g) + H_2O(l) \longleftrightarrow H^+(aq) + HCO_3^-(aq)$$
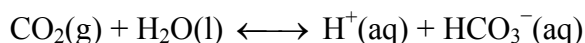
The resulting conductivity, usually about 1–3 μS/cm, can be accurately measured using the narrower 0–200 μS/cm setting and calibration for the Conductivity Probe. You could do this as a teacher demonstration, or instruct your students to do it as an extension to the experiment.

At the 0–200 μS/cm setting, students will also notice that the conductivity of boric acid is higher than distilled water, 0.05 M methanol, or 0.05 M ethylene glycol. This way, they can see that boric acid is a weak acid that ionizes to a very small extent. For example, we get a reading of 3.2 μS/cm for 0.05 M boric acid, but only 1.0 μS/cm for distilled water, and 1.0 μS/cm for 0.05 M methanol, using the 0–200 μS/cm setting.

8. If you wish to calibrate the Conductivity Probe to improve conductivity readings at low concentrations (as discussed in item 7 above), follow these directions:

First Calibration Point

a. Choose Set Up Sensors ►Calibrate ► Two Point from the 🖳 Experiment menu.
b. For the first calibration point, the Conductivity Probe should simply be in the air (out of any liquid or solution).
c. Enter **0** as the first reference value.
d. When the voltage stabilizes, select OK.

Second Calibration Point

e. Place the Conductivity Probe into a standard solution that is equivalent to 10,000 μS/cm. **Note:** This standard can be prepared by dissolving 5.566 g of solid sodium chloride, NaCl, in enough distilled water for 1 liter of solution.
f. Enter **10000** as the second reference value (in μS/cm).
g. When the voltage stabilizes, select OK.
h. Select OK to complete the calibration.

SAMPLE RESULTS

Solution	Conductivity (µS/cm)
A - $CaCl_2$	9362
A - NaCl	5214
A - $AlCl_3$	11707
B - $HC_2H_3O_2$	461
B - HCl	17330
B - H_3PO_4	6661
B - H_3BO_3	0
C - $H_2O_{distilled}$	0
C - H_2O_{tap}	(varies) 20 – 1000
C - CH_3OH	0

ANSWERS TO QUESTIONS

1. All three are ionic. They completely dissociate in water.

2. $AlCl_3 \longrightarrow Al^{3+} + 3\ Cl^-$ (4 moles of ions per mole)

    $CaCl_2 \longrightarrow Ca^{2+} + 2\ Cl^-$ (3 moles of ions per mole)

    $NaCl \longrightarrow Na^+ + Cl^-$ (2 moles of ions per mole)

    Even though all three solutions have the same initial concentration, 0.05 M, $AlCl_3$ dissociates to yield the largest number of moles of ions per mole, and as a result exhibits the highest conductivity in this series. $CaCl_2$ is next, and NaCl yields the fewest moles of ions per mole.

3. All three are molecular acids. HCl is a strong acid. H_3PO_4 is borderline between strong and weak, but is usually classified as a weak acid. Acetic acid, $HC_2H_3O_2$ is the next weakest acid and H_3BO_3 is the weakest.

4. $HCl \longrightarrow H^+ + Cl^-$ $H_3PO_4 \longleftrightarrow H^+ + H_2PO_4^-$

    $HC_2H_3O_2 \longleftrightarrow H^+ + C_2H_3O_2^-$ $H_3BO_3 \longleftrightarrow H^+ + H_2BO_3^-$
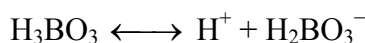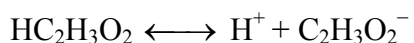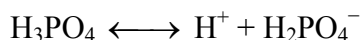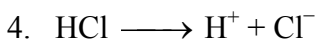
5. Since H_3PO_4 and H_3BO_3 are two of the weak acids in this series, one would conclude that the subscript "3" contributes little to their strengths. The equations for their dissociations indicate that only one H^+ dissociates to any appreciable extent from either of these weak acids. The dissociations of the second and third H^+ ions are insignificant by comparison.

6. All four compounds in Group C are molecular. None of them dissociates significantly.

7. Even though the water itself is molecular, it contains ionic impurities, such as Ca^{2+}, Mg^{2+}, HCO_3^-, and Cl^-. The ionic impurities contribute significantly to the conductivity of the solution. These ionic impurities have been removed from distilled water.

Conductivity of Solutions: The Effect of Concentration

If an ionic compound is dissolved in water, it dissociates into ions and the resulting solution will conduct electricity. Dissolving solid sodium chloride in water releases ions according to the equation:

$$NaCl(s) \longrightarrow Na^+(aq) + Cl^-(aq)$$

In this experiment, you will study the effect of increasing the concentration of an ionic compound on conductivity. Conductivity will be measured as concentration of the solution is gradually increased by the addition of concentrated NaCl drops. The same procedure will be used to investigate the effect of adding other solutions with the same concentration (1.0 M), but different numbers of ions in their formulas: aluminum chloride, $AlCl_3$, and calcium chloride, $CaCl_2$. The Conductivity Probe will be used to measure conductivity of the solution. Conductivity is measured in microsiemens per centimeter ($\mu S/cm$).

OBJECTIVES

In this experiment, you will

- Use a Conductivity Probe to measure the conductivity of solutions.
- Investigate the relationship between the conductivity and concentrations of a solution.
- Investigate the conductivity of solutions resulting from compounds that dissociate to produce different number of ions.
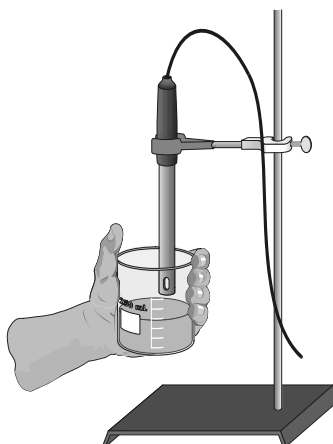
Figure 1

MATERIALS

TI-Nspire handheld **or**	100 mL beaker
computer and TI-Nspire software	distilled water
data-collection interface	wash bottle
Vernier Conductivity Probe	1.0 M NaCl
ring stand	1.0 M $AlCl_3$
utility clamp	1.0 M $CaCl_2$
stirring rod	

PROCEDURE

1. Obtain and wear goggles.

2. Add 70 mL of distilled water to a clean 100 mL beaker. Obtain a dropper bottle that contains 1.0 M NaCl solution.

3. Set the switch on the side of the Conductivity Probe to the 0–2000 µS/cm range. Connect the Conductivity Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

4. Choose New Experiment from the 🎛 Experiment menu. Choose Collection Mode ► Events with Entry from the 🎛 Experiment menu. Enter **Volume** as the Name and **drops** as the Units. Select OK.

5. Before adding any drops of solution:

    a. Start data collection (▶).
    b. Carefully raise the beaker and its contents up around the Conductivity Probe until the hole near the probe end is completely submerged in the solution being tested. **Important:** Since the two electrodes are positioned on either side of the hole, this part of the probe must be completely submerged.
    c. Before you have added any drops of NaCl solution, click the Keep button (📷). Enter **0**, the volume (in drops) and then select OK to save this data pair for this experiment.
    d. Lower the beaker away from the probe.

6. You are now ready to begin adding salt solution.

    a. Add 1 drop of NaCl solution to the distilled water. Stir to ensure thorough mixing.
    b. Carefully raise the beaker and its contents up around the Conductivity Probe until the hole near the probe end is completely submerged in the solution being tested.
    c. Briefly swirl the beaker contents. Monitor the conductivity of the solution for about 5 seconds.
    d. When the conductivity readings stabilize, click the Keep button (📷). Enter **1** as the volume in drops and then select OK. The conductivity and volume values have now been saved for the second trial.
    e. Lower the beaker away from the probe.

7. Repeat the Step 6 procedure, entering **2** this time.

8. Continue this procedure, adding 1-drop portions of NaCl solution, measuring conductivity, and entering the total number of drops added, until a total of 8 drops has been added.

9. Stop data collection (⏹).

10. To analyze the relationship between conductivity and volume plot the linear regression curve on your graph.

    a. Choose Curve Fit ►Linear from the ▣ Analyze menu. **Note:** Since increasing the volume (drops) of NaCl increases the concentration of NaCl in the solution, the graph actually represents the relationship between *conductivity* and *concentration*. The linear-regression statistics for these two lists are displayed for the equation in the form

    $$y = mx + b$$

    where *y* is conductivity, *x* is volume, *m* is the slope, and *b* is the y-intercept.

    b. Record the value for the slope, *m*, in your data table.

11. Click the Store Latest Data Set button (▣) to save the first run. Repeat Steps 5–10, this time using 1.0 M $AlCl_3$ solution in place of 1.0 M NaCl solution.

12. Click the Store Latest Data Set button (▣) to save the second run. Repeat Steps 5–10, this time using 1.0 M $CaCl_2$ solution.

13. To view a graph of concentration *vs.* volume showing all three data runs, click **run3** and select All. All three runs will now be displayed on the same graph axes.

14. (optional) Print a copy of the graph displayed in Step 13. Label each run as "1.0 M NaCl," "1.0 M $AlCl_3$," or "1.0 M $CaCl_2$."

DATA

Solution	Slope, *m*
1.0 M NaCl	
1.0 M $AlCl_3$	
1.0 M $CaCl_2$	

QUESTIONS

1. Describe the appearance of each of the three curves on your graph in Step 13.

2. Describe the change in conductivity as the concentration of the NaCl solution was increased by the addition of NaCl drops. What kind of mathematical relationship does there appear to be between conductivity and concentration?

3. Write a chemical equation for the dissociation of NaCl, $AlCl_3$, and $CaCl_2$ in water.

4. Which graph had the largest slope value? The smallest? Since all solutions had the same original concentration (1.0 M), what accounts for the difference in the slope of the three plots? Explain.

Conductivity of Solutions:
The Effect of Concentration

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. We suggest that you set up the Conductivity Probes before the experiment. Set the selection switch on the amplifier box of the probe to the 0–2000 µS/cm range.

3. Distilled water and tissue can be used to clean the Conductivity Probe. See the Conductivity Probe booklet that comes with the Conductivity Probe for information on how the probes work, how to care for the probes, and calibrations.

4. All solutions are 1.0 M concentration. Have them available in dropper bottles (prepare all solutions in distilled water):

   1.0 M $CaCl_2$ (11.1 g of solid calcium chloride, $CaCl_2$, per 100 mL of solution) Hazard Code: D—Relatively non-hazardous. Alternatively, 14.7 g $CaCl_2 \cdot 2H_2O$, per 100 mL of solution. **HAZARD ALERT:** Toxic by ingestion. Hazard Code: D—Relatively non-hazardous.

   1.0 M NaCl (5.85 g of solid sodium chloride, NaCl, per 100 mL solution) **HAZARD ALERT:** Moderately toxic. Hazard Code: D—Relatively non-hazardous.

   1.0 M $AlCl_3$ (24.15 g of solid aluminum chloride, $AlCl_3 \cdot 6H_2O$, per 100 mL of solution). Hazard Code: D—Relatively non-hazardous. Alternatively, 13.35 g anhydrous $AlCl_3$ per 100 mL of solution. **HAZARD ALERT:** Reacts very violently with water; toxic by inhalation and ingestion; strong skin irritant. Hazard Code: A—Extremely hazardous.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual*, (800) 452-1261, www.flinnsci.com.

5. For consistent results, students should dispense drops with the dropper bottle held in a vertical position.

6. Conductivity readings are normally reported in microsiemens per centimeter, or µS/cm. This SI derived unit has replaced the conductivity unit, micromho/cm.

7. Note that the ratio of slopes of NaCl, $CaCl_2$, and $AlCl_3$ is quite consistent with the ratio of ions produced upon dissociation:

   - Ratio of slopes: 44.5 to 101.5 to 128.1
   - Ratio of moles of ions, upon dissociation: 2 to 3 to 4

SAMPLE RESULTS
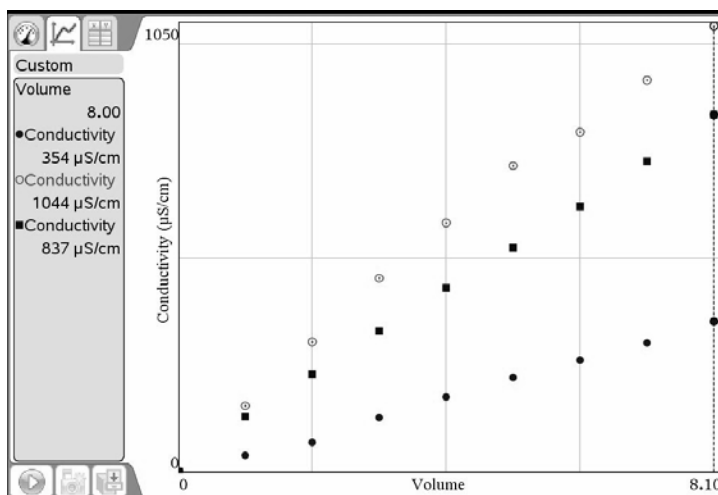
Graph of Conductivity vs. *Volume of salt for NaCl (●), AlCl₃ (○), and CaCl₂ (■).*

Solution	Slope, *m*
1.0 M NaCl	44.5
1.0 M AlCl₃	128.1
1.0 M CaCl₂	101.5

ANSWERS TO QUESTIONS

1. At low concentrations, each curve is nearly linear. The slope value was different for each of the three solutions: $AlCl_3$ was highest, $CaCl_2$ second highest, and NaCl lowest.

2. Conductivity increases as concentration is increased. The relationship appears to be direct.

3. $NaCl \longrightarrow Na^+ + Cl^-$ (2 moles of ions per mole)

   $AlCl_3 \longrightarrow Al^{3+} + 3\ Cl^-$ (4 moles of ions per mole)

   $CaCl_2 \longrightarrow Ca^{2+} + 2\ Cl^-$ (3 moles of ions per mole)

4. $AlCl_3$ has the largest slope value, NaCl the smallest. Even though all three solutions have the same initial concentration, 1.0 M, $AlCl_3$ dissociates to yield the largest number of moles of ions per mole (4). This results in $AlCl_3$ yielding more ions in solution, and the largest slope in this series. $CaCl_2$ is next with 3 moles of ions per mole, and NaCl yields the fewest, 2.

Additivity of Heats of Reaction: Hess's Law

In this experiment, you will use a Styrofoam-cup calorimeter to measure the heat released by three reactions. One of the reactions is the same as the combination of the other two reactions. Therefore, according to Hess's law, the heat of reaction of the one reaction should be equal to the sum of the heats of reaction for the other two. This concept is sometimes referred to as the *additivity of heats of reaction.* The primary objective of this experiment is to confirm this law. The reactions we will use in this experiment are:

(1) Solid sodium hydroxide dissolves in water to form an aqueous solution of ions.

$$NaOH(s) \longrightarrow Na^+(aq) + OH^-(aq) \quad \Delta H_1 = ?$$
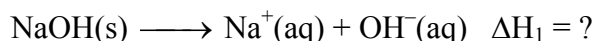
(2) Solid sodium hydroxide reacts with aqueous hydrochloric acid to form water and an aqueous solution of sodium chloride.

$$NaOH(s) + H^+(aq) + Cl^-(aq) \longrightarrow H_2O(l) + Na^+(aq) + Cl^-(aq) \quad \Delta H_2 = ?$$
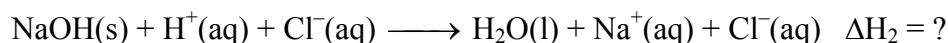
(3) Solutions of aqueous sodium hydroxide and hydrochloric acid react to form water and aqueous sodium chloride.

$$Na^+(aq) + OH^-(aq) + H^+(aq) + Cl^-(aq) \longrightarrow H_2O(l) + Na^+(aq) + Cl^-(aq) \quad \Delta H_3 = ?$$
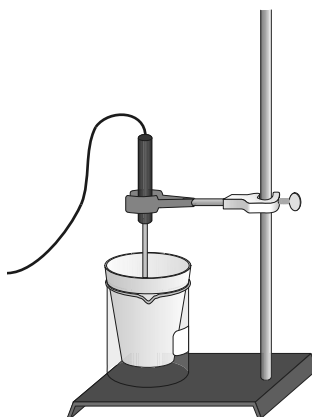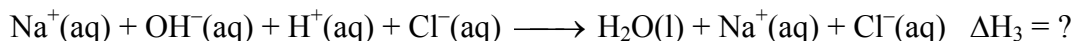
Figure 1

You will use a Styrofoam cup in a beaker as a calorimeter, as shown in Figure 1. For purposes of this experiment, you may assume that the heat loss to the calorimeter and the surrounding air is negligible. Even if heat is lost to either of these, it is a fairly constant factor in each part of the experiment, and has little effect on the final results.

OBJECTIVES

In this experiment, you will

- Combine equations for two reactions to obtain the equation for a third reaction.
- Use a calorimeter to measure the temperature change in each of three reactions.
- Calculate the heat of reaction, ΔH, for the three reactions.
- Use the results to confirm Hess's law.

MATERIALS

TI-Nspire handheld **or**   100 mL of water
   computer and TI-Nspire software   4.00 g of solid NaOH
EasyTemp **or** Go!Temp, **or**   ring stand
   Temperature Probe and data-collection interface   utility clamp
50 mL of 1.0 M NaOH   stirring rod
50 mL of 1.0 M HCl   Styrofoam cup
100 mL of 0.50 M HCl   250 mL beaker

PRE-LAB QUESTIONS

In the space below, combine two of the above equations algebraically to obtain the third equation. Indicate the number of each reaction on the shorter lines.

_____   _____

_____   _____

_____   _____

PROCEDURE

Reaction 1

1. Obtain and wear goggles.

2. Use a utility clamp to suspend a Temperature Probe from a ring stand as shown in Figure 1.

3. Connect the Temperature Probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using an EasyTemp or Go!Temp, you do not need a data-collection interface.)

4. Choose New Experiment from the ⚗ Experiment menu. For this experiment, the default data-collection parameters for a temperature probe will be used (Rate: 2 samples per second; Duration: 180 seconds).

5. Place a Styrofoam cup into a 250 mL beaker as shown in Figure 1. Measure out 100.0 mL of water into the Styrofoam cup. Lower the Temperature Probe into the solution.

6. Weigh out about 2 g of solid sodium hydroxide, NaOH, and record the mass to the nearest 0.01 g in Table 2. Since sodium hydroxide readily picks up moisture from the air, it is necessary to weigh it and proceed to the next step without delay. **CAUTION:** Handle the NaOH and resulting solution with care. They are extremely corrosive.

7. Start data collection (▶). Monitor temperature (in °C) on the screen. It may take several seconds for the Temperature Probe to equilibrate at the temperature of the solution. After three or four readings at the same temperature have been obtained, add the solid NaOH to the Styrofoam cup. Using the stirring rod, stir continuously until the temperature has maximized and then begun to drop.

8. Data collection will stop after 3 minutes. If desired, you can stop data collection early (⏹).

9. To confirm the initial (t_1) and maximum (t_2) temperature values, click any data point and use ► and ◄ move along the curve on the displayed graph. Record these values in Table 1.

10. Rinse and dry the Temperature Probe, Styrofoam cup, and stirring rod. Dispose of the solution as directed by your instructor.

Reaction 2

11. Click the Store Latest Data Set button (▣) to save the data from Reaction 1. Repeat Steps 5–10, using 100.0 mL of 0.50 M hydrochloric acid, HCl, instead of water. Use the same amount of solid NaOH as before. **CAUTION:** *Handle the HCl solution and NaOH solid with care.*

Reaction 3

12. Click the Store Latest Data Set button (▣) to save the data from Reaction 2. Repeat Steps 5–10, initially measuring out 50.0 mL of 1.0 M HCl (instead of water) into the Styrofoam calorimeter. In Step 5, instead of solid NaOH, measure 50.0 mL of 1.0 M NaOH solution into a graduated cylinder. After 3–4 temperature readings have been taken to determine the initial temperature of the 1.0 M HCl, add the 1.0 M NaOH solution to the Styrofoam cup. **CAUTION:** Handle the HCl and NaOH solutions with care.

DATA

Table 1			
	Reaction 1	Reaction 2	Reaction 3
Mass of solid NaOH	g	g	(no solid NaOH mass)
Final temperature, t_2	°C	°C	°C
Initial temperature, t_1	°C	°C	°C

PROCESSING THE DATA

1. Determine the mass, m, of 100 mL of solution for each reaction (assume the density of each solution is 1.00 g/mL).

2. Determine the temperature change, Δt, for each reaction.

3. Calculate the heat released by each reaction, q, by using the formula:

$$q = C_p \cdot m \cdot \Delta t \ (C_p = 4.18 \text{ J/g°C})$$

Convert joules to kJ in your final answer.

4. Find ΔH ($\Delta H = -q$).

5. Calculate moles of NaOH used in each reaction. In Reactions 1 and 2, this can be found from the mass of the NaOH. In Reaction 3, it can be found using the molarity, M, of the NaOH and its volume, in L.

6. Use the results of the Step 4 and Step 5 calculations to determine Δ*H*/mol NaOH in each of the three reactions.

7. To verify the results of the experiment, combine the heat of reaction (Δ*H*/mol) for Reaction 1 and Reaction 3. This sum should be similar to the heat of reaction (Δ*H*/mol) for Reaction 2. Using the value in Reaction 2 as the accepted value and the sum of Reactions 1 and 3 as the experimental value, find the percent error for the experiment.

Table 2: use with Processing the Data			
	Reaction 1	Reaction 2	Reaction 3
Mass (total) of solution	g	g	g
Change in temperature, Δ*t*	°C	°C	°C
Heat, *q*	kJ	kJ	kJ
Δ*H*	kJ	kJ	kJ
Moles of NaOH	mol	mol	mol
ΔH/mol	kJ/mol	kJ/mol	kJ/mol
Experimental value			kJ/mol
Accepted value			kJ/mol
Percent error			%

TEACHER INFORMATION

Additivity of Heats of Reaction: Hess's Law

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. Preparation of solutions:

   0.5 M HCl (42.8 mL of concentrated HCl per 1 L solution) **HAZARD ALERT:** Highly toxic by ingestion or inhalation; severely corrosive to skin and eyes. Hazard Code: A—Extremely hazardous.

   1.0 M HCl (85.6 mL of concentrated HCl per 1 L solution) **HAZARD ALERT:** Highly toxic by ingestion or inhalation; severely corrosive to skin and eyes. Hazard Code: A—Extremely hazardous.

   1.0 M NaOH (40.0 g of solid NaOH per 1 L solution) **HAZARD ALERT:** Corrosive solid; skin burns are possible; much heat evolves when added to water; very dangerous to eyes; wear face and eye protection when using this substance. Wear gloves. Hazard Code: B—Hazardous.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual*, (800) 452-1261, www.flinnsci.com. See *Appendix F* for more information.

2. It is very important to prepare the solutions at least one day in advance so they will be at room temperature prior to doing the experiment.

3. You should discuss with your students three assumptions made in this lab. One is that the specific heat capacity, C_p, for the aqueous solutions is assumed to be the same as that of pure water, 4.18 J/g°C. They are, in fact, very nearly the same. The second assumption is that the density of the aqueous solutions is 1.00 g/mL. Since this is very nearly the case, we can use a mass of 100 g for 100 mL of solution. The procedure for Reaction 3 uses the assumption that initial HCl solution and NaOH solution temperatures are the same. If you make up the solutions at least one day in advance and store them together, the two temperatures will be the same or nearly the same.

ANSWERS TO PRE-LAB QUESTIONS

Reaction 2 is a combination of Reactions 1 and 3

(1) $NaOH(s) \longrightarrow Na^+(aq) + OH^-(aq)$

(3) $Na^+(aq) + OH^-(aq) + H^+(aq) + Cl^-(aq) \longrightarrow H_2O(1) + Na^+(aq) + Cl^-(aq)$

(2) $NaOH(s) + H^+(aq) + Cl^-(aq) \longrightarrow H_2O(1) + Na^+(aq) + Cl^-(aq)$
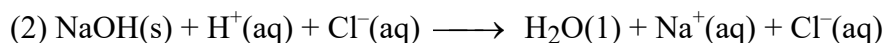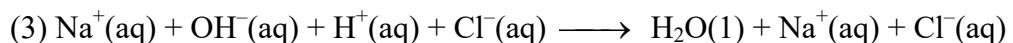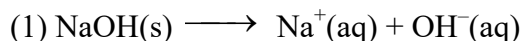
SAMPLE RESULTS

<table>
<tr><td colspan="4" align="center">Table 1</td></tr>
<tr><td></td><td align="center">Reaction 1</td><td align="center">Reaction 2</td><td align="center">Reaction 3</td></tr>
<tr><td>Mass of solid
NaOH</td><td align="center">2.00 g</td><td align="center">1.92 g</td><td align="center">(no solid NaOH mass)</td></tr>
<tr><td>Final
temperature, t_2</td><td align="center">27.0°C</td><td align="center">33.8°C 29.1°C</td><td></td></tr>
<tr><td>Initial temperature, t_1</td><td align="center">22.0°C</td><td align="center">22.2°C 22.3°C</td><td></td></tr>
</table>

<table>
<tr><td colspan="4" align="center">Table 2</td></tr>
<tr><td></td><td align="center">Reaction 1</td><td align="center">Reaction 2</td><td align="center">Reaction 3</td></tr>
<tr><td>Mass (total)
of solution</td><td align="center">100.0 g</td><td align="center">100.0 g</td><td align="center">100.0 g</td></tr>
<tr><td>Change in
temperature, Δt</td><td align="center">5.0°C</td><td align="center">11.6°C</td><td align="center">6.8°C</td></tr>
<tr><td>ΔH</td><td align="center">$\Delta H = -q = -(2.09 \text{ kJ})$

-2.09 kJ</td><td align="center">$\Delta H = -q = -(4.85 \text{ kJ})$

-4.85 kJ</td><td align="center">$\Delta H = -q = -(2.84 \text{ kJ})$

-2.84 kJ</td></tr>
<tr><td>Moles of NaOH</td><td align="center">(2.00 g)(1 mol/40 g) =

0.0500 mol</td><td align="center">(1.92 g)(1 mol/40 g) =

0.0480 mol</td><td align="center">(1 mol/L)(0.050 L) =

0.0500 mol</td></tr>
<tr><td>ΔH/mol</td><td align="center">$\dfrac{-2.09 \text{ kJ}}{0.0500 \text{ mol}} =$

-41.8 kJ/mol</td><td align="center">$\dfrac{-4.85 \text{ kJ}}{0.0480 \text{ mol}} =$

-101 kJ/mol</td><td align="center">$\dfrac{-2.84 \text{ kJ}}{0.0500 \text{ mol}} =$

-56.8 kJ/mol</td></tr>
<tr><td>Experimental value</td><td colspan="3">kJ/mol (Reaction 1 + Reaction 3) -41.8 kJ + $(-56.8$ kJ$)$ = -98.6 kJ/mol</td></tr>
<tr><td>Accepted value kJ/mol</td><td colspan="2">(Reaction 2)</td><td align="right">-101 kJ/mol</td></tr>
<tr><td>Percent error</td><td colspan="2">$\dfrac{|-101-(-98.6)|}{|-101|}$ x 100 =</td><td align="center">2.4 %</td></tr>
</table>

Acid Rain

In this experiment, you will observe the formation of four acids that occur in acid rain:

- carbonic acid, H_2CO_3
- nitrous acid, HNO_2
- nitric acid, HNO_3
- sulfurous acid, H_2SO_3

Carbonic acid occurs when carbon dioxide gas dissolves in rain droplets of unpolluted air:

$$(1) \ \ CO_2(g) + H_2O(l) \longrightarrow H_2CO_3(aq)$$
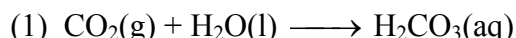
Nitrous acid and nitric acid result from a common air pollutant, nitrogen dioxide (NO_2). Most nitrogen dioxide in our atmosphere is produced from automobile exhaust. Nitrogen dioxide gas dissolves in rain drops and forms nitrous and nitric acid:

$$(2) \ \ 2\,NO_2(g) + H_2O(l) \longrightarrow HNO_2(aq) + HNO_3(aq)$$
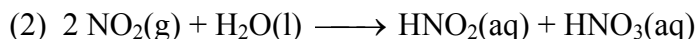
Sulfurous acid is produced from another air pollutant, sulfur dioxide (SO_2). Most sulfur dioxide gas in the atmosphere results from burning coal containing sulfur impurities. Sulfur dioxide dissolves in rain drops and forms sulfurous acid:

$$(3) \ \ SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$$
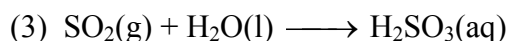
In the procedure outlined below, you will first produce these three gases. You will then bubble the gases through water, producing the acids found in acid rain. The acidity of the water will be monitored with a pH Sensor.
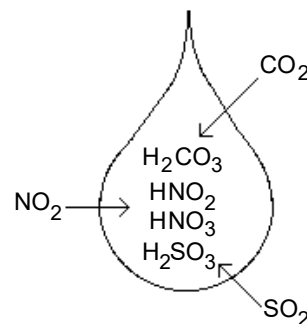
OBJECTIVES

In this experiment, you will

- Generate three gaseous oxides, CO_2, SO_2, and NO_2.
- Simulate the formation of acid rain by bubbling each of the three gases into water and producing three acidic solutions.
- Measure the pH of the three resulting acidic solutions to compare their relative strengths.

MATERIALS

TI-Nspire handheld **or**	utility clamp
computer and TI-Nspire software	solid $NaNO_2$
data-collection interface	solid $NaHCO_3$
Vernier pH Sensor	solid $NaHSO_3$
wash bottle with distilled water	1 Beral pipet with 1.0 M HCl
100 mL beaker	3 Beral pipets with a 2 cm stem
25 x 150 mm test tube	3 Beral pipets with a 15 cm stem
ring stand	tap water

PROCEDURE

1. Obtain and wear goggles.

2. Obtain three short-stem and three long-stem Beral pipets. Label the short-stem pipets with the formula of the solid they will contain: "NaHCO$_3$", "NaNO$_2$", and "NaHSO$_3$". Label the long-stem pipets with the formula of the gas they will contain: "CO$_2$", "NO$_2$" and "SO$_2$". You can use a 100 mL beaker to support the pipets.

3. Obtain a beaker containing solid NaHCO$_3$. Squeeze the bulb of the pipet labeled "NaHCO$_3$" to expel the air, and place the open end of the pipet into the solid NaHCO$_3$. When you release the bulb, solid NaHCO$_3$ will be drawn up into the pipet. Continue to draw solid into the pipet until there is enough to fill the curved end of the bulb, as shown in Figure 1.

Figure 1

4. Repeat the Step 3 procedure to add solid NaNO$_2$ and NaHSO$_3$ to the other two Beral pipets. *CAUTION: Avoid inhaling dust from these solids.*

5. Obtain a Beral pipet with 1.0 M HCl from your teacher. **CAUTION:** *HCl is a strong acid. Gently hold the pipet with the stem pointing up, so that HCl drops do not escape*. Insert the narrow stem of the HCl pipet into the larger opening of the pipet containing the solid NaHCO$_3$, as shown in Figure 2. Gently squeeze the HCl pipet to add about 20 drops of HCl solution to the solid NaHCO$_3$. When finished, remove the HCl pipet. Gently swirl the pipet that contains NaHCO$_3$ and HCl. Carbon dioxide, CO$_2$, is generated in this pipet. Place it in the 100 mL beaker, with the stem up, to prevent spillage.

Figure 2

6. Repeat the procedure in Step 5 by adding HCl to the pipet containing solid NaHSO$_3$. Sulfur dioxide, SO$_2$, is generated in this pipet.

7. Repeat the procedure in Step 5 by adding HCl to the pipet containing solid NaNO$_2$. Nitrogen dioxide, NO$_2$, is generated in this pipet. When you have finished this step, return the HCl pipet to your teacher. Leave the three gas-generating pipets in the 100 mL beaker until Step 10.

8. Connect the pH Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

9. Choose New Experiment from the 🌡 Experiment menu. Enter **2** as the rate (samples/second). The number of points collected should be 241. Select OK.

10. Use a utility clamp to attach a 20 x 150 mm test tube to the ring stand. Add about 4 mL of tap water to the test tube. Remove the pH Sensor from the pH storage solution, rinse it off with distilled water, and place it into the tap water in the test tube.

11. Squeeze all of the air from the bulb of the long-stem pipet labeled "CO$_2$". Keep the bulb completely collapsed and insert the long stem of the pipet down into the gas-generating pipet labeled "NaHCO$_3$", as shown in Figure 3. Be sure the tip of the long-stem pipet remains above the liquid in the gas-generating pipet. Release the pressure on the bulb so that it draws gas up into it. Store the long-stem pipet and the gas-generating pipet in the 100 mL beaker.
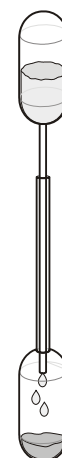
Figure 3

12. Repeat the procedure in Step 11 using the pipets labeled "NaNO$_2$" and "NO$_2$".

13. Repeat the procedure in Step 11 using the pipets labeled "NaHSO$_3$" and "SO$_2$".

14. Insert the long-stem pipet labeled "CO$_2$" into the test tube, alongside the pH Sensor, so that its tip extends into the water to the bottom of the test tube, as shown in Figure 4.

15. Start data collection (▶). After 15 seconds have elapsed, gently squeeze the bulb of the pipet so that bubbles of CO$_2$ *slowly* bubble up through the solution. Use both hands to squeeze *all* of the gas from the bulb. Data collection will end after 2 minutes.

16. When data collection is complete, a graph of pH *vs.* time will be displayed. Click any data point and use ▶ and ◀ to determine the initial pH (before CO$_2$ was added). Record this value. Then determine the final pH value (after CO$_2$ was added and pH stabilized) and record this value.

17. Rinse the pH Sensor thoroughly with distilled water and return it to the pH storage solution. Discard the contents of the test tube as directed by your teacher. Rinse the test tube *thoroughly* with tap water. Add 4 mL of tap water to the test tube. Place the pH Sensor in the test tube. Click the Meter View tab (📷) to check to see that the input display shows a pH value that is about the same as the previous initial pH. If not, rinse the test tube again.

Figure 4

18. Click the Store Latest Data Set button (📇) to save the first run data. Repeat Steps 15–17 using NO$_2$ instead of CO$_2$.

19. Click the Store Latest Data Set button (📇) to save the second run data. Repeat Steps 15–17 using SO$_2$ instead of CO$_2$.

20. When you are finished, rinse the pH Sensor with distilled water and return it to the pH storage solution. Return the six pipets to the location designated by your teacher.

21. To view a graph of pH *vs.* time showing all three data runs, click **run3**, and select All. The three runs will now be displayed on the same graph.

22. (optional) Print a copy of the graph displayed in Step 21. Label each run as CO$_2$, NO$_2$, or SO$_2$.
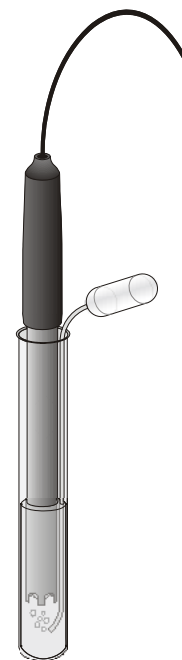
DATA

Gas	Initial pH	Final pH	Change in pH (ΔpH)
CO$_2$			
NO$_2$			
SO$_2$			

PROCESSING THE DATA

For each of the three gases, calculate the change in pH (ΔpH), by subtracting the final pH from the initial pH. Record these values in the Data table.

QUESTIONS

1. In this experiment, which gas caused the smallest drop in pH?

2. Which gas (or gases) caused the largest drop in pH?

3. Coal from western states such as Montana and Wyoming is known to have a lower percentage of sulfur impurities than coal found in the eastern United States. How would burning low-sulfur coal lower the level of acidity in rainfall? Use specific information about gases and acids to answer the question.

4. High temperatures in the automobile engine cause nitrogen and oxygen gases from the air to combine to form nitrogen oxides. What two acids in acid rain result from the nitrogen oxides in automobile exhaust?

5. Which gas and resulting acid in this experiment would cause rainfall in *unpolluted* air to have a pH value less than 7 (sometimes as low as 5.6)?

6. Why would acidity levels usually be lower (pH higher) in actual rainfall than the acidity levels you observed in this experiment? Rainfall in the United States generally has a pH between 4.5 and 6.0.

TEACHER INFORMATION

Acid Rain

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. The 1.0 M HCl solution can be prepared by adding 8.6 mL of concentrated acid per 100 mL of solution. **HAZARD ALERT:** Highly toxic by ingestion or inhalation; severely corrosive to skin and eyes. Hazard Code: A—Extremely hazardous.

    Draw the HCl solution into the Beral pipets through the short, narrow stem. Since a trial requires approximately 1 mL of 1.0 M HCl, or a total of 3 mL for 3 gases, fill the bulb 3/4 full (3–4 mL).

3. Solid $NaHCO_3$, $NaHSO_3$, and $NaNO_2$ can be placed in 100 mL beakers to a depth of 1–2 cm.

    HAZARD ALERTS:

    Sodium bisulfite: Severe irritant to skin and tissue as an aqueous solution; moderately toxic. Hazard Code: C—Somewhat hazardous.

    Sodium nitrite: Strong oxidizer; fire and explosion risk if heated; highly toxic by ingestion and inhalation. Hazard Code: B—Hazardous.

    The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual*, (800) 452-1261, www.flinnsci.com. See *Appendix F* for more information.

4. Thin-stem Beral pipets may be purchased from Flinn Scientific. The part numbers are:

    AP1718   Pkg. of 20

    AP1444   Pkg. of 500

    At a price of about $0.05 each, the pipets may be considered disposable. You can empty the pipets and discard or recycle them after using. You may also choose to empty, clean, and reuse the pipets.

5. One advantage of the microscale version of this experiment is that it avoids the odors of the two noxious gases, NO_2 and SO_2. Very little of either gas escapes into the room. You can operate the laboratory ventilation system during the experiment as a further precaution.

6. To make a narrower stem for the gas-collecting pipets and HCl pipets, it is necessary to stretch out the stem of the Beral pipet. To do this, place the pipet bulb in the palm of one hand with your thumb against the stem where it joins the bulb. Firmly grip the middle of the stem with your other hand and pull hard on the stem until it yields to the pressure and stretches out to a uniform narrow diameter. You can easily stretch it to the length needed for the gas-collecting pipets. Cut off the stems to a length of 15 cm for the gas pipets, and to a length of 4 cm for the HCl pipets. For the gas-generating pipet, cut the stem of a new Beral pipet to a length of 2 cm. Since it has a wider stem, the HCl and gas-collecting pipets will easily fit into it.

7. The directions in the experiment call for the use of a 100 mL beaker as a support for the Beral pipets. The pipets are placed in the beaker in an upright position, with the bulbs down.

Test tube racks for 13 × 100 mm test tubes or 24 well microscale well plates also work well as supports for the Beral pipets.

8. The procedure directs students to obtain the 1.0 M HCl from the teacher, and then return it. For safety reasons, we felt it might be better for teachers to directly account for pipets containing HCl. The directions also have students return the used gas-generating and gas-collecting pipets at the end of the period. Whether you choose to dispose, recycle, or reuse the pipets, we recommend that your students not empty or clean the pipets. This way, accidents that might result from carelessly squeezing pipets containing HCl can be avoided. Empty the gas-generating pipets under a fume hood.

9. If you choose to reuse the gas-collecting pipets, you need to ensure that they are perfectly dry. The SO_2 and NO_2 gases are highly soluble, even in small droplets of water. Draw air in and out of the pipets 10 to 15 times to dry the bulbs.

10. To save time, you may choose to perform Step 3 of the procedure ahead of time. Students have very little difficulty adding the $NaHCO_3$ and $NaHSO_3$ powders to the Beral pipets, but have more trouble adding the larger granules of $NaNO_2$.

11. The equations for the production of each of the gases, as performed in this experiment, are:

Carbon dioxide: $NaHCO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(1) + CO_2(g)$

Sulfur dioxide: $NaHSO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(1) + SO_2(g)$

Nitrogen dioxide: $3\ NaNO_2(s) + 3\ HCl(aq) \longrightarrow 3\ NaCl(aq) + HNO_3(aq) + 2\ NO(g) + H_2O$

   $2\ NO(g) + O_2(g) \longrightarrow 2\ NO_2(g)$

12. Even though the procedure calls for tap water, distilled water can also be used. We use tap water because it normally contains enough dissolved CO_2, HCO_3^-, and CO_3^{2-} to give it a small amount of buffering capacity. This stabilizes the pH reading when the pH Sensor is first placed in the water and avoids fluctuations or gradual changes in pH that students encounter with distilled water. In the sample graphs on the next page, the buffering effect causes a smaller drop in pH in the first 5–10 seconds after the gas is added, followed by a more rapid drop.

13. This is a good time to discuss the topic of anhydrides with your students. All three of these gases are oxides of non-metals and represent good examples of *acidic anhydrides*.

14. A 20 × 150 mm test tube works well in this experiment. Test tubes size 18 × 150 mm will not easily allow the narrow stem of the pipet to fit alongside the pH Sensor.

15. It is not necessary to calibrate your pH sensor, the stored pH calibration works well for this experiment.

SAMPLE RESULTS

Gas	Initial pH	Final pH	Change in pH (ΔpH)
CO_2	7.21	6.36	−0.85
NO_2	7.13	4.29	−2.84
SO_2	7.04	3.45	−3.59
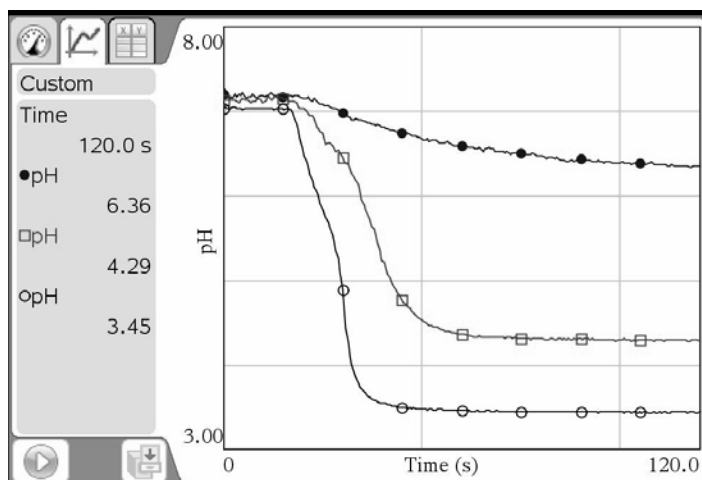
pH vs. *time graph for CO$_2$ ($\bullet$), NO$_2$($\square$), and SO$_2$ ($\circ$) dissolving in water*

ANSWERS TO QUESTIONS

1. Carbon dioxide, CO_2, caused the smallest drop in pH (ΔpH = –0.85).

2. Sulfur dioxide, SO_2, caused the largest drop in pH (ΔpH = –3.59). Nitrogen dioxide, NO_2, causes a drop in pH about the same as SO_2 (ΔpH = –2.84).

3. When low-sulfur coal is burned, it produces less sulfur dioxide. With lower concentrations of sulfur dioxide in the atmosphere, less sulfurous acid will be produced by the reaction:

$$SO_2(g) + H_2O(1) \longrightarrow H_2SO_3(aq)$$
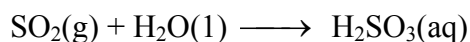
4. Nitrous acid, HNO_2, and nitric acid, HNO_3, are produced by the reaction:

$$2\ NO_2(g) + H_2O(g) \longrightarrow HNO_2(aq) + HNO_3(aq)$$
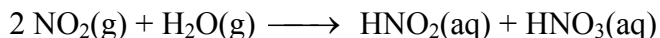
5. Carbon dioxide gas, a natural component of the atmosphere, dissolves in rainwater and forms carbonic acid, H_2CO_3.

6. The acidity level is lower in actual rainfall because the concentration of SO_2, NO_2, and CO_2 gases in the atmosphere is much lower than in this experiment.

Graph Matching

One of the most effective methods of describing motion is to plot graphs of position, velocity, and acceleration *vs.* time. From such a graphical representation, it is possible to determine in what direction an object is going, how fast it is moving, how far it traveled, and whether it is speeding up or slowing down. In this experiment, you will use a Motion Detector to determine this information by plotting a real time graph of *your* motion as you move across the classroom.

The Motion Detector measures the time it takes for a high frequency sound pulse to travel from the detector to an object and back. Using this round-trip time and the speed of sound, the distance to the object can be determined; that is, its position. The change in the position data can then be used to calculate the object's velocity and acceleration. All of this information can be displayed in a graph. A qualitative analysis of the graphs of your motion will help you understand the concepts of kinematics.

walk back and forth in front
of the wall with the
TI-Nspire and Motion Detector
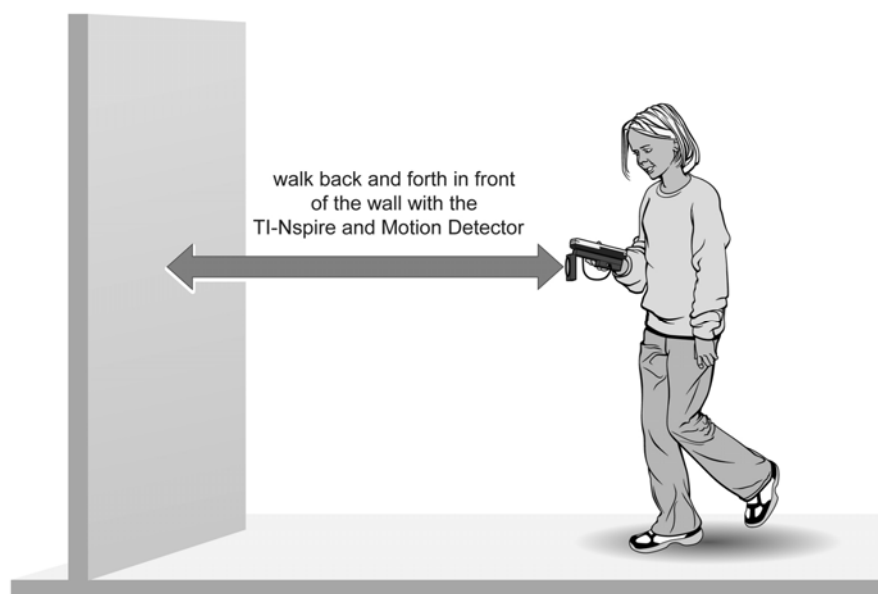
OBJECTIVES

- Analyze the motion of a student walking across the room.
- Predict, sketch, and test position *vs.* time kinematics graphs.
- Predict, sketch, and test velocity *vs.* time kinematics graphs.

MATERIALS

TI-Nspire handheld **or**	meter stick
computer and TI-Nspire software	masking tape
CBR 2 **or** Go! Motion, **or**	
Motion Detector and data-collection interface	

PRE-LAB QUESTIONS

1. Sketch the position *vs.* time graph for each of the following situations. Use a coordinate system with the origin at far left and positive distances increasing to the right.

   a. An object at rest
   b. An object moving in the positive direction with a constant speed
   c. An object moving in the negative direction with a constant speed
   d. An object that is accelerating in the positive direction, starting from rest

2. Sketch the velocity *vs.* time graph for each of the situations described above.

PROCEDURE

1. Find an open area at least 4 m long in front of a wall. Use short strips of masking tape on the floor to mark distances of 1 m, 2 m, and 3 m from the wall. You will be measuring distances from the Motion Detector in your hand to the wall.

2. If your Motion Detector has a switch, set it to Normal. Connect the Motion Detector to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using a CBR 2 or Go!Motion, you do not need a data-collection interface.)

3. Choose New Experiment from the 🎬 Experiment menu. Choose Collection Setup from the 🎬 Experiment menu. Enter **10** as the experiment duration in seconds. The number of points collected should be 201. Select OK.

4. Click the Graph View tab (📈). Choose Show Graph ▶ Graph 1 from the 📈 Graph menu. Only the Position vs. Time Graph will be displayed.

Part I Preliminary Position *vs.* Time Experiments

5. Open the hinge on the Motion Detector. When you collect data, hold the Motion Detector so the round, metal detector is always pointed directly at the wall. Sometimes you will have to walk backwards.

6. Monitor the position readings. Move back and forth and confirm that the values make sense.

7. Make a graph of your motion when you walk away from the wall with constant velocity. To do this, stand about 1 m from the wall, start data collection (▶), and walk backward, slowly away from the wall.

8. Use the Draw Prediction tool (from the 📊 Analyze menu) to show what the distance *vs.* time graph will look like if you walk faster. Check your prediction with the Motion Detector. Start data collection (▶) when you are ready to begin walking.

9. Try to match the shape of the distance *vs.* time graphs that you sketched in the Preliminary Questions section by walking back and forth in front of the wall.

Part II Position *vs.* Time Graph Matching

10. Choose New Experiment from the 🎬 Experiment menu. Choose Collection Setup from the 🎬 Experiment menu. Enter **10** as the experiment duration in seconds. The number of points collected should be 201. Select OK.

11. Click the Graph View tab (⬚). Choose Motion Match ► New Position Match from the ⬚ Analyze menu. A target graph will be displayed for you to match.

12. Write down how you would walk to reproduce the target graph. Sketch or print a copy of the graph.

13. To test your prediction, choose a starting position. Start data collection (⬚), then walk in such a way that the graph of your motion matches the target graph on the screen.

14. If you were not successful, try step 13 again. Repeat this process until your motion closely matches the graph on the screen. Print or sketch the graph with your best attempt.

15. Perform a second graph match by choosing Motion Match ► New Position Match from the ⬚ Analyze menu. This will generate a new target graph for you to match.

16. Answer the Analysis questions for Part II.

Part III Preliminary Velocity *vs*. Time Experiments

17. Insert a new Problem into your TI-Nspire document and add a DataQuest App to the problem.

18. Choose New Experiment from the ⬚ Experiment menu. Choose Collection Setup from the ⬚ Experiment menu. Enter **10** as the experiment duration in seconds. The number of points collected should be 201. Select OK.

19. Click the Graph View tab (⬚). Choose Show Graph ► Graph 2 from the ⬚ Graph menu. Only the Velocity vs. Time Graph will be displayed.

20. Make a graph of your motion when you walk away from the wall with constant velocity. To do this, stand about 1 m from the wall, start data collection (⬚), and walk backward, slowly away from the wall.

21. Use the Draw Prediction tool (from the ⬚ Analyze menu) to show what the velocity *vs.* time graph will look like if you move toward the wall at the same speed you walked away from the wall. Check your prediction with the Motion Detector. Start data collection (⬚) when you are ready to begin walking.

22. Try to match the shape of the velocity *vs.* time graphs that you sketched in the Preliminary Questions section by walking back and forth in front of the wall.

Part IV Velocity *vs*. Time Graph Matching

23. Choose New Experiment from the ⬚ Experiment menu. Choose Collection Setup from the ⬚ Experiment menu. Enter **10** as the experiment duration in seconds. The number of data points collected will be 201. Select OK.

24. Click the Graph View tab (⬚). Choose Motion Match ► New Velocity Match from the ⬚ Analyze menu. A target graph will be displayed for you to match. Choose Window Settings from the ⬚ Graph menu, then enter **–2** for Y Min and **2** for Y Max.

25. Write down how you would walk to produce this target graph. Sketch or print a copy of the graph.

26. To test your prediction, choose a starting position and stand at that point. Start data collection (⊙), then walk in such a way that the graph of your motion matches the target graph on the screen. It will be more difficult to match the velocity graph than it was for the position graph.

27. If you were not successful, try Step 26 again. Repeat this process until your motion closely matches the graph on the screen. Print or sketch the graph with your best attempt.

28. Perform a second velocity graph match by choosing Motion Match ► New Velocity Match from the ⬛ Analyze menu. This will generate a new target velocity graph for you to match.

29. Remove the masking tape strips from the floor.

QUESTIONS

Part II Position *vs*. Time Graph Matching

1. Describe how you walked for each of the graphs that you matched.

2. Explain the significance of the slope of a position *vs*. time graph. Include a discussion of positive and negative slope.

3. What type of motion is occurring when the slope of a position *vs*. time graph is zero?

4. What type of motion is occurring when the slope of a position *vs*. time graph is constant?

5. What type of motion is occurring when the slope of a position *vs*. time graph is changing? Test your answer to this question using the Motion Detector.

6. Return to the procedure and complete Parts III and IV.

Part IV Velocity *vs*. Time Graph Matching

7. Describe how you walked for each of the graphs that you matched.

8. What type of motion is occurring when the slope of a velocity *vs*. time graph is zero?

9. What type of motion is occurring when the slope of a velocity *vs*. time graph is not zero? Test your answer using the Motion Detector.

EXTENSIONS

1. Create a graph-matching challenge. Sketch a position *vs*. time graph on a piece of paper and challenge another student in the class to match your graph. Have the other student challenge you in the same way.

2. Create a velocity *vs*. time challenge in a similar manner.

TEACHER INFORMATION

Graph Matching

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. Motion Detectors without a range switch do not properly detect objects closer than 0.5 m. The maximum range is about 6 m, but stray objects in the wide detection cone can be problematic at this position.

3. This experiment may be the first time your students use the Motion Detector. A little coaching on its use now will save time later in the year as the Motion Detector is used in many experiments. Here are some hints for effective use of the Motion Detector.

   - When using the Motion Detector, it is important to realize that the ultrasound is emitted in a cone about 30º wide. Anything within the cone of ultrasound can cause a reflection and possibly an accidental measurement. A common problem in using Motion Detectors is getting unintentional reflections from a desk, chair, or computer in the room.
   - If you begin with a velocity or acceleration graph and obtain a confusing display, switch back to the position graph to see if it makes sense. If not, the Motion Detector may not be properly detecting the target.
   - Tilting the Motion Detector slightly can minimize unintended reflections.

4. If you are using a computer, you may have to place the motion detector on a table and walk towards and away from the motion detector. Here are some tips for collecting data when an object is moving in front of a stationary motion detector.

   - You may want to have your students hold a large book out in front of them as they walk in front of the Motion Detector. This will tend to produce better graphs because it smoothes out the motion.
   - Sometimes a target may not supply a strong reflection of the ultrasound. For example, if the target is a person wearing a bulky sweater, the resulting graph may be inconsistent.
   - If the velocity and acceleration graphs are noisy, try to increase the strength of the ultrasonic reflection from the target by increasing the target's area.

5. It is very helpful to use masking tape and place 1 meter marks on the floor. The student instructions ask students to place the tape on the floor. If this is not practical in your classroom, lay meter sticks on the floor to show distances from the motion detector.

6. Students at first may find it difficult to match a position *vs.* time graph. Be sure to encourage them to repeat data collection until they get acceptable results. This may take some practice and will be easiest if the person who is walking can see the screen.

7. Students will find that matching the velocity graphs will be more difficult than the position graphs. The biggest problem will be to generate a smooth graph since the trunk of the body undergoes accelerations during each step. The best results occur with small, shuffling steps.

8. This activity can be split over two days if desired. On the first day, have students do Parts I and II. On the second say, have them do parts III and IV.

SAMPLE RESULTS
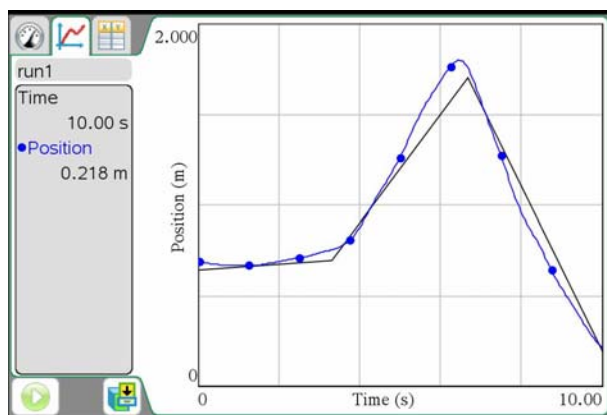
Typical position match.   *Typical velocity match.*
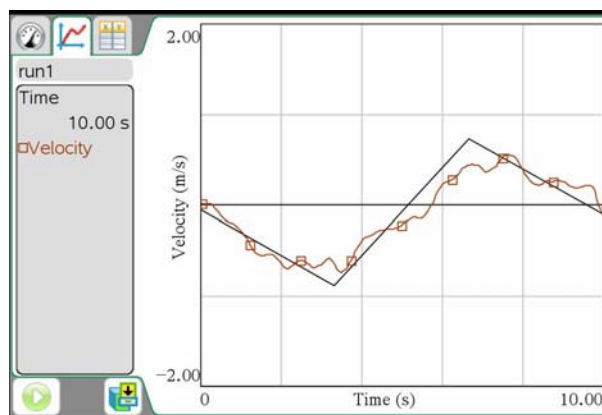
ANSWERS TO QUESTIONS

Part II Position *vs.* Time Graph Matching

1. Answers will vary.

2. A positive slope on a position *vs.* time graph corresponds to moving *away* from the Motion Detector and positive velocity. A negative slope corresponds to motion toward the detector and negative velocity.

3. A zero slope for a position *vs.* time graph corresponds to zero velocity.

4. A constant slope for a position *vs.* time graph corresponds to a constant velocity.

5. A changing slope in a position *vs.* time graph corresponds to a changing velocity; that is, either speeding up or slowing down.

Part IV Velocity *vs.* Time Graph Matching

7. Answers will vary.

8. A zero slope on a velocity *vs.* time graph represents zero acceleration.

9. A non-zero slope on a velocity *vs.* time graph represents a non-zero acceleration; that is, speeding up or slowing down.

Ball Toss

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

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

OBJECTIVES

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

MATERIALS

TI-Nspire handheld **or**   volleyball or basketball
  computer and TI-Nspire software
CBR 2 **or** Go!Motion **or**
  Motion Detector and data-collection interface

PRE-LAB QUESTIONS

1. Think about the changes in motion a ball will undergo as it travels straight up and down. 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

1. Place the Motion Detector on a table or chair, away from other objects.

2. If your Motion Detector has a switch, set it to Normal. Connect the Motion Detector to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using a CBR 2 or Go!Motion, you do not need a data-collection interface.)

3. Set up data collection.

    a. Choose New Experiment from the 🖾 Experiment menu.
    b. Choose Collection Setup from the 🖾 Experiment menu. Enter **25** as the rate in samples/second. The number of points collected should be 126.
    c. Select the Strip Chart option
    d. Select OK.

4. Collect the data.

    a. *This step may require some practice.* Hold the ball in two hands about 0.5 m above the motion detector. Toss the ball straight upward above the Motion Detector and let it fall back toward the Motion Detector. Be sure to pull your hands away from the ball after it starts moving so they are not picked up by the Motion Detector. A toss that goes to about 1.0 m above the Motion Detector works well.
    b. Have your partner start data collection (⏵). **Note:** Data will be collected until you stop data collection but only the last 5 seconds of data will be retained.
    c. Toss the ball as described in Step a. Continue tossing until you have one good toss.
    d. Have your partner stop data collection (⏹) before any of the data from your desired toss is discarded.
    e. Check with your instructor if you are not sure whether you need to repeat the data collection. If necessary, repeat Steps b–d until you have the desired data.

5. Modify your graph to show only your desired toss.

    a. From the position *vs.* time graph, select a region of data that includes the desired toss. The region should be about 1.5 seconds in duration and included points both before and after the toss.
    b. Choose Strike Data from the 🖾 Data menu, then select the Outside Selected Region option.
    c. Check with your instructor if you are not sure if your selected region is appropriate for the analysis of the data. If necessary, restore your data and select the region again.

6. Use Data Markers to identify the following points on your position vs. time graph.

    *   The point where you started to toss the ball.
    *   The point where the ball leaves your hand.
    *   The point where the ball reaches its maximum height.
    *   The point where the ball is first caught.
    *   The point where the ball comes to rest in your hands.

    a. To add a data marker, click on the graph and use ▶ and ◀ to locate the points.
    b. Move your cursor over the Graph View details box and launch the contextual menu (handheld – /b; computer – right-click). Select the Add Data Marker option.
    c. Add a brief description of the point in the text field.

7. Either print or sketch the three motion graphs. To display an acceleration *vs.* time graph, change the y-axis of the velocity or position graph to Acceleration.

DATA

Position *vs*. Time

Velocity *vs*. Time
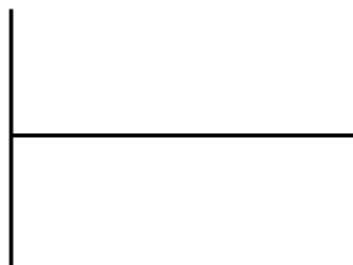
Acceleration *vs*. Time
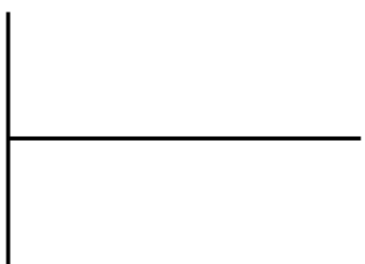
PROCESSING THE DATA

1. Label these points directly on the printed or sketched graphs.

   a. Identify the region when the ball was being tossed but still in your hands.
      - Label this region on the velocity *vs*. time graph.
      - Label this same region on the acceleration *vs*. time graph.

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

   c. Determine the position, velocity, and acceleration at these specific points.
      - On the velocity *vs*. time graph, locate where the ball had its maximum velocity, after the ball was released. Mark the spot and record the value on the graph.
      - On the position *vs*. time graph, locate the maximum height of the ball during free fall. Mark the spot and record the value on the graph.

2. The motion of an object in free fall is modeled by $y = v_0t + \frac{1}{2} gt^2$, where y is the vertical position, v_0 is the initial velocity, t is time, and g is the acceleration due to gravity (9.8 m/s^2). This is a quadratic equation whose graph is a parabola.

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

   a. If the data are not already selected, select the data points in the region where the ball was in freefall. Choose Curve Fit ▶ Position ▶ Quadratic from the 🗠 Analyze menu.

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

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

   a. Select the data points in the region that corresponds to when the ball was in freefall.
   b. Choose Curve Fit ► Velocity ► Linear from the ⬛ Analyze menu.
   c. Record the parameters of the curve fit in the data table.

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

   a. If the data are not already selected, select the data points in the region where the ball was in freefall. Choose Statistics ► Acceleration from the ⬛ Analyze menu.
   b. Record the mean acceleration value in your data table.

	Analysis Parameters		
	A *or* M *or* Average	B	C
Distance (Ax^2 + Bx + C)			
Velocity (Mx + B)			
Average acceleration			

QUESTIONS

1. Based on your graphs, what was the velocity of the ball at the top of its motion? What was the acceleration of the ball at the top of its motion?

2. How closely does the coefficient of the x^2 term of the Quadratic fit of the position data compare to ½ *g*?

3. How closely does the coefficient of the x term of the linear fit of the velocity data compare to the accepted value of *g*?

4. How closely does the average acceleration of the free fall motion data compare to the accepted value for *g*?

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

EXTENSIONS

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

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

3. Perform the same lab using a beach ball or other very light, large ball. See the questions in Extension 2 above.

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

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

TEACHER INFORMATION

Ball Toss

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. A volleyball or a basketball works well in this lab. Since these are rather large, a buoyant force and air resistance will affect the acceleration. The students will probably not get 9.8 m/s^2, but the shapes of the curves will be correct. Smaller objects that yield better *g* values are difficult to use because they do not reflect the ultrasound well. Do not use a light ball such as a beach ball, since air resistance is too large compared to the gravitational force. The analysis of the motion of a beach ball is suggested as an extension.

3. Using a beach ball will yield more air resistance and buoyant force effects, while using a baseball or dense rubber ball will do the opposite. Careful analysis may show some small differences between the dense balls and the others. Over a short distance and with the velocities relatively low, air resistance does not become a major factor, except for the beach ball. Nerf$^®$ or foam balls do not work well for this experiment.

4. There are several keys to collecting good data. It will help if you demonstrate the toss before the students begin. Here are some tips:

    *   Hold the ball with your hands on the sides of it. After you release the ball, get your hands out of the way.
    *   Do not toss the ball using one hand underneath the ball. Your hand will interfere with the data collection.
    *   It is not necessary to toss the ball high. A height of 0.5 to 1.0 m above the release point works well.
    *   The ball must stay directly above the Motion Detector during its motion.

5. Motion detectors without a mode switch do not properly detect objects closer than 0.5 m. As a result, such motion detectors must be farther away from the experiment than described in the student notes. In contrast, Motion detectors *with* a mode switch will detect objects as close as 0.15 m. Ideally, an experiment will be set up so that the target is nearly this close at the point of closest approach, giving the best possible data.

6. This activity makes use of the Strip Chart feature in DataQuest. Based on the setup, only the last five seconds of data will be retained after stopping data collection. It is strongly recommend that students work in pairs when collecting data where one person throws the ball and the other person starts and stops data collection.

SAMPLE RESULTS
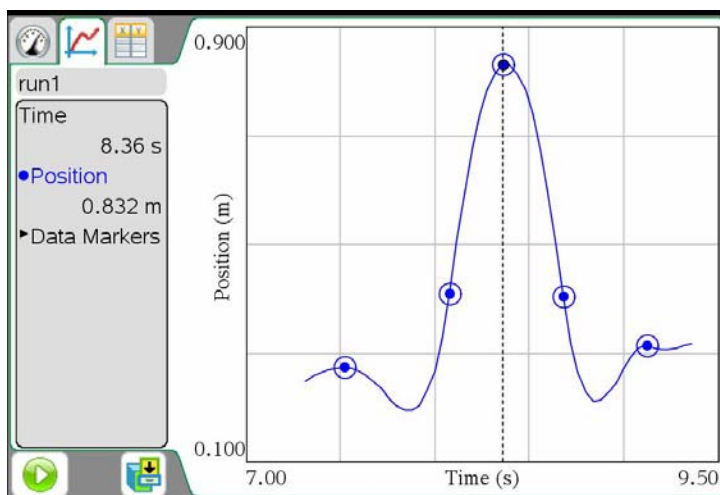
Typical position vs. *time graph.*
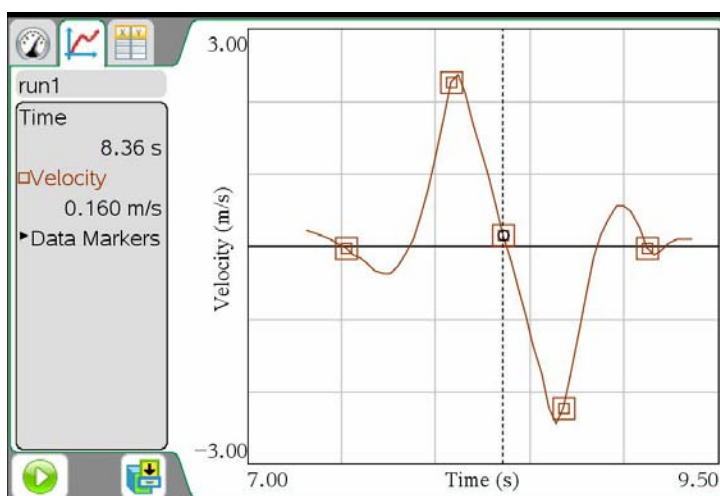
Typical velocity vs. *time graph.*
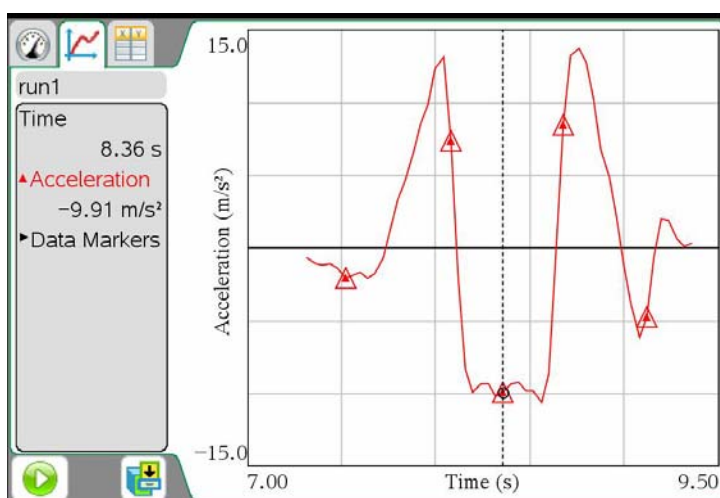
Typical acceleration vs. *time graph.*

	Analysis Parameters		
	A *or* M *or* Average	B	C
Distance ($Ax^2 + Bx + C$)	– 4.79	80.38	– 335.9
Velocity ($Mx + B$)	– 9.67	81.02	
Average acceleration	– 9.58		

ANSWERS TO QUESTIONS

1. The velocity when the ball is at the top should be close to 0 m/s. The acceleration when the ball is at the top should be close to – 9.80 m/s^2.

2. In this example, the coefficient of the x^2 term is – 4.79. For free fall without air resistance, 1/2 *g* should be – 4.90.

3. When a straight line is fit to the velocity graph, the slope of the line is – 9.67 m/s^2, compared to the acceleration due to gravity of – 9.80 m/s^2.

4. The mean acceleration from the acceleration graph is – 9.58 m/s^2, compared to the acceleration due to gravity of – 9.80 m/s^2.

5. The acceleration of the ball was consistently smaller than the accepted acceleration due to gravity. This is largely due to air resistance and the buoyancy of the surrounding air.

EXTENSIONS

1. Since the balls used in this lab are rather large, a buoyant force and air resistance will affect the acceleration. The students will probably not get 9.8 m/s^2, but the shapes of the curves will be correct. Smaller objects that yield better *g* values are difficult to use because they do not reflect the ultrasound well. Variations in your measurements will indicate that there is error in determining the distance that will affect your results.

2. For the half-trip up, the net force on the ball is affected by the upward-directed buoyant force and the downward-directed air resistance. For the half-trip down, the net force on the ball is affected by the upward-directed buoyant force and air resistance.

3. Using a beach ball will yield more air resistance and buoyant force effects. You should expect a lower value for g in this case.

4. Using a baseball or dense rubber ball will yield less air resistance and buoyant force effects. Careful analysis may show some small differences between the dense balls and the others.

Newton's Second Law

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

A Force Sensor and an Accelerometer will let you measure the force on a cart simultaneously with the cart's acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton's second law of motion.
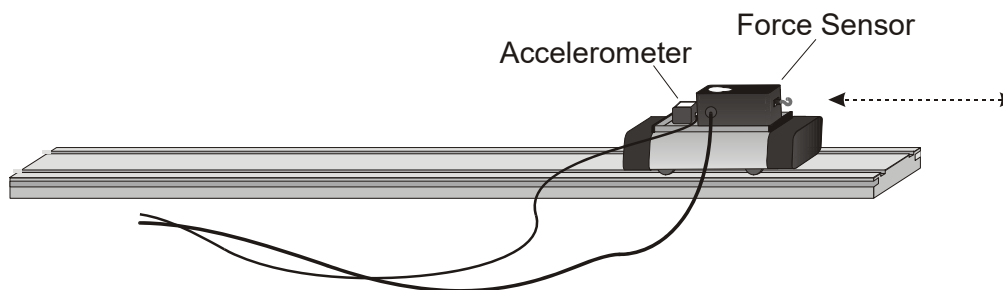
Figure 1

OBJECTIVES

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

MATERIALS

TI-Nspire handheld **or**	Vernier Force Sensor
computer and TI-Nspire software	low-friction dynamics cart
data-collection interface	0.50 kg mass
Vernier Low-g Accelerometer	

PRE-LAB QUESTIONS

1. When you push on an object, how does the magnitude of the force affect its motion? If you push harder, is the change in motion smaller or larger? Do you think this is a direct or inverse relationship?

2. Assume that you have a bowling ball and a baseball, each suspended from a different rope. If you hit each of these balls with a full swing of a baseball bat, which ball will change its motion by the greater amount?

3. In the absence of friction and other forces, if you exert a force, *F*, on a mass, *m*, the mass will accelerate. If you exert the same force on a mass of 2*m*, would you expect the resulting acceleration to be twice as large or half as large? Is this a direct or inverse relationship?

PROCEDURE

1. Attach the Force Sensor to a dynamics cart so you can apply a horizontal force to the hook, directed along the sensitive axis of your particular Force Sensor. Next, attach the Accelerometer so the arrow is horizontal and parallel to the direction that the cart will roll. Orient the arrow so that if you *pull* on the Force Sensor the cart will move in the direction of the arrow. Find the mass of the cart with the Force Sensor and Accelerometer attached. Record the mass in the data table.

2. Set the range switch on the Force Sensor to 10 N. Connect the Force Sensor and the Accelerometer to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the 🖳 Experiment menu. This experiment uses the default collection rate of 50 samples per second and experiment duration of 10 seconds.

4. Zero the sensors.

   a. Place the cart on a level surface.
   b. With the cart stationary and no force applied to the Force Sensor, wait for the acceleration and force readings to stabilize.
   c. Choose Set Up Sensors ► Zero ► All Sensors from the 🖳 Experiment menu. The readings for both sensors should be close to zero.

Trial I

5. You are now ready to collect force and acceleration data. Grasp the Force Sensor hook. Start data collection (⏺) and take several seconds to *gently* move the cart back and forth on the table. Vary the motion so that both small and moderate forces are applied. Make sure that your hand is only touching the hook on the Force Sensor and not the Force Sensor itself or the cart body.

6. Acceleration and force data are displayed on separate graphs. Sketch the graphs in your notes. How are the graphs similar? How are they different?

7. One way to see how similar the acceleration and force data are is to make a new plot of force *vs.* acceleration, with no time axis.

   a. Insert a second DataQuest Application on a new page. Click on the Graph View tab (📈) to display the graphs.
   b. Choose Show Graph ►Graph 1 from the 📈 Graph menu to view a single graph.
   c. Choose Point Options from the 📋 Options menu. Select **None** as the Mark and clear the Connect Data Points checkbox. This will remove the point protectors and the line connecting the data points on the subsequent graph.
   d. Select OK.
   e. Change the x-axis to Acceleration and the y-axis to Force.

8. Fit a line to the graph of force *vs.* acceleration

    a. Choose Curve Fit ► Linear from the ⚡ Analyze menu. The linear-regression statistics for these two data columns are displayed in the form:

    $$y = mx + b$$

    where *x* is acceleration, *y* is force, *m* is the slope, and *b* is the y-intercept. Record this equation in the data table.
    b. Print or sketch your graph.

9. Using the regression equation, determine the acceleration of the cart when a force of 1.0 N has acted upon it. Record the force and acceleration in the data table.

10. Repeat Step 9 using a force of −1.0 N.

Trial 2

11. Attach the 0.50 kg mass to the cart. Record the mass of the cart, sensors, and additional mass in the data table.

12. Go to page 1.1 in the document, which shows both the Force *vs.* Time and Acceleration *vs.* Time graphs. Click the Store Latest Data Set button (📇) to save the trial 1 data. You are now ready to collect trial 2 data.

13. Repeat Steps 5 and 6 for the cart with the additional 0.50 kg mass.

14. Go to page 1.2 in the document, which shows the force *vs.* acceleration graph. Repeat Steps 8–10 for the cart with the additional 0.50 kg mass.

DATA

Trial I

Mass of system with sensors (kg)	

Regression equation for force *vs.* acceleration data

Acceleration at 1.0 N Force		Acceleration at −1.0 N Force	

Trial 2

Mass of system with sensors and additional mass (kg)	

Regression equation for force *vs.* acceleration data

Acceleration at 1.0 N Force		Acceleration at −1.0 N Force	

QUESTIONS

1. Compare the graphs of force *vs.* time and acceleration *vs.* time for a particular trial.

2. Are the net force on an object and the acceleration of the object directly proportional? Explain, using experimental data to support your answer.

3. What are the units of the slope of the force *vs.* acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).

4. For each trial, compare the slope of the regression line to the mass being accelerated. What does the slope represent?

5. Write a general equation that relates all three variables: force, mass, and acceleration.

EXTENSION

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

Newton's Second Law

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment is not intended for use with Easy or Go! Products since data from two sensors must be collected at the same time. While you can use two different handhelds, each with their own sensor or multiple Go! Products on the same computer, to collect the data, a single, multi-channel interface is preferred.

3. Traditional experiments for Newton's second law often use motion detectors or spark timers to measure distance data and calculate acceleration. This experiment uses an Accelerometer to actually measure the acceleration. This device, along with the Force Sensor, makes it easy to quickly collect accurate force and acceleration data.

4. In this experiment, the students will analyze the force *vs.* acceleration graph. During this analysis they will perform a linear fit on the data. The slope of this fit should be close to the mass of the cart and added objects. To get the best possible results, you may want to calibrate both the Force Sensor and Accelerometer.

5. Since the Accelerometer is sensitive to inclination, the students are instructed to make sure the surface is level and to zero the sensors prior to data collection.

6. The mass used in this experiment is the *inertial mass*, as opposed to the *gravitational mass*. You may wish to make this distinction with your students.

7. If the accelerometer data seem noisy, make sure that the sensor is securely fastened to the cart. If it isn't fastened firmly, it could rattle and introduce more noise to the data set.

8. It is critical that the only external horizontal force applied to the cart come through the force sensor. If the cables drag, then there will be other forces not measured by the force sensor. Be sure to have the students move the cables with the cart.

9. Explore all magnitudes of force by moving the cart back and forth in a random way. Do NOT just pull the cart at a uniform speed or at uniform acceleration, since you'll concentrate points in a small region of the force *vs.* acceleration plot that way.

ANSWERS TO PRE-LAB QUESTIONS

1. The larger the force, the more the motion changes. This is a direct relationship.

2. The baseball will change its motion more than the bowling ball.

3. The new acceleration would be half as large. This is an inverse relationship between mass and acceleration.

SAMPLE RESULTS
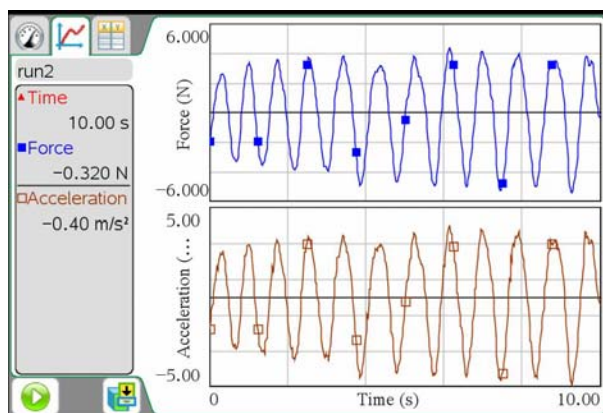
Typical force vs. time and acceleration vs. time graphs.
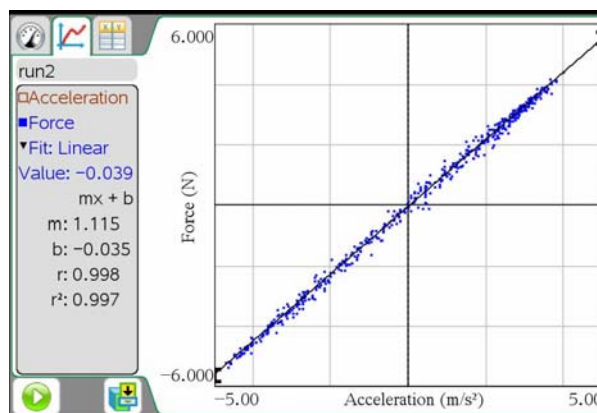
Typical force vs. acceleration graph shown with a linear fit

Trial I

Mass of cart with sensors (kg)	0.66 kg

Regression line for force *vs.* acceleration data			
y = 0.62 x + -0.013			
Acceleration at 1.0 N Force	0.607 m/s^2	Acceleration at -1.0 N Force	-0.633 m/s^2

Trial 2

Mass of cart with sensors (kg)	1.16 kg

Regression line for force *vs.* acceleration data			
y = 1.115 x + -0.035			
Acceleration at 1.0 N Force	1.080 m/s^2	Acceleration at -1.0 N Force	-1.150 m/s^2

ANSWERS TO QUESTIONS

1. The graphs look very similar, showing that force and acceleration are closely related. The peaks on one graph occur at the same time on each graph.

2. Force and acceleration are directly proportional. This relationship can be seen when the graphs of force *vs.* time and acceleration *vs.* time are compared. Also, the graph of force *vs.* acceleration shows a linear relationship.

3. $\dfrac{N}{\left(\dfrac{m}{s^2}\right)} = \dfrac{\left(kg \cdot \dfrac{m}{s^2}\right)}{\left(\dfrac{m}{s^2}\right)} = kg$

4. In Trial 1, the mass was 0.66 kg while the slope of the linear regression line was 0.62 N/(m/s^2). In Trial 2, the mass was 1.16 kg while the slope of the linear regression line was 1.115 N/(m/s^2). In both cases the mass was within the uncertainty of the fitted slope. The slope corresponds to the combined mass of the cart, sensors, and any added mass.

5. $F = m \cdot a$

Static and Kinetic Friction

If you try to slide a heavy box resting on the floor, you may find it difficult to get the box moving. *Static friction* is the force that is acting against the box. If you apply a light horizontal push that does not move the box, the static friction force is also small and directly opposite to your push. If you push harder, the friction force increases to match the magnitude of your push. There is a limit to the magnitude of static friction, so eventually you may be able to apply a force larger than the maximum static force, and the box will move. The maximum static friction force is sometimes referred to as *starting friction*. We model static friction, F_{static}, with the inequality $F_{static} \leq \mu_s N$ where μ_s is the coefficient of static friction and N the *normal* force exerted by a surface on the object. The normal force is defined as the perpendicular component of the force exerted by the surface. In this case, the normal force is equal to the weight of the object.

Once the box starts to slide, you must continue to exert a force to keep the object moving, or friction will slow it to a stop. The friction acting on the box while it is moving is called *kinetic friction*. In order to slide the box with a constant velocity, a force equivalent in magnitude to the force of kinetic friction must be applied. Kinetic friction is sometimes referred to as *sliding friction*. Both static and kinetic friction depend on the surfaces of the box and the floor, and on how hard the box and floor are pressed together. We model kinetic friction with $F_{kinetic} = \mu_k N$, where μ_k is the coefficient of kinetic friction.

In this experiment, you will use a Force Sensor to study static friction and kinetic friction on a wooden block. A Motion Detector will also be used to analyze the kinetic friction acting on a sliding block.

OBJECTIVES

- Use a Force Sensor to measure the force of static and kinetic friction.
- Determine the relationship between force of static friction and the weight of an object.
- Measure the coefficients of static and kinetic friction for a particular block and track.
- Use a Motion Detector to independently measure the coefficient of kinetic friction and compare it to the previously measured value.
- Determine if the coefficient of kinetic friction depends on weight.

MATERIALS

TI-Nspire handheld **or**	string
computer and TI-Nspire software	block of wood with hook
data-collection interface	balance or scale
Vernier Force Sensor	mass set
Motion Detector *or* CBR 2 *or*	graph paper (optional)
Go!Motion	

PRE-LAB QUESTIONS

1. In pushing a heavy box across the floor, is the force you need to apply to start the box moving greater than, less than, or the same as the force needed to keep the box moving? On what1 are you basing your choice?

2. How is the force of friction related to the weight of the box? Explain.

PROCEDURE

Part I Investigating Friction

1. Measure the mass of the block and record it in the data table.

2. Set the range switch on the Force Sensor to 10 N. Connect the Force Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the 🗊 Experiment menu. Choose Collection Setup from the 🗊 Experiment menu. Enter **5** for the duration. The number of points collected should be 251. Select OK.

4. Zero the Force Sensor.

    a. Hold the Force Sensor so the working axis is horizontal.
    b. With the Force Sensor axis held horizontally and no force applied, choose Set Up Sensors ► Zero from the 🗊 Experiment menu. When the process is complete, the readings for the sensors should be close to zero.

5. Tie one end of a string to the hook on the Force Sensor and the other end to the hook on the wooden block. Place a total of 1 kg mass on top of the block, fastened so the masses cannot shift. Practice pulling the block and masses with the Force Sensor using a straight-line motion. Slowly and gently pull horizontally with a small force. *Very gradually*, taking one full second, increase the force until the block starts to slide, and then keep the block moving at a constant speed for another second.

6. Sketch a graph of force *vs.* time for the force you felt on your hand. Label the portion of the graph corresponding to the block at rest, the time when the block just started to move, and the time when the block was moving at constant speed.

7. Hold the Force Sensor in position, ready to pull the block, but with no tension in the string.

8. Start data collection (🖝). Wait a moment, then pull the block as before, taking care to increase the force gradually.

9. Inspect your graph. Repeat Step 8 as needed until you have a graph that reflects the desired motion, including pulling the block at constant speed once it begins moving. Print or sketch the graph for later reference.

Part II Peak Static Friction and Kinetic Friction

In this section, you will measure the peak static friction force and the kinetic friction force as a function of the normal force on the block. In each run, you will pull the block as before, but by changing the masses on the block, you will vary the normal force on the block.
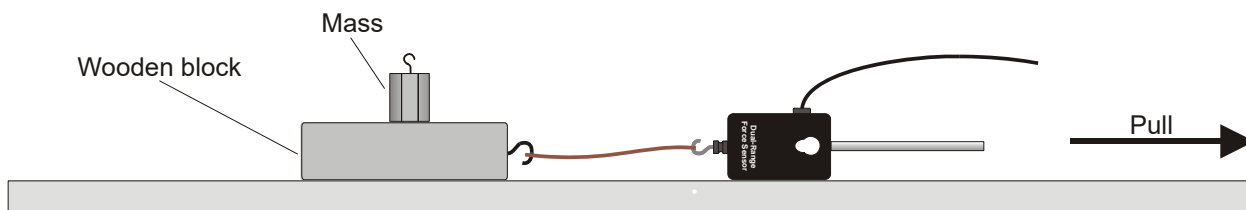
Figure 1

10. Remove all masses from the block.

11. Insert a new Problem into your TI-Nspire document and add a DataQuest App to the problem. Choose New Experiment from the 🗗 Experiment menu. Choose Collection Setup from the 🗗 Experiment menu. Enter **5** for the duration. The number of points collected should be 251. Select OK.

12. Zero the force sensor (see Step 4).

13. Collect force *vs.* time data using the procedure described in Steps 7–9.

14. The maximum value of the force occurs when the block started to slide. Click near this point and use ► and ◄ to highlight the point. The coordinates of the point are displayed in the Graph View details box. Record the maximum force in your data table.

15. Determine the average friction force while the block was moving at constant velocity.

   a. Select the data in the approximately constant-force region.
   b. Choose Statistics from the 🗗 Analyze menu. The statistics for the selected region will be displayed.
   c. Record the mean force value in your data table.

16. Repeat Steps 13–15 for two more measurements. Be sure to Store the Latest Data Set (🗗) before each new run. Average the results to determine the reliability of your measurements. Record the values in the data table.

17. Add masses totaling 500 g to the block. Repeat Steps 13–16. Be sure to Store the Latest Data Set (🗗) before each new run.

18. Add an additional 500 g and repeat Steps 13–16. Be sure to Store the Latest Data Set (🗗) before each new run.

Part III Kinetic Friction Again

In this section, you will measure the coefficient of kinetic friction a second way and compare it to the measurement in Part II. Using a Motion Detector, you can measure the acceleration of the block as it slides to a stop. This acceleration can be determined from the velocity *vs.* time graph. While sliding, the only force acting on the block in the horizontal direction is that of friction. From the mass of the block and its acceleration, you can find the frictional force and finally, the coefficient of kinetic friction.

Wooden block

Figure 2

19. Disconnect the Force Sensor and interface from the TI-Nspire handheld or computer.

20. Place the Motion Detector on the lab table about 2 m from a block of wood, as shown in Figure 2. Use the same surface you used in Part II. Position the Motion Detector so that it will detect the motion of the block as it slides toward the detector.

21. If your Motion Detector has a switch, set it to Normal. Connect the Motion Detector to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using a CBR 2 or Go! Motion, you do not need a data-collection interface.)

22. Insert a new **Problem** into your TI-Nspire document and add a DataQuest App to the problem.

23. Choose New Experiment from the Experiment menu. For this part of the experiment, the default data-collection parameters for a motion detector will be used (Rate: 20 samples per second; Duration: 5 seconds).

24. Click on the Graph View tab ( ). Choose Show Graph ►Graph 2 from the Graph Menu. The graph display should now only show the velocity *vs.* time graph.

25. Practice sliding the block toward the Motion Detector by giving the block a very short push, so that the block leaves your hand and slides to a stop. Minimize the rotation of the block. After it leaves your hand, the block should slide about 1 m before it stops, and it must not come any closer to the Motion Detector than 0.15 m for Motion Detectors with a switch or 0.5 m for those without.

26. Start data collection ( ). After a moment, give the block a brief push so that it slides toward the Motion Detector.

27. Examine the graph of velocity *vs.* time. The velocity graph should have a portion with a linearly changing section before the block comes to rest corresponding to the freely sliding motion of the block. Repeat data collection if needed.

28. Fit a straight line to this portion of the data, the slope of which is the block's acceleration.

    a. Select the data in the region of the graph that is decreasing linearly.
    b. Choose Curve Fit ►Velocity ►Linear from the Analyze menu to fit a straight line to the velocity data.
    c. Record the magnitude of the slope of the fitted line, which is the block's acceleration, in your data table.

29. Repeat Steps 26–28 two more times. Be sure to Store the Latest Data Set ( ) before each collection.

30. Fasten masses totaling 500 g so they will not separate from the block. Store the Latest Data Set ( ), and repeat Steps 26–29. Record acceleration values in your data table.

DATA

Part I Investigating Friction

Mass of block	kg

Part II Peak Static Friction and Kinetic Friction

	Total mass (kg)	Normal force (N)	Peak static friction			Average peak static friction (N)
			Trial 1	Trial 2	Trial 3	
Block						
Block + 0.5 kg						
Block + 1.0 kg						

	Total mass (kg)	Normal force (N)	Kinetic friction			Average kinetic friction (N)
			Trial 1	Trial 2	Trial 3	
Block						
Block + 0.5 kg						
Block + 1.0 kg						

Part III Kinetic Friction

Data: Block with No Additional Mass			
Trial	Acceleration (m/s^2)	Kinetic friction force (N)	μ_k
1			
2			
3			
Average coefficient of kinetic friction:			

Data: Block with 500 g Additional Mass			
Trial	Acceleration (m/s^2)	Kinetic friction force (N)	μ_k
1			
2			
3			
Average coefficient of kinetic friction:			

PROCESSING THE DATA

Part I Investigating Friction

1. Inspect your graph of the force *vs.* time graph drawn in Part I. Label the portion of the graph corresponding to the block at rest, the time when the block just started to move, and the time when the block was moving at constant speed.

Part II Peak Static Friction and Kinetic Friction

2. Calculate the *normal force* of the table on the block alone and with each combination of added masses. Since the block is on a horizontal surface, the normal force will be equal in magnitude and opposite in direction to the weight of the block and any masses it carries. Fill in the Total Mass and Normal Force entries for both Part II Data Tables.

3. Plot a graph of the maximum static friction force (*y*-axis) *vs.* the normal force (*x*-axis).

    a. Disconnect all sensors from your handheld or computer.
    b. Insert a new problem in your TI-Nspire document and insert the DataQuest App.
    c. Click on the Table View tab (▦) to view the table.
    d. Double-click on the x-column to open the column options.
    e. Change the Name to **Normal Force**. Enter **Normal** as the Short Name and **N** as the units. Select OK.
    f. Double-click on the y-column.
    g. Change the Name to **Friction Force**. Enter **Friction** as the short name and **N** as the units. Select OK.
    h. Double-click the run name and enter **Static Friction** as the Data Set name. Select OK.
    i. Enter the data in the table.

4. Since $F_{maximum\ static} = \mu_s\ N$, the slope of this graph is the coefficient of static friction μ_s. Find the numeric value of the slope, including any units. Should a line fitted to these data pass through the origin?

    a. Click on the Graph View tab (⤴) to view the graph.
    b. Select Curve Fit ► Linear from the ◪ Analyze menu.

5. In a similar graphical manner, find the coefficient of kinetic friction, μ_k. Use a plot of the average kinetic friction forces *vs.* the normal force. Recall that $F_{kinetic} = \mu_k\ N$. Should a line fitted to these data pass through the origin?

    a. Click on the Table View tab (▦) to view the table.
    b. Select New Data Set from the ▦ Data menu.
    c. Double-click the run name and enter **Kinetic Friction** as the Data Set name. Select OK.
    d. Enter the data in the table.
    e. Switch to Graph View to view the data.
    f. Select Curve Fit ► Linear from the ◪ Analyze menu.

Part III Kinetic Friction

6. Your data from Part III also allow you to determine μ_k. The kinetic friction force can be determined from Newton's second law, or $\Sigma F = ma$. From the mass and acceleration, find the friction force for each trial, and enter it in the data table.

7. From the friction force, determine the coefficient of kinetic friction for each trial and enter the values in the data table. Also, calculate an average value for the coefficient of kinetic friction for the block and for the block with added mass.

QUESTIONS

Part I Starting Friction

1. Consider the force *vs.* time graph you created in Part I. Compare the force necessary to keep the block sliding compared to the force necessary to start the slide. How does your answer compare to your answer to question 1 in the Pre-Lab Questions section?

2. The *coefficient of friction* is a constant that relates the normal force between two objects (blocks and table) and the force of friction. Based on your graph from Part I, would you expect the coefficient of static friction to be greater than, less than, or the same as the coefficient of kinetic friction?

Part II Peak Static Friction and Kinetic Friction

3. Should the graph of the maximum static friction force *vs.* the normal force (see Processing the Data Step 3) pass through the origin? Explain.

4. Should the graph of the average kinetic friction force *vs.* the normal force (see Processing the Data Step 5) pass through the origin? Explain.

Part III Kinetic Friction

5. Draw a free-body diagram for the sliding block.

6. Does the coefficient of kinetic friction depend on speed? Explain, using your experimental data.

7. Does the force of kinetic friction depend on the weight of the block? Explain.

8. Does the coefficient of kinetic friction depend on the weight of the block?

9. Compare your coefficients of kinetic friction determined in Part III to that determined in Part II. Discuss the values. Do you expect them to be the same or different?

EXTENSIONS

1. How does the surface area of the block affect the force of friction or the coefficient of friction? Devise an experiment that can test your hypothesis.

2. Examine the force of static friction for an object on an incline. Find the angle that causes a wooden block to start to slide. Calculate the coefficient of friction and compare it to the value you obtain when the angle of the incline is 0°.

3. Try changing the coefficient of friction by using wax or furniture polish on the table. How much does it change?

Static and Kinetic Friction

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. For consistent results in this experiment, be sure that the wooden block and table surfaces are clean and free of grease. A missing peak in the static friction force or a variable force during the constant-speed portion of the motion are both indications that the surfaces of the block or table need cleaning. One way to prepare a new, clean surface is to wrap the block in a sheet of paper.

3. You may choose to use the 50 N range instead of the 10 N range if friction forces are large.

4. Dynamics carts with friction pads can be used as an alternative to the wooden block.

5. Coach students to increase the applied force very slowly and evenly. The tendency is to increase the applied force too rapidly.

6. You may want to prepare special wooden blocks for this experiment with drilled holes for your particular mass sets. It is then very easy for students to change the total mass of the block system, and the holes prevent the masses from shifting.

7. Blocks can be stacked to increase mass, but take care that the system moves as a rigid unit.

8. In using the Motion Detector, it is important to realize that the ultrasound is emitted in a cone about 30º wide. Anything within the cone of ultrasound can cause a reflection and possibly an accidental measurement. A common problem in using Motion Detectors is getting unintentional reflections from a desk, chair, or computer in the room.

9. Motion detectors without a mode switch do not properly detect objects closer than 0.5 m. As a result, such motion detectors must be farther away from the experiment than described in the student notes. In contrast, Motion detectors *with* a mode switch will detect objects as close as 0.15 m. Ideally, an experiment will be set up so that the target is nearly this close at the point of closest approach, giving the best possible data.

10. Sometimes a target may not supply a strong reflection of the ultrasound. Attaching a piece of rigid card stock to the block can improve the reflection but it will also increase the error as air resistance will also act to stop the block.

11. A natural break point is between Parts II and III. If the lab needs to be shortened, Part III could be omitted. Many physics teachers feel, however, that the best part of the lab is Part III because it connects Newton's second law directly to the friction equation in the solution of the problem. It also addresses the most confusing concepts to the student – the forces on a freely moving object.

12. **Note on Extension 2:** An alternative way of measuring friction coefficients is to tilt an inclined plane up until the block just starts sliding. At that point, the normal force is $mg \cos \theta$ and the force down the ramp is $mg \sin \theta$, so you can find the coefficient of static friction from $\mu_s = F_{static}/F_N = \tan \theta$. If you tip it up but bump the block until it slides with a constant

velocity, you can find the kinetic friction coefficient by $\mu_k = F_{kinetic}/F_N = \tan\theta$. Have students compare the coefficients of static friction measured using the two methods.

13. It is not necessary to calibrate the Force Sensors because a small error in friction coefficient is not important for this lab; some teachers may nevertheless want to add calibration to the procedure.

ANSWERS TO PRE-LAB QUESTIONS

1. From everyday experience, it is more difficult (that is, it requires more force) to start a box sliding than to keep it sliding.

2. The force of friction increases with the weight of the box. You see this from everyday experience again, since light boxes are generally easier to push than are heavy boxes.

SAMPLE RESULTS

Part I Investigating Friction
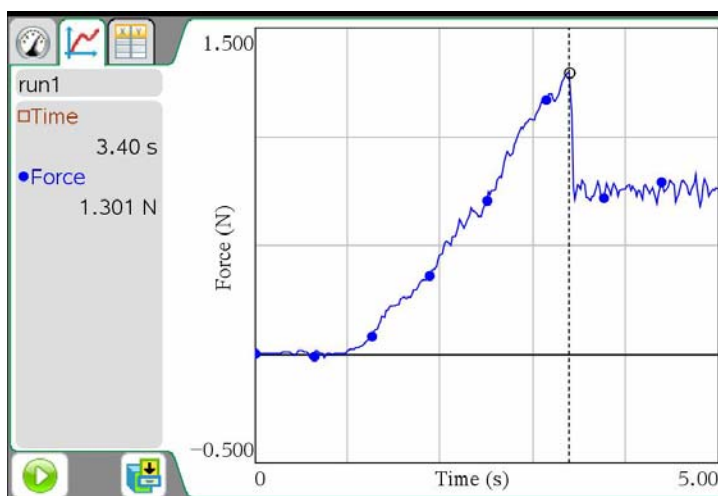
For all Force Sensor runs, the data will have the same qualitative shape as shown here. The magnitudes will vary as the mass carried by the block is changed.

Mass of block	0.28	kg

Part II Peak Static Friction and Kinetic Friction

Total mass (kg)	Normal force (N)	Peak static friction			Average peak static friction (N)
		Trial 1	Trial 2	Trial 3	
0.28	2.74 0.55	0.54 0.53			0.54
0.78	7.64 1.84	1.66 1.75			1.75
1.28	12.54	3.26	3.34 2.88		3.16

Total mass (kg)	Normal force (N)	Kinetic friction			Average kinetic friction (N)
		Trial 1	Trial 2	Trial 3	
0.28	2.74 0.46	0.45 0.48			0.46
0.78	7.64 1.26	1.24 1.32			1.27
1.28	12.54	2.25	2.19 2.33		2.26

Part III Kinetic Friction

Data: Block with No Additional Mass			
Trial	Acceleration (m/s^2)	Kinetic friction force (N)	μ_k
1	3.43	0.96 0.35	
2	3.46	0.97 0.35	
3	3.49	0.98 0.36	
Average coefficient of kinetic friction:			0.35

Data: Block with 500 g Additional Mass			
Trial	Acceleration (m/s^2)	Kinetic friction force (N)	μ_k
1	3.06	2.39 0.31	
2	3.36	2.62 0.34	
3	3.23	2.52 0.33	
Average coefficient of kinetic friction:			0.32

ANSWERS TO QUESTIONS

1. The block started to move just at the peak of the static friction force. Then the applied force was smaller, indicating the kinetic friction force is smaller than the peak static friction force.

2. The coefficient of static friction would then be larger than the coefficient of kinetic friction.

3. The line should pass through the origin.

4. The line should pass through the origin.

5. As sketched here, the block is moving to the right so the friction force is to the left. The normal force and weight are of the same magnitude and are in opposite directions. Considering the forces in the horizontal direction, $\Sigma F_x = ma_x$, so the mass and acceleration product is equal to the friction force.
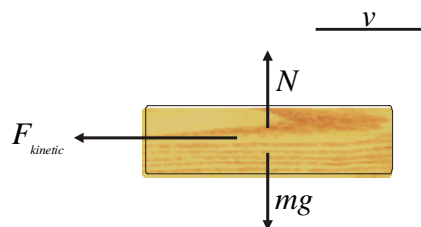
6. No, the coefficient of kinetic friction does not depend on speed, at least in the range of speeds used in this experiment. We can see this from the constant acceleration of the block as it slows. A constant force creates a constant acceleration.

7. Yes, the data show that as the weight of the block increases, the force of kinetic friction increases.

8. No, the coefficient of kinetic friction does not depend on the weight of the block. We can see this from the approximate constancy of the various measurements of μ_k.

9. The values are approximately the same, which is consistent with the model for kinetic friction of $F_{kinetic} = \mu_k N$. The model does not distinguish between constant-acceleration and constant-speed motion.

Simple Harmonic Motion

Lots of things vibrate or oscillate. A vibrating tuning fork, a moving child's playground swing, and the loudspeaker in a radio are all examples of physical vibrations. There are also electrical and acoustical vibrations, such as radio signals and the sound you get when blowing across the top of an open bottle.

One simple system that vibrates is a mass hanging from a spring. The force applied by an ideal spring is proportional to how much it is stretched or compressed. Given this force behavior, the up and down motion of the mass is called *simple harmonic* and the position can be modeled with

$$y = A\cos(2\pi f t + \phi)$$

In this equation, *y* is the vertical displacement from the equilibrium position, *A* is the amplitude of the motion, *f* is the frequency of the oscillation, *t* is the time, and ϕ is a phase constant. This experiment will clarify each of these terms.
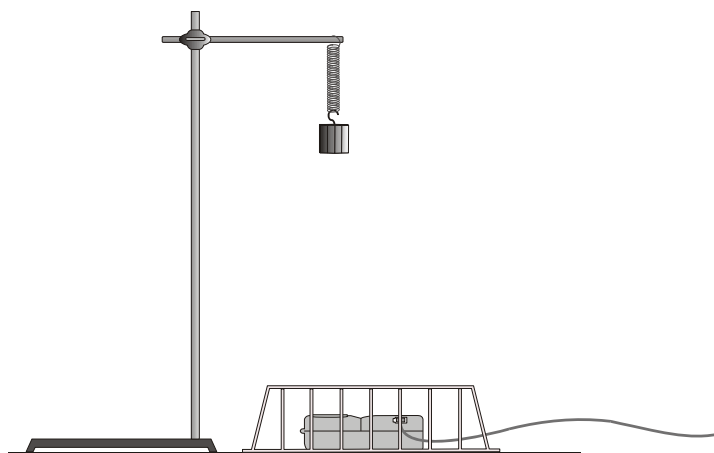
Figure 1

OBJECTIVES

- Measure the position and velocity as a function of time for an oscillating mass and spring system.
- Compare the observed motion of a mass and spring system to a mathematical model of simple harmonic motion.
- Determine the amplitude, period, and phase constant of the observed simple harmonic motion.

MATERIALS

TI-Nspire handheld **or**
   computer and TI-Nspire software
CBR 2 **or** Go!Motion, **or**
   Motion Detector and data-collection interface
ring stand, rod, and right angle clamp

wire basket
200 g and 300 g masses
spring, with a spring constant of
   approximately 10 N/m
zip ties

PRELIMINARY QUESTIONS

1. Attach the 200 g mass to the spring and hold the free end of the spring in your hand, so the mass and spring hang down with the mass at rest. Lift the mass about 10 cm and release. Observe the motion. Sketch a graph of position *vs.* time for the mass.

2. Just below the graph of position *vs.* time, and using the same length time scale, sketch a graph of velocity *vs.* time for the mass.

PROCEDURE

1. Place the Motion Detector about 50 cm below the mass. Make sure there are no objects near the path between the detector and mass, such as a table edge. Place the wire basket over the Motion Detector to protect it.

2. Attach the spring to a horizontal rod connected to the ring stand and hang the mass from the spring as shown in Figure 1. Securely fasten the 200 g mass to the spring and the spring to the rod using zip ties so the mass cannot fall.

3. If your Motion Detector has a switch, set it to Normal. Connect the Motion Detector to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using a CBR 2 or Go! Motion, you do not need a data-collection interface.)

4. Be sure your handheld or computer software is set to perform angle calculations in Radians.

5. Choose New Experiment from the 🎛 Experiment menu. For this experiment, the default data-collection parameters for a Motion Detector will be used (Rate: 20 samples per second; Duration: 5 seconds).

6. Click the Graph View tab (📈). Choose Show Graph ► Graph 1 from the 📈 Graph menu. Only the Position vs. Time Graph will be displayed.

7. With the spring in its resting position, zero the motion detector by choosing Set Up Sensors ► Zero from the 🎛 Experiment menu. The values should be close to zero.

8. Make a preliminary run to make sure things are set up correctly. Lift the mass upward about five centimeters and release. The mass should oscillate along a vertical line only, and should never come closer than 15 cm to the Motion Detector. Start data collection (▶).

9. After five seconds, data collection will stop. The position graph should show a clean sinusoidal curve. If it has flat regions or spikes, reposition the Motion Detector and try again.

10. Measure the time interval between adjacent maximum positions. This is the *period*, *T*, of the motion. The frequency, *f*, is the reciprocal of the period, $f = 1/T$. Based on your period measurement, calculate the frequency. Record the period and frequency of this motion in Table 1.

11. The amplitude, *A*, of simple harmonic motion is the maximum distance from the equilibrium position. Estimate values for the amplitude from your position graph. Enter the values in Table 1.

12. Click the Store Latest Data Set button (📇) to save the first run. Repeat Steps 8–11 with the same 200 g mass, with an amplitude greater than 5 cm, but less than 10 cm.

13. Click the Store Latest Data Set button (⬚) to save the second run. Change the mass to 300 g and repeat Steps 7–11. Use an amplitude of about 5 cm for this trial.

DATA

Table 1				
Run	*Mass* (g)	*A* (m)	*T* (s)	*f* (Hz)
1				
2				
3				

Model equation with parameters	

PROCESSING THE DATA

1. You can compare your experimental data to the sinusoidal function model. Try it with your 300 g data. To model this relationship, you will use the model

$$Y = \textbf{a}*\cos(2\pi*\textbf{b}*(x - \textbf{c})) + \textbf{d}$$

Comparing terms, listing the textbook model's terms first, the amplitude *A* corresponds to the parameter **a**, *f* corresponds to **b**, ϕ, the phase shift, corresponds to $-2\pi*\textbf{b}*\textbf{c}$. The time, *t*, is represented by the variable *x*. The textbook model gives the displacement from equilibrium. Although you zeroed the motion detector while in the equilibrium position, the constant **d** will allow you to adjust for errors.

a. Prepare to model your data by choosing Model from the ⬚ Analyze menu.
b. Type the equation a*cos(2π*b*(x – c)) + d.
c. Select OK.
d. Enter the amplitude you measured for run3 for **a**. Adjust the spin increment for **a** to 0.001.
e. Enter the frequency in Hz you determined for run3 for **b**. Adjust the spin increment for **b** to 0.001.
f. Enter the *time* that corresponds to the first peak of the position data for **c**. Adjust the spin increment for **c** to 0.001.
g. Enter 0 for the initial value for **d**. Adjust the spin increment for **d** to 0.001. Select OK.

2. Adjust the model until it matches closely the experimental data.

a. The parameter values are located to the left of the graph in the Graph View details box. Adjust the **c** and **d** values until your model comes very close to the experimental data. You may need to adjust **a** and **b** slightly from your measured values. Continue to adjust the values until the model matches very closely with the experimental data.
b. Record the model equation in the data table.

3. Choose Show Graph ▶ Graph 2 from the ⬚ Graph menu. This will show the Velocity graph. Using data for the 300-g mass, use Data Markers to mark the times at which the velocity is the greatest.

a. To add a data marker, click on the graph and use ► and ◄ to locate the points.

b. Move your cursor over the Graph View details box and launch the contextual menu (handheld – /b; computer – right-click). Select the Add Data Marker option.

c. Choose Show Graph ► Graph 2 from the ⩓ Graph menu. This will show both the position and velocity graphs for the data. Examine the marked points and look for any relationships between position and velocity when velocity is a maximum.

4. Repeat Step 3 above this time identifying the points where the velocity is a minimum.

5. Repeat Step 3 this time identifying the points where the velocity is zero.

QUESTIONS

1. Compare your position graphs to your sketched prediction in the Pre-Lab Questions. How are the graphs similar? How are they different?

2. Compare your velocity graphs to your sketched prediction in the Pre-Lab Questions. How are the graphs similar? How are they different?

3. Relative to the equilibrium position, where is the mass when the velocity is zero? Where is the mass when the velocity is greatest?

4. View the graphs of the last run. Compare the position *vs.* time and the velocity *vs.* time graphs. How are they the same? How are they different?

5. Does the frequency, *f*, appear to depend on the amplitude of the motion? Do you have enough data to draw a firm conclusion?

6. Does the frequency, *f*, appear to depend on the mass used? Did it change much in your tests?

7. Does the model fit the data well? How can you tell?

8. Predict what would happen to the plot of the model if you doubled the parameter for **a** (the amplitude) by sketching both the current model and the new model with doubled **a**. Double the parameter for **a** to test your prediction.

9. Predict how the model plot would change if you doubled **b**, and then check by modifying the model definition.

EXTENSIONS

1. Investigate how changing the spring amplitude changes the period of the motion. Take care not to use a large amplitude so that the mass does not come closer than 15 cm to the detector or fall from the spring.

2. How will *damping* change the data? Tape a small paper plate to the bottom of the mass and collect additional data. You may want to take data for more than 10 seconds. Does the model still fit well in this case?

3. Do additional experiments to discover the relationship between the mass and the period of this motion.

TEACHER INFORMATION

Simple Harmonic Motion

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. Students often have a hard time relating textbook discussions of simple harmonic motion to experimental data. This activity has them determine the parameters in $y = A\cos(2\pi ft + \phi)$ for their own data. Since ϕ is difficult to guess, the model $A\cos(2\pi \mathbf{b}(x - \mathbf{c}))$ is used where $\phi = -2\pi \mathbf{b}*\mathbf{c}$.

3. Students tend to use a larger amplitude than is needed, causing the stand to flex or the mass to fall. A 10 cm amplitude should be the largest used in this lab.

4. Students may have difficulty entering and adjusting the model. Refer to the instructions for using models in *Appendix B* or *Appendix C*.

5. Be sure the Motion Detector can "see" the mass throughout its range of motion. The position graph is much easier to use for troubleshooting than the velocity graph. Using a 2.5 to 3 inch diameter circular piece of index card attached to the bottom of the mass can help the motion detector see the mass. However, the card will dampen the oscillations slightly.

6. Motion detectors without a mode switch do not properly detect objects closer than 0.5 m. As a result, such motion detectors must be farther away from the experiment than described in the student notes. In contrast, Motion detectors *with* a mode switch will detect objects as close as 0.15 m. Ideally, an experiment will be set up so that the target is nearly this close at the point of closest approach, giving the best possible data.

7. Inexpensive or bent springs will not give sinusoidal velocity graphs. The best springs are sold as "simple harmonic motion" springs. Some long springs sold for studies of waves can be cut into sections and used for this lab, although these are still not as good as specialized harmonic motion springs.

8. If your spring is much different from 10 N/m stiffness, you may need to adjust the mass used to keep the period around one second.

9. If the ring stand flexes during oscillation, the motion will not be simple harmonic. A rigid support is needed.

10. The motion of the mass should be only up and down, with no side-to-side sway. Internal oscillations of the spring can also affect the motion.

11. A wire basket should be used to protect the Motion Detector from falling weights; it should be positioned such that the Motion Detector can "see" through it. Large twist ties or Zip ties should be used to securely attach the mass to the spring.

12. In this experiment, we have the students lift the mass to start the oscillation, rather than pulling down on the mass. This makes it less likely the mass will fly off the spring.

13. The TI-Nspire must be in radian mode for this experiment.

   For Handhelds: To verify the mode, hover the cursor over the battery indicator. To change the setting, Press ⌂on then select Settings ► Settings ► General.

   For Computers: To verify the mode, hover the cursor over Settings label along the bottom of the screen. To change the setting select Settings ►Document Settings from the File menu.

ANSWERS TO PRELIMINARY QUESTIONS

1. Sketches should be similar to data graphed above. (Note that any origin can be chosen by the student.)

2. The zero velocity points should correspond to the maximum and minimum distances from the origin. The sign of the slope of the position plot should correspond to the sign of the velocity at a specific time.

SAMPLE RESULTS

Table 1				
Run	Mass (g)	A (m)	T (s)	f (Hz)
1	200	0.021	0.65	1.54
2	200	0.059	0.65	1.54
3	300	0.055	0.80	1.25

Model equation with parameters	$0.055*\cos(2\pi*1.29*(x - 0.160) - 0.001$
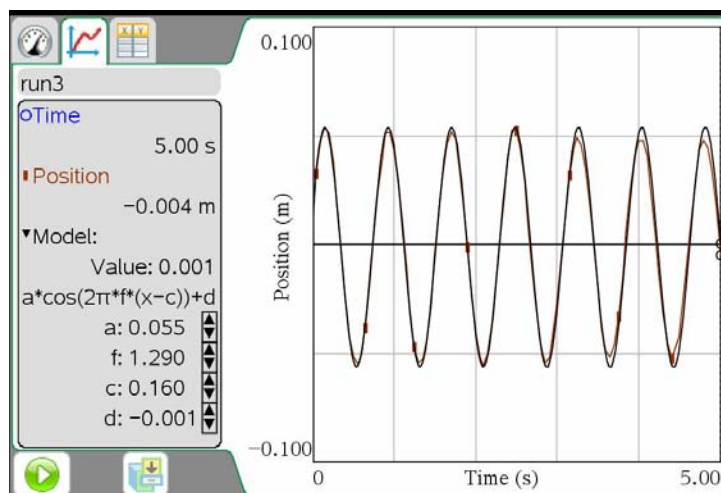
Pendulum data shown with model.

The parameters in the textbook equation that corresponds to the model equation are A (0.055), f (1.29), and ϕ (-1.3). A value of 0.055 for A corresponds to a 5.5 cm maximum displacement from equilibrium. A value of 1.29 for f corresponds to a frequency of 1.29 Hz.

ANSWERS TO QUESTIONS

1. Answers will vary. The position graphs of the collected data should be similar to the student predictions.

2. Answers will vary. The velocity graphs of the collected data should be similar to the student predictions.

3. The zero velocity points should correspond to the maximum and minimum distances from the origin. The velocity has the largest magnitude when the mass is passing through the equilibrium position.

4. When the velocity has the largest magnitude, the mass is passing through the equilibrium position. When the velocity is zero, the mass is at a maximum or minimum position. The sign of the slope of the position plot should correspond to the sign of the velocity at a specific time.

5. The frequency, f, is approximately the same for the two amplitudes used. To demonstrate that the frequency is independent of amplitude would require measuring the frequency at many additional amplitudes.

6. The frequency, f, does depend on the mass, since the frequency was smaller for the larger mass.

7. The sample data above show a nearly completed adjustment of the model to the data. Increasing values of ϕ shift the graph to the left and accounts for the position of the mass when data collection begins.

8. Doubling the amplitude, A, will change the model plot, increasing the maximum distance from the detector, and decreasing the minimum distance.

9. If f is doubled, the plot of the model will complete twice as many cycles during the time plotted.

Capacitors

The charge q on a capacitor's plate is proportional to the potential difference V across the capacitor. We express this with

$$V = \frac{q}{C}$$

where C is a proportionality constant known as the *capacitance*. C is measured in the unit of the farad, F, (1 farad = 1 coulomb/volt).

If a capacitor of capacitance C (in farads), initially charged to a potential V_0 (volts) is connected across a resistor R (in ohms), a time-dependent current will flow according to Ohm's law. This situation is shown by the RC (resistor-capacitor) circuit below when the switch is closed.
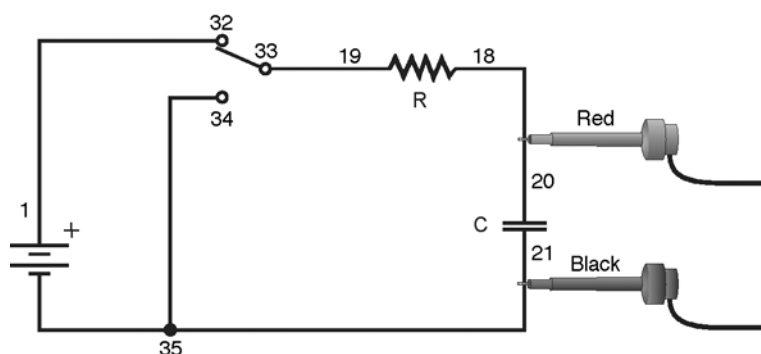
Figure 1

As the current flows, the charge q is depleted, reducing the potential across the capacitor, which in turn reduces the current. This process creates an exponentially decreasing current, modeled by

$$V(t) = V_0 e^{-\frac{t}{RC}}$$

The rate of the decrease is determined by the product RC, known as the *time constant* of the circuit. A large time constant means that the capacitor will discharge slowly.

OBJECTIVES

- Measure an experimental time constant of a resistor-capacitor circuit.
- Compare the time constant to the value predicted from the component values of the resistance and capacitance.
- Measure the potential across a capacitor as a function of time as it discharges.
- Fit an exponential function to the data. One of the fit parameters corresponds to an experimental time constant.

MATERIALS

TI-Nspire handheld **or**
   computer and TI-Nspire software
data-collection interface
Voltage **or** Differential Voltage Probe
connecting wires

Vernier Circuit Board **or**
   10 µF non-polarized capacitor
47 kΩ and 100 kΩ resistors
2 C- or D-cell batteries with holder
single-pole, double-throw switch

PRE-LAB QUESTIONS

1. Consider a candy jar, initially with 1000 candies. You walk past it once each hour. Since you don't want anyone to notice that you're taking candy, each time you take just 10% of the candies remaining in the jar. Sketch a graph of the number of candies remaining as a function of time.

2. How would the graph change if instead of removing 10% of the candies, you removed 20%? Sketch your new graph.

PROCEDURE

1. Connect the circuit as shown in Figure 1 above with the 10 µF capacitor and the 100 kΩ resistor. Record the values of your resistor and capacitor in your data table, as well as any tolerance values marked on them.

2. Connect the clip leads on your voltage probe across the capacitor, with the red (positive lead) to the side of the capacitor connected to the resistor. Connect the black lead to the other side of the capacitor.

3. Connect your voltage probe to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

4. Choose New Experiment from the 🔬 Experiment menu. Choose Collection Setup from the 🔬 Experiment menu. Enter **20** as the rate (samples/second) and **5** as the experiment duration in seconds. The number of points collected should be 101. Select OK.

5. Set the switch in its other (open) position to allow the capacitor to fully discharge. When the readings have stabilized, choose Setup Sensors ► Zero from the 🔬 Experiment menu.

6. Set the switch to the closed position illustrated in Figure 1. Wait at least 10 seconds to ensure the capacitor is fully charged.

7. Start data collection (▶). When data starts to appear in the graph, throw the switch to its open position to discharge the capacitor. After data collection is complete, a graph of voltage *vs.* time will be displayed.

8. Fit the exponential function y = A*e^ (-Cx) to your data.

   a. Select the decay region of the data. Be sure to only include values that are positive.
   b. Choose Curve Fit ► Natural Exponential from the 📊 Analyze menu.
   c. Record the value of the fit parameters in your data table. Notice that the C used in the curve fit is not the same as the C used to stand for capacitance.

9. Print or sketch the graph of voltage *vs.* time.

10. Click the Store Latest Data Set button (🖳) to save the first run. Modify the circuit to replace the 100 kΩ resistor with a 47 kΩ resistor. Repeat Steps 5–9.

DATA

	Resistor	Capacito r	Time constant	Fit Parameters		
Trial	R (Ω)	C (F)	RC (s)	A	C	1/C
Discharge 1						
Discharge 2						

PROCESSING THE DATA

1. In the data table, calculate the time constant of the circuit used; that is, the product of resistance in ohms and capacitance in farads. Note that 1 Ω·F = 1 s.

2. From the fit parameter C, calculate and enter in the data table 1/C for each trial.

QUESTIONS

1. Compare the fit equation to the mathematical model for a capacitor discharge proposed in the introduction,

$$V(t) = V_0 e^{-\frac{t}{RC}}$$

Interpret the fit parameters A and C. What aspects of your experiment do they measure? What are their units?

2. How do the values for 1/C (Processing the Data Step 2) compare to the values of the time constant of your circuit (Processing the Data Step 1).

3. Note that resistor and capacitor are not marked with their exact values, but only approximate values with a tolerance. Ask your instructor the tolerance of the resistors and capacitors you are using. If there is a discrepancy between the two quantities compared in Question 2, can the tolerance values explain the difference?

4. What is the effect of reducing the resistance of the resistor on the way the capacitor discharged?

EXTENSIONS

1. Make a plot of ln(V) *vs.* time for the capacitor discharge. What is the meaning of the slope of this plot? How is it related to the RC constant?

2. What percentage of the initial potential remains after one time constant has passed? After two time constants? Three?

3. Use a Current Probe and Differential Voltage Probe to simultaneously measure the current through the resistor and the potential across the capacitor. How will they be related?

4. Instead of a resistor, use a small flashlight bulb. To light the bulb for a perceptible time, use a large capacitor (approximately 1 F). Collect data. Explain the shape of the graph.

5. Try different value resistors and capacitors and see how the capacitor discharge curves change.

6. Try two 10 µF capacitors in parallel. Predict what will happen to the time constant. Repeat the discharge measurement and determine the time constant of the new circuit using a curve fit.

7. Try two 10 µF capacitors in series. Predict what will happen to the time constant. Repeat the discharge measurement and determine the time constant for the new circuit using a curve fit.

Capacitors

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. We designed this experiment around resistors and capacitors available at Radio Shack.

3. This experiment can be done with either the Differential Voltage Probe or the Voltage Probe. The 30-Volt Voltage probe is not recommend for this lab.

4. If possible, prepare students by doing an experiment with a 1 F capacitor and a flashlight bulb. Charge the capacitor and discharge through the bulb. Observe the brightness decrease with time. By using the large 1 F capacitor, the change is brought to a human scale.

5. The experiment calls for 10 μF, non-polarized capacitors, since they can be placed in the circuit either way. These are often sold for use in loudspeaker crossover circuits. Any voltage rating can be used, but lower voltage-rated capacitors are usually less expensive. If you choose to use an ordinary polarized electrolytic capacitor, the negative side of the capacitor must be connected to the negative battery terminal (with the resistor in between), or the circuit will not work. In fact, if wired backward, electrolytic capacitors can be destroyed.

6. Resistors are typically marked with a tolerance of 5 or 10%. Capacitors often have 10% or 20% tolerances. Do not expect outstanding agreement with the marked values. You may want to have students measure the resistance with a good ohmmeter and the capacitance with a trusted capacitance meter, if available.

7. Other combinations for *R* and *C* can be used. If the time constant *RC* is significantly different from 2 s, then you will need to adjust the data collection parameters. As a general guide, take data for a duration of approximately 5 time constants, and during that time gather about 500 points. If the time constant is too short, it becomes difficult to coordinate discharging the capacitor by throwing the switch and initiating data collection.

8. You may want to show students that the ohm × farads is equivalent to seconds:

$$\text{ohm} \times \text{farad} = \left(\frac{\text{volt}}{\text{ampere}} \right) \times \left(\frac{\text{coulomb}}{\text{volt}} \right) = \left(\frac{\text{coulomb}}{\text{ampere}} \right) = \frac{\text{coulomb}}{\left(\dfrac{\text{coulomb}}{\text{second}} \right)} = \text{second}$$

9. If you have the student flip the switch on the circuit just as they start data collection, the entire graph will be of charging or discharging. In these cases, the value of the A fit parameter will be a meaningful value. For discharges, it will be the initial voltage.

10. If you are using a multi-channel interface like the TI-Nspire Lab Cradle, this activity can be done using triggering. To set up triggering do the following:

    a. Charge the capacitor for 10 seconds with the switch in the closed position.
    b. Watch the reading on the screen and note the maximum value reached. You will need this value in a later step.

c. Choose Advanced Set Up ► Triggering ► Set Up from the ⚗ Experiment menu.

d. Select your voltage probe as the sensor to use as the trigger.

e. Select **Decreasing through Threshold** as the type of trigger to use.

f. Enter a trigger level of 90% of the maximum voltage you observed in step b as the threshold in units of the sensor. For example, if your maximum voltage was 5 V, enter 4.5.

g. Select OK.

h. After you start data collection, you will see the *Waiting for Trigger* message. Open the switch to discharge the capacitor. Data collection will begin automatically when the voltage decreases across the trigger threshold. Your graph will be displayed after data collection is complete.

ANSWERS TO PRE-LAB QUESTIONS

1. Graph is a decaying exponential. The first few values are 1000, 900, 810… (with integer part of 10% taken each time).

2. Second graph decays more quickly: 1000, 800, 640…

SAMPLE RESULTS
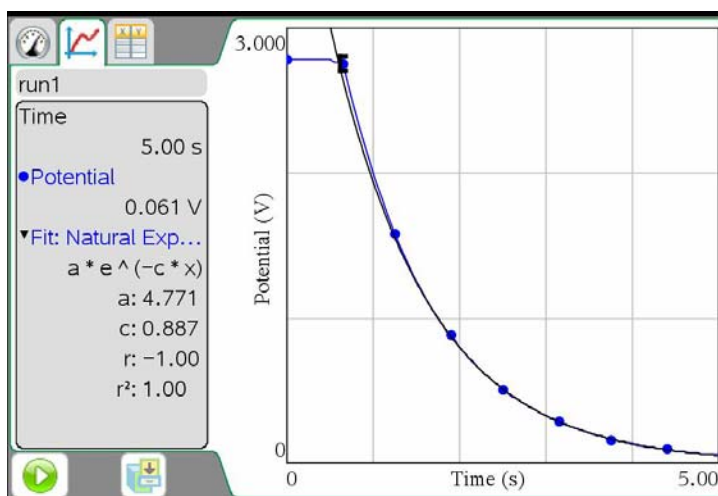
Typical graph of 100 kΩ resistor shown with natural exponential curve fit.

Trial	Resistor R (Ω)	Capacitor C (F)	Time constant RC (s)	Fit parameters		
				A	C	1/C
Discharge 1	$100{\times}10^{3}$	$10{\times}10^{-6}$	1.0	4.77	0.89 1.12	
Discharge 2	$47{\times}10^{3}$	$10{\times}10^{-6}$	0.47	9.5	1.74	0.58

ANSWERS TO QUESTIONS

1. The inverse of the fit constant C is approximately the same as the time constant. The fit parameter A corresponds to the potential across the capacitor at $t = 0$, in volts. The parameter C corresponds to 1/RC and has units of inverse seconds.

2. Since the capacitor values are typically good to only ±20%, some variation is to be expected.

3. Students can calculate maximum and minimum possible values for the product of resistance and capacitance and see if values calculated from the curve fits fall within that range.

4. Decreasing the value of the resistor allowed the capacitor to discharge and charge more quickly.

EXTENSIONS

1. The slope of this line is the opposite of the C value in the natural exponential model. The absolute value of the reciprocal of the slope is the time constant.
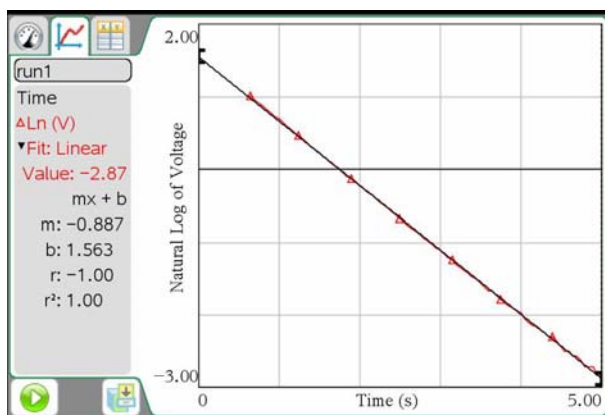
2. After one time constant, approximately e^{-1} or 37% of the potential remains. After two time constants, the potential is reduced to 13% of the initial potential and after three the potential is down to 5%.

4. The light bulb is not *ohmic*; that is, the current is not proportional to the potential across it. As the current starts to flow through the wires, the bulb's filament is cool. The wires warm up quickly and their resistance increases. As a result, a graph of potential *vs.* time is not a simple exponential.

5. Different values for *R* and *C* will create different time constants. If, however, the product *RC* is the same, the time constant will be the same.

6. Capacitors in parallel behave as a single capacitor with the sum of the individual capacitances. The time constant should be doubled.

7. Two equal capacitors in series behave as a single capacitor with half the capacitance of one of the individual capacitors. The time constant will be cut in half.

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, 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:

$$y = A \sin(2\pi f t)$$

In the case of sound, a longitudinal wave, the *y* refers to the change in air pressure that makes up the wave. *A* is the amplitude of the wave (a measure of loudness), and *f* is the frequency. Time is represented with *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.
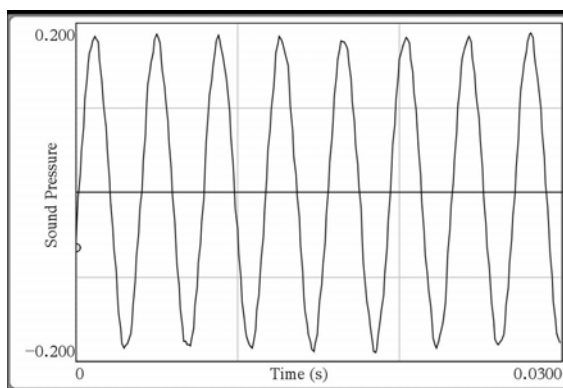
Figure 1

OBJECTIVES

- Measure the frequency and period of sound waves from tuning forks or an electronic keyboard.
- Measure the amplitude of sound waves from tuning forks or an electronic keyboard.
- Observe beats between the sounds of two tuning forks or two keys on an electronic keyboard.

MATERIALS

TI-Nspire handheld **or**   Vernier Microphone
  computer and TI-Nspire software   2 tuning forks or an electronic keyboard
  data-collection interface

PRELIMINARY QUESTIONS

1. Why are instruments tuned before being played as a group? In which 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?

PROCEDURE

1. Connect the Microphone to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

2. Be sure your handheld or computer software is set to perform angle calculations in Radians.

3. Choose New Experiment from the 🖧 Experiment menu. For Part I of the experiment, the default data-collection parameters for a microphone will be used (Rate: 10,000 samples per second; Duration: 0.03 seconds).

4. To center the waveform on zero, it is necessary to zero the Microphone channel. With the room quiet, choose Set Up Sensor ► Zero from the 🖧 Experiment menu. When the process is complete, the reading for the sensor should be close to zero.

Part I Simple Waveforms

5. Produce a sound with a tuning fork or keyboard, and hold it close to the Microphone. Start data collection (▶). When data collection is complete, a graph will be displayed.

6. The data should be sinusoidal in form, similar to the graph in Figure 1. If you are using a tuning fork, strike it against a soft object such as a rubber mallet or the rubber sole of a shoe. Striking it against a hard object can damage it. If you strike it too hard or too softly, the waveform may be rough; collect data again.

7. Print or make a sketch of your graph. Record the note you played in Tables 1, 2 and 3.

8. To examine the data pairs on the displayed graph, click any data point. Use ► and ◄ to record the times for the first and last peaks of the waveform. Count the number of complete cycles that occur between your first measured time and the last. Divide the difference, Δt, by the number of cycles to determine the period of the tuning fork. Record these values in Table 1.

9. Calculate the frequency of the tuning fork based on the period you calculated in Step 8. Record this value in Table 1.

10. Examine the graph again to find the maximum and minimum sound values for an adjacent peak and trough. Calculate the amplitude of the wave by taking half of the difference between the maximum and minimum y values. Record the values in Table 2.

11. To compare your data to the textbook sinusoidal model, $y = A\sin(2\pi f\,t)$, you will use the sinusoidal curve fit y = **a** * sin(**b***x + **c**) + **d**. Comparing terms, listing the textbook model's terms first, the amplitude *A* corresponds to the curve fit parameter **a**, *f* corresponds to **b**/2π. The curve fit parameters **c** and **d** shift the fitted function left-right and up-down, respectively and may be necessary to obtain a good fit. The time *t* is represented by *x*.

    To fit your data using a sinusoidal curve fit, choose Curve Fit ► Sinusoidal from the ⬛ Analyze menu. If your model does not fit the data, adjust the region used for the curve fit by moving the brackets (**[** or **]**) to make the region smaller. Record the parameter values in Table 3.

12. Calculate the frequency of the tuning for using the curve fit equation's value for **b**. Record this value in Table 3.

13. Click the Store Latest Data Set button (⬛) to save the first run data. Repeat Steps 5–12 for the second frequency or tuning fork.

   Part II Beats

14. 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 listen to beats, strike your tuning forks at the same time (simultaneously) or simultaneously hold down two keys on the keyboard 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.

15. To capture the beats it is necessary to collect data for a longer period of time.

    a. Insert a new **Problem** into your TI-Nspire document and add a DataQuest App to the problem. Choose New Experiment from the ⬛ Experiment menu.
    b. Choose Collection Setup from the ⬛ Experiment menu. Enter **2500** as the rate (samples/second) and **0.08** as the experiment duration in seconds. The number of points collected should be 201.
    c. Select OK.

16. Start the two tones sounding then start data collection (⬛). When using tuning forks, strike them equally hard and hold them the same distance from the Microphone.

17. Note the shape of your waveform graph. You should see a time variation of the sound amplitude. 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 Table 4.

18. Record the times for the first and last amplitude maxima. To do this, click any data point. Divide the difference, Δ*t*, by the number of cycles to determine the period of beats (in s). Calculate the *beat frequency* in Hz from the beat period. Record these values in Table 4.

DATA

Part I Simple Waveforms

Table 1						
Tuning fork or note	Number of cycles	Time of first max (s)	Time of last max (s)	Δt (s)	Period (s)	Calculated frequency (Hz)

Table 2			
Tuning fork or note	Peak	Trough	Amplitude

Table 3					
Tuning fork or note	Parameter **a**	Parameter **b** (s^{-1})	Parameter **c**	Parameter **d**	Calculated frequency (Hz)

Part II Beats

Table 4					
Number of cycles	Time of first max (s)	Time of last max (s)	Δt (s)	Beat (s)	Calculated beat frequency (Hz)

QUESTIONS

Part I Simple Waveforms

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

2. Compare the curve fit frequency calculated in Step 12 to the frequency calculated in Step 9. Which would you expect to be more accurate? Why?

3. Calculate the percent error between the curve fit frequency and the frequency of the tuning fork or keyboard note for both of the notes played.

4. Compare the parameter **a** to the amplitude of the waveform.

Part II Beats

5. Is there any way the two individual frequencies can be combined to give the beat frequency you measured earlier? Compare your conclusion with information given in your textbook.

EXTENSIONS

1. 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 does such a product work?

2. 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 $\sin(2\pi f_2 t)$.

3. 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?

4. 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?

Sound Waves and Beats

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment cannot be done with Easy or Go! Products since data collection rates are greater than 200 samples/second. The microphone requires sample rates around 10,000 samples per second. You must use a multi-channel sensor interface for this experiment.

3. In the first part of this lab, the students are investigating pure tones, such as those produced by a tuning fork. It is important to use quality tuning forks with large tines. These tuning forks produce a relatively loud signal. Tuning forks with frequencies from 256 Hz to 512 Hz are recommended. When using tuning forks, they have to be struck by a soft object such a rubber mallet, rubber sole, or the fleshy part of the hand. When struck with hard objects, the tuning forks produce overtones. It is also important to hold the tuning fork close to the Microphone.

4. When doing a sinusoidal curve fit on the data from a single sound source, the results may not match the data as expected. To get a better match of the data, adjust the region used for the curve fit by moving the brackets (**[** or **]**) to make the region smaller. See *Appendix B* or *C*.

5. An electronic keyboard also works well, but it needs to be set to a voice which produces as nearly a sine wave as possible. On some keyboards, this is the "flute" sound. Disable any vibrato effects, since they work by varying the frequency of the tone.

6. Since an important part of this lab is observing beats, it is important to make a good choice of frequencies. A good combination for tuning forks is C at 256 Hz and D at 288 Hz. On the keyboard you can use B and G. The difference between the notes should be at least 40 Hz.

7. Collecting a beat pattern with tuning forks is difficult to do. Try to strike each of them equally hard and hold them equidistant from the Microphone.

8. The TI-Nspire must be in radian mode for this experiment.

   For Handhelds: To verify the mode, hover the cursor over the battery indicator. To change the setting, press ⌂on then select Settings ► Settings ► General.

   For Computers: To verify the mode, hover the cursor over Settings label along the bottom of the screen. To change the setting select Settings ►Document Settings from the File menu.

9. You may want to have your students model the data instead of doing a sinusoidal regression.

   a. Choose Model from the ▣ Analyze menu.
   b. Enter the equation, a*sin(2π*b*(x − c)) + d.
   c. Enter your estimate for the amplitude as your value for **a**.
   d. Enter your the frequency of your sound source as your value for **b**.
   e. Initially use zero for **c** and **d**.
   f. Select OK.
   g. Adjust the values in your model to obtain a good match.

ANSWERS TO PRE-LAB QUESTIONS

1. If they are not tuned, the sound is unpleasant. If the tuning is particularly bad, beats may be heard.

2. If a pressure increase and a pressure decrease from two different waves were to occur in the same location, the net effect would be a small pressure change or no pressure change.

SAMPLE RESULTS

Part I Simple Waveforms
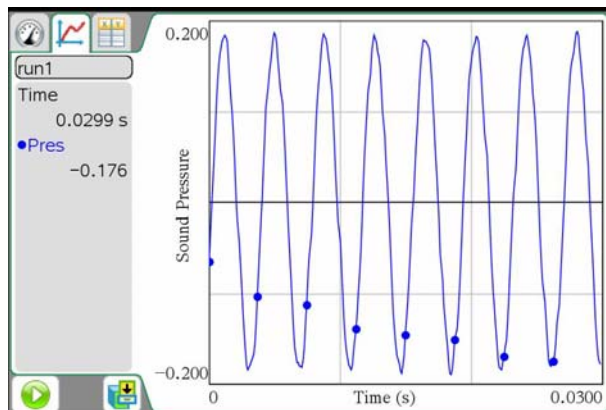
Frequency of 256 (C) Hz   *Frequency of 288 (C) Hz*
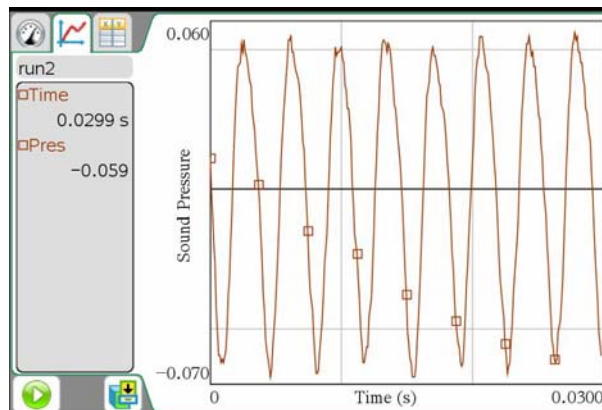
Table 1						
Tuning fork or note	Number of cycles	First maximum (s)	Last maximum (s) (s) (s)	Δt (s)	Period	Calculated frequency (Hz)
C – 256 Hz	7	0.0012	.0281	0.0269	0.00384	260
D – 288 Hz	7	0.0026	0.0278	0.0252	0.0036	278

Table 2			
Tuning fork or note	Peak	Trough	Amplitude
C – 256 Hz	0.184	–0.183	0.184
D – 288 Hz	0.053	–0.067	0.060

Table 3					
Tuning fork or note	Parameter a	Parameter b (s^{-1})	Parameter c	Parameter d	Calculated frequency (Hz)
C – 256 Hz	.183	1637	–0.375	0.001	261
D – 288 Hz	0.057	1731	3.137	0	276

Part II Beats
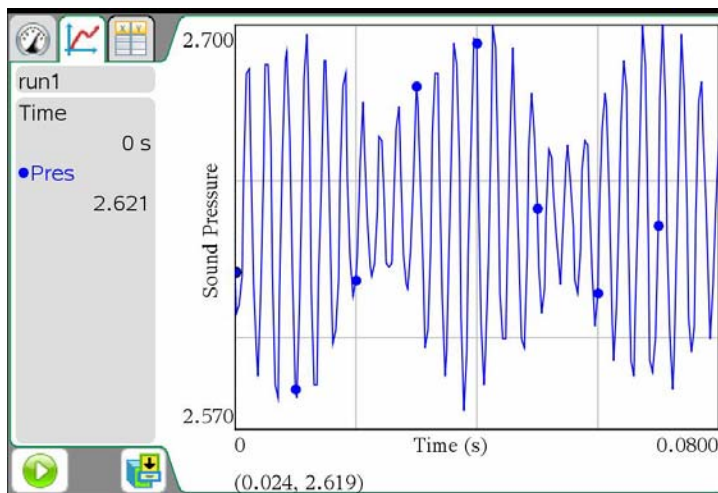
Table 4					
Number of cycles	First maximum (s)	Last maximum (s)	Δt (s)	Period (s)	Calculated frequency (Hz)
2	0.010	0.071	0.061	0.0305	32.8

ANSWERS TO QUESTIONS

1. The model should match the data. Often there are variations in the amplitude of the collected data while the curve fit will not show any variation. The frequency should be a close match.

2. The frequency determined by the curve fit takes into account all the data, while the peak-counting method uses only select parts of the data. As a result, the curve fit frequency should be more accurate.

3. The percent error for the note C-256 from the sample data is $\dfrac{|261-256|}{256} \times 100 = 2.0\%$.

    The percent error for the note D-288 is $\dfrac{|276-288|}{288} \times 100 = 4.2\%$.

4. These values should be close. The amplitude determined by the curve fit takes into account all the data, while the adjacent crest and trough method uses only select parts of the data. As a result, the curve fit amplitude should be more accurate.

5. The beat frequency is equal to the difference in frequency of the two individual tones. The expected value for the sample data is 32 Hz. The experimental value was 32.8 Hz.

Speed of Sound

Compared to most objects, sound waves travel very fast. It is fast enough that measuring the speed of sound is a technical challenge. One method you could use would be to time an echo. For example, if you were in an open field with a large building a quarter of a kilometer away, you could start a stopwatch when a loud noise was made and stop it when you heard the echo. You could then calculate the speed of sound.

To use the same technique over short distances, you need a faster timing system. In this experiment, you will use this technique with a Microphone sensor to determine the speed of sound at room temperature. The Microphone will be placed next to the opening of a hollow tube. When you make a sound such as snapping your fingers next to the opening, the interface will begin collecting data. After the sound reflects off the opposite end of the tube, a graph will be displayed showing the initial sound and the echo. You will then be able to determine the round trip time and calculate the speed of sound.
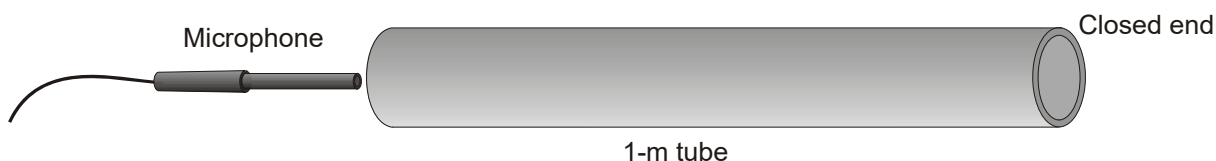
Figure 1

OBJECTIVES

- Measure how long it takes sound to travel down and back in a long tube.
- Determine the speed of sound.
- Compare the speed of sound in air to the accepted value.

MATERIALS

TI-Nspire handheld **or**	tube, 1–2 meters long
computer and TI-Nspire software	book or plug to cover end of tube
data-collection interface	meter stick or tape measure
Vernier Microphone	dog training clicker
Thermometer or Temperature Probe	

PRELIMINARY QUESTION

A common way to measure the distance to lightning is to start counting, one count per second, as soon as you see the flash. Stop counting when you hear the thunder and divide by five to get the distance in miles. Use this information to estimate the speed of sound in m/s.

PROCEDURE

1. Use the thermometer or temperature probe to measure the air temperature of the classroom. Record the room temperature in your data table.

2. Close the end of the tube. This can be done by inserting a plug or standing a book against the end so it is sealed. Measure the length of the tube and record in the data table.

3. Place the Microphone as close to the end of the long tube as possible, as shown in Figure 2. Position the Microphone so that it can detect the initial sound and the echo coming back down the tube.

Open end of tube
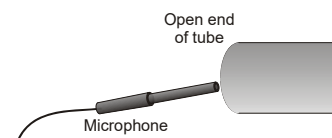
Microphone

Figure 2

4. Connect the Microphone to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

5. Choose New Experiment from the 🔬 Experiment menu. Choose Collection Set up from the 🔬 Experiment menu. Enter **5000** as the rate (samples per second). The number of points collected should be 151. Select OK

6. Choose Set Up Sensors ► Zero from the 🔬 Experiment menu. This will center the data around the x-axis and is needed for using the trigger threshold indicated in Step 7d.

7. Set up the interface to trigger on the first loud sound the Microphone detects.

   a. Choose Advanced Set Up ► Triggering ► Set Up from the 🔬 Experiment menu.
   b. Select the Microphone as the sensor to use as the trigger.
   c. Select **Increasing through Threshold** as the type of trigger to use.
   d. Enter **0.1** as the trigger threshold in the units of the sensor. This means that data collection will begin when voltage increases across this trigger level.
   e. Select OK.

8. Start data collection (▶). When you see the message *Waiting for Trigger*, click the dog training clicker near the opening of the tube. Data collection will begin when the trigger level is reached. After data collection is complete, a graph of Sound Pressure *vs*. Time will be displayed.

9. If you are successful, the graph will resemble the one in Figure 3. You may not see a third reflection. In this figure, each of three highest peaks corresponds to the same point on a waveform. The first peak is the initial sound, the second is the first reflection, and the third is a second reflection. Repeat data collection if necessary.

10. Tap any data point on a graph and use ► and ◄ to identify the time of the initial sound and first reflection. Record these values in the data table.

11. Repeat Steps 7–10 for a total of five trials. Be sure to click the Store Latest Data Set button (📥) prior to collecting each new run.
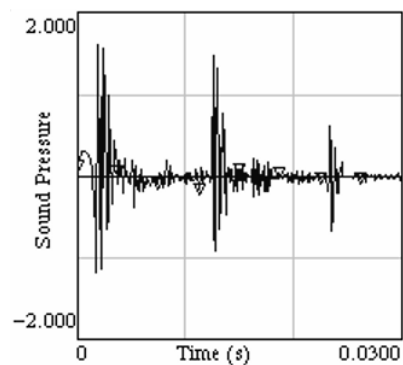
Figure 3

DATA

Temperature of room (°C)	
Length of tube (m)	

Trial	Time of direct sound start (s)	Time of echo start (s)	Time Interval (s)
1			
2			
3			
4			
5			
Average			

Speed (m/s)	

PROCESSING THE DATA

1. From the time-pairs you recorded in the data table, calculate the differences to find the time interval, and then calculate the average time interval.

2. Calculate the speed of sound. Remember that your average time interval represents the time for sound to travel down the tube and back.

QUESTION

The accepted speed of sound at atmospheric pressure and 0°C is 331.5 m/s. The speed of sound increases 0.607 m/s for every Celsius degree. Calculate the speed of sound at the temperature of your room and compare your measured value to the accepted value.

EXTENSIONS

1. Repeat this experiment, but collect data using a tube with an open end. How do the reflected waves for the closed-end tube compare to the reflections with an open-end tube? Explain any differences. Calculate the speed of sound and compare it to the results with a tube with a closed end.

2. Try performing this experiment without a tube. You need an area with a smooth surface. Multiple reflections may result (floor, ceiling, windows, etc.), adding to the complexity of the recorded data.

3. Fill a tube with another gas, such as carbon dioxide or helium. Be sure to flush the air out with the experimental gas. For heavier-than-air gases, such as carbon dioxide, orient the tube vertically and use a sealed lower end. Invert the tube for lighter-than-air gases.

4. Use this technique to measure the speed of sound in air at different temperatures.

5. Develop a method for measuring the speed of sound in a medium that is not a gas.

Speed of Sound

1. Editable Microsoft Word versions of the student pages and pre-configured TI-Nspire files can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. This experiment cannot be done with Easy or Go! Products since data collection rates are greater than 200 samples/second. The microphone requires sample rates around 10,000 samples per second.

3. In this experiment, you can use long tubes that are used for shipping equipment, tubes used for rolling carpet, and PVC pipe. Pipe with a diameter of 10 cm works well, but you may obtain useful results with a smaller diameter. If you use a larger diameter pipe, you must adjust your measurement accordingly (L + 0.4D where D is the diameter).

4. To create a closed end, a book can be placed against the end of the tube. Observant students will note differences if the book is gradually moved away from the physical end of the tube between successive trials. A tight seal is not required. Many packing tubes come with end caps that are convenient for this experiment.

5. Dog training clickers can be purchased at local pet stores. Finger snaps can be used as an alternative.

6. After the students start data collection, data collection will not begin until the sound level reaches a specified trigger value. It may be necessary to adjust this value if data collection begins too soon or not at all. If you need to adjust the trigger point, follow the directions in the student version of the lab. Monitor the sound level and then set the trigger level to be slightly larger than the current reading.

7. Reflections from the open end of the tube are inverted, while reflections from a closed end are not. This can be seen if a very short sound impulse is used.

8. M. G. Raymer and Stan Micklavzina describe a method of studying sound impulses in a tube. Their technique is very similar to the technique used in this lab. They generate short pulses, making it easy to see the phase change upon reflection from an open end. For more information, see "Demonstrating Sound Impulses in Pipes," *The Physics Teacher*, March 1995.

ANSWER TO PRE-LAB QUESTION

The light from a lightning strike arrives almost instantly, while the sound is delayed by the comparatively slow speed of sound. Since you are counting once a second, then a count of five for a lightning strike one mile away yields (to a generous two significant digits)

$$\frac{1\,\text{mile}}{5\,\text{s}} \times \frac{5280\,\text{feet}}{1\,\text{mile}} \times \frac{1\,\text{m}}{3.28\,\text{feet}} = 320\,\frac{\text{m}}{\text{s}}$$

SAMPLE RESULTS
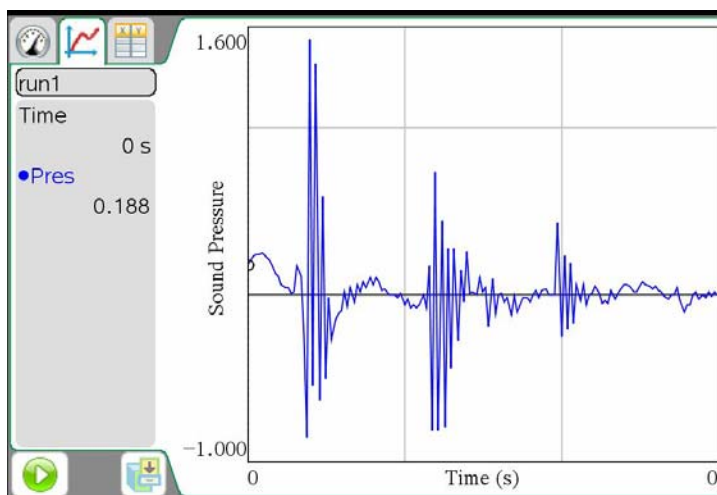
Temperature of room (°C)	22.7
Length of tube (m)	1.39

Trial	Time of direct sound start (s)	Time of echo start (s)	Time Interval (s)
1	0.0038	0.0118 0.0080	
2	0.0030	0.0110 0.0080	
3	0.0032	0.0112 0.0080	
4	0.0006	0.0086 0.0080	
5	0.0000	0.0080 0.0080	
		Average:	0.0080

Speed (m/s)	347.5

ANSWERS QUESTIONS

The accepted speed of sound at 22.7 °C is v = 331.5 m/s + (0.607 * 22.7) = 345.3 m/s. Since the speed measurement is precise to two significant digits, the experimental result is in agreement with the accepted speed.

Electronic Resources

The electronic resources that accompany this book include the following:

Science with TI-Nspire.pdf–Searchable PDF of the entire book

📁 **Student**–The PDF and Word subfolders contain files for each of the 33 student activities in this book. **Note**: The Word folder includes a subfolder for TI-Nspire key fonts. Some of the activities make use of these fonts. For these files, it is necessary to move the fonts into your system font folder so the characters can be rendered appropriately.

📁 **Teacher**–PDF for each of the teacher information files

📁 **TNS Files**–Contains the TI-Nspire (.tns) files for each of the 33 student activities

   📁 **Other Sensors**

      📁 **CBR2-Go!Motion**–Versions of Activities 26, 27, 29, and 30 that use a CBR 2 or Go!Motion motion detector instead of a standard Motion Detector used with an interface

      📁 **EasyTemp-Go!Temp**–Versions of Activities 1, 7, 8, 18, 20 and 24 that use an EasyTemp or Go!Temp temperature probe instead of the Stainless Steel Temperature Probe used with an interface

      📁 **TI Light Probe**–A version of Activity 6 that uses a Texas Instruments Light Probe instead of the Vernier Light Sensor

      📁 **Voltage Probe**–A version of Activity 31 that uses a ±10 V Voltage Probe instead of the Vernier Differential Voltage Probe

Using the TNS Files

The TNS files have been preconfigured to match each activity. Data collection parameters and document formatting have been set up in advance to help facilitate the activity. Students open the file, connect the sensor(s) to the handheld or computer, and collect data. Additionally, the files include all of the questions presented in the lab, allowing students to enter their answers directly in the file. Teachers using the TI-Nspire Navigator system or TI-Nspire CX Docking Station can electronically collect the student responses for grading and class discussion.

As lab instructions are not included in the TNS files, the TNS files are intended to be used in conjunction with the student version of the activity.

For handhelds–Use the TI-Nspire Computer Link, TI-Nspire Navigator, or TI-Nspire computer software to transfer the TNS files to your TI-Nspire handhelds. Open the file on your handheld. These files can be used with any TI-Nspire handheld (CX II, CX, Touchpad, or Clickpad) running software version 3.0 or newer.

For computers–Start the TI-Nspire software, then open the file of your choice from the Science with TNS Files folder. Files can be opened directly or copied onto your hard drive first. These files can be used with TI-Nspire software (version 3.0 or newer).

Using DataQuest on a Handheld

This appendix gives an overview of using the Vernier DataQuest application on a TI-Nspire handheld. It includes information on accessing the common tools in the DataQuest Application.

DataQuest is included in TI-Nspire handheld software versions 3.0 and newer. If you have an older version of TI-Nspire software, you can get updates at education.ti.com.
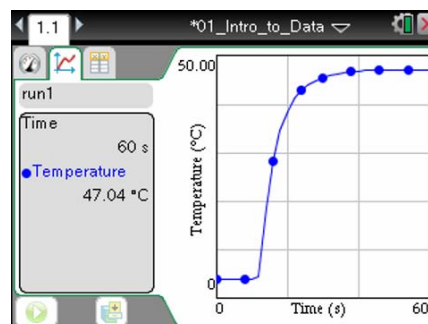
The TI-Nspire Software

Access Menus

DataQuest can be used to collect, display, and analyze data. Most features can be accessed using the application menus. To access the menus, press [menu].
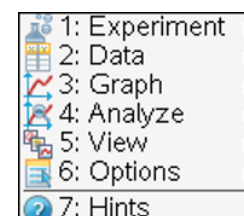
Access Context Menus

To access context menus, move the cursor over the object using the touchpad or arrow keys, and press [ctrl] [menu]. Meters, View details boxes, graphs, and the table all have contextual menus.

Open a New Document

To open a new document, press [⌂ on] then select New Document. Having only one TI-Nspire document opened when using DataQuest is recommended.

Add a Page or Problem

To add a new page or problem to your TI-Nspire document, press [doc▾] ([ctrl] [⌂] for clickpad handhelds) and choose Problem or Page from the Insert menu. For touchpad handhelds, you can also add a page by pressing [ctrl] [doc▾].
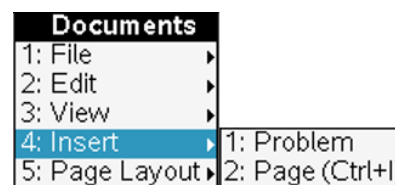
Save a document

To save your TI-Nspire document, press [doc▾] ([ctrl] [⌂] for clickpad handhelds) and choose Save from the File menu or press [ctrl] [S].

Scratch Pad Calculator

The Scratch Pad Calculator is a built-in calculator that can be used to perform calculations while you are conducting an experiment. To use the Scratch Pad Calculator, press [▦]. (On a click pad handheld, press [⌂] then select the Scratchpad Calculate option.)
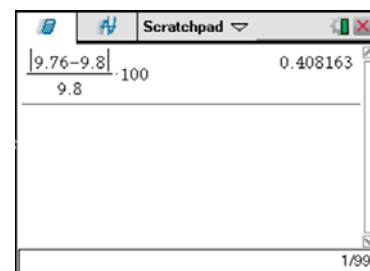
Start DataQuest

DataQuest should automatically start when you connect a TI-Nspire
Lab Cradle, EasyLink interface, EasyTemp temperature probe, or Texas
Instruments CBR 2™ motion detector to your handheld.

Manually Launch DataQuest

To start DataQuest manually, press ⌂on then select Ⓐ. You can also
press docᵥ (ctrl ⌂ for clickpad handhelds) and choose Vernier
DataQuest from the Insert menu.

Views in DataQuest

There are three views in the DataQuest application: Meter, Graph, and Table.
Click a tab to change views or press menu then choose the desired view from
the ⧉ View menu.

On the left side of the screen in each view, you will see the View details box.
The Meter View details box shows the data-collection settings. The Graph
View details box shows graph trace and analysis information. The Table View
details box shows data set variable information.
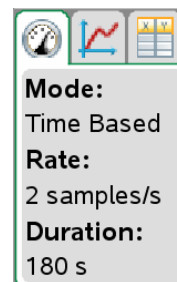
Data Collection Settings

Change the Data-Collection Mode

1. Press menu then choose Collection Mode from the ⚙ Experiment
    menu.

2. Select the data-collection mode you want to use.

    *Note: Changing modes will require you to discard any collected
    data. To avoid losing data, save the current document and open a new document, or insert a
    new problem in the current document.*
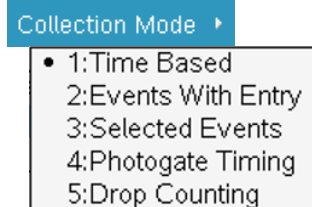
3. A dialog showing the data-collection settings for the mode you have selected will be
    displayed. Adjust the settings as desired for your experiment. Use tab to move between
    entry lines.

4. When you are done setting up the data collection, select OK.

Change Data-Collection Settings

When you have already set up the data-collection mode and want to
make changes to the settings, you can change the values you have
entered.

1. Press menu then choose Collection Setup from the ⚙ Experiment
    menu.

2. Make the necessary changes and select OK.
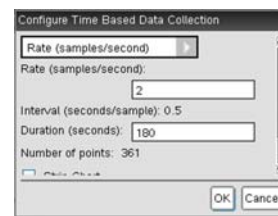
Sensor Settings

Change Units

1. Press menu then choose Set Up Sensors ► Change Units from the
   🖳 Experiment menu.

2. Select the unit you want to use. The readings from the sensor and any
   collected data will be displayed in the new unit.
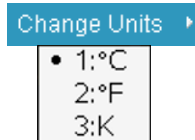
Calibrate a Sensor

Not all sensors can be calibrated. Check the sensor booklet for specific information about your
sensor. For most experiments, the sensor's stored calibration is recommended. In some instances,
you may want to calibrate a sensor to get readings that are even more accurate.

1. Press menu then choose Set Up Sensors ► Calibrate from the
   🖳 Experiment menu. Select the appropriate calibration option for your
   situation:

   - Manual Entry – Use Manual Entry when you know the calibration
     equation and want to enter the coefficients directly.
   - Two Point – Use Two Point for most calibrations.
   - Single Point – Use Single Point when only one known calibration value is attainable (for
     example, calibrating a Barometer to match the current atmospheric pressure). Single Point
     calibration will only affect the intercept of the calibration equation.

2. Perform a live calibration (Two Point or Single Point).

   a. Place the sensor in the desired calibration environment, enter the
      reference value, wait for the voltage readings to stabilize, and
      select Keep.
   b. Two Point only – place the sensor in a second calibration
      environment, enter the reference value, wait for the voltage
      readings to stabilize, and select Keep.

3. Note the updated calibration equation, modify if necessary (Manual
   Entry), and select OK.

Zero a Sensor

Not all sensors can be zeroed. Check the sensor booklet for specific
information about your sensor.

To zero a sensor, press menu then select Set Up Sensors ► Zero from the 🖳 Experiment menu.
Note: When you have more than one sensor you want to zero, select the All Sensors option.

Reverse a Sensor

Not all sensors can be reversed. Check the sensor booklet for specific
information about your sensor.

Press menu then choose Set Up Sensors ► Reverse from the 🖳 Experiment menu. The sign of
the sensor reading is changed as noted in the example.

Sensors that do not Auto-ID

The DataQuest Application supports older sensors that do not auto-ID. To manually set up a sensor, connect the sensor to the interface and the interface to your handheld. Press menu then choose Advanced Set Up ▶ Configure Sensor from the 🔬 Experiment menu, and select the interface and channel your sensor is connected to. Select your sensor from the drop down list and click OK.
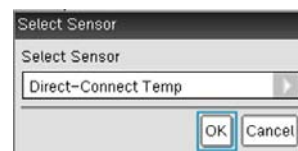
Sensors that do not auto-ID must be set up everytime they are used and will not be identified by the software when opening a saved file.

Data Collection

Start Data Collection

To start data collection, click the Start Collection button or press menu then choose Start Collection from the 🔬 Experiment menu.

Keep Data Points (Event Based Data Collection)

To store a data point during Events with Entry or Selected Events experiments, click the Keep button or press menu then choose Keep from the 🔬 Experiment menu.

Stop Data Collection

To stop data collection, click the Stop Collection button or press menu then select Stop Collection from the 🔬 Experiment menu.

Extend Data Collection (Time Graph Collection)

To extend a time graph experiment to one and one-half times the current duration, press menu then choose Extend Collection from the 🔬 Experiment menu before or during a collection. The time listed in the menu will be the new duration for the experiment.

Store Data Sets

To store a data set, click the Store Latest Data Set button or press menu then choose Store Data Set from the 🔬 Experiment menu.

Graphical Display of the Data

By default, DataQuest will graph the most recent (latest) data set on the graph. When two or more of the same type of sensor are connected, data from those sensors will be plotted on the same graph.

When you have two different types of sensors connected, data from the different sensors will be plotted on two separate graphs.

When a Motion Detector is connected, two graphs will be displayed – position and velocity.
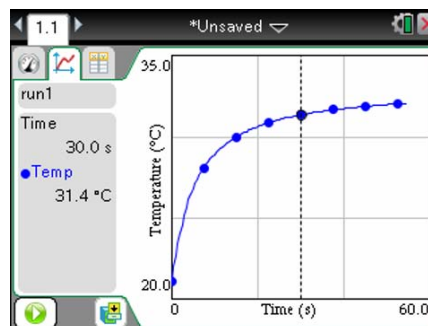
Show Graphs

To change the graph displayed, press [menu] then select Show Graph from the ⊯ Graph menu. You can select Graph 1, Graph 2, or Both. The two graphs can have different dependent (y-axis) data with different ranges; however, they must have the same independent data and range.

Change what is graphed on the axes

To change the data columns plotted on a graph, move the cursor to the axis label and press [ctrl] ⌖, or press [menu] then select X-Axis Column or Y-Axis Columns from the ⊯ Graph menu. Select from the available columns. Use the More option to plot multiple columns on the same axes.
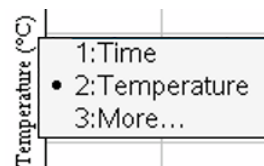
Change which data set is graphed

To plot a different data set or multiple data sets on the same graph, click the run indicator or press [menu] then choose Select Run from the ⊯ Graph menu.

Select All to display all data sets.

Select More to display any combination of stored data sets.
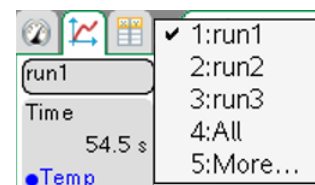
Adjust the Graph Window Settings

To manually adjust the window settings, click the axis labels or press [menu] then choose Window Settings from the ⊯ Graph menu.

Draw Prediction

Use the draw prediction feature before data collection to predict the outcome of the data collection. To add a prediction to a graph, press [menu], choose Draw Prediction from the ⊠ Analyze menu, then select Draw. Click the graph in the desired locations. When finished press [esc].

To remove a prediction, press [menu] then choose Draw Prediction from the ⊠ Analyze menu, and select Clear.

Analyze Data

You can perform multiple types of analysis on your data. For most analysis options, the results will apply to all data points unless a region of data is selected first. Press [menu] then choose your desired analysis option from the ⊠ Analyze menu.

Interpolate

Use Interpolate to examine a graph trace between and beyond the graphed data points. The examine line will move from pixel to pixel instead of data point to data point. This is recommended when examining curve fits.

Tangent

Use Tangent to get a measure of the rate of change of the data at a specific point. A segment is drawn on the graph to help visualize the rate and the rate of change (labeled slope) is displayed in the Graph View details box.

Integral

Use Integral to get a measure of the area between your data and the x-axis. Find the area under all data points or under a selected region of the data. You can adjust the region used by clicking and dragging the brackets. The integral region is shaded on the graph and the area is displayed in the Graph View details box.

Statistics

Use Statistics to find minimum, maximum, mean, and standard deviation of your data. Find these values for all data points or a selected region of the data. You can adjust the region used by clicking and dragging the brackets. The statistical values are displayed in the Graph View details box.

Curve Fits

Use Curve Fits to find the best-fit equation of a curve fit function. Curve fit all data points or a selected region of the data. You can adjust the region used by clicking and dragging the brackets. The curve fit equation is graphed on the axes and the equation values are displayed in the Graph View details box.

Model

Use Model to manually fit a mathematical equation to your data. A model differs from a Curve Fit in that there are no statistical or iterative processes used to determine the best fit. You can define your models using any function of the variable *x*.

To enter a model:

1. Press ⌨menu⌨, then choose Model from the ⬛ Analyze menu.

2. Select one of the predefined equations or enter your own. The model must be a function of the variable x.

3. Enter your estimates for the coefficient values.

4. Modify the spin increment value if desired.

5. Select OK.
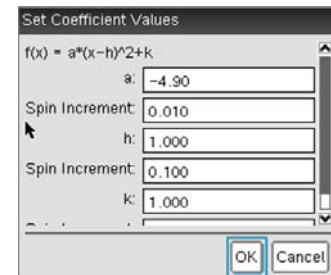
You can adjust the coefficients in your model to obtain a good match of your data.

- Click (⬚) on the spin increment buttons (⬚).
- Click (⬚) on the coefficient and type a new value.
- Move the cursor to the Graph View Details, press ⌨ctrl⌨ ⌨menu⌨ then select the Modify Model option.
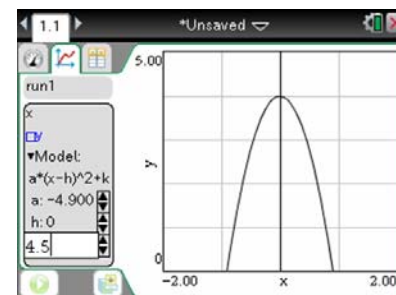
Remove an analysis feature from a graph

Use the remove option to remove an analysis (integral, statistics, curve fit, or model) from a graph. To do this, press [menu] then choose Remove from the [▣] Analyse Menu. If there are more than one, the analysis options will be listed in the order in which they were created.

Select a Region on a Graph

Select a region when you want to look more closely at a specific region of data or analyze only a portion of the data.

To select a region:

1. Move the cursor to the place you want to start the selected region.

2. Press [ctrl][✥] to start the selection.

3. Move the cursor to select the region.

4. Press [✥] or [esc] to end the selection.
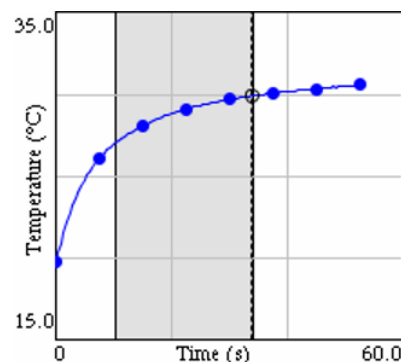
The selected region is indicated by shading. Once a region is selected, you can:

- Zoom in on the region (Press [menu] then choose Zoom In from the [✍] Graph menu).

- Analyze the region (see above).

- Strike the data within or outside the selected region (see below).

Modify the range of an analysis

Once you have used one of the analysis tools, you can modify the range over which the analysis will apply. To do this directly on the graph, move the cursor over one of the brackets, when the cursor changes to a white arrow, press [ctrl][✥] to grab the bracket, then use the touch pad or arrow keys to move the bracket. Press [esc] to release the bracket.

To do this from a menu, move the cursor over the Graph View details box, press [ctrl][menu], then choose the Modify Range option. If you have more than one analysis, choose the one you want to adjust or choose the Modify All option to apply the change to all of the existing ranges.
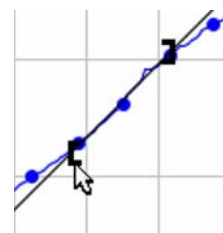
Strike Data

When there are data points that you wish not to have considered in the graphing or analysis of your data, you can "strike" that data. Striking data does not delete the data; rather, data is displayed in the data table with a single line drawn through it and calculated column cells based on struck data will be blank. Struck data is not displayed on the graph.

To strike data, select a region, press [menu], then choose Strike Data from the [▦] Data menu. Select whether to strike through data inside or outside the selected region.

Restore Data

Use this option to restore struck data. Select a region (optional), press [menu] then choose Restore Data from the [▦] Data menu. Select whether to restore data In Selected Region, Outside Selected Region, or Restore All Data.

Tabular Display of the Data

DataQuest also displays data in a data table. In addition to viewing collected sensor data, you can enter data manually and perform column calculations. Use the scroll bar and scroll buttons to view the data.

Data collected will populate the Latest Data Set in the table. This data set is identified with **red, bolded text** on *CX* handhelds (**bolded text** on other handhelds) in the Table View Details box. Storing a Data Set will change the data set

identified as the Latest.

Data Set Options

To change the name of a run or to add notes about the data set, double-click the run name or move the cursor to the table, press `ctrl` `menu` then select Data Set Options.
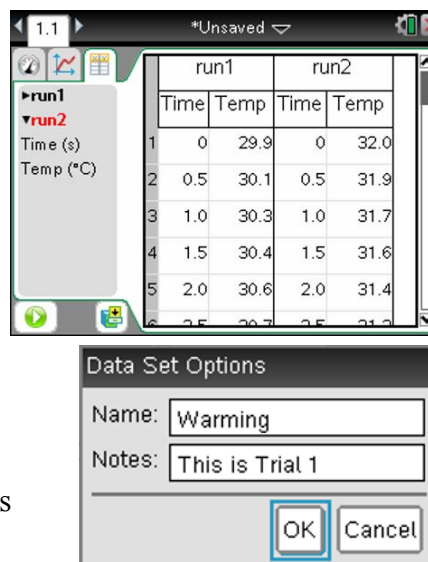
Column Options

Use the column options to change the name of the column and to modify the display precision of any column. Press `menu`, choose Column Options from the ▦ Data menu, then select the column you wish to modify.

Calculated Columns

Calculated columns are used to generate data based on existing columns in a data set. For example, you may want to calculate gravitational potential energy from height measurements or you may want to linearize pressure-volume data by plotting pressure vs. the reciprocal of the volume data.

To add a calculated column, press `menu` then choose New Calculated Column from the ▦ Data menu. The equation you enter must use one of the data columns in the data set.

Manually Entered Data

For experiments that require hand-entered data, launch DataQuest in a new document or problem without any sensors connected. Use the default *x* and *y* columns to manually enter data values. You can use the Column Options to rename your columns if desired (see above).

To add additional manual columns, press `menu` then choose New Manual Column from the ▦ Data menu.

Point Options dialog

DataQuest Options

Points Options

Use the point options to determine how the data are drawn on the graph. To access the Point options, press [menu] then choose Point Options from the [=] Options menu.

Mark refers to the symbol used to distinguish the different traces on a graph. The Mark options are None, Regional, or All. You can also choose whether to have the data points drawn connected.

Regional/Connected is the default for Time Graph data collection. All/Not Connected is the default for Event based data collection.
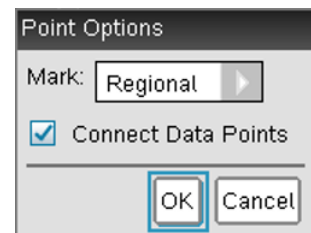
Autoscale Settings

Use the Autoscale Settings to set the scaling behavior of the application during and after data collection. To access Autoscale Settings, press [menu] then choose Autoscale Settings from the [=] Options menu.

- Autoscale Larger – expands the graph range when needed to ensure each data point appears on the graph. This is the default setting and only applies while collecting data.

- Autoscale From Zero – adjusts the graph range to ensure all data points and the origin (0,0) are displayed with little or no extra space. This only applies after collection is complete.

- Autoscale to Data – adjusts the graph range to show all data points with little or no extra space around the points. This is the default setting and only applies after data collection.

- Do Not Auto Scale – maintains the current window range regardless of the collected data. This can be applied either during or after collection.

Derivative Settings

Use the derivative settings to set the number of points used in derivative calculation. The default value is five. To access this setting, press [menu] then choose Derivative Setting from the [=] Options menu.
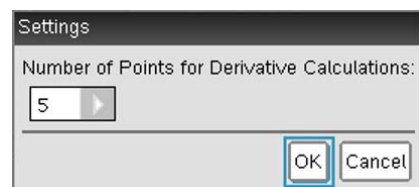
Print All Settings

Use the Print All settings to determine which DataQuest views are printed when the Print All printing option is used. Choose from Print Current View (default), Print All Views, or select any one or combination of views to print. The Print All Settings are specific to each DataQuest App so multiple instances of the app must be set up separately.
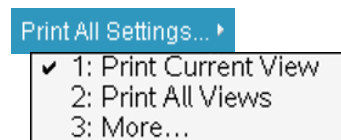
To access Print All Settings, press [menu] then choose Print All Settings from the [=] Options menu. ***Note:*** *You cannot print a document directly from a handheld. You can only print from the TI-Nspire computer software.*

Show/Hide Meters

You can display (or hide) a meter for any column of data. This is useful for calculated columns of data. To select which meters to display, press [menu] then choose Show/Hide Meters from the Options menu. **Note:** Meters for calculated columns will only show live values during data collection.
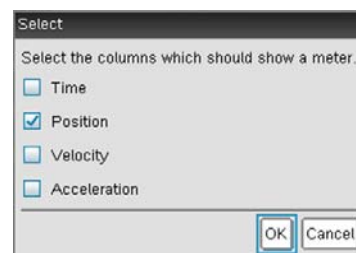
Hide View Details (Show View Details)

The View details boxes, tabs, and collection buttons can be hidden if desired. To hide the View details, press [menu] then choose Hide View Details from the Options menu. When the details are hidden, use the menus to change views and control data collection.

Note: View details will automatically be hidden in some split screen views and when the application window gets too small.

To show View details when they are hidden, press [menu] then choose Show View Details from the Options menu.
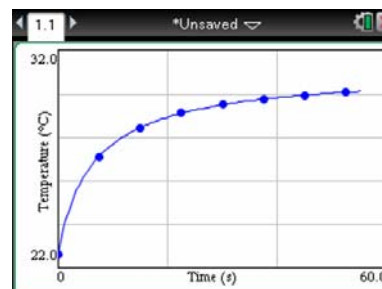
Print a Document

You cannot print a document directly from a handheld. You can only print from the TI-Nspire computer software. See *Appendix* C for more details regarding printing.

Battery Level

The battery icon located in the upper right portion of the screen will display the current battery level available to the handheld. Move your cursor over the battery icon to get an approximate percent of battery life remaining. The level is a combination of all battery types that apply – handheld AAA, handheld rechargeable, and Lab Cradle rechargeable.

For more detailed information regarding the charge level of the different battery types, press [⌂ on], choose Settings, then select Status.
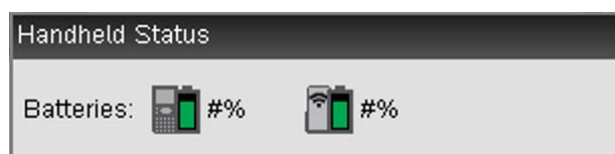
We recommend not letting your battery level go below 25% as this can affect the identification of your sensors.

The TI-Nspire Lab Cradle can be used to collect data on a handheld while powered using the AC adaptor that comes with the Lab Cradle.
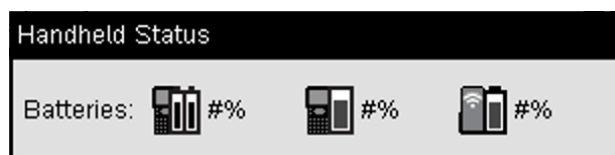
DataQuest Cursors

The DataQuest application uses several different cursors to help identify when there is some special feature available to you through mouse interaction (clicking, right-clicking, clicking and dragging, etc.). The table below will give you a brief explanation of the different cursors used.

Cursor	Description
▶	**Pointer** – The standard cursor you see when using DataQuest.
⟷	**Horizontal Resize Cursor** – This cursor is shown when you are over the location of an object that can be resized in a horizontal direction. The locations where the Horizontal Resize cursor appears are: ► The right edge of and View Details box in Meter, Graph and Table View. This will allow you to resize the details box. ► The left one-third of the horizontal (x-) axis. This allows you to dynamically adjust the x-min window-setting value without changing the x-max value. ► The right one-third of the horizontal (x-) axis. This allows you to dynamically adjust the x-max window-setting value without changing the x-min value. ► The left edge of a table cell. This allows you to adjust the width of the column to the left of the cursor. Press [ctrl][🖰] to grab the object and resize it. After the object has been grabbed, the cursor changes to 🖐. Move the cursor left or right to resize the object. Press [esc] to release the object.
↨	**Vertical Resize Cursor** – This cursor is shown when you are over the location of an object that can be resized in a vertical direction. The locations where the Vertical Resize cursor appears are: ► The space between two DataQuest graphs when both graphs are shown. This will allow you to resize the two graphs as desired. The default is to show both graphs the same height. ► The top one-third of the vertical (y-) axis. This allows you to dynamically adjust the y-max window-setting value without changing the y-min value. ► The bottom one-third of the vertical (y-) axis. This allows you to dynamically adjust the y-min window-setting value without changing the y-max value. Press [ctrl][🖰] to grab the object and resize it. After the object has been grabbed, the cursor changes to 🖐. Move the cursor left or right to resize the object. Press [esc] to release the object.
✛	**Translation Cursor** – This cursor is shown when you are over the location of an object that can be repositioned up-and-down or left-and-right. The locations where the Translation cursor appears are: ► The middle one-third of the horizontal (x-) axis. This allows you to dynamically adjust the x-min and x-max window setting values by the same amount, simultaneously. The graph will appear to move left or right. ► The middle one-third of the vertical (y-) axis. This allows you to dynamically adjust the y-min and y-max window setting values by the same amount, simultaneously. The graph will appear to move up and down. Press [ctrl][🖰] to grab the object and resize it. Move the cursor to resize the object. When you move the object, the cursor changes to 🖐. Press [esc] to release the object.
I	**Text Edit Cursor** – This cursor is shown when you are over the numeric graph-axis labels. Press [🖰] to edit the value. Press [enter] to save the change. Press [esc] to exit without making a change.

Cursor	Description
▷	**Hollow Pointer** – This cursor is shown when the object underneath is selectable in some way. The locations where the Hollow Pointer appears are: ► The graph-axes text label. Press ⌈ctrl⌉⌈menu⌉ to change what is graphed on the axis. ► The analysis selected-region brackets (**[** or **]**). Press ⌈ctrl⌉⌈🖰⌉ to grab a bracket. Move the cursor left or right to adjust the region used in the analysis calculation. Press ⌈esc⌉ to release the bracket.
✏	**Pencil Cursor** – This cursor is shown when Draw Prediction is active. Move the cursor to the desired location and press ⌈🖰⌉ to add a point. Repeat as necessary. Press ⌈esc⌉ to end your prediction.

Using DataQuest on a Computer

This appendix gives an overview of using the Vernier DataQuest application on a computer running the TI-Nspire software. It includes information on accessing the common tools in the DataQuest Application.

DataQuest is included in TI-Nspire computer software versions 3.0 and newer. If you have an older version of TI-Nspire software, you can get updates at education.ti.com.
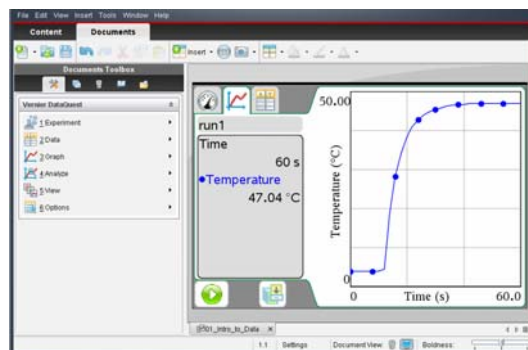
The TI-Nspire Software

Access Menus

DataQuest can be used to collect, display, and analyze data. Most features can be accessed using the application menus found in the Document Tools shown in the Documents Toolbox. If the Documents Toolbox is not displayed, you can show the menus by selecting **Document Tools** from the Window menu.

Access Context Menus

To access context menus on a Windows® computer, right-click the object. To access context menus on a Macintosh® computer, control-click the object. (In this document, right-click is synonyms with control-click on a Mac.)
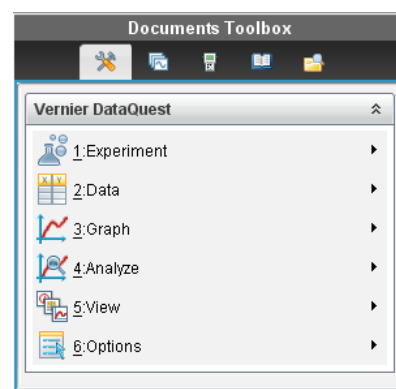
Open a New Document

To open a new document, choose New TI-Nspire Document from the File menu. Having only one TI-Nspire document opened when using DataQuest is recommended.

Add a Page or Problem

To add a new page or problem to your TI-Nspire document, choose Page or Problem from the Insert menu.
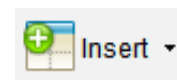
Save a document

To save your TI-Nspire document, choose Save Document from the File menu.

Scratch Pad Calculator

The Scratch Pad Calculator is a built-in calculator that can be used to perform calculations while you are conducting an experiment. To use the Scratch Pad Calculator, choose Keypad (student software) or TI-SmartView™ Emulator (teacher software) from the Window menu. Press 🖩 on the keypad to access the Scratch Pad Calculator.
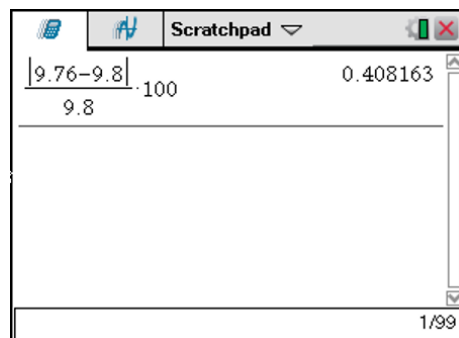
Start DataQuest

DataQuest should automatically start when TI-Nspire software is running on your computer and you connect a TI-Nspire Lab Cradle, Go! Link interface, Go!Temp temperature probe, or Go!Motion motion detector.

Manually Launch DataQuest

To start DataQuest manually, choose 🖾 Vernier DataQuest from the Insert menu.
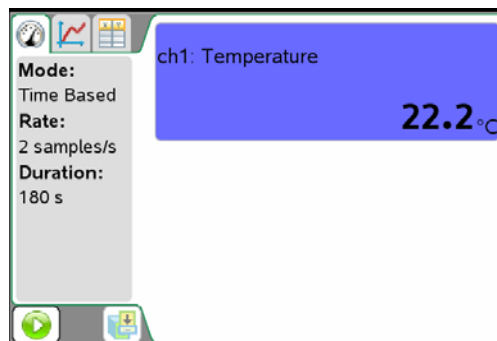
Views in DataQuest

There are three views in the DataQuest application: Meter, Graph, and Table. Click a tab to change views or choose the desired view from the 🖫View menu.

On the left side of the screen in each view, you will see the View details box. The Meter View details box shows the data-collection settings. The Graph View details box shows graph trace and analysis information. The Table View details box shows data set variable information.
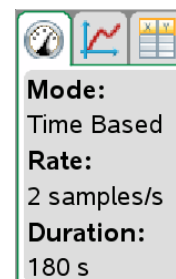
Data Collection Settings

Change the Data-Collection Mode

1. Choose Collection Mode from the 🧮 Experiment menu or right click the Meter Details and select Collection Mode.

2. Select the data-collection mode you want to use.

   Note: Changing modes will require you to discard any collected data. To avoid losing data, save the current document and open a new document, or insert a new problem in the current document.

3. A dialog showing the data collection settings for the mode you have selected will be displayed. Adjust the settings as desired for your experiment.

4. When you are done setting up the data collection, select OK.
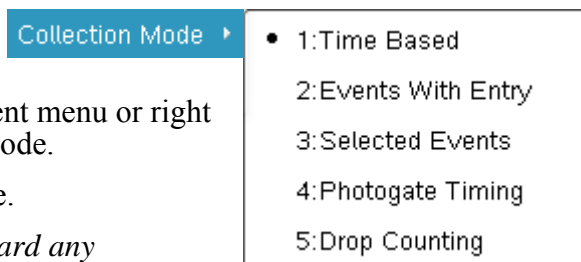
Change Data-Collection Settings

When you have already set up the data-collection mode and want to make changes to the settings, you can change the values you have entered.

1. Choose Collection Setup from the 🧮 Experiment menu or right-click the Meter View details box and select Collection Setup.

2. Make the necessary changes and select OK.
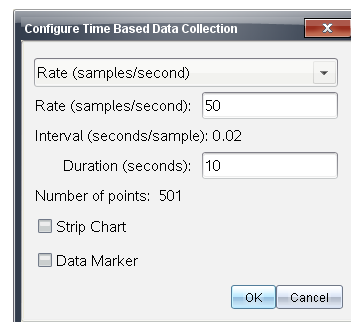
Sensor Settings

Change Units

1. Choose Set Up Sensors ► Change Units from the 🖳 Experiment menu or right-click the sensor's meter and select Change Units.

2. Select the unit you want to use. The readings from the sensor and any collected data will be displayed in the new unit.
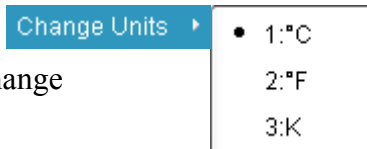
Calibrate a Sensor

Not all sensors can be calibrated. Check the sensor booklet for specific information about your sensor. For most experiments, the sensor's stored calibration is recommended. In some instances, you may want to calibrate a sensor to get readings that are even more accurate.

1. Choose Set Up Sensors ► Calibrate from the 🖳 Experiment menu or right-click the sensor's meter and select Calibrate. Select the appropriate calibration option for your situation:

   - Manual Entry – Use Manual Entry when you know the calibration equation and want to enter the coefficients directly.
   - Two Point – Use Two Point for most calibrations.
   - Single Point – Use Single Point when only one known calibration value is attainable (for example, calibrating a Barometer to match the current atmospheric pressure). Single Point calibration will only affect the intercept of the calibration equation.

2. Perform a live calibration (Two Point or Single Point).

   a. Place the sensor in the desired calibration environment, enter the reference value, wait for the voltage readings to stabilize, and select Keep.
   b. Two Point only – place the sensor in a second calibration environment, enter the reference value, wait for the voltage readings to stabilize, and select Keep.

3. Note the updated calibration equation, modify if necessary (Manual Entry), and select OK.

Zero a Sensor

Not all sensors can be zeroed. Check the sensor booklet for specific information about your sensor.

To zero a sensor, select Set Up Sensors ► Zero from the 🖳 Experiment menu or right-click the sensor's meter and select Zero. **Note:** When you have more than one sensor you want to zero at the same time, select Set Up Sensors ► Zero ► All Sensors from the 🖳 Experiment menu.

Reverse a Sensor

Not all sensors can be reversed. Check the sensor booklet for specific information about your sensor.

Choose Set Up Sensors ► Reverse from the 🖳 Experiment menu or right-click the sensor's meter and select Reverse. The sign of the sensor reading is changed as noted in the example.

Sensors that do not Auto-ID

The DataQuest Application supports older sensors that do not auto-ID. To manually set up a sensor, connect the sensor to the interface and the interface to your computer. Choose Advanced Set Up ► Configure Sensor from the 🐾 Experiment menu, and select the interface and channel your sensor is connected to . Select your sensor from the drop down list and click OK.
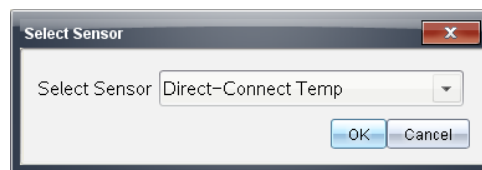
Sensors that do not auto-ID must be set up everytime they are used and will not be identified by the software when opening a saved file.

Data Collection

Start Data Collection

To start data collection, click the Start Collection button or choose Start Collection from the 🐾 Experiment menu.

Keep Data Points (Event Based Data Collection)

To store a data point during Events with Entry or Selected Events experiments, click the Keep button or choose Keep from the 🐾 Experiment menu.

Stop Data Collection

To stop data collection, click the Stop Collection button or select Stop Collection from the 🐾 Experiment menu.

Extend Data Collection (Time Graph Collection)

To extend a time graph experiment duration to one and one-half times the current duration, choose Extend Collection from the 🐾 Experiment menu before or during a collection. The time listed in the menu will be the new duration for the experiment.

Store Data Sets

To store a data set, click the Store Current Data Set button or choose Store Data Set from the 🐾 Experiment menu.

Graphical Display of the Data

By default, DataQuest will graph the most recent (latest) data set on the graph. When two or more of the same type of sensor are connected, data from those sensors will be plotted on the same graph.

When you have two different types of sensors connected, data from the different sensors will be plotted on two separate graphs.

When a Motion Detector is connected, two graphs will be displayed – position and velocity.

Science with Vernier using TI-Nspire Technology
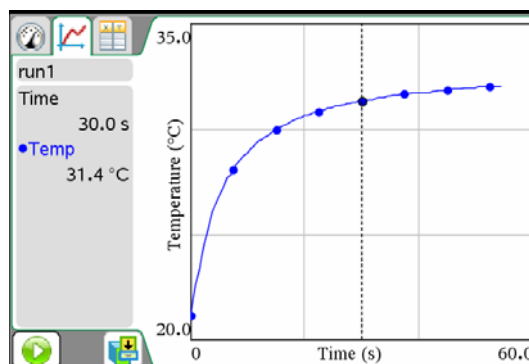
Show Graphs

To change the graph displayed, select Show Graph from the ⚡ Graph menu. You can select Graph 1, Graph 2, or Both. The two graphs can have different dependent (y-axis) data with different ranges; however, they must have the same independent data and range.

Change what is graphed on the axes

To change the data columns plotted on a graph, right click the axis label, or select X-Axis Column or Y-Axis Columns from the ⚡ Graph menu. Select from the available columns. Use the More option to plot multiple columns on the same axes.
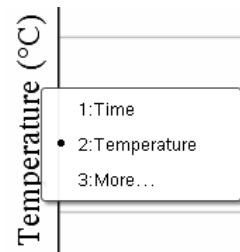
Change which data set is graphed

To plot a different data set or multiple data sets on the same graph, click the run indicator or choose Select Run from the ⚡ Graph menu.

Select All to display all data sets.

Select More to display any combination of stored data sets.
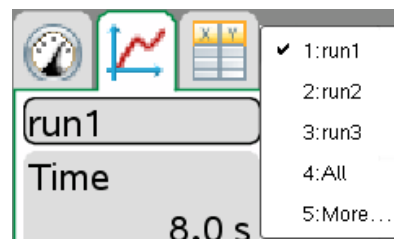
Adjust the Graph Window Settings

To manually adjust the window settings, click the axis labels or choose Window Settings from the ⚡ Graph menu.
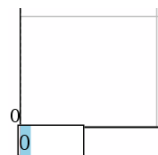
Draw Prediction

Use the draw prediction feature before data collection to predict the outcome of the data collection. To add a prediction to a graph, choose Draw Prediction from the ⚡ Analyze menu and select Draw. Click the graph in the desired locations. When finished press the Esc key.

To remove a prediction, choose Draw Prediction from the ⚡ Analyze menu, and select Clear.
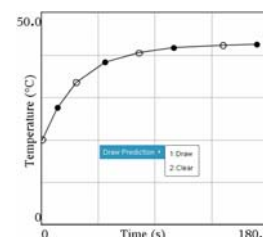
Analyze Data

You can perform multiple types of analysis on your data. For most analysis options, the results will apply to all data points unless a region of data is selected first. Choose your desired analysis option from the ⚡ Analyze menu.

Interpolate

Use Interpolate to examine a graph trace between and beyond the graphed data points. The examine line will move from pixel to pixel instead of data point to data point. This is recommended when examining curve fits.

Tangent

Use Tangent to get a measure of the rate of change of the data at a specific point. A segment is drawn on the graph to help visualize the rate and the rate of change (labeled slope) is displayed in the Graph View details box.

Integral

Use Integral to get a measure of the area between your data and the x-axis. Find the area under all data points or under a selected region of the data. You can adjust the region used by clicking and dragging the brackets. The integral region is shaded on the graph and the area is displayed in the Graph View details box.

Statistics

Use Statistics to find minimum, maximum, mean, and standard deviation of your data. Find these values for all data points or a selected region of the data. You can adjust the region used by clicking and dragging the brackets. The statistical values are displayed in the Graph View details box.

Samples: 101
min: 0.163
max: 0.593
mean: 0.394
dev: 0.127

Curve Fits

Use Curve Fits to find the best-fit equation of a curve fit function. Curve fit all data points or a selected region of the data. You can adjust the region used by clicking and dragging the brackets. The curve fit equation is graphed on the axes and the equation values are displayed in the Graph View details box.

Curve Fit ▶
1: Linear
2: Quadratic
3: Cubic
4: Quartic
5: Power (ax^b)
6: Exponential (ab^x)
7: Logarithmic
8: Sinusoidal
9: Logistic (d ≠ 0)
A: Natural Exponential
B: Proportional

Model

Use Model to manually fit a mathematical equation to your data. A model differs from a Curve Fit in that there are no statistical or iterative processes used to determine the best fit. You can define your models using any function of the variable *x*.

To enter a model:

1. Choose Model from the ![Analyze icon] Analyze menu.

2. Select one of the predefined equations or enter your own. The model must be a function of the variable x.

3. Enter your estimates for the coefficient values.

4. Modify the spin increment value if desired.

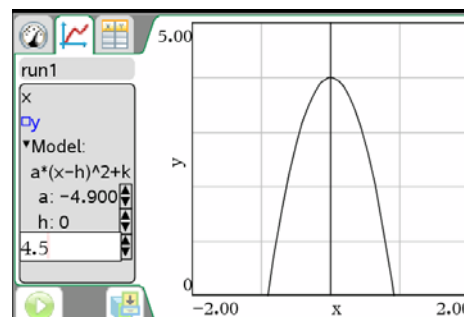5. Select OK.

You can adjust the coefficients in your model to obtain a good match of your data.

- Click on the spin increment buttons (![spin icon]).
- Click on the coefficient and type a new value.
- Right-click the Graph View details box, then select the Modify Model option.

Set Coefficient Values

f(x) = a*(x–h)^2+k

a: −4.900
Spin Increment: 0.010
h: 0
Spin Increment: 0.100
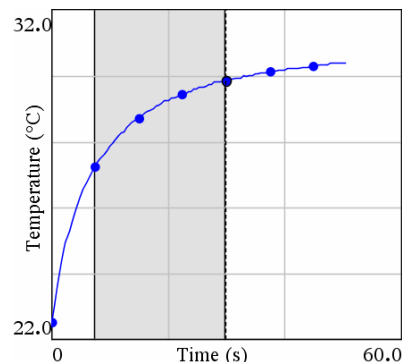k: 1.000
Spin Increment: 0.100

Remove an analysis feature from a graph

Use the remove option to remove an analysis (integral, statistics, curve fit, or model) from a graph. To do this, choose Remove from the ![Analyse icon] Analyse Menu. If there are more than one, the analysis options will be listed in the order in which they were created.

Select a Region on a Graph

When you want to look more closely at a specific region of data or analyze only a portion of the data, you can click and drag across the graph to select a region. The selected region is indicated by shading. Once a region is selected, you can:

- Zoom in on the region (Choose Zoom In from the ![Graph icon] Graph menu)

- Analyze the region (see above)

- Strike the data within or outside the selected region (see below).

Strike Data

When there are data points that you wish not to have considered in the graphing or analysis of your data, you can "strike" that data. Striking data does not delete the data; rather, data is displayed in the data table with a single line drawn through it and calculated column cells based on struck data will be blank. Struck data is not displayed on the graph.

To strike data, select a region, then choose Strike Data from the ![Data icon] Data menu. Select whether to strike through data inside or outside the selected region.

Restore Data

Use this option to restore struck data. Select a region (optional), then choose Restore Data from the ![Data icon] Data menu. Select whether to restore data In Selected Region, Outside Selected Region, or Restore All Data.

Tabular Display of the Data

DataQuest also displays data in a data table. In addition to viewing collected sensor data, you can enter data manually and perform column calculations. Use the scroll bar and scroll buttons to view the data.

Data collected will populate the Latest Data Set in the table. This data set is identified with **red, bolded text** in the Table View Details box. Storing a Data Set will change the data set identified as the Latest.

Data Set Options

To change the name of a run or to add notes about the data set, double-click the run name or right-click the table and select Data Set Options.
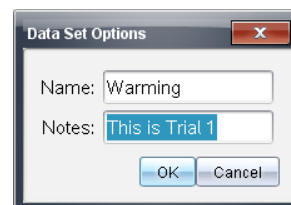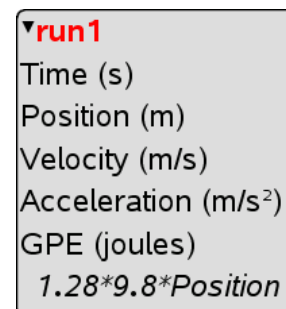
Column Options

Use the column options to change the name of the column and to modify the display precision of any column. Choose Column Options from the ⊞ Data menu and select the column you wish to modify.

Calculated Columns

Calculated columns are used to generate data based on existing columns in a data set. For example, you may want to calculate gravitational potential energy from height measurements or you may want to linearize pressure-volume data by plotting pressure vs. the reciprocal of the volume data.

To add a calculated column, choose New Calculated Column from the ⊞ Data menu. The equation you enter must use one of the data columns in the data set.

Manually Entered Data

For experiments that require hand-entered data, launch DataQuest in a new document or problem without any sensors connected. Use the default *x* and *y* columns to manually enter data values. You can use the Column Options to rename your columns if desired (see above).

To add additional manual columns, choose New Manual Column from the ⊞ Data menu.
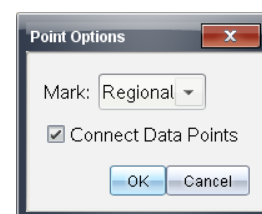
DataQuest Options

Points Options

Use the point options to determine how the data are drawn on the graph. To access the Point options, choose Point Options from the ⊞ Options menu.

Mark refers to the symbol used to distinguish the different traces on a graph. The Mark options are None, Regional, or All. You can also choose whether to have the data points drawn connected.
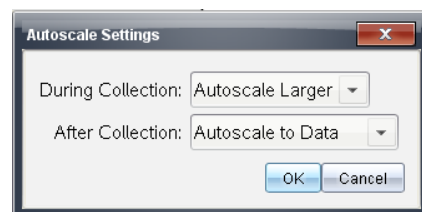
Regional/Connected is the default for Time Graph data collection. All/Not Connected is the default for Event based data collection.

Autoscale Settings

Use the Autoscale Settings to set the scaling behavior of the application during and after data collection. To access Autoscale Settings, choose Autoscale Settings from the Options menu.

- Autoscale Larger – expands the graph range when needed to ensure each data point appears on the graph. This is the default setting and only applies while collecting data.

- Autoscale From Zero – adjusts the graph range to ensure all data points and the origin (0,0) are displayed with little or no extra space. This only applies after collection is complete.

- Autoscale to Data – adjusts the graph range to show all data points with little or no extra space around the points. This is the default setting and only applies after data collection.

- Do Not Auto Scale – maintains the current window range regardless of the collected data. This can be applied either during or after collection.

Derivative Settings

Use the derivative settings to set the number of points used in derivative calculation. The default value is five. To access this setting, choose Derivative Setting from the Options menu.
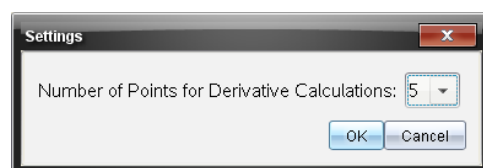
Print All Settings

Use the Print All settings to determine which DataQuest views are printed when the Print All printing option is used. Choose from Print Current View (default), Print All Views, or select any one or combination of views to print. The Print All Settings are specific to each DataQuest App so multiple instances of the app must be set up separately.
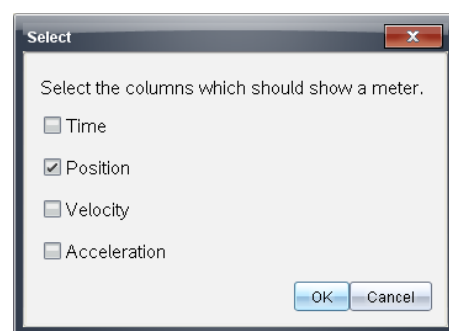
To access Print All Settings, choose Print All Settings from the Options menu.

Show/Hide Meters

You can display (or hide) a meter for any column of data. This is useful for calculated columns of data. To select which meters to display, choose Show/Hide Meters from the Options menu. **Note:** Meters for calculated columns will only show live values during data collection.

Hide View Details (Show View Details)

The View details boxes, tabs, and collection buttons can be hidden if desired. To hide the View details, choose Hide View Details from the 📇 Options menu. When the details are hidden, use the menus to change views and control data collection.

Note: View details will automatically be hidden in some split screen views and when the application window gets too small.

To show View details when they are hidden, choose Show View Details from the 📇 Options menu.
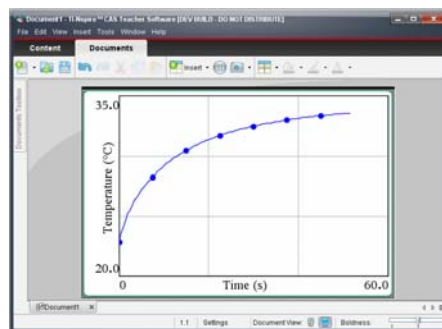
Print a Document

To print a TI-Nspire document, choose Print from the File menu, or use Ctrl+P. When printing, you have two options, Print All and Viewable Screen. Viewable Screen is the default print option.

Print Viewable Screen is a what-you-see-is-what-you-get (WISIWYG) style of printing. Each page in your TI-Nspire Document is printed as it appears on the screen.

Print All will print all information for a specific application whether or not it appears on the screen. Print All includes printing a full page for each selected view along with the each view's details (for example, data collection settings and analysis details). Which views print is determined by the Print All Settings (see above).
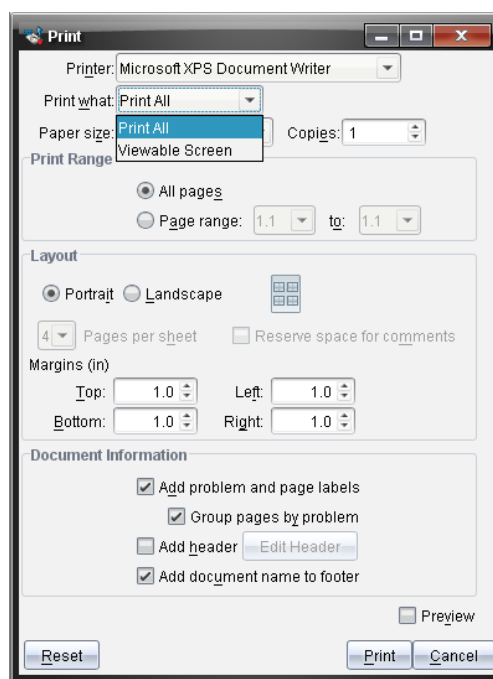
DataQuest Cursors

The DataQuest application uses several different cursors to help identify when there is some special feature available to you through mouse interaction (click, right-click, click-and-hold, and more). The table below will give you a brief explanation of the different cursors used.

Cursor	Description
▶	**Pointer** – The standard cursor you see when using DataQuest.
↔	**Horizontal Resize Cursor** – This cursor is shown when you are over the location of an object that can be resized in a horizontal direction. The locations where the Horizontal Resize cursor appears are: ► The right edge of and View Details box in Meter, Graph and Table View. This will allow you to resize the details box. ► The left one-third of the horizontal (x-) axis. This allows you to dynamically adjust the x-min window-setting value without changing the x-max value. ► The right one-third of the horizontal (x-) axis. This allows you to dynamically adjust the x-max window-setting value without changing the x-min value. ► The left edge of a table cell. This allows you to adjust the width of the column to the left of the cursor. **Click-and-hold** to grab the object and resize it. After the object has been grabbed, the cursor changes to 🖐. Move the cursor left or right to resize the object. Release to anchor the object.
↕	**Vertical Resize Cursor** – This cursor is shown when you are over the location of an object that can be resized in a vertical direction. The locations where the Vertical Resize cursor appears are: ► The space between two DataQuest graphs when both graphs are shown. This will allow you to resize the two graphs as desired. The default is to show both graphs the same height. ► The top one-third of the vertical (y-) axis. This allows you to dynamically adjust the y-max window-setting value without changing the y-min value. ► The bottom one-third of the vertical (y-) axis. This allows you to dynamically adjust the y-min window-setting value without changing the y-max value. **Click-and-hold** to grab the object and resize it. After the object has been grabbed, the cursor changes to 🖐. Move the cursor left or right to resize the object. Release to anchor the object.
✛	**Translation Cursor** – This cursor is shown when you are over the location of an object that can be repositioned up-and-down or left-and-right. The locations where the Translation cursor appears are: ► The middle one-third of the horizontal (x-) axis. This allows you to dynamically adjust the x-min and x-max window setting values by the same amount, simultaneously. The graph will appear to move left or right. ► The middle one-third of the vertical (y-) axis. This allows you to dynamically adjust the y-min and y-max window setting values by the same amount, simultaneously. The graph will appear to move up and down. **Click-and-hold** to grab the object and resize it. Move the cursor to resize the object. When you move the object, the cursor changes to 🖐. Release to anchor the object.

Cursor	Description
I	**Text Edit Cursor** – This cursor is shown when you are over the numeric graph-axis labels. **Click** to edit the value. Press **Enter** to save the change. Press **Esc** to exit without making a change.
▷	**Hollow Pointer** – This cursor is shown when the object underneath is selectable in some way. The locations where the Hollow Pointer appears are: ► The graph-axes text label. Right-click to change what is graphed on the axis. ► The analysis selected-region brackets (**[** or **]**). **Right-click** to grab a bracket. Move the cursor left or right to adjust the region used in the analysis calculation. Release to anchor the bracket.
✏	**Pencil Cursor** – This cursor is shown when Draw Prediction is active. Move the cursor to the desired location and **Click** to add a point. Repeat as necessary. Press **Esc** to end your prediction.

Vernier Products for Science
with TI-Nspire Technology

All software and laboratory interfacing hardware required for the experiments contained in this book are available from Vernier Software & Technology and can be found in this appendix.

	Computers	TI-Nspire handhelds
Multi-Sensor Data-Collection Interfaces		
TI-Nspire Lab Cradle The TI Interface is a low-cost data-collection interface that connects to the USB port of a computer or slide onto the back of a TI-Nspire handheld. The Lab Cradle has five sensor ports – three analog and two digital.	√	√
Single-Sensor Data-Collection Interfaces		
EasyLink EasyLink is a single channel interface that connects to the USB port of the TI-Nspire handheld. It supports over 40 analog sensors, including Gas Pressure, pH, and Conductivity.	Requires Mini-USB adapter*	√
Go! Link Go! Link is a single channel interface that connects directly to the USB port on a computer. It supports over 40 analog sensors, including Gas Pressure, pH, and Conductivity.	√	Requires USB-Mini adapter*
Direct Connect USB Sensors		
EasyTemp EasyTemp is a temperature probe with a mini USB connector that allows you to connect it directly to the USB port of a TI-Nspire handheld. It has stainless steel housing and a temperature range of –20°C to 110°C.	Requires Mini-USB adapter*	√
Go! Temp Go! Temp is a temperature probe with a USB connector that allows you to connect the probe directly to a USB port of computer. It has stainless steel housing and a temperature range of –20°C to 110°C.	√	Requires USB-Mini adapter
CBR 2 The CBR 2 motion detector collects distance, velocity, and acceleration data while connected directly to a TI-Nspire handheld. It can also be connected to TI-Nspire Lab Cradle (using MDC-BTD cable*). Range: 15 cm to 6 m	Requires Mini-USB adapter*	√
Go! Motion The Go!Motion motion detector collects distance, velocity, and acceleration data while connected directly to the USB port of a computer. It can also be connected to TI-Nspire Lab Cradle (using MDC-BTD cable*). Range: 15 cm to 6 m	√	Requires USB-Mini adapter

* Sold separately

Data-Collection Software

Computers

The Vernier DataQuest™ Application for TI-Nspire technology found in the TI-Nspire computer software running version 3.0 or newer.

TI-Nspire Handheld

The Vernier DataQuest™ Application for TI-Nspire technology is found in TI-Nspire handhelds running operating system 3.0 or newer.

Vernier Products for Science using TI-Nspire Technology

Item	Order Code
TI-Nspire Lab Cradle	TI-NSLABC
Vernier EasyLink	EZ-LINK
Vernier Go! Link	GO-LINK
CO_2 Gas Sensor	CO2-BTA
Colorimeter	COL-BTA
Conductivity Probe	CON-BTA
Differential Voltage Probe	DVP-BTA
Dissolved Oxygen Probe	DO-BTA
Dual-Range Force Sensor	DFS-BTA
Gas Pressure Sensor	GPS-BTA
Hand-Grip Heart Rate Monitor	HGH-BTA
Light Sensor	LS-BTA
Low-g Accelerometer	LGA-BTA
Magnetic Field Sensor	MG-BTA
Microphone	MCA-BTA
Motion Detectors	
CBR 2	CBR2
Motion Detector	MD-BTD
Go! Motion	GO-MOT
pH Sensor	PH-BTA
Temperature Probes	
Easy-Temp	EZ-TMP
Go! Temp	GO-TEMP
Stainless Steel Temperature Probe	TMP-BTA
Vernier Circuit Board	VCB
USB-Mini Adaptor	USB-MINI
Mini-USB Adaptor	MINI-USB
CBR or Go!Motion to Lab Cradle cable	MDC-BTD

Vernier Sensors for Science with TI-Nspire Technology

CO_2 Gas Sensor

The CO_2 Gas Sensor measures gaseous carbon dioxide levels It has two settings: low range (0–10,000 ppm) and high range (0–100,000 ppm). This probe is great for measuring changes in CO_2 levels during plant photosynthesis and respiration. With this sensor, you can easily monitor changes in CO_2 levels occurring in respiration of organisms as small as crickets or beans! A chamber with probe attachment is included for running controlled experiments with small plants and animals.

Colorimeter

The four-wavelength (430 nm, 470 nm, 565 nm, and 635 nm) Vernier Colorimeter allows you to study the light absorption of various solutions. It is great for Beer's law experiments, determining the concentration of unknown solutions, or studying changes in concentration vs. time. Fifteen 3.5 mL cuvettes are included.

Conductivity Probe

This probe is great for environmental testing for salinity, total dissolved solids (TDS), or conductivity in water samples. Biology students can use it to investigate the difference between ionic and molecular compounds, strong and weak acids, salinity, or ionic compounds that yield different ratios of ions. The Conductivity Probe can monitor concentration or conductivity at three different sensitivity settings: 0–200 µS/cm, 0–2000 µS/cm, and 0–20,000 µS/cm.

Differential Voltage Probe

Use the Differential Voltage Probe to monitor voltages in low-voltage DC and AC circuits. The differential voltage range is ±6 V. This sensor works well for most "battery and bulb" circuits, or to explore series and parallel circuits.

Dissolved Oxygen Probe

Use the Dissolved Oxygen Probe to determine the concentration of oxygen in aqueous solutions in the range of 0–14 mg/L (ppm). It has built-in temperature compensation and a fast response time. This probe is great for water quality, biology, or ecology. Included with the probe is a zero-oxygen solution, two membrane caps, a 100% calibration bottle, and electrode filling solution. Replacement membranes are available (order code MEM).

Dual-Range Force Sensor

This low-cost force sensor has two ranges: –10 to +10 N and –50 to +50 N. It can be easily mounted on a ring stand or dynamics cart, or used as a replacement for a spring scale. Use it to study friction, simple harmonic motion, impact in collisions, or centripetal force.

Gas Pressure Sensor

The Gas Pressure Sensor can be used for a variety of experiments in biology where gases, such as oxygen and carbon dioxide, are either produced or consumed in a reaction. The pressure range is 0 to 2.1 atm (0 to 210 kPa). It comes with a variety of pressure-sensor accessories, including a syringe, plastic tubing with two Luer-lock connectors, two rubber stoppers with Luer-lock adapters, and one two-way valve.

Hand-Grip Heart Rate Monitor	The Hand-Grip Heart Rate Monitor is ideal for determining a person's heart rate while mobile or stationary. With this sensor, heart rate can be monitored during, as well as after exercise. The sensor consists of wireless hand grips and a receiver module that plugs into any of our data-collection devices. The hand grips sense the electrical signals generated by the heart, much like an EKG. For each pulse detected, a signal is transmitted to the receiver module, and the individual's pulse rate is calculated. The Hand-Grip Heart Rate Monitor includes one transmitter and one receiver.
Light Sensor	The Vernier Light Sensor approximates the human eye in spectral response and can be used over three different illumination ranges, selected with a switch. It can be used for inverse square law experiments or for studying solar energy.
Low-g Accelerometer	The Low-g accelerometer can be used to study one-dimensional motion in a car (real or toy), elevator, pendulum bob, or amusement park ride. The range is ±50 m/s^2 or ±5 g's
Magnetic Field Sensor	This sensor, which uses a Hall Effect transducer, is sensitive enough to measure the Earth's magnetic field. It can also be used to study the field around permanent magnets, coils, and electrical devices.
Microphone	The Vernier Microphone housed in a wand, with an electret microphone on one end. Use it to display and study the waveform of sounds from voices, musical instruments, or tuning forks.
Motion Detector	The Go!Motion, TI-CBR 2, and Vernier Motion Detector 2 function like sonar. This device emits ultrasonic pulses at a rate up to 50 times per second. The time it takes for the reflected pulses to return is used to calculate distance, velocity, and acceleration. The range is 0.15 to 6 meters.
pH Sensor	Our pH Sensor is a Ag-AgCl gel-filled combination electrode and amplifier. It includes a convenient storage solution container that can be attached directly to the electrode. Range: 0 to 14 pH units
Stainless Steel Temperature Probe	The Stainless Steel Temperature Probe is an accurate, durable, and inexpensive sensor for measuring temperature. Range: –40°C to +135°C

Equipment and Supplies

A list of equipment and supplies for all the experiments is given below. The amounts listed are for a class of up to 30 students working in groups of two, three, or four students in a classroom equipped with eight stations. The materials have been divided into **nonconsumables**, **consumables**, and **chemicals**. Most consumables and chemicals will need to be replaced each year. Most nonconsumable materials may be used many years without replacement. Some substitutions can be made.

Nonconsumables

Item	Amount	Experiment
balance	1	29
battery, D-size	16	31
battery holder, for 2 D-size batteries	8	31
beaker, 50 mL	16	9, 22
beaker, 100 mL	16	14, 21, 23, 25
beaker, 250 mL	16	1, 9, 12, 15, 22, 24
beaker, 400 mL	8	5, 10, 18
beaker, 600 mL	24	12
bottle, Nalgene, 250 mL	8	14
bottle, sampling, 500 mL	32	5
bottle, spray	2	13
bowl	8	4
bulb, incandescent, clear (150 W)	8	4, 6, 8
can, metal	8	7
capacitor, 10 μF non-polarized	8	31
clamp, dialysis tubing	16	10
clamp, plastic tubing	16	13
clamp, right angle	16	30
clamp, utility	16	6, 7, 8,10, 11, 13, 18, 22, 23, 24, 25
connecting wires	32	31

cup, 12 oz. plastic	8	5
dynamics cart	16	28
fan	2	13
floodlight, 100 watt	8	13
globe	8	8
goggles	class set	9, 10, 11, 12, 20, 21, 22, 23, 24, 25
graduated cylinder, 10 mL	8	12, 18, 21
graduated cylinder, 50 mL	8	9
heater, small electric	2	13
keyboard, electronic, music (optional)	8	32
lab apron	class set	9
lamp	8	4, 6, 8, 13
magnet, bar	8	2
mass set	8	28, 29, 30
meter stick	8	26, 33
milk jug (1 gallon)	8	4
paper in-basket, wire	8	27, 30
pipet, 10 mL graduate	32	21
pipet pump (or pipet bulb)	8	21
plastic tubing w/Luer-lock fitting	16	12
protractor	8	3, 8
razor blade, knife or scalpel	8	13
resistor, 47 kΩ	8	31
resistor, 100 kΩ	8	31
ring stand	8	6, 7, 10, 11, 13, 18, 22, 23, 24, 25, 30
rod, metal (12 in)	8	30
rubber stopper assembly	8	12
ruler, metric	8	3, 4, 6, 8, 13

scissors	2	2, 10
spoon, plastic	8	7
spring, 10 N/m constant	8	30
stepping stool, 45 cm (18 inches) high	4	16
stirring rod, glass	16	10, 18, 21, 23, 24
switch, single-pole, double throw	8	31
syringe, plastic	8	13, 19
test tube, 18 × 150 mm	40	10, 12
test tube, 25 × 150 mm	40	18, 21, 25
test tube, 25 × 150 mm screw top	64	15
test tube rack	16	10, 12, 15, 21
thermometer	8	12, 14, 33
tube, cardboard or plastic (1–2 m)	8	33
tuning forks (256 Hz and 288 Hz)	8 of each	32
volleyball or basketball	8	27
wash bottle	8	5, 9, 22, 25
watch, clock, or stopwatch	8	4, 16
wooden block with hook	8	29

Consumables

Item	Amount	Experiment
Alka Seltzer	5 tablets	9
aluminum foil	1 roll	6, 15
antacid tablets	20 g	9
aspirin	20 g	9
beral pipets	300	10, 12, 13, 25
Bufferin	20 g	9
card, small index	16	30
cup, Styrofoam	8	24

dental floss	1 roll	10
dialysis tubing, 2.5 cm × 12 cm	1/2 roll	10
distilled water	40 L	5, 9, 10, 11, 15, 21, 22, 23, 24, 25
egg white	20 g	9
filter paper, 2.5 cm x 2.5 cm	48 pieces	20
fruit juice	200 mL	9
gelatin	200 mL	9
graph paper	40 pcs	9, 13, 29
ice	8 bags	1, 4, 7, 12, 14, 18
liver	20 g	9, 12
marble (rock)	20 g	9
paper, black	8 pieces	6
paper, several colors	16 pieces	6
paper, white	8 pieces	6
paper clip	16 or 24	2
Parafilm, 5 x 5 cm	64	15
peas (garden)	400	14
plant, aquatic (elodea or anacharis)	16	15
plant cuttings	8	13
plastic bag, gallon	4	13
pond water	7 L	11, 15
potato, whole	9	9
quartz (rock)	20 g	9
rubber bands, small	40	20
snails, aquatic	16	15
soda water	200 mL	9
soil samples	buckets	4
starch	20 g	9

stickers, small (optional)	8 or 16	2
straw, plastic	8	6
string	1 roll	8, 29
tape, masking	2 rolls	2, 3, 4, 6, 8, 13, 20, 26, 30
tissue (preferably lint-free)	box	21, 22
vitamin B	20 g	9
vitamin C	20 g	9
yeast	6 pkgs	9, 12
zip ties	32	30

Chemicals

Item	Amount	Experiment
acetic acid (17.4 M)	70 mL	22
aluminum chloride	100 g	11, 22, 23
boric acid	5 g	22
buffer solution, pH 4	500 mL	9, 12
buffer solution, pH 7	1 liter	9, 12
buffer solution, pH 10	500 mL	9, 12
1-butanol	100 mL	20
calcium chloride	30 g	11, 22, 23
ethanol	800 mL	11, 20
glucose	25 g	11
n-hexane	100 mL	20
hydrochloric acid (0.1 M)	100 mL	9
hydrochloric acid (12 M)	300 mL	22, 24, 25
hydrogen peroxide (3%)	750 mL	12
methanol	150 mL	20, 22
nickel (II) sulfate	30 g	21

n-pentane	100 mL	20
phosphoric acid (14.8 M)	5 mL	22
1-propanol	100 mL	20
sodium bicarbonate	120 g	25
sodium bisulfite	10 g	25
sodium chloride (table salt)	350 g	9, 10, 11, 16, 17, 18, 22, 23
sodium hydroxide	100 g	24
sodium hydroxide (0.1 M)	100 mL	9
sodium nitrite	10 g	25
sucrose	600 g	10, 11

Suppliers

Flinn Scientific Inc.
1-800-452-1261
www.flinnsci.com

Hach Company
1-800-227-4224
www.hach.com

Frey Scientific
1-800-225-FREY
www.freyscientific.com

Ward's Natural Science
1-800-962-2660
www.wardsci.com

Fisher Science Education
1-800-955-1177
www.fisheredu.com

Safety Information

Chemical Hazard Information

The reference source for the chemical hazard information in this book is the 2002 edition of Flinn Scientific's *Chemical & Biological Catalog Reference Manual*. Flinn Scientific, Inc. is an acknowledged leader in the areas of chemical supply, apparatus and laboratory equipment supply, and chemical safety. Flinn's *Chemical & Biological Catalog Reference Manual* is an outstanding reference to be used as you order chemicals, store chemicals, mix solutions, use chemicals in you classroom, and dispose of chemicals. Most of the chemicals and the equipment used in *Biology with Vernier* are available from this catalog. We strongly urge you to obtain and use a current copy of the above mentioned publication by contacting Flinn Scientific at the address below:

> Flinn Scientific, Inc.
> P.O. Box 219
> Batavia, Illinois 60510
> Telephone (800) 452-1261
> www.flinnsci.com

The Flinn hazard code is used in the teacher information section of many tests in *Biology with Computers* to describe any possible hazards associated with the chemical reagents used. The Flinn hazard code (A–D) is defined as follows:

A. Extremely Hazardous. This category includes, but is not limited to, concentrated acids, severely toxic, severely corrosive, unstable and /or explosive chemicals.

B. Hazardous. This category includes, but is not limited to, chemicals that are toxic/poisons, corrosive, contain heavy metals, and/or are alleged/proven carcinogens.

C. Somewhat Hazardous. This category includes, but is not limited to, chemicals that are highly flammable/combustible, moderately toxic and/or oxidants.

D. Relatively Non-Hazardous. This category includes, but is not limited to, chemicals that are irritants and/or allergens.

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(by Experiment Number)

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