ScienceWorkshop

Starter Labs with Computers

Student Workbook

Science and math activities using the
ScienceWorkshop® programs and interfaces
from PASCO scientific

Copyright Information

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Introductory Physics

Quick Reference Guide for *DataStudio*

Create an Experiment
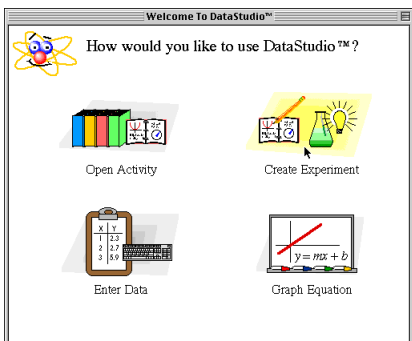
(1) Double-click a sensor.
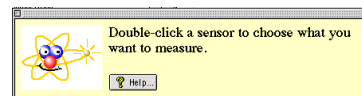
(2) Double-click a display.
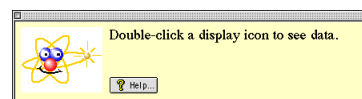
What You Want To Do	How You Do It	Button
Start recording data	Click the 'Start' button or select 'Start Data' on the Experiment menu (or on the keyboard press CTRL - R (Windows) or Command - R (Mac))	▶ Start
Stop recording (or monitoring) data	Click the 'Stop' button or select 'Stop Data' on the Experiment menu (or on the keyboard press CTRL - . (period) (Win) or Command - . (Mac))	■ Stop
Start monitoring data	Select 'Monitor Data'on the Experiment menu (or on the keyboard press CTRL - M (Win) or Command - M (Mac))	**none**

On the Graph Display	In the Graph Toolbar	Button
Re-scale the data so it fills the Graph display window	Click the 'Scale to Fit' button.	
Pinpoint the x- and y-coordinate values on the Graph display	Click the 'Smart Tool' button. The coordinates appear next to the 'Smart Tool'.	
'Zoom In' or 'Zoom Out'	Click the 'Zoom In' or 'Zoom Out' buttons.	
Magnify a selected portion of the plotted data	Click the 'Zoom Select' button and drag across the data section be to magnified.	
Create a Calculation	Click the 'Calculate' button	
Add a text note to the Graph	Click the 'Note' button.	
Select from the Statistics menu	Click the Statistics menu button	
Add or remove a data run	Click the 'Add/Remove Data' menu button	
Delete something	Click the 'Delete' button	
Select Graph settings	Click the 'Settings' menu button	

Experiment Setup Window

To 'Calculator' window

To 'Curve Fit' window

Sensor icon

Sensors list

To 'Sampling Options' window

Graph Display

Graph Toolbar

Legend
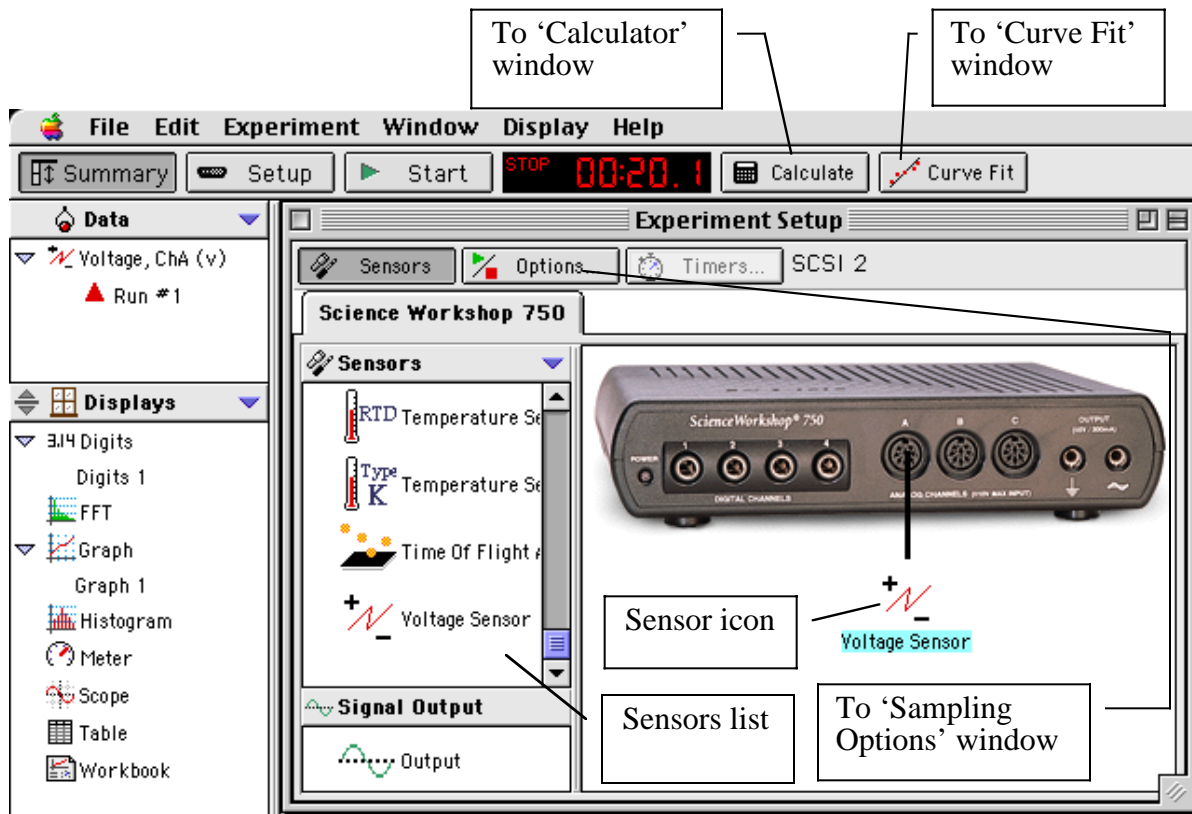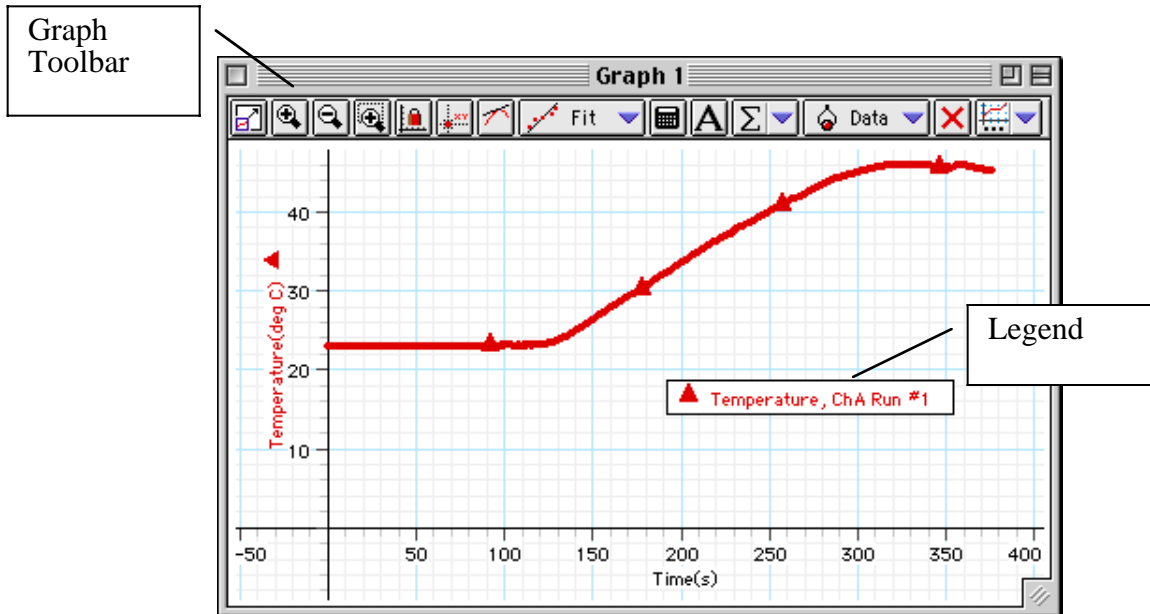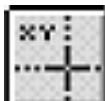
Quick Reference Guide for *ScienceWorkshop*

In the Experiment Setup Window:

What You Want To Do To	How You Do It	What the Button Looks Like
Begin recording data	Click the Record (REC) button	
	or select Record on the Experiment menu	
	(or on the keyboard press CTRL - R (Windows) or Command - R (Mac))	
Stop recording (or monitoring) data	Click the Stop (STOP) button	
	or select Stop on the Experiment menu	
	(or on the keyboard press CTRL - . (period) (Win) or Command - . (Mac))	
Begin monitoring data	Click the Monitor (MON) button	
	or select Monitor on the Experiment menu	
	(or on the keyboard press CTRL - M (Win) or Command - M (Mac))	

On the Graph Display:

Re-scale the data so it fills the Graph display window	Click the Graph display and click the Autoscale button	
Pinpoint the x- and y-coordinate values on the Graph display	Click the Smart Cursor button and move the cross hairs onto the graph (the exact values for the coordinates will appear next to each axis label)	
Magnify a selected portion of the plotted data	Click the Magnify button, and drag across the data section be to magnified	
Activate the Statistics Menu	Click the Statistics button	
Open the Statistics Menu	Click the Statistics Menu button	
See a list of all your Data Runs	Click the Data button	
Select Data Runs for display	Click the Run # in the Data menu (Shift-click to select more than one run)	
Add another plot to your Graph display	Click the Add-A-Plot button and select the desired input from the pop-up menu	
Import match data and plot it on the Graph display	Copy the match data to the clipboard, click the Plot Data Options button, and click Paste, OK, OK	

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Experiment Setup Window

Monitor button

Stop button

Digital Channel icons

Minimize button (click to show only the left panel of the Setup window)

Record button

Pause button

Data Runs will be listed here.

Click to adjust sampling rate.

Experiment Notes button

Analog Channel icons

Experiment Calculator button

Digital plug icon

Display icons

Analog plug icon

Graph Display

Y-axis (Click to change range of y-axis.)

Statistics Menu button

Plot Input menu button

Plot Data Options (e.g., import match data.)

DATA menu button (Select Data Runs for the display.)

Magnify button

Statistics button

Smart Cursor button

Display Options button

Add-A-Plot menu button

Autoscale button

X-axis Input button

X-axis (Click to change range of x-axis.)

Statistics Area

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Preface

I.   Overview of <u>Starter Labs with Computers Student Workbook</u> (CI-7091)

This workbook has thirty-four activities in the following areas: biology/ecology, chemistry, general science, mathematics, and physics. The activities use one of three sensors: light, temperature, or voltage. Each activity in this workbook is similar to an activity in another *ScienceWorkshop* lab manual.

Each activity has the following parts:

Equipment List	Procedure
Purpose (What Do You Think?)	Analyzing the Data
Background	Lab Report
Safety Reminders	

Equipment List

The list includes PASCO equipment (in **bold** font), other equipment, chemicals and consumables, and quantities.

Purpose (What Do You Think?)

The purpose includes a question for you to answer in the Lab Report section.

Background

This section provides information about the concepts in the activity.

Safety Reminders

General safety reminders include following instructions for using the equipment, taking precautions when handling glassware or chemicals, and wearing protective gear (e.g., splash shield or goggles, gloves, and an apron).

Procedure

The procedure is a *basic outline* of how to get started, how to set up equipment, and how to use *DataStudio* or *ScienceWorkshop* to record data. The procedure has four sections:

- Set up the interface.

- Open the *DataStudio* or *ScienceWorkshop* file.

- Set up the equipment.

- Do the experiment (record the data).

Analyzing the Data

This section outlines methods and makes suggestions for using built-in analysis tools in the software to analyze the data.

Lab Report

The Lab Report section is where you can record your data and answer the questions.

II.   Safety Reminders

> *PASCO scientific* assumes no responsibility or liability for use of the equipment, materials, or descriptions in this book.

- Take safety precautions to protect yourself during <u>all</u> activities in the lab, and especially during the lab activities in this manual.

- It is not possible to include every safety precaution or warning! Please use extra care when setting up and using equipment, glassware, and especially chemicals.

- In those activities where you use chemicals, be sure to wear protective gear such as a lab coat or apron, gloves, and protective goggles or a splash shield to protect your eyes and face.

SAFETY REMINDERS

- Wear protective gear.

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

Remember, if you have any questions about safety or about using the equipment, ASK!

Instructions – Using the Interface and *DataStudio*

There are several features that make *DataStudio* a unique and powerful teaching tool for science and math. Section #1 covers the mechanics of the interface. Section #2 covers setting up an experiment with the software. Section #3 covers data analysis in more detail.

Hint: Working at a computer with *DataStudio* up and running while reading these instructions will bring a "hands-on" experience to the user and enhance the learning process.

Section # 1: ScienceWorkshop 500 Interface

Data Logging with the *ScienceWorkshop* 500 Interface Box

If you want to disconnect the interface box and use it for data logging, be sure to install four AA batteries in the bottom of the interface.

After you have set up an experiment in *DataStudio*, click the 'Logging' button in the Experiment Setup window in the software. Follow the instructions about saving your experiment. Disconnect the interface from the computer and the power supply. (Make sure that the switch on the back of the interface is in the ON position.)

Data Logging Instructions

LOG Button

Digital Channels 1 and 2

Analog Channels A, B, and C

After you have disconnected for logging, use the **LOG button** when you want to record data. Press the Log button once to begin data collection, and press it a second time to end that data run. Repeat this sequence to collect more sets of data points that will be called RUN #2, RUN #3, etc

Caution: In the remote data logging mode, the ON switch at the back of the box must remain on at all times. Loss of power will result in loss of data.

After you have collected data, reconnect the interface to the computer and the power supply.

Click the 'Connect' button in the Experiment Setup window in the software. Your data will download automatically.

The **green LED (light-emitting diode)** on the front of the interface box indicates the mode of the interface box. A green light indicates that the power is ON. When you disconnect the interface for remote data logging the light will flash slowly when in the sleep mode and rapidly when you are collecting data. (Refer to the label on the top of the interface for details).

The **Analog Channels** allow up to three analog sensors to be plugged into the *500* interface. You can plug in an analog sensor's DIN plug in only one way. The Starter Bundle includes three analog sensors: Light, Temperature, and Voltage.

The **Digital Channels** allow one or two digital sensors to be plugged into the *500* interface. The Photogate and Motion Sensor are examples of digital sensors. The Starter Bundle does not include a digital sensor.

Section #2: Setting Up Your Own Experiment in DataStudio

The Summary List and the Setup Window

Start *DataStudio*. In the 'Welcome to DataStudio™' window, click 'Create Experiment'.
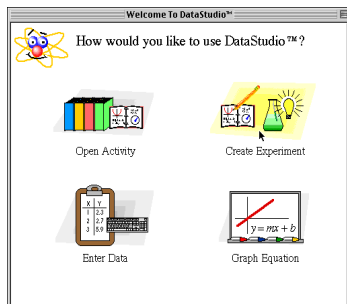
The first step to becoming proficient with *DataStudio* is to understand the Summary List and the Experiment Setup window. The Summary List shows runs of data (under 'Data') and the available displays (under 'Displays'). The Experiment Setup window shows the list of sensors (under 'Sensors') and the interface that is connected.
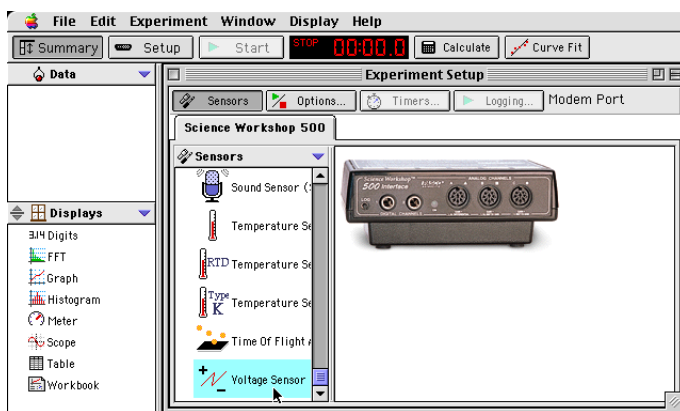
Select a sensor. The sensors are listed by name. Scroll through the list to find the 'Voltage Sensor', and then double-click the sensor to select it.
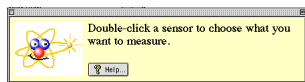
The Voltage Sensor icon appears below Channel A of the interface, and 'Voltage, ChA (v)' appears in the Data list.
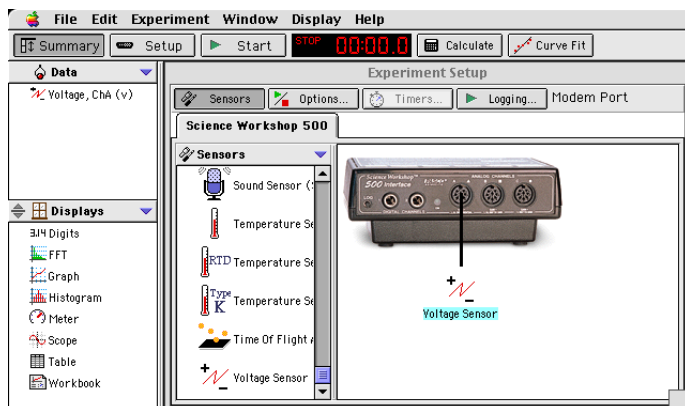
Now, select a display. Double-click 'Graph' in the Displays list.
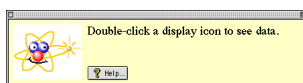
Graph 1 opens, and 'Graph 1' appears in the Displays list. Also, 'Voltage, ChA NO DATA' appears in the Graph's legend.
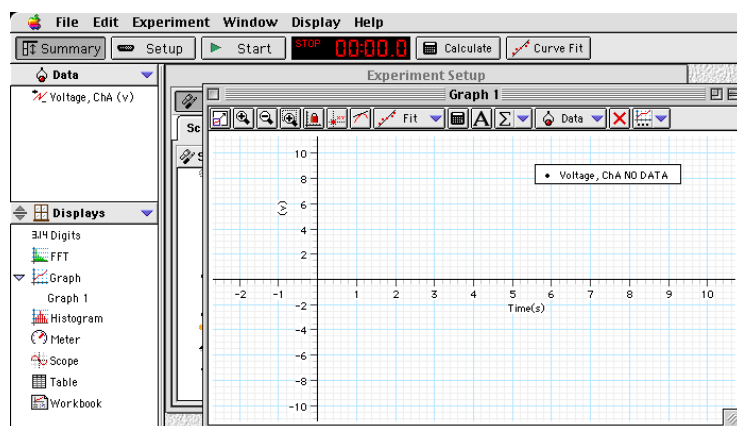
Finally, click the 'Start' button (▶ Start) to begin recording data.

When you are finished, click 'Stop'.
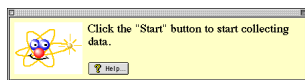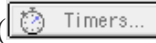
The Menu Bar 🍎 **File Edit Experiment Window Display Help**

The **menu bar** at the top of the Experiment Setup window is very similar to menus bars found in Macintosh® and Windows® programs.

- Use the **File** menu to make a new activity, open an activity, save an activity, save an activity with a specific filename or in a specific location, import data, export data, select options (for saving *to* or opening *from* a particular directory), setup the page for printing, print, or quit.

- Use the **Edit** menu to undo, cut, copy, paste, delete, or select all.

- Use the **Experiment** menu to control the data collection, delete the last data run, disconnect for data logging or re-connect after data logging, set sampling options, open a new empty data table, or add a display.

- Use the **Window** menu to close, minimize, or maximize a window, to tile or cascade windows, or to select a window so it 'pops-to-the-top'.

- Use the **Display** menu to export data or a picture of a display or to activate any of the buttons in a display's toolbar.

- Use the **Help** menu to open the online help files, see the most recent help message, turn on or turn off the tips and confirmation windows, or change the license key.

Features of the Experiment Setup Window

In addition to the Sensors list, the Experiment Setup window has a button to open the 'Sampling Options' window (⚡ Options...), a button to open the 'Timers' window (⏱ Timers...) (for use with Photogates), and a 'Logging' button (▶ Logging...) for use when you disconnect the interface for data logging.

Note: After you click the 'Logging' button, a 'Connect' button (⌐ Connect) appears. If you disconnect for data logging and then re-connect after collecting data, click the 'Connect' button after you re-connect the interface to the computer and power supply.

Use the 'Sampling Options' window to set a 'Delayed Start', an 'Automatic Stop' or to set the 'Manual Sampling Control'.
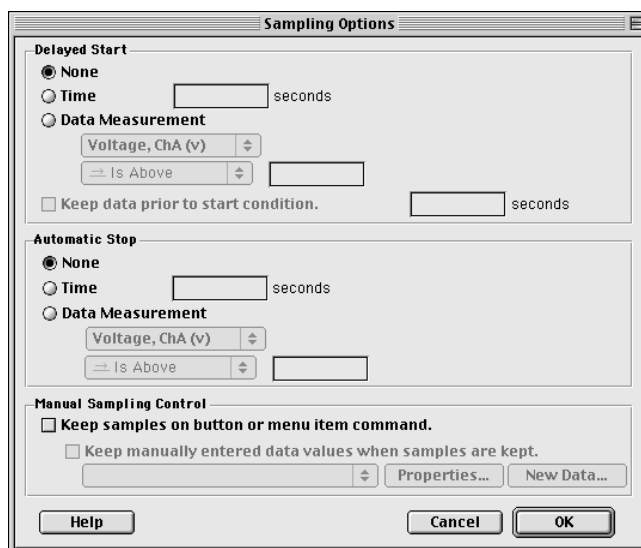
Section #3: Data Analysis

DataStudio offers several ways to analyze data:

- Use the built-in analysis tools in the Graph display toolbar

- Use the 'Calculator' to create calculations based on your measured data or on a range of numbers that you select.

- Use the 'Curve Fit' to compare your data to mathematical models.

In the **Graph display toolbar**, the built-in analysis tools include the 'Smart Tool' button ( ), the 'Slope Tool' button ( ), the 'Fit' menu button ( ), the 'Calculate' button ( ), and the 'Statistics' menu button ( ).
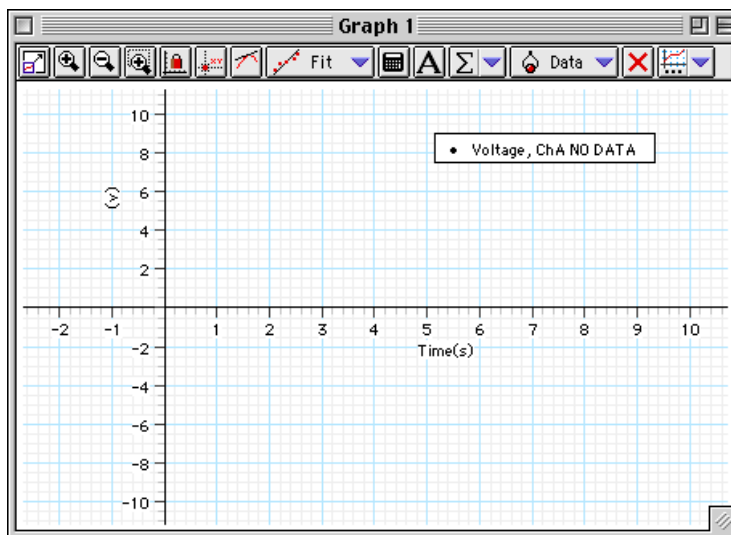
- Use the 'Smart Tool' to see the coordinates of any point.

- Use the 'Slope Tool' to see the slope of a line tangent to a point on a curve.

- Use the 'Fit' menu button to select a mathematical model.

- Use the 'Calculate' button to create a calculation on the data in your Graph.

- Use the 'Statistics' menu button to select basic statistics such as 'Minimum' or 'Maximum' or to find the area under a curve.
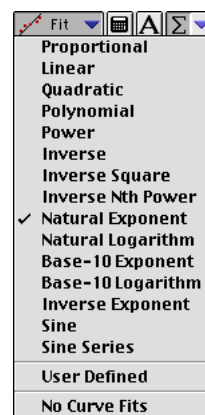
Click the 'Calculate' button in the main toolbar ([Calculate]) to open the '**Calculator**' window:
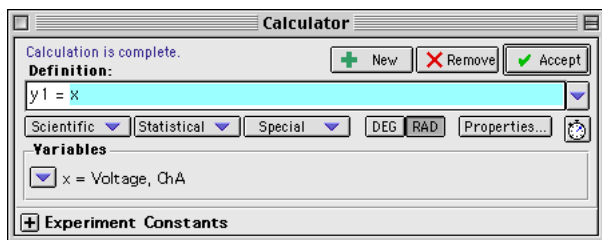
Use the 'Definition:' area to create your own calculation, or use the 'Scientific', 'Statistical', or 'Special' menus to select a specific calculation to apply to your data. After you have created the calculation, click 'Accept'. Your calculation will appear in the Data list. You can drag your calculation to a Graph display, for example

Click the 'Curve Fit' button in the main toolbar ([Curve Fit]) to open the **'Curve Fit'** window. Click the 'New' button.
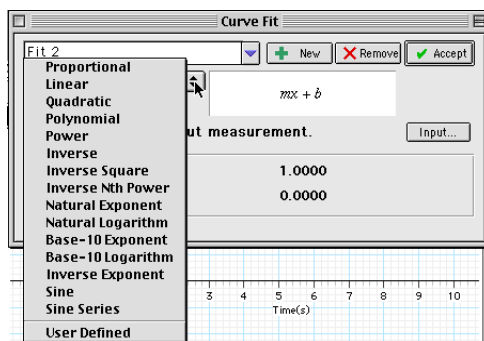
Select a mathematical model, or select 'User Defined' to create your own.
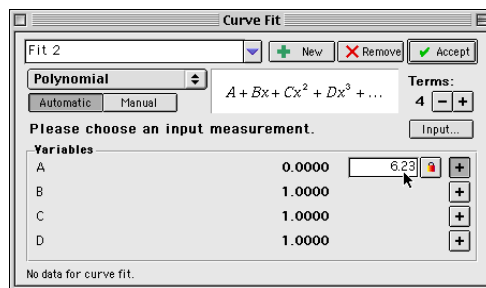
You can enter values for the coefficients or 'lock' a coefficient. After you have created the mathematical model, click 'Accept'. Your curve fit will appear in the Data list. You can drag your curve fit to a Graph display, for example.

Online Help

Click 'Contents' or 'Search…' in the Help menu to open the online help file. You can use the online help file to learn about any button, icon, menu, control, function or feature of the program.

Instructions – Using *ScienceWorkshop®*

There are several features that make *ScienceWorkshop* a unique and powerful teaching tool for science and math. Section #1 covers the mechanics of the software and hardware. Section #2 covers the data analysis tools in more detail.

Hint: Working at a computer with *ScienceWorkshop* up and running while reading these instructions will bring a "hands-on" experience to the user and enhance the learning process. You should keep the *Quick Reference Guide for ScienceWorkshop* available as a reference.

Section # 1: Experiment Setup

The *ScienceWorkshop* 500 Interface Box

Use the **LOG button** when you want to disconnect the interface from the computer and take it into the field for data collection. Press it once to begin data collection, and press it a second time to end that data run. Repeat this sequence to collect more sets of data points that will be called RUN #2, RUN #3, etc. If you want to disconnect the interface box from the power supply, be sure to install four AA batteries in the bottom of the interface. (Make sure that the switch on the back of the interface is in the ON position.)
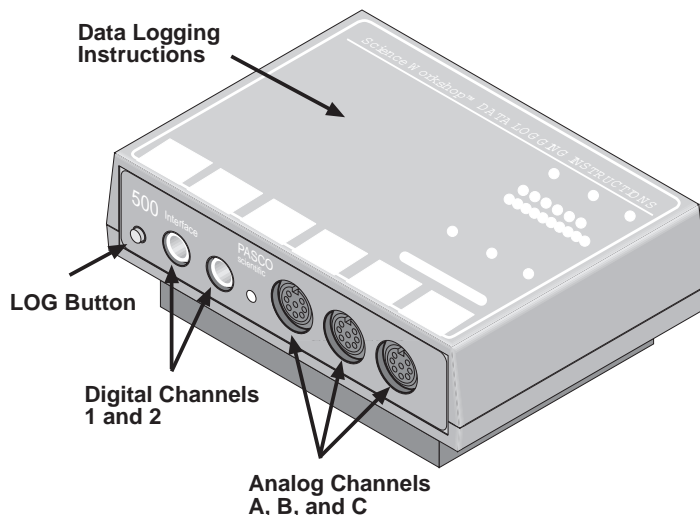
Data Logging Instructions

LOG Button

Digital Channels 1 and 2

Analog Channels A, B, and C

Caution: In the remote data logging mode, the ON switch at the back of the box must remain on at all times. Loss of power will result in loss of data.

The **green LED (light-emitting diode)** on the front of the interface box indicates the mode of the interface box. A green light indicates that the power is ON. When you disconnect the interface for remote data logging the light will flash slowly when in the sleep mode and rapidly when you are collecting data. (Refer to the label on the top of the interface for details).

The **Analog Channels** allow up to three analog sensors to be plugged into the *500* interface. You can plug in an analog sensor's DIN plug in only one way. The Starter Bundle includes three analog sensors: Light, Temperature, and Voltage.

The **Digital Channels** allow one or two digital sensors to be plugged into the *500* interface. The Photogate and Motion Sensor are examples of digital sensors. The Starter Bundle does not include a digital sensor.

The Experiment Setup Window

The first step to becoming proficient with *ScienceWorkshop* is to understand the various icon and buttons in the **Experiment Setup** window. The window is automatically displayed whenever a new *ScienceWorkshop* file is opened. If you get a "Can't find interface box" message, the interface is either missing or not properly connected. Be sure that the power to the interface box is ON and that the connector cables are secure.
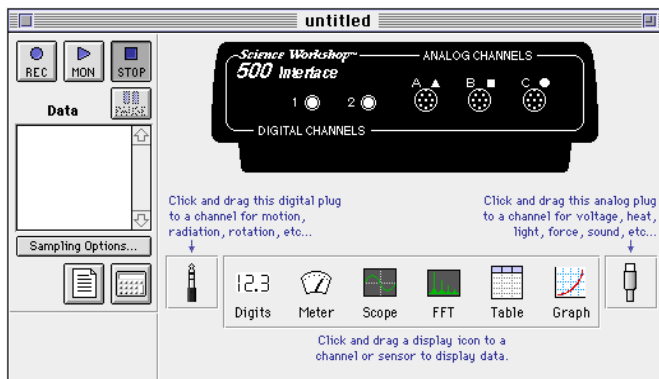
The Menu Bar   **File   Edit   Experiment   Display**

The **menu bar** at the top of the Experiment Setup window is very similar to menus bars found in Macintosh® and Windows® programs.

- Use the **File** menu to open, close, save, print, and import data.

- Use the **Edit** menu to copy, cut, clear, and paste data or runs of data.

- Use the **Experiment** menu to control the data collection.

    You can also use the Experiment menu to **Record**, **Monitor**, **Pause,** or **Stop** data collection (as if you had used the buttons in the Experiment Setup window). You can use this menu to access the sampling options, disconnect/connect (for remote data logging), display the Experiment Setup window, or go to the Experiment Notes and Calculator windows.

- Use the **Display** menu to select any of the six display windows (either to set up a new display or toggle to a display already in use).

Features of the Experiment Setup Window

The **Record button** is in the top left corner of the Experiment Setup window. Press this button to collect data and store the data in memory. The flashing bar below the button shows when *ScienceWorkshop* is collecting data.

The **Monitor Data button** is next to the **Record** button. Press this button to collect and display data in a *view* mode only. None of the data are saved in memory. For example, use this feature when you want to check to see if a sensor is working properly, and also when viewing data in the Scope display.

Press the **Stop button** to stop data collection in both the record and monitor modes.

Press the **Pause button** to temporarily interrupt data collection. Press it again when you want to continue collecting data.

| Sampling Options... | Press the **Sampling Option button** to open a window where you can select the Periodic Samples rate, the Start and Stop Conditions, and Keyboard Sampling. The default Periodic Samples rate is 10 samples per second (10 Hz) for an analog sensor and 10,000 samples per second for a digital sensor. You can vary the Periodic Samples rate from 20,000 Hz (Fast) to 3600 seconds (Slow).

Suggested Periodic Sampling rates for common measurements:

Temperature Sensor   2 – 10 Hz
Light Sensor   10 Hz
Voltage Sensor   10 Hz

Press the **Experiment Calculator button** to open the Experiment Calculator window that allows you to do mathematical operations on collected data. You can also use it as a stand-alone calculator.

Drag the **digital plug icon** to Digital Channel 1 or 2 to add a digital sensor to the Experiment Setup window, and then select the correct digital sensor from the list of sensors that opens. Click **OK** to return to the Experiment Setup window.

Drag the **analog plug icon** to Analog Channel A, B, or C to add an analog sensor to the Experiment Setup window. Then select the correct analog sensor from the list of sensors than opens. Click **O K** to return to the Experiment Setup window.

Setting Up Your Own Experiment in *ScienceWorkshop*

1.   Drag an **analog plug icon** or a **digital plug icon** to the icon that corresponds to the channel on the *500* Interface box that you plugged the sensor into.
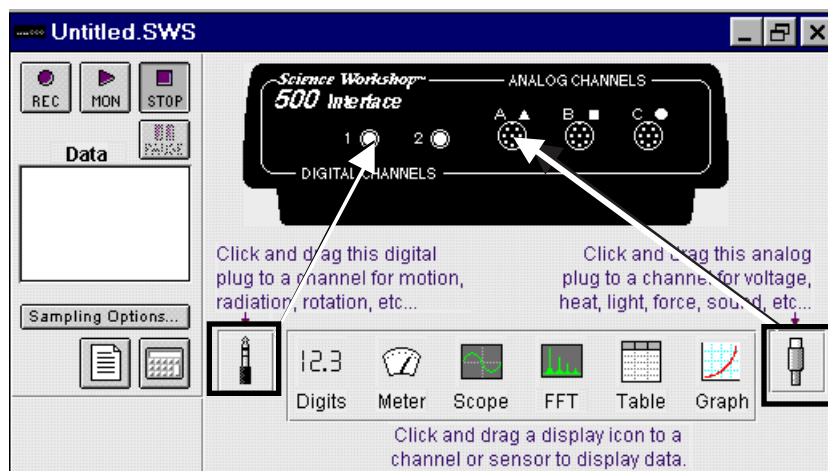
2.　　　Choose the sensor from the sensor list that pops up. Click **OK** to return to the Experiment Setup window.
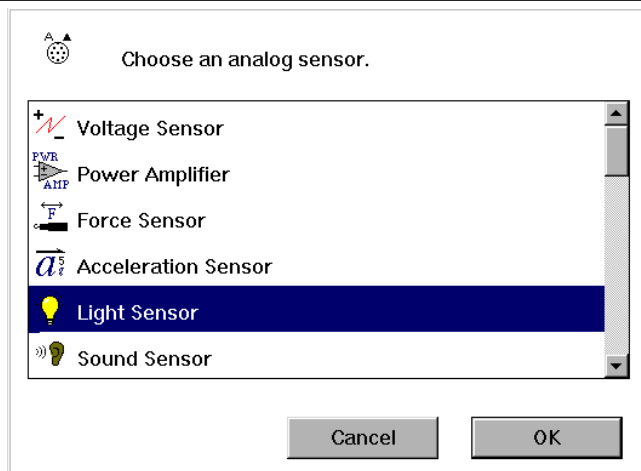
3.　　　Drag a display icon to the Sensor icon.

> *You are ready to collect data!*
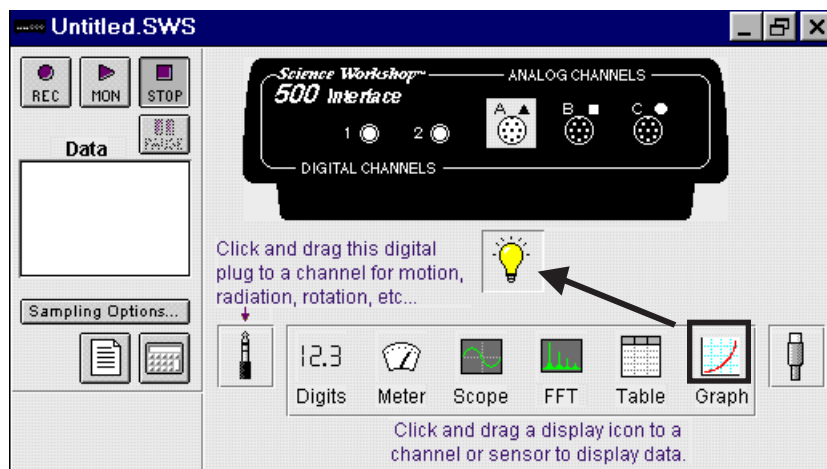
Note: ScienceWorkshop has many advanced features. Refer to the *ScienceWorkshop* User's Guide that came with the interface for more information.

Section #2: Data Analysis

Analysis: The Smart Cursor
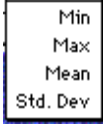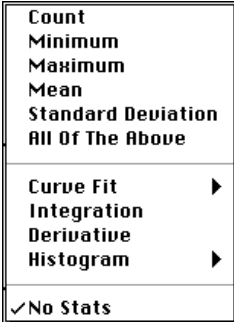
The Smart Cursor allows you to investigate individual points on a graph.

Procedure: Click the **Smart Cursor** in any display that has the Smart Cursor icon (for example, the Graph display). The cursor changes to a cross hair and the y and x values for that individual position will be displayed on the y-axis and x-axis. If you desire to have the change in y or x coordinates displayed, click-and-drag the Smart Cursor over the desired area. The difference (y2 - y1 and x2 - x1) will be displayed on the y-axis and x-axis. (This ability to display the change in x and the change in y in a selected area is called the delta feature.)

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The Statistics Tool $\boxed{\Sigma}$
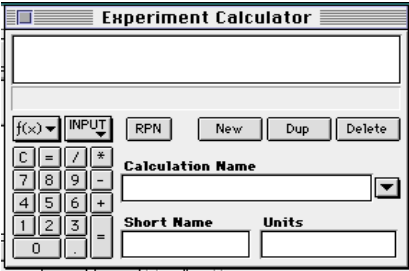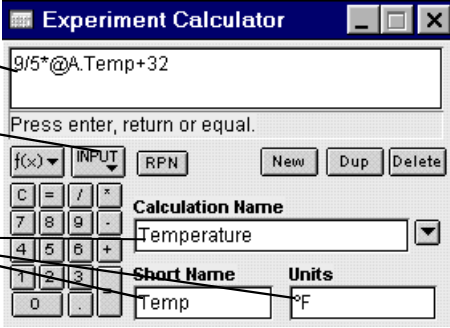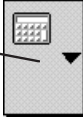
The Table and Graph displays have built-in statistics. Click the **Statistics button** to open the statistics area at the bottom of a Table or on the right side of a Graph.

Statistics menu for a Table display	Min Max Mean Std. Dev
In the Graph display, click the Statistics Menu button to see the statistics options.	$\boxed{\Sigma \blacktriangledown}$
Statistics menu for a Graph display	Count Minimum Maximum Mean Standard Deviation All Of The Above Curve Fit ▶ Integration Derivative Histogram ▶ ✓No Stats
Curve Fit submenu	Linear Fit Logarithmic Fit Exponential Fit Power Fit Polynomial Fit Sine Series Fit

Linear Fit will generate a basic slope equation with the slope of the best-fit line being the **a2** value in the display.

The Experiment Calculator

Use the **Experiment Calculator** feature of *ScienceWorkshop* to create a new calculation that is based on the input data. For example, if data is displayed in degrees Celsius, you can use the calculator to create a calculation to display the temperature data in degrees Fahrenheit or degrees Kelvin.

To set up a calculation, click the **Calculator button** 🖩 in the Experiment Setup window. You can also open the Experiment Calculator by selecting **Calculator Window** from the **Experiment** menu.

Experiment Calculator window	

Example: Converting the temperature data from degrees Celsius to degrees Fahrenheit for plotting on the Graph display.	**1.** Type the formula here (Select the variable to be modified from the Input Menu) **2.** Fill in these dialog boxes **3.** Click **=** or press ENTER	
Changing the plotting parameters of the Graph display	**4.** On the Graph display, click the **Plot Input Menu** button, and select **Calculations, Temperature, (Temp ˚F)** (Temperature will be plotted in ⁰F)	

Note: The values for this calculation can also be displayed in any Table, Digits, or Meter display. To do this, select **Calculations, Temperature, (Temp ˚F)** from the**Input** menu of the display.

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Tutorial Activities – Exploration of Sensors

Practice using the three sensors included in the Starter Bundle.

Light Sensor

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.

2. Connect the cable to the Light Sensor's DIN plug and then connect the cable into **Analog Channel A** on the interface.

3. Set the GAIN switch on the top of the Light Sensor to **1**.

4. Start the software and set up the Light Sensor.
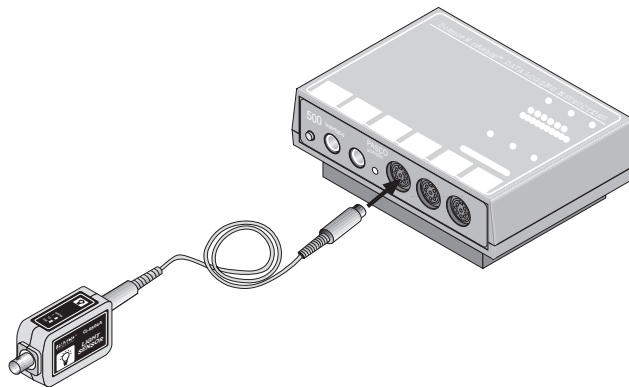
- In *DataStudio*, double-click 'Light Sensor' in the Sensors list in the Experiment Setup window. The Light Sensor icon will appear below Channel A of the interface. 'Voltage, ChA' and 'Light Intensity, ChA' will appear in the Data list.
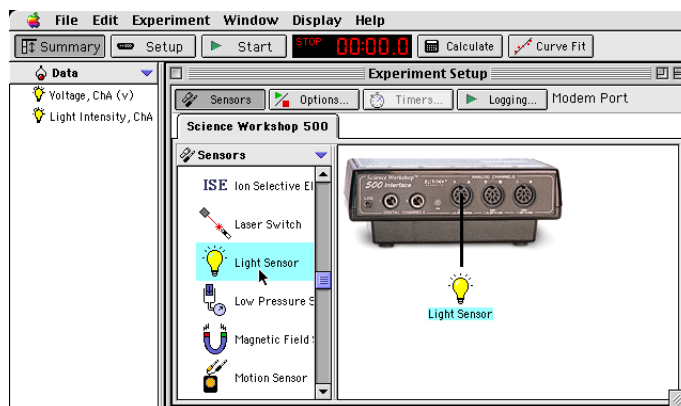
- In *ScienceWorkshop*, click-and-drag the **'**analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select 'Light Sensor' from the list of sensors and click 'OK' to return to the Experiment Setup window. The 'Light Sensor' icon appears below Channel A of the interface.
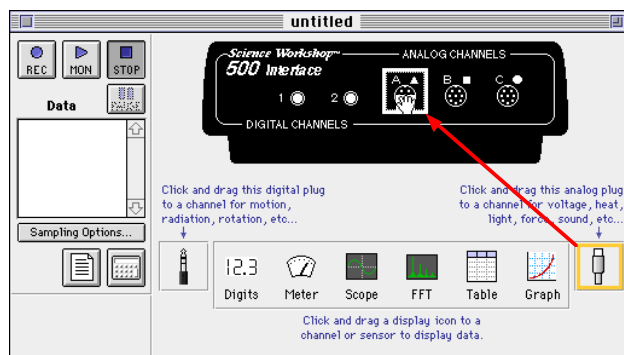
5.   Set up a Graph display.

•   In *DataStudio*, double-click 'Graph' in the Display list (or drag the 'Graph' icon from the
      Display list and drop it on 'Light Intensity, ChA' in the Data list.) The Graph display
      shows 'Voltage, ChA', and 'Graph 1' appears in the Display list.
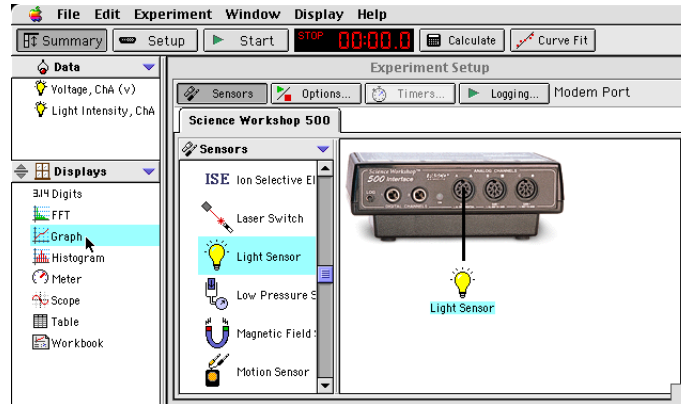
•   To make the Graph show light intensity instead of voltage, click-and-drag 'Light Intensity,
      ChA' from the Data list to the vertical axis of the Graph display.

Drag 'Light Intensity,
Ch A' to the Y-axis.
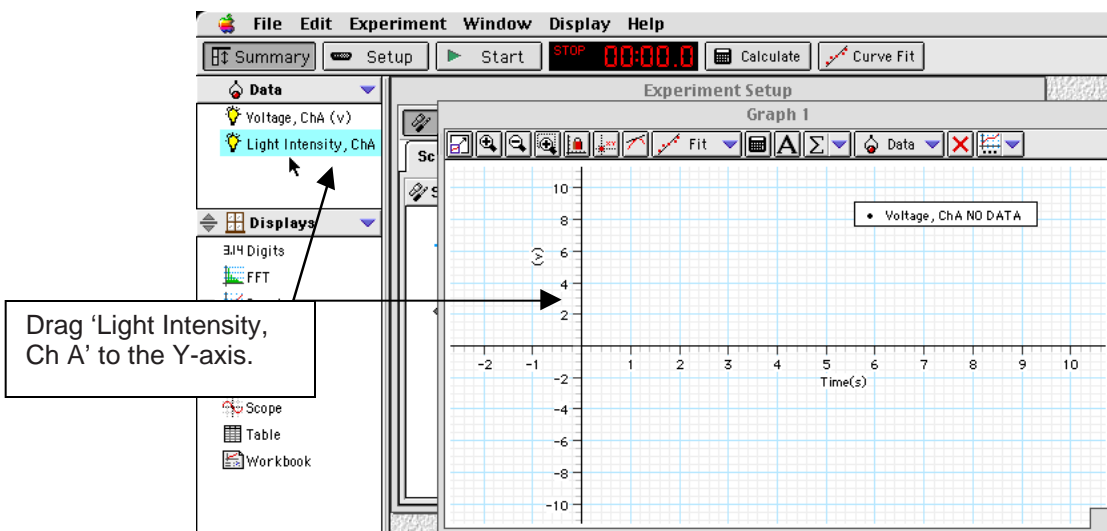
•   The Graph display will show '% max' on the Y-axis.
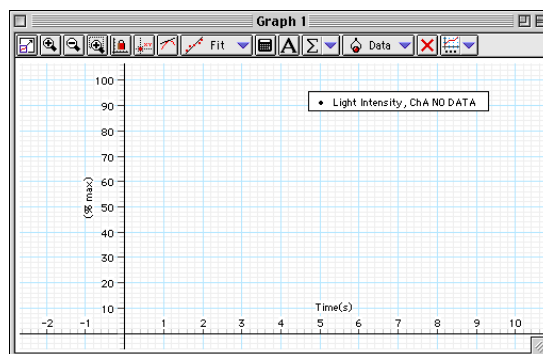
- In *ScienceWorkshop*, click-and-drag the 'Graph display' icon to the Light Sensor icon in the Experiment Setup window. The Graph display will show 'Intensity (% max)' versus Time (s).
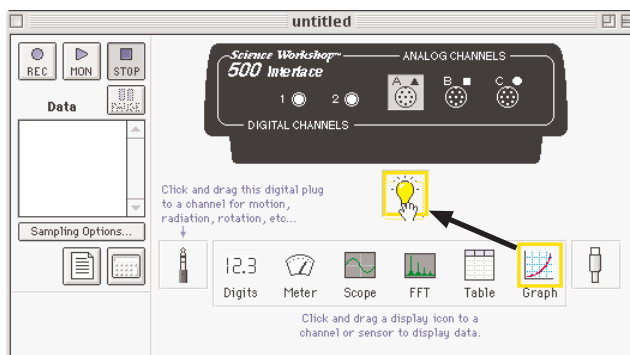
6. Record data.

- In *DataStudio*, click the 'Start' button (▶ Start). In *ScienceWorkshop*, click the 'REC' button (REC).

- Wave your hand over the Light Sensor, point it at different light sources, and note the intensity changes on the Graph display.

- Click 'Stop' to end data recording.

Temperature   Sensor

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Temperature Sensor's DIN plug into **Analog Channel A** on the interface.

3. Start the software and set up the Temperature Sensor. (See the previous section.)

4. Set up a Graph display. (See the previous section.)

5. Set up a Digits display.

• In *DataStudio*, double-click 'Digits' in the Display list (or drag the 'Digits' icon from the Display list and drop it on 'Temperature, ChA (deg C)' in the Data list.) The 'Digits 1' display shows 'deg C', and 'Digits 1' appears in the 'Display' list.
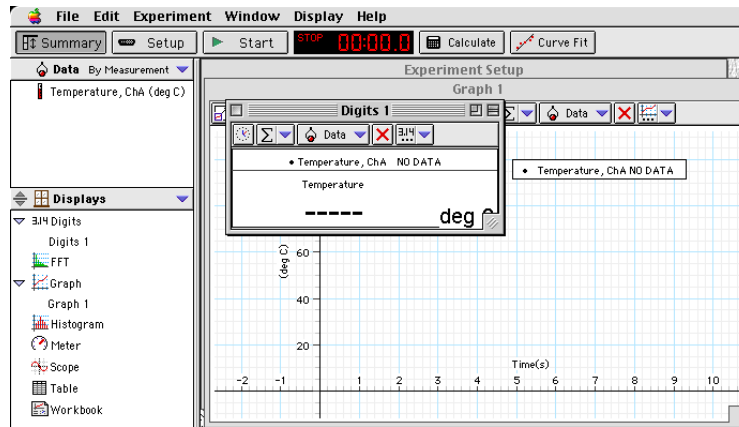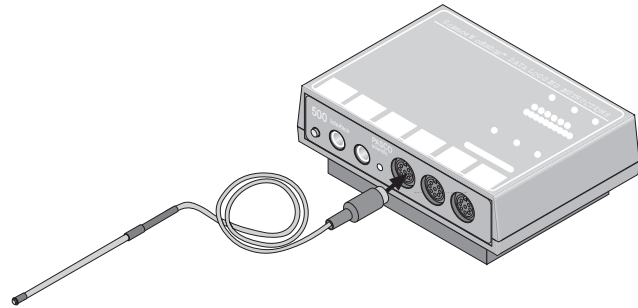
• In *ScienceWorkshop*, click and drag the 'Digits display' icon to the Temperature Sensor icon in the Experiment Setup window.
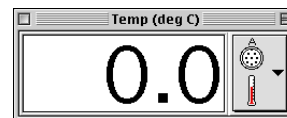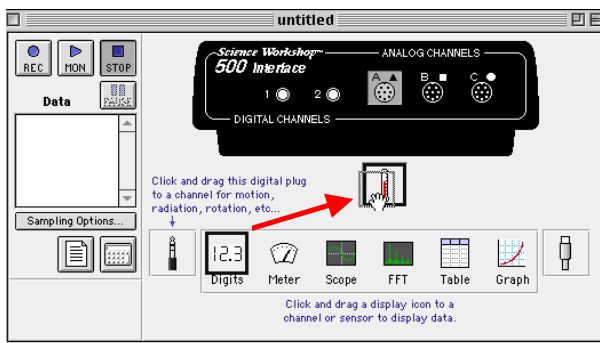
• The Digits display shows 'Temp (deg C)'.

6. Start recording data. (See the previous section.) Vary the temperature at the location of the sensor (hot and cold water work just fine). Allow the program to record for about 90 seconds and then stop recording data.

7. Analyze the data.

•   In *DataStudio*, click the 'Statistics menu' button () in the Graph toolbar. Select 'Show All' from the menu.

```
✓ Minimum
✓ Maximum
✓ Mean
✓ Standard Deviation
✓ Count
  Show All
  Hide All
  Area
```

•   In *ScienceWorkshop*, click the 'Statistics' button () to open the Statistics area in the Graph display. Click the 'Statistics menu' button () and select 'All Of The Above' from the menu.
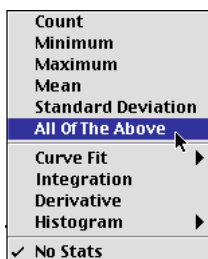
```
  Count
  Minimum
  Maximum
  Mean
  Standard Deviation
  All Of The Above
  Curve Fit        ▶
  Integration
  Derivative
  Histogram        ▶
✓ No Stats
```

Voltage Sensor

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.

2. Get a 1.5 volt battery.

3. Connect the Voltage Sensor's DIN plug into **Analog Channel A** on the interface.

4. Start the software and set up the Voltage Sensor. (See the first section.)
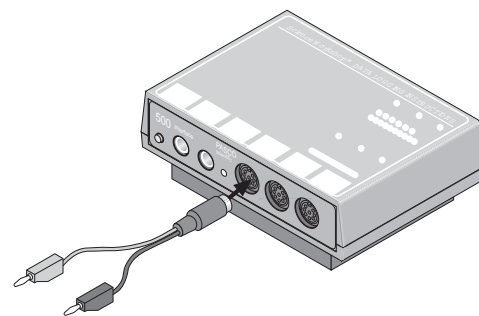
5. Set up a 'Meter' display.

•   In *DataStudio*, double-click 'Meter' in the Display list (or drag the 'Meter' icon to 'Voltage, ChA' in the Data list. The Meter display shows 'Voltage, ChA' and 'Meter 1' appears in the Display list.
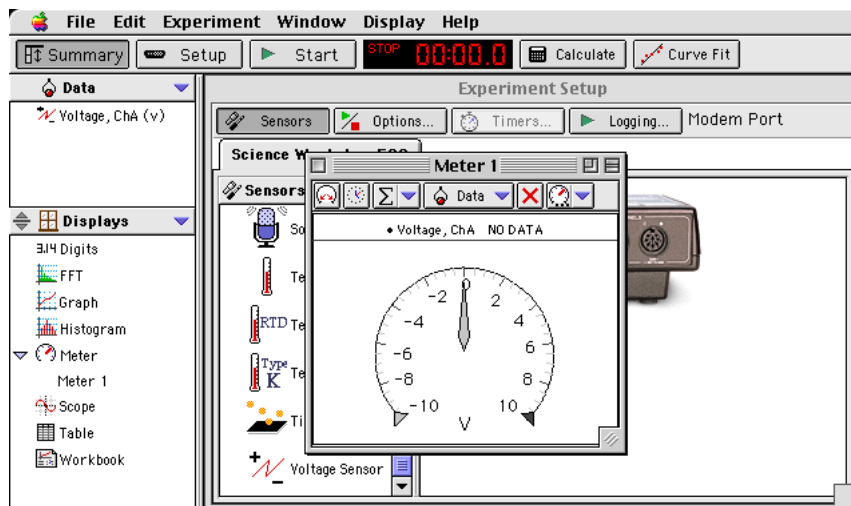
•   In *ScienceWorkshop*, click and drag the 'Meter display' icon to the Voltage Sensor icon in the Experiment Setup window. The Meter display shows 'Voltage (V)'.
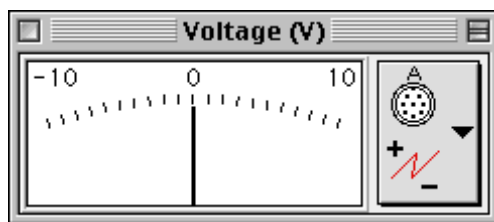
6. Start recording data. Touch the red Voltage Sensor lead to one end of the battery and the black Voltage Sensor lead to the other end. If the Meter display shows negative volts, reverse the Voltage Sensor leads on the battery.

7. After about 90 seconds, stop recording data.

Remember to Use the Online Help

In *DataStudio*, click 'Contents' or 'Search…' in the Help menu to open the online help file. You can use the online help file to learn about any button, icon, menu, control, function or feature of the program.

In *ScienceWorkshop* for Macintosh, click 'Show Balloons' in the Help menu.

Activity SL01: Energy Content of Foods
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Biochemistry	B02 Food Energy.DS	B02 Food Energy	B02_FOOD.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Temperature Sensor (CI-6505A)	1	Slit stopper	1
Balance (SE-8723)	1	Stirring rod	2
Base and Support Rod (ME-9355)	1	Protective gear	PS
Container (metal can), small	1	**Chemicals and Consumables**	**Qty**
Clamp, Buret (SE-9446)	1	Food samples	2
Food holder	1	Matches	2
Graduated cylinder, 100 mL	1	Water	100 mL
Ring, 4 inch	1	Wood splint	2

Imagine the Following

A sports team at your school needs to find out what kind of 'snack food' can give them the most energy. The team has asked you for help. Can you measure the amount of energy in a sample of food?

What Do You Think?

All human activity requires "burning" food for energy. When samples of different kinds of food are burned, which of the food samples will produce the most energy?

- **Marshmallow? Peanut? Cashew? Popcorn?**

- **How will you compare one food sample to another?**

- **Does the amount of the food sample make a difference?**

- **Does the time that the food takes to burn make a difference?**

Take time to write answers to these questions in the Lab Report section.

Background

When burning food heats a known quantity of water, the amount of heat given off by the food is theoretically equal to the amount of heat gained by the water. The following is an equation that describes this idea:

$$Q = m \times c \times \Delta T$$

where Q is the amount of heat, m is the mass of the water, c is the *specific* heat of the water, and ΔT is the change in temperature of the water.

The specific heat of water is:

$$c = 1 \frac{\text{calorie}}{\text{gram} \cdot ^\circ C} = 4.18 \frac{\text{joule}}{\text{gram} \cdot ^\circ C}$$

SAFETY REMINDERS

- Follow directions carefully when using the equipment for this activity.

- Take care when using matches and wooden splints.

- Wear protective gear (e.g., goggles, gloves, an apron).

**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

In this activity, burn a sample of food under a container of water to heat the water. Use a Temperature Sensor to measure the change in temperature of the water as it is heated by the burning food. Use *DataStudio* or *ScienceWorkshop* to record and analyze the data.

Compare the amount of heat given off by one type of food to the amount of heat given off by a different type of food.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the temperature sensor into Analog Channel A of the interface.

3. Open the file titled as shown:
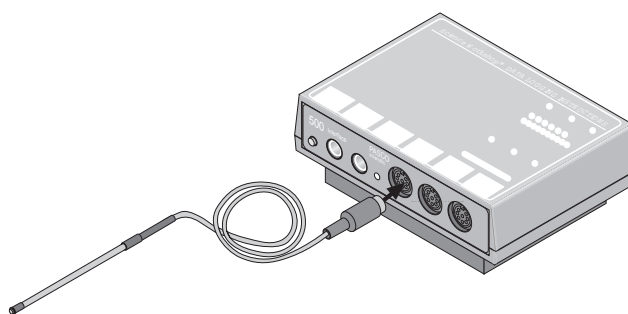
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
B02 Food Energy.DS	B02 Food Energy	B02_FOOD.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* file has a Digits display, a Graph display, and a Table display of Temperature versus Time.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

1. Set up the equipment as shown.

2. Put the bottom of the container about 2.5 cm above the food holder.

    Do you need to measure the amount of water that will be heated?

    Do you need to record the type of food being tested?

    Do you need to measure the initial mass of the food sample that will be burned?
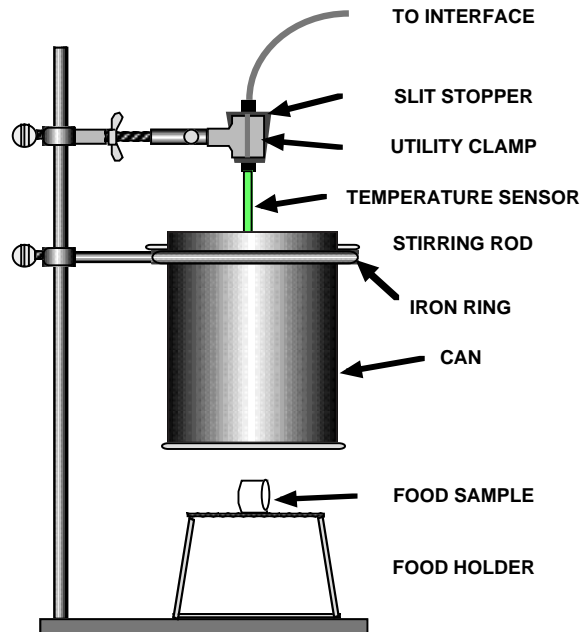
PART IIIA: Data Recording

1. Start recording data.

2. Light the wooden splint with a match and use the splint to light your food sample. Quickly place the burning food sample directly under the center of the container. Leave the sample under the container until the food sample stops burning.

CAUTION: Keep hair, clothing, and other items away from open flames.

3. Leave the sensor in the water for at least 45 seconds after the food has stopped burning. Stir the water until the temperature stops rising. *Stop* recording data when the temperature stops rising.

    Do you need to measure the final mass of the remains of the burned food sample?

4. Repeat the data recording process for the second food sample. Use a new quantity of cold water.

    What measurements do you need to record?

Analyze the Data

1. Use your recorded data to find the *change* in temperature of the water heated by the first food sample.

   What measurements do you need to record?

2. Repeat the analysis for the second run of data.

3. Calculate the heat absorbed by the water, **Q,** for each food sample. Remember the equation:

$$Q = m \times c \times \Delta T$$

   For water, the specific heat "*c*" is 4.18 J/g°C.

   How would you convert the heat absorbed from *joules* to *kilojoules* (kJ)?

4. Determine the mass of the food that burned.

5. Calculate the *energy content*, or *ratio* of heat (in kilojoules) divided by the mass of burned food (in grams), for each food sample.

   How do your results compare with others in your class?

Record your results in the Lab Report section.

Lab Report - Activity SL01: Energy Content of Foods

What Do You Think?

All human activity requires "burning" food for energy. When samples of different kinds of food are burned, which of the food samples will produce the most energy?

Data Table

Item	Sample 1	Sample 2	Sample 3	Sample 4
mass of empty container	g	g	g	g
mass of container + water	g	g	g	g
mass of water	g	g	g	g
initial mass, sample + holder	g	g	g	g
final mass, sample + holder	g	g	g	g
change of mass, food sample	g	g	g	g
initial temperature	C	C	C	C
final temperature	C	C	C	C
temperature change, ΔT	C	C	C	C
heat, Q	kJ	kJ	kJ	kJ
energy content	kJ/g	kJ/g	kJ/g	kJ/g

Class Results Table: Average Energy Content for each food type:

Food Type	Marshmallows	Peanuts	Cashews	Popcorn
Energy content	kJ/g	kJ/g	kJ/g	kJ/g

Questions

1. Which food had the highest energy content?

2. Which food had the lowest energy content?

3.   Food energy is expressed in a unit called a *Calorie*. There are 4.18 kilojoules (or 4180 joules) in one Calorie. Based on the class average for peanuts, calculate the number of Calories in a 50-gram package of peanuts.

4.   Two of the foods in the activity have a high *fat* content (peanuts and cashews) and two have a high *carbohydrate* content (marshmallows and popcorn). From your results, what can you conclude about the relative energy content of *fats* and *carbohydrates*?

5.   What advice would you give to a sports team about the energy content of these foods?

6.   Do you think that all of the energy released by the burning food sample was absorbed by the water?

        Why or why not?

7.   What are some things you would do to change the procedure in this activity?

Activity SL02: Regulation of Body Heat
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Physiology	B11 Body Heat.DS	B11 Regulation of Body Heat	B11_BODY.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Temperature Sensor (CI-6505A)	2	Small fan*	1
Clock	1	Protective gear	PS
Gloves	1 pair	**Chemicals and Consumables**	**Qty**
Mittens	1 pair	Rubber bands, small	3
Ruler	1	Tape	1 roll

(*or hair dryer that blows unheated air)

What Do You Think?

How does your body regulate (control) its internal temperature?

Take time to write an answer to this question in the Lab Report section.

Background

Your body produces metabolic heat as a by-product of every reaction that occurs inside you. The more active you are, the more heat your body produces. Your body radiates the heat generated by metabolic reactions to maintain your internal temperature. Your internal temperature must remain relatively constant because your enzymes work best at 37 ˚C.

SAFETY REMINDER

- Follow all safety instructions.

**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

For this activity, use one Temperature Sensor to measure the temperature of the air just above the skin of the palm of your hand, or the temperature of the skin itself on the palm of your hand. Use the second Temperature Sensor to measure the temperature of the environment in which your hand is placed (called the **ambient temperature**). Use *DataStudio* or *ScienceWorkshop* to record the data from both Temperature Sensors.

Compare the normal temperature of the air near your skin to the **ambient temperature** for several different conditions: air flowing over the skin, hand in glove with no air flowing over the glove, and hand in glove with air flowing over the glove.

Note: This activity requires two people.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

- Connect the DIN plug of one Temperature Sensor into Channel A and the DIN plug of the other Temperature Sensor into Channel B on the interface.
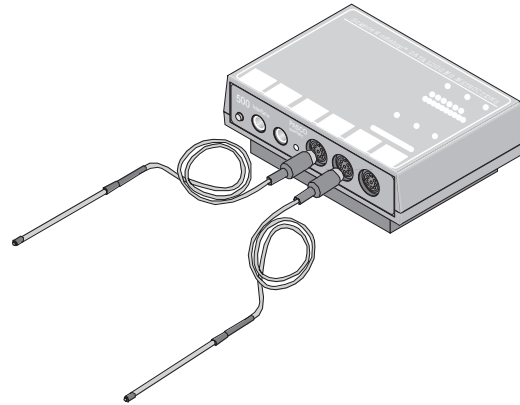
- Open the file titled as shown:

DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
B11 Body Heat.DS	B11 Regulation of Body Heat	B11_BODY.SWS

- The *ScienceWorkshop* file has graph display of temperature vs time.

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

PART II: Sensor Calibration and Equipment Setup

   You do need to calibrate the Temperature Sensors.

Equipment Setup

1. Wrap a small rubber band around the Channel A Temperature Sensor, about 1/4" from the tip. The rubber band will keep the tip of the sensor from touching your skin during the parts of the data recording process when you will be measuring the temperature of the air next to your skin.

2. Tape the Channel A Temperature Sensor to the palm of your hand. Align the sensor cable with your arm so you can put a glove or mitten on your hand over the sensor.
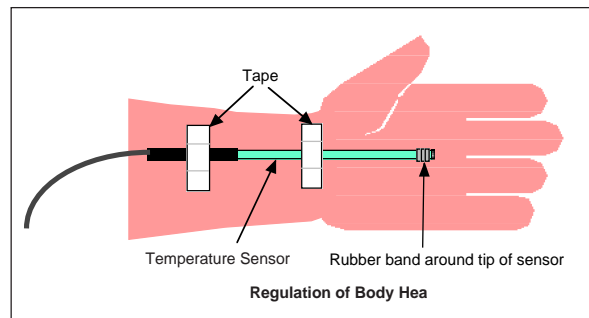
3. Flex your hand backward in such a way that the rubber band is NOT touching the palm. Don't let the palm of your hand make contact with the rubber band on the tip of the sensor until you are ready to record data. (Your goal is to start data recording with both Temperature Sensors at approximately the same temperature.)

   Why should both sensors be at approximately the same temperature at the beginning?

PART IIIA: Data Recording – Effects of Air Flow, No Skin Contact

1.   Hold the Channel B Temperature Sensor in a position parallel to your hand but so its tip is not touching anything.

2.   Flex your hand forward so the skin on the palm of your hand makes contact with the rubber band on the tip of the Temperature Sensor, but not the tip of the sensor itself.

Channel A Temperature Sensor

Channel BTemperature Sensor
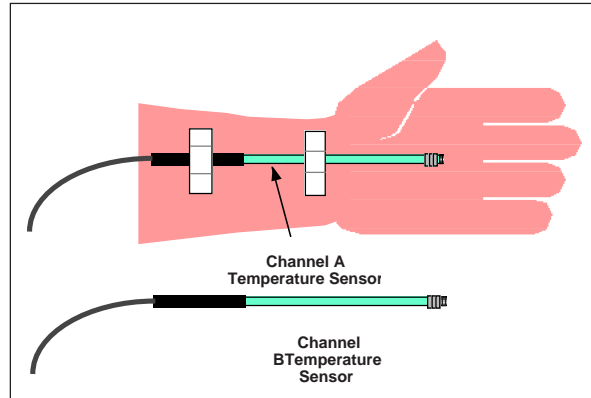
Why should the sensor be close to the skin but not touching it?

3.   Start recording data.

    Watch the two temperatures on the Digits displays.

4.   AFTER TWO MINUTES, turn the fan on. Place your hand and the Channel B Temperature Sensor in the flow of air about 30 centimeters (12 inches) in front of the fan. Continue to record data for another two minutes.

5.   Stop recording data.

6.   Turn off the fan. Flex your hand backwards so the tip of the sensor is away from the palm of your hand.

7.   Monitor the temperature data. Watch both Digits displays until both sensors show approximately the same temperature (within a few degrees).

    Why do the two sensors need to return to the same temperature?

8.   When both sensors are at approximately the same temperature, stop monitoring the data and prepare for the next part of the data recording process.

PART IIIB: Data Recording – Effects of Air Flow, Direct Skin Contact

1. Carefully remove the rubber band from the tip of the sensor.

2. Flex your hand <u>forward</u> so the skin of the palm of your hand makes direct contact with the tip of the sensor. Place the Channel B sensor so it is parallel to your hand but its tip is not touching anything.

3. Start recording data.

4. AFTER TWO MINUTES, turn the fan on. Place your hand and the Channel B Temperature Sensor in the flow of air about 30 centimeters (12 inches) in front of the fan. <u>Continue to record data for another two minutes.</u>

5. Stop recording data.

6. Turn off the fan. Flex your hand <u>backward</u> so the tip of the sensor is away from the palm of your hand.

7. Start monitoring the temperature data. Watch both Digits displays until both sensors show approximately the same temperature.

8. When both sensors are at approximately the same temperature, stop monitoring the data and prepare for the next part of the data recording process.

PART IIIC: Data Recording – Hand in Glove

1. With your hand flexed away from the tip of the sensor, wrap the rubber band around the tip of the sensor again.

2. Flex your hand forward so the skin on the palm of your hand makes contact with the rubber band on the tip of the sensor. Carefully but quickly put the glove on your hand over the sensor. Put the Channel B Temperature Sensor so it is parallel to your gloved hand, but its tip is not touching anything.

3. Start recording data.

4. AFTER TWO MINUTES, turn the fan on. Place your gloved hand and the Channel B Temperature Sensor in the flow of air about 30 centimeters (12 inches) in front of the fan. <u>Continue to record data for another two minutes</u>

5. Stop recording data.

6. Turn off the fan.

7. Remove the glove. Carefully remove the Channel A Temperature Sensor from your hand.

🖉 **Analyzing the Data**

1. Set your Graph so it displays your first run of data (**No Skin Contact**) for both Temperature Sensor A and Temperature Sensor B.

2. Find the temperature at the beginning of the plots for Temperature Sensor A and for Temperature Sensor B.

• Hint: In a Graph display, use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop* or use a Table display and look at the first row in the display.

3. Use display's tools to find the maximum temperature during the first two minutes (before the fan is turned on) in the plots for Temperature Sensor A and Temperature Sensor B.

• Hint: In a Table display, set the statistics to show the maximum value.

4. After you find the maximum temperature, use the display's tools to find the minimum temperature during the last two minutes (after the fan is turned on) in the plots for both temperatures.

• Hint: In a Table display, set the statistics to show the minimum value.

5. Set your Graph so it displays your second run of data (Direct Skin Contact) and repeat the data analysis process to find the beginning, maximum, and minimum temperatures for both the skin and the air.

6. Set your Graph so it displays your third run of data (Hand in Glove) and repeat the data analysis process to find the beginning, maximum, and minimum temperatures for both the skin and the air for the third run of data.

Record your results in the Lab Report Section

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Lab Report - Activity SL02: Regulation of Body Heat

What Do You Think?

How does your body regulate (control) its internal temperature?

Data Table

	'Hand' Temperature Sensor (Ch. A)			'Air' Temperature Sensor (Ch. B)		
Run #	1	2	3	1	2	3
Initial Temperature						
Maximum Temperature (before fan)						
Minimum Temperature (during fan)						

Questions

Cooling Effects of Air Flow

1. For the first run of data before the fan is turned on, describe the temperature from the 'hand' Temperature Sensor compared to the temperature from the 'air' Temperature Sensor when the 'hand' sensor is near the palm of the hand, but not in contact with the skin.

2. For the first run of data, what happens to the temperature from the 'hand' Temperature Sensor when the fan is turned on?

3. For the first run of data, what happens to the temperature from the 'air' Temperature Sensor when the fan is turned on?

4. Compare the second run of data to the first run of data. What difference (if any) is there when the tip of the 'hand' Temperature Sensor is in contact with the skin of the palm of the hand?

5.   How does air flow on your hand make your hand cooler? Does perspiration play a role in cooling?

Effect of Gloves

6.   How did the glove affect the temperature near your skin before the fan is turned on?

7.   Did you feel a cooling effect when you placed your gloved hand in front of the fan? More or less than without the glove? Why?

8.   What happened to the temperature from the 'hand' Temperature Sensor when the fan is turned on?

9.   Explain the insulation concepts that make gloves work.

Activity SL03: Insulating Properties of Water and Soil (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Environment	B18 Insulation	B11 Insulation Properties	B11_SOIL.SWS

Equipment Needed	Qty	Insulation material	------
Temperature Sensor (CI-6505A)	2	Protective gear	PS
Base and Support Rod (ME-9355)	1	**Chemicals and Consumables**	**Qty**
Clamp, Buret (SE-9446)	2	Ice, crushed	500 mL
Beaker, 1 L	2	Soil	1 L
Freezer	1	Tape	1 roll
Heat Lamp	1	Water	1 L

What Do You Think?

Which substance is a better "insulator", water or soil? In other words, which substance would let thermal energy move through it the quickest?

Take time to write answers to these questions in the Lab Report section.

Background

Have you ever been to the beach on a hot day? Did the sand burn your bare feet? Did the water seem much cooler than the sand?

One way that temperature changes is by a process called *convection*. Convection is defined as the transfer of heat by movement of a gas or liquid. For example, cold water is denser (maximum density at 4° C) and sinks while warm water is less dense and rises. So water forms a circular convection current with the cool water sinking and warm water rising.

Another way that temperature changes is by a process called *conduction*. Conduction is defined as the transfer of heat through *direct* contact of one molecule with the next.

Heat transfer occurs when thermal energy moves through a substance. A good insulator has a slow heat transfer rate. A poor insulator has a fast heat transfer rate. The rate of heat transfer for a substance depends on many factors such as what it is made of or whether it is densely packed or loosely packed.

SAFETY REMINDER	
• Follow all safety instructions.	THINK SAFETY ACT SAFELY BE SAFE!

For You To Do

Use Temperature Sensors to measure the temperature at two different depths in water and in soil. Use *DataStudio* or *ScienceWorkshop* to record and display the data.

Start with both the water and the soil at a cold temperature, and then expose the samples to a heat source (the lamp) for equal amounts of time. Compare the change in temperature in the water to the change in temperature in the soil.

> **Will the lamp need to be the same height above the water sample as it is above the soil sample? Why or why not?**

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect one Temperature Sensor to Analog Channel A and the other to Analog Channel B on the interface.
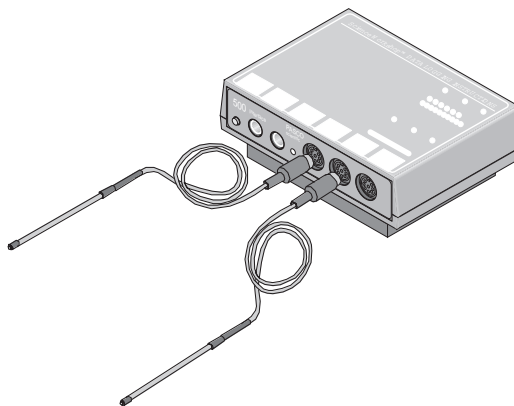
3. Open the file titled as shown:

DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
B18 Insulation	B11 Insulation Properties	B11_SOIL.SWS

•   The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

•   The *ScienceWorkshop* file has Digits displays and a Graph display

Pre-Lab

Prepare the soil sample. Put some soil in a beaker, and then put the beaker in a freezer overnight.

> **Do you need to record the amount of soil you put into the beaker?**

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensors.

Equipment Setup A: Insulation Properties of Water

1. Fill a 1000-mL beaker half full with water. Set up the Channel A Temperature Sensor so the tip of the sensor is 2 cm below the surface of the water. Make sure the tip does not touch the beaker.

2. Set up the Channel B Sensor in the same manner, but position its tip near the bottom of the beaker, about 1 cm above the bottom. Make sure the tip does not touch the bottom.
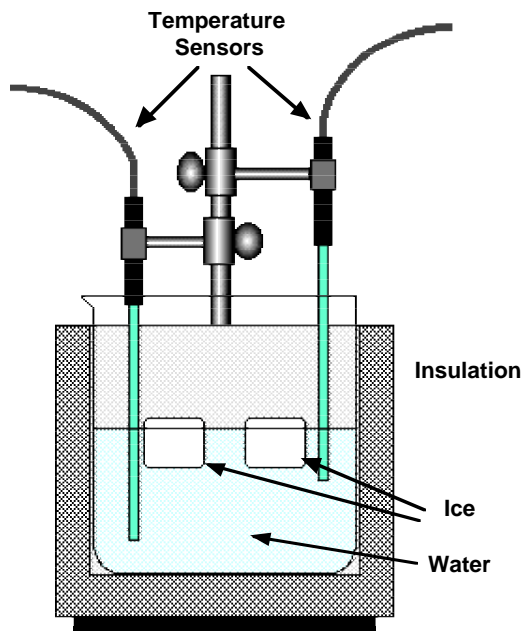
PART IIIA. Data Recording: Insulation Properties of Water

1. Use the software program to *monitor* the initial temperature readings at the two different depths.

    Hint: Use 'Monitor Data' in *DataStudio* or 'Monitor' in *ScienceWorkshop*. Use the Digits displays to measure the initial temperatures.

2. After you make a record of the temperatures at the two different depths, get ready to start recording data.

    Hint: Record your temperature data in the Lab Report section.

3. *Gently place* crushed ice on the surface of the water. DO NOT drop the ice in the beaker. The ice should remain on the surface, not travel to the bottom and then float back up. Note the time when you placed the ice on the surface.

4. Start recording data.

    Note: Data recording is preset to last for 30,000 seconds.

5. Now place the beaker under a lamp. Measure and record how high the lamp is above the beaker.

6. Leave overnight. Data recording will automatically stop after 30,000 seconds (8.3 hours).

Equipment Setup B: Insulating Properties of Soil

1.   Retrieve the beaker of soil from the freezer.

2.   Set up the two Temperature Sensors at different depths in the soil. Place the Channel A sensor 2 cm below the surface and the Channel B sensor about 5 cm below the surface. Make sure the first sensor does not touch the bottom of the beaker.

    Hint: Place tape on the sensors at 2 cm and 5 cm from the tip. The marks will tell you when the sensors are at the correct depth.

3.   Place the beaker on an insulating material, such a thick cloth or a rubber mat. Place the beaker under the same lamp you used to heat the water.

    Why should the lamp be at the same height above the beaker of soil as it was above the beaker of water?

PART IIIB. Data Recording: Insulating Properties of Soil

1.   Start recording data.

2.   Leave overnight. Data recording will automatically stop after 30,000 seconds (8.3) hours.

Analyzing the Data

1.   Set up your Graph display so it shows your temperature data for the temperature change in the water.

2.   Use the displays to find the maximum temperature of the water for the sensor near the surface and for the sensor near the bottom of the beaker. Record the time that matches the maximum temperature for each sensor.

    Hint: In the Graph display, use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*.
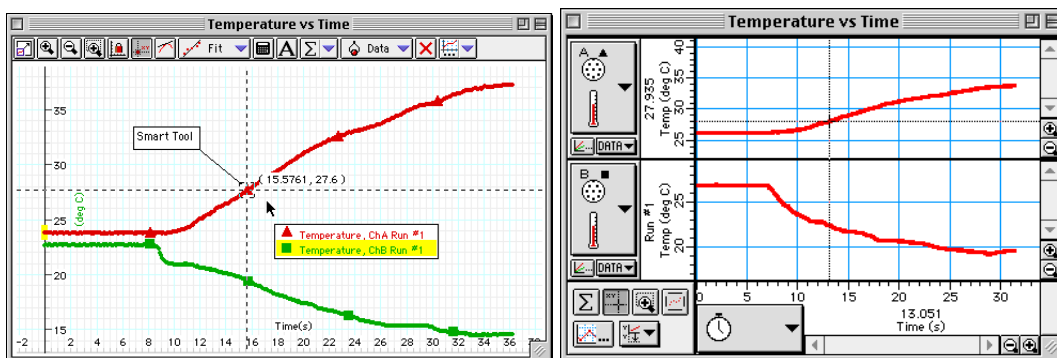
3.   Next, set up your display so it shows the temperature data for the temperature change in the soil.

4.   Use the displays to find the maximum temperature of the soil for the two sensors. Record the time that matches the maximum temperature for each sensor.

Record your results in the Lab Report Section

Lab Report - Activity B18: Insulating Properties of Water and Soil

What Do You Think?

Which substance is a better "insulator", water or soil? In other words, which substance would let thermal energy move through it the quickest?

Data Table

Item	Water		Soil	
	Channel A	Channel B	Channel A	Channel B
Minimum temperature	4 ˚C	4 ˚C	-8 ˚C	-8 ˚C
Maximum temperature	20 ˚C	20 ˚C	20 ˚C	20 ˚C
Time to maximum temperature	8 hr	8 hr	5 hr	6 hr

Questions

1.   Using the graphs, describe the temperature changes for both beakers? Were the changes gradual or quick? How long did it take for significant temperature changes to take place?

Insulation Properties of Water

2.   Was there a temperature difference between the two sensors? Why? Use the concept of convection to explain.

3.   Ice is less dense than water. How does this fact benefit the aquatic life that lives in lakes and ponds?

Insulating Properties of Soil

4.   Were there temperature differences between the two sensors?

5.   Which took longer to warm up when placed under a lamp: the ice water or the frozen soil? Why?

6.   Does the density of soil affect the rate of temperature change? Form a hypothesis? How would you test it?

7.   Why do you burn your hand if pick a hot pot, but do not if you use a pot holder? Explain in terms of conduction.

Activity SL04: Clarity and Turbidity in Water
(Light Sensor)

Area	Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Ecology	Water quality	S04 Clarity.DS	S04 Clarity	S04_CLAR.SWS

- This activity has two parts: a **COLLECT** part and a **LAB** part.

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	Ruler, metric	1
Base & Support Rod (ME-9355)	1	Secchi disk symbol	1
Beaker, 1000 mL	2	**Per Student**	**Qty**
Bottle, square, clear, ~125 mL	1	Personal flotation device	1
Clamp, Buret (SE-9446)	2	Rubber boots (or waders)	1 pr
Clamp, Multi (SE-9442)	1	**Consumables**	**Qty**
Container, ~ 3 L	1	Cardboard box, ~15 by 15 by 12 cm	1
Graduated cylinder, 100 mL	2	*Dirt (optional)*	100 g
Light source, DC (e.g., pen light)	1	Label	1
Marking pen	1	Tape	1 roll
Rod, Lab Stand, 45 cm (ME-8736)	1	Water	2 L

VOCABULARY	clarity	erosion	suspension	turbidity	

What Do You Think?

What is the relationship between the clarity of water in a natural system and the turbidity of the water?

Take time to write an answer to this question in the Lab Report section.

Background

As the number of particles of solid matter (e.g., dirt) suspended in water increases, less light can pass through it. **Turbidity** is a measure of how deep you can see an object below the surface of the water. **Clarity** is a measure of how much light passes through a certain amount of water.

Reduced light penetration through water can have several consequences. When less light penetrates, aquatic plant growth will be limited.

Fewer aquatic plants mean less photosynthesis and therefore less oxygen in the water. This affects the fish and other organisms that feed on plants and rely upon the oxygen given off by the plants. A second consequence of extra material suspended in water is that the material absorbs heat from the sun and increases the water temperature. This also decreases the amount of oxygen that is in the water. Causes of turbidity are algae and inorganic material from soil erosion.
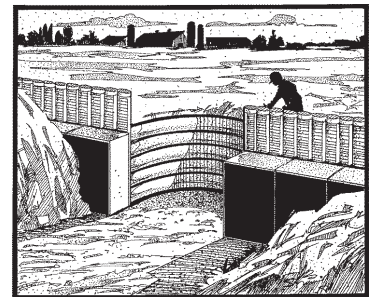
You will collect water from a river or stream. In the lab part, you will use a Secchi disk symbol to measure the turbidity of the water and then you will use a Light Sensor and light source to measure the clarity of the water.

SAFETY REMINDERS (COLLECT)

- Follow directions carefully when using the equipment for this activity.

- Wear a personal flotation device (life jacket).

- Wear clothing that is appropriate for this outdoor activity.

**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

In this activity, collect (or make) a sample of dirty water to test. In the lab, use a *Secchi* disk symbol and graduated cylinder to measure the *turbidity* of the water. Calibrate the Light Sensor and then use the Light Sensor to measure the *clarity* of the water. Finally, compare the turbidity of the water to the clarity of the water.

[ ]   PRE-LAB: COLLECT THE SAMPLE

1.   Use a container to collect about 2 liters of non-clear water from a river, lake or pond. Put a label on the container and mark the label with the location of the water source.

(Alternate Procedure: Add a small amount of dirt to 2 liters of water and shake vigorously to thoroughly mix the dirt and water.)

[ ]   A. SET UP THE EQUIPMENT

Equipment Setup for Turbidity

A Secchi disk is a circular disk, 20 cm (0.20 m) in diameter, that is divided into four quarters. The quarters are alternately painted black and white. A cord or chain is attached to the disk so the disk can be lowered vertically into the water. The cord or chain is calibrated in equal intervals so the depth can be measured.

You will use a Secchi disk *symbol* instead of a Secchi disk.

1.   Place the Secchi disk symbol on a flat surface.

2.   Place a graduated cylinder on the center of the disk.

Cylinder

*Secchi disk
symbol*
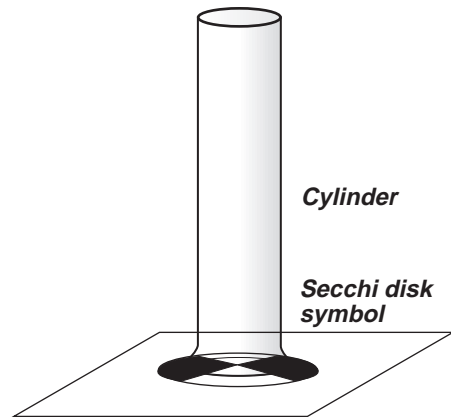
Equipment Setup for Clarity

1. Use a base and support rod, a lab stand rod, a multi-clamp (right-angle clamp), and two buret clamps to make a stand for the pen light and Light Sensor.

2. Adjust the position of the pen light and the Light Sensor so the square bottle just fits between them. Line up the pen light and the sensor so the light goes in a straight line through the bottle to the sensor.

   Put strips of tape on the table to trace the position of the square bottle.
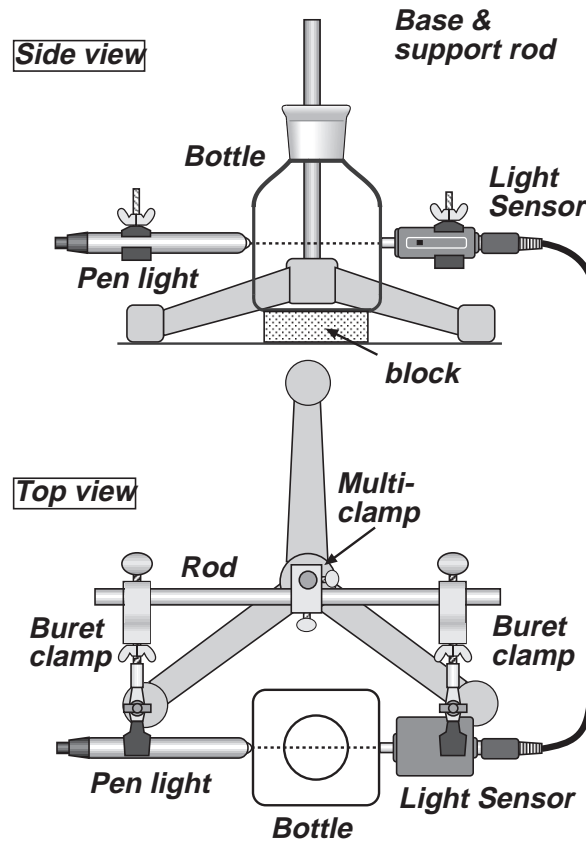
3.   Use a cardboard box to make a "light shield" that can fit over the pen light, square bottle, and sensor.

Box in perspective view

Cut-outs for the Light Sensor and the pen light.

Top view

Pen light   **Light Sensor**

Outline of box
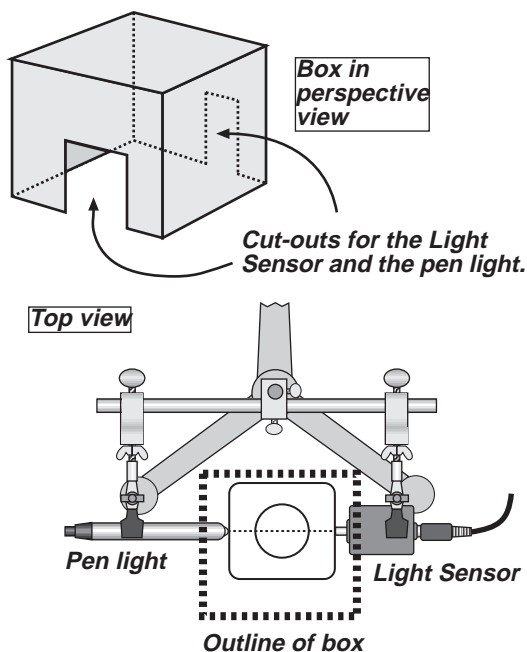
[ ]   B. SET UP THE EXPERIMENT

Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the Light Sensor DIN plug into Analog Channel A on the interface.

3.   Open the file titled as shown:
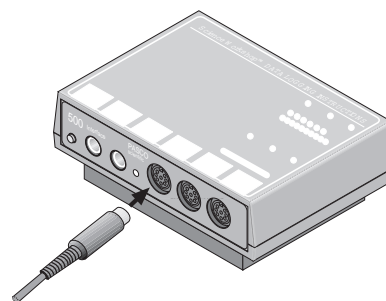
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
S04 Clarity.ds	S04 Clarity	S04_CLAR.SWS

•   The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

•   The *ScienceWorkshop* file has a Table display. Data recording is preset to stop at 60 seconds.

Sensor Calibration

4.   Calibrate the Light Sensor using the pen light. Put clear water in the square bottle. Let the light transmitted through the clear water be "100% intensity".

Hint: Refer to the On-Line Help file in *DataStudio*, or the *ScienceWorkshop* Instructions in the introduction to the lab manual.

[ ]   C. DO THE EXPERIMENT

For the first part of your data collecting, measure the turbidity of the water sample.

For the second part of your data collecting, use the Light Sensor and pen light to measure the clarity of the water.

Data Recording Part 1: Turbidity

1.   Put about 800 mL of your water sample in a beaker.

2.   Look down through the graduated cylinder at the Secchi disk symbol. Slowly pour some of the water from the beaker into the cylinder. Keep looking at the Secchi disk symbol as you pour the water.
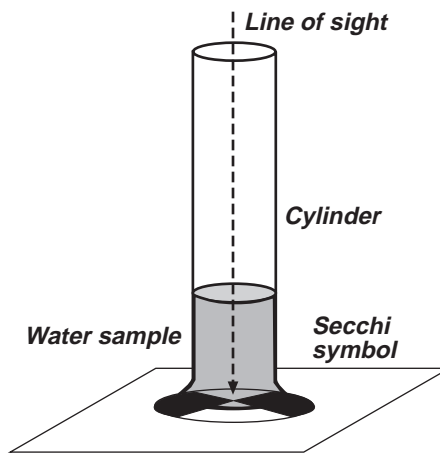
3.   When you can barely see the symbol through the water, *stop* for a moment. Let the water become still. If you can see any of the symbol through the water, slowly pour more water into the cylinder until you can't see the Secchi disk symbol any more.

4.   Record the depth of the water at which you could no longer see the Secchi disk symbol.

    Put you data in the Lab Report section.

Data Recording Part 2: Clarity

1.   Pour 100 mL of your water sample from the beaker into the square bottle. Turn on the pen light. Place the square bottle exactly between the Light Sensor and the pen light. Cover the sensor, bottle, and light with the cardboard box "light shield".

2.   Start recording data. After data recording stops automatically, remove the box and the bottle, but leave the pen light "on". Empty and clean the square bottle.
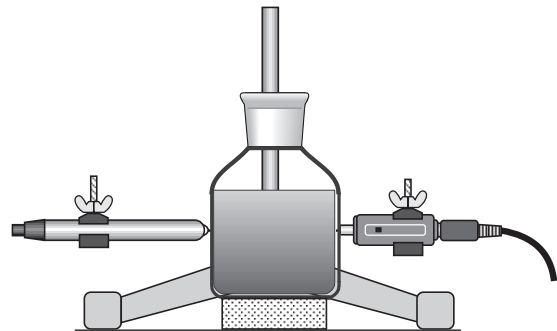
Data Recording Part 2 (continued)

Repeat the data recording process two more times.

3.   Make a second water sample by putting 50 mL of your original water sample into a clean graduated cylinder. Add 50 mL of clear water. Pour sample #2 into a clean beaker and mix thoroughly. Clean the graduated cylinder. Measure the turbidity and clarity of this second water sample. After measuring, clean the beaker, cylinder, and square bottle.

> **Remember: Measure the *turbidity* using the Secchi disk symbol. Measure the *clarity* using the Light Sensor and the pen light.**
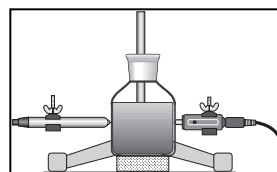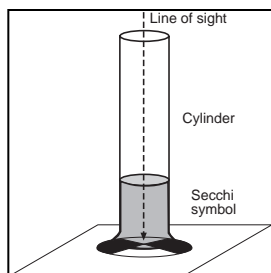
> **Note: The second water sample is diluted 1: 1:1 (50%).**

4.   Make a third water sample by putting 33 mL of your original water sample into a clean graduated cylinder. Add 67 mL of clear water. Repeat the data recording process.

> **Note: The third water sample is diluted 1:2 (33%).**

[ ]   D. ANALYZE THE DATA

1.   Use the Table display to examine each run of data.

> **Hint: Drag data runs to the Table display in *DataStudio* to add data runs to the Table. Use the 'Add Column' menu in *ScienceWorkshop* to add data runs to the Table.**

2.   Determine the average intensity of light that was transmitted through each sample of water. Record the average intensity of light for each sample.

Record your results in the Lab Report section.

Lab Report - Activity SL04: Clarity and Turbidity in Water Lab Report

What Do You Think?

What is the relationship between the clarity of water in a natural system and the turbidity of the water?

Data Table

Sample	Turbidity (depth of water in cm)	Clarity (% max of light intensity)
1 (undiluted)		
2 (1:1)		
3 (1:2)		

Questions

1. How does your hypothesis (answer to "What Do You Think?") compare with the results?

2. Why is it important that sunlight be able to be transmitted through the water?

3. What might improve the clarity of the water in a natural system?

4. Predict how the turbidity of water in a natural system might be different at different times of the year. Explain your reasoning.

5. Optional: If you collected your water from a natural source, describe your field site: Do streams, ditches, or drains feed into your site? Is there new construction or bare soil that might easily erode? What features might contribute to the turbidity?

Complete the Following

VOCABULARY
clarity:
erosion:
suspension:
turbidity:

Activity SL05: Reducing Turbidity in Water
(Light Sensor)

Area	Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Ecology	Water quality	S05 Turbidity.DS	S05 Turbidity	S05_TURB.SWS

• This activity has two parts: a **COLLECT** part and a **LAB** part.

Equipment Needed	Qty	Per Student	Qty
Light Sensor (CI-6504A)	1	Personal flotation device	1
Balance, Triple Beam (SE-8723)	1	Rubber boots (or waders)	1 pr
Base & Support Rod (ME-9355)	1	Protective gear	1 set
Bottle, square, clear, ~500 mL	3		
Clamp, Buret (SE-9446)	2	**Chemicals and Consumables**	**Qty**
Clamp, Multi (SE-9442)	1	Aluminum sulfate ($Al_2(SO_4)_3$)	5 g
Container, ~ 3 L	1	Calcium oxide (CaO)	2.5 g
Graduated cylinder, 100 mL	1	Iron (II) chloride ($FeCl_2$)	2.5 g
Light source, DC (e.g., pen light)	1	Cardboard box, ~15 by 15 by 12 cm	1
Knife	1	Label	3
Marking pen	1	Water (muddy)	2 L
Rod, Lab Stand, 45 cm (ME-8736)	1	Weighing paper	3

VOCABULARY	floc	flocculation	gelatinous	sedimentation

What Do You Think?

How does the rate of reducing turbidity in water by sedimentation (allowing suspended matter to settle) compare to the rate of reducing turbidity by flocculation (using chemicals to remove suspended matter)?

Take time to write an answer to this question in the Lab Report section.

Background

One of the first steps in making water safe to drink is to remove any suspended matter from the water. Because much of the suspended matter in water settles to the bottom if allowed to set undisturbed, a water treatment plant puts water in holding areas for several hours. Some of the suspended matter sinks to the bottom, leaving the top portion of water less turbid. This process is **sedimentation**.

Smaller particles of suspended matter may not settle to the bottom no matter how much time the water sets undisturbed. In order to remove these smaller particles, water treatment plants use a process called **flocculation**. Chemical such as aluminum sulfate ("alum") or a mixture of calcium oxide ("lime") and iron chloride are added to the water. These chemicals form fluffy, gelatinous solids called floc. As the floc forms it gets larger and heavier and sinks to the bottom.

As floc drifts downward, the smaller particles of suspended matter clings to it. Once the floc arrives at the bottom, the top portion of the water is less turbid. Both processes may be used to remove suspended matter from water. Neither process harms the water.

You will collect some muddy, turbid water. You will measure how fast sedimentation makes the muddy water become clearer compared to how fast flocculation makes the muddy water become clearer.
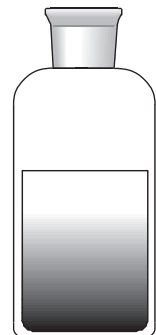
SAFETY REMINDERS (COLLECT)

- Wear a personal flotation device (life jacket) when collecting water samples for this activity.
- Wear clothing that is appropriate for the outdoor part of this activity.

SAFETY REMINDERS (LAB)

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

In this activity, use the Light Sensor to measure the clarity of the water samples. You will let one container set undisturbed so the rate of reducing turbidity by sedimentation can be measured. You will add aluminum sulfate to a second container, and a mixture of calcium oxide and iron chloride to the third container in order to measure the clarity due to flocculation.

[ ]   PRE-LAB: COLLECT THE SAMPLE

1. Use a container to collect about 2 liters of non-clear water from a river, lake or pond. Put a label on the container and mark the label with the location of the water source.

Alternate Procedure: Add a small amount of dirt to 2 liters of water and shake vigorously to thoroughly mix the dirt and water.

[ ]   A. SET UP THE EQUIPMENT

2. In the lab, measure out 5 g of aluminum sulfate (alum), 2.5 g of iron chloride, and 2.5 g of calcium oxide (lime) onto individual weighing papers.

3. Label the three square bottles. Label one bottle "CONTROL", a second bottle "ALUM", and a third bottle "IRON CHLORIDE + LIME".

4. Use a base and support rod, a lab stand rod, a multi-clamp (right-angle clamp), and two buret clamps to make a stand for the pen light and Light Sensor.

5. Adjust the position of the pen light and the Light Sensor so the square bottle just fits between them. Line up the pen light and the sensor so the light goes in a straight line through the bottle to the sensor.

   When the Light Sensor, bottle, and pen light are lined up, put strips of tape on the table to trace the position of the square bottle.
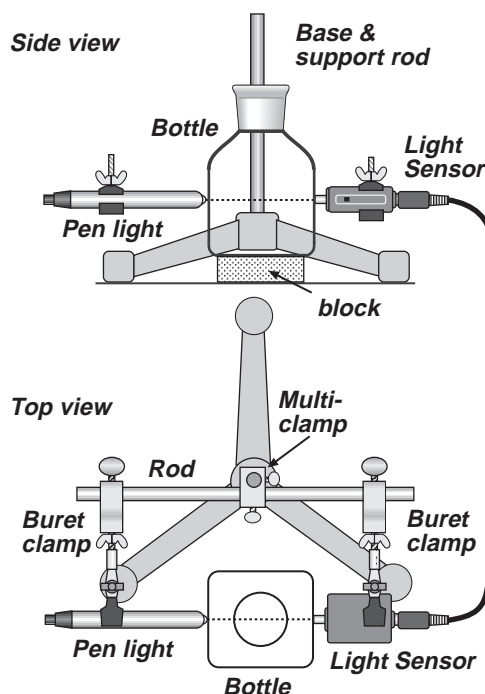
6.   Use a cardboard box to make a "light shield" that can fit over the pen light, square bottle, and sensor.

Box in perspective view

Cut-outs for the Light Sensor and the pen light.

Top view

Pen light   **Light Sensor**

Outline of box
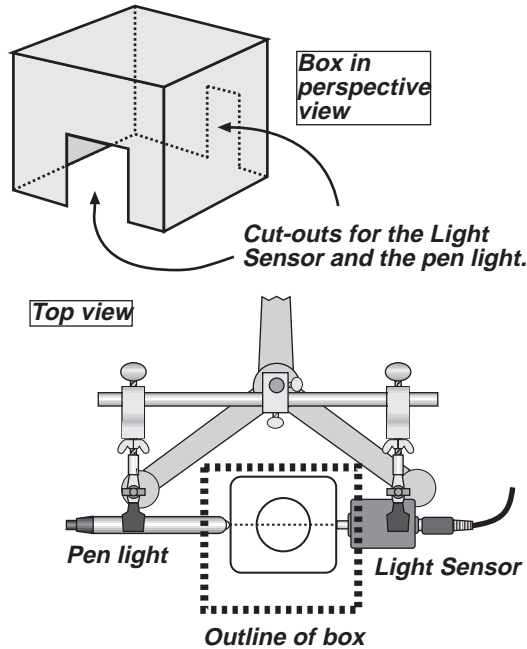
[ ]   B. SET UP THE EXPERIMENT

Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the Light Sensor DIN plug into Analog Channel A on the interface.

3.   Open the file titled as shown:
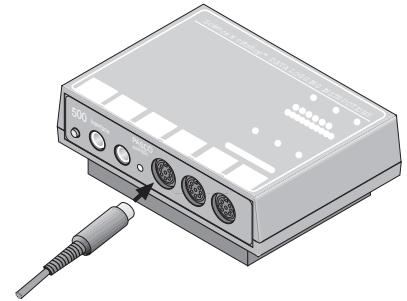
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
ES05 Turbidity.ds	S05 Turbidity	S05_TURB.SWS

•   The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

•   The *ScienceWorkshop* file has a Digits display and a Table display. Data recording is preset to stop at 30 seconds.

Sensor Calibration

4.   Calibrate the Light Sensor using the pen light. Put clear water in the square bottle. Let the light transmitted through the clear water be "100% intensity".

    Hint: Refer to the On-Line Help file in *DataStudio*, or the *ScienceWorkshop* Instructions in the introduction to the lab manual.

[ ]   C. DO THE EXPERIMENT

1.   Set up the water samples:

a)   Fill each of the three square bottles with 500 mL of muddy, turbid water.

b)   Add 5 g of *aluminum sulfate* to the bottle labeled ALUM.

c)   Add 2.5 g of *iron chloride* and 2.5 g of *calcium oxide* to the bottle labeled IRON CHLORIDE + LIME.

2.   Shake the bottle labeled CONTROL. Turn on the pen light. Put the bottle exactly between the Light Sensor and pen light. Add the cardboard "light shield" over the sensor and light.

Data Recording Part 1: Beginning

1.   When you are ready, record the amount of transmitted light for the water sample in the bottle.

2.   Repeat the process for the bottle labeled ALUM, and then for the bottle labeled IRON CHLORIDE + LIME.

Data Recording Part 2: After 30 Minutes

1.   Allow the three bottles to set *undisturbed* for 30 minutes.

2.   Repeat the measurement of transmitted light for each bottle.

   Do you need to make the measurement in the same order: CONTROL, then ALUM, then IRON CHLORIDE + LIME?

NOTE: Move the bottles *very* carefully. Don't shake them or swirl the water.

Data Recording Part 3: After Overnight Rest

1.   Allow the three bottles to set *undisturbed* overnight.

2.   Repeat the measurement of transmitted light for each bottle.

3.   Dispose of the water samples as instructed.

[ ]   D. ANALYZE THE DATA

1.   Use the Table display to examine each run of data.

   Hint: Drag data runs to the Table display in *DataStudio* to add data runs to the Table. Use the 'Add Column' menu in *ScienceWorkshop* to add data runs to the Table.

2.   Determine the average intensity of light that was transmitted through each sample of water at each of the three times. Record the average intensity of light for each sample.

3.   Record the light intensity (% max) for each sample of water for each of the three times.

Record your results in the Lab Report section.

Lab Report - Activity SL05: Reducing Turbidity in Water Lab Report

What Do You Think?

How does the rate of reducing turbidity in water by sedimentation (allowing suspended matter to settle) compare to the rate of reducing turbidity by flocculation (using chemicals to remove suspended matter)?

Data Table (Light Sensor)

Trial #	Sample	Time	Clarity (% max light intensity)
1	CONTROL	beginning	
2	ALUM	beginning	
3	IRON CHLORIDE + LIME	beginning	
4	CONTROL	after 30 min.	
5	ALUM	after 30 min.	
6	IRON CHLORIDE + LIME	after 30 min.	
7	CONTROL	after overnight	
8	ALUM	after overnight	
9	IRON CHLORIDE + LIME	after overnight	

*The iron chloride/lime combination clouded the water at the very beginning. The iron chloride/lime combination produced the most sediment on the bottom of the bottle.

Questions

1. How does your hypothesis compare with the results?

2. How does sedimentation (the CONTROL) compare to flocculation for the rate of clarifying water?

3. Which chemical (ALUM or the IRON CHLORIDE + LIME) clarified the water more rapidly?

Complete the following:

VOCABULARY
floc:
flocculation:
gelatinous:
sedimentation:

Activity SL06: Freezing and Melting of Water
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Phase change	C02 Freeze Water.DS	C02 Freeze & Melt Water	C02_MELT.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Ice, cube	12 - 15
Base and Support Rod (ME-9355)	1	Salt	40 mL
Beaker, 500 mL	1	Water	500 mL
Clamp, Buret (SE-9446)	1		
Clock	1		
Graduated cylinder, 100 mL	1		
Slit stopper	1		
Stirring rod	1		
Test tube	1		
Protective gear	PS		

What Do You Think?

How does the freezing temperature of water compare to the melting temperature of ice? Are they the same or not?

Take time to write answers to these questions in the Lab Report section.

Background

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.
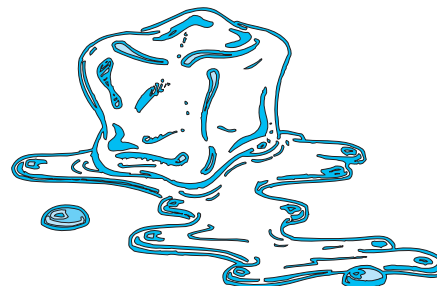
SAFETY REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

Use the Temperature Sensor to measure the change in temperature of a sample of water as it freezes in an ice water bath. Then measure the change in temperature as the frozen water melts after being removed from the water bath. Use *DataStudio* or *ScienceWorkshop* to record and analyze the data.

PART I: Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the DIN plug of the Temperature
     Sensor into Analog Channel A of the
     interface.
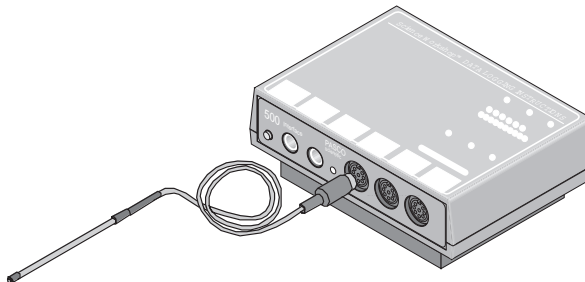
3.   Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C02 Freeze Water.DS	C02 Freeze & Melt Water	C02_MELT.SWS

*   The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

*   The *ScienceWorkshop* file has a Digits display, a Graph display, and a Table display of
    Temperature versus Time.

*   Data recording is set for one measurement per 30 seconds. Data recording stops
    automatically at 1800 seconds (30 minutes).

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

1. Set up the equipment as shown. Put about 100 mL of water and 5 or 6 ice cubes into a 500-mL beaker.
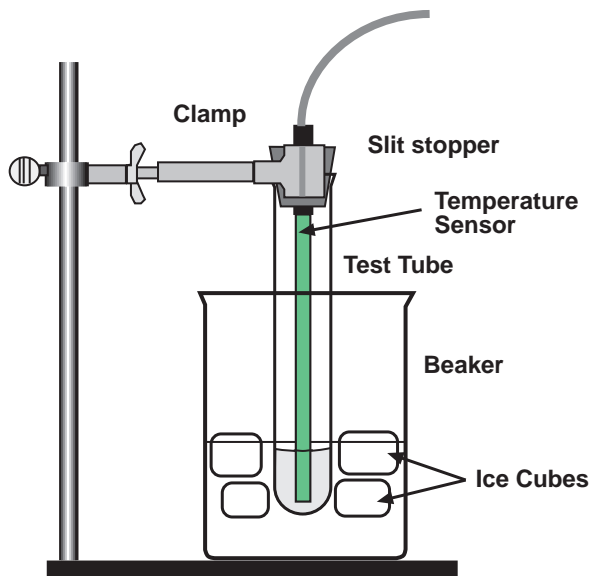
4. Put 5 mL of water into a test tube. Set up the test tube so it is *above* the ice water bath at the beginning.

5. Place the Temperature Sensor into a slit stopper and place the stopper in the test tube so the end of the sensor is in the water inside the test tube.

PART IIIA: Data Recording for Freezing

1. When everything is ready, start recording data. Then *lower the test tube* into the ice-water bath. (The computer will record data for a total of 30 minutes.)

2. Soon after lowering the test tube, add about 40 mL of salt to the beaker while stirring with a stirring rod. Continue to stir the ice-water bath during this part of the procedure.

    What do you think the salt does to the temperature of the ice water?

3. Gently but continuously move the sensor during the first 10 minutes of this part.

    Be careful to keep the sensor in, and not above, the ice as it forms.

4. When 10 minutes have gone by, stop moving the sensor and allow it to freeze into the ice.

    Observe how the ice forms in the test tube as the water freezes.

    Add more ice cubes to the beaker as the original ice cubes get smaller.

5. Continue recording data until the data recording stops automatically at 30 minutes.

6. Keep the test tube submerged in the ice-water bath for now.

PART IIIB: Data Recording for Melting

1.   Get ready for a second run of data recording.

2.   Start recording data. Then raise the test tube and fasten it into position *above* the edge of the beaker.

3.   Do not move the sensor during this part of the procedure. (Let it stay in the ice.)

4.   Dispose of the ice water in the beaker as directed.

5.   Put about 250 mL of warm water in the beaker and get ready to place the beaker under the test tube. *When 10 minutes have passed*, lower the test tube and its contents into this warm-water bath.

6.   When 15 minutes have passed, stop the data recording.

Analyzing the Data

•   Set up your Table display so it shows both runs of data (that is, Run #1 for freezing and Run #2 for melting).

       Hint: Drag data runs to the Table display in *DataStudio* to add data runs to the Table. Use the 'Add Column' menu in *ScienceWorkshop* to add data runs to the Table.

2.   Set up your Graph display so it shows both runs of data.

       (If desired, rescale the Graph to fit the data.)

Record your results in the Lab Report section.

Lab Report - Activity SL06: Freezing and Melting of Water

What Do You Think?

How does the freezing temperature of water compare to the melting temperature of ice? Are they the same or not?

Questions

1. What happened to the water temperature during freezing? What happened to the water temperature during melting?

2. According to your data and graph, what is the freezing temperature of water?

   Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop* in order to determine the coordinates at any particular point.) What seems to be the melting temperature? Express your answers to the nearest 0.1 C.

3. How does the freezing temperature of water compare to its melting temperature?

4. What happens to the kinetic energy of the water in the test tube during each of the following parts of the activity? (Does it increase, decrease, or remain the same?)

   a. when temperature changes at the beginning and end of Part IIIA

   b. when temperature remains constant in Part IIIA

   c. when temperature changes at the beginning and end of Part IIIB

   d. when temperature remains constant in Part IIIB

Activity SL07: Heat of Fusion for Ice
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Phase change	C03 Heat of Fusion.DS	C03 Heat of Fusion	C03_ICET.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Temperature Sensor (CI-6505A)	1	Stirring rod	1
Balance (SE-8723)	1	Tongs	1
Base and Support Rod (ME-9355)	1	Protective gear	PS
Beaker, 250 mL	2	**Chemicals and Consumables**	Qty
Clamp, Buret (SE-9446)	1	Ice, cubes	7 – 8
Graduated cylinder, 100 mL	1	Styrofoam cup	1
Slit stopper	1	Water, warm (about 60˚ C)	1 L

What do you think?

How does water in the solid phase (ice) become water in the liquid phase, in terms of energy transfer? Does this phase change require energy and does it occur at various temperatures or at a *fixed* temperature for a pure crystalline solid?

If a change in energy of a system is required to bring about a phase change, how much energy is required to melt a specific amount of the solid?

Take time to write answers to these questions in the Lab Report section.

Background

The change of phase from the solid state to the liquid state is called melting. The temperature at which this occurs for a pure crystalline solid is called its melting point (MP).

Ice made from uncontaminated water can be considered a pure crystalline solid.

The amount of heat energy per gram required to melt a pure crystalline solid at its melting point is called its "Heat of Fusion". The units for Heat of Fusion are joule/gram.

To calculate the energy that flows from the melting ice, you can use the relationship

$$q = C_p \cdot m \cdot \Delta T$$

where **q** stands for thermal energy (joules), C_p is specific heat(J/g ˚C), **m** is mass in grams, and ΔT is the change in temperature (˚C). For water, C_p is 4.18 J/g ˚C.

SAFETY REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

In this activity you will observe ice melting in both a qualitative and a quantitative manner.

In the first part of the activity, observe a phase change for ice while measuring the temperature of the system. Use the Temperature Sensor to measure the temperature of a container of ice as small amounts of warm water are added to the ice. Use *DataStudio* or *ScienceWorkshop* to record and display the temperature data.

> **What kind of energy transfer (loss or gain) occurs when ice melts?**

In the second part of the activity, use the Temperature Sensor to measure the temperature change while ice melts in warm water. Use *DataStudio* or *ScienceWorkshop* to record and display the temperature data. Measure the amount of ice that melts. Use your measurements of the change in temperature and the amount of ice that melted to calculate the Heat of Fusion for ice. Compare your calculation for the Heat of Fusion for ice to the accepted value for the Heat of Fusion.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor into Analog Channel A of the interface.
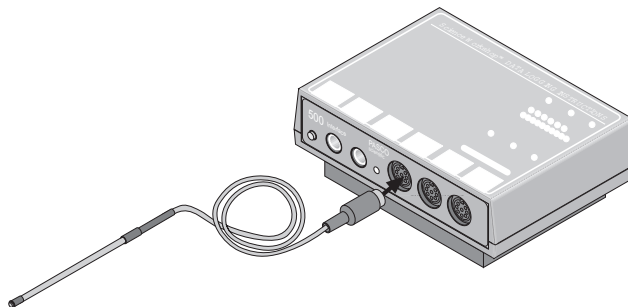
3. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C02 Heat of Fusion.DS	C02 Heat of Fusion	C02_ICET.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* file has a Digits display and a Table display of Temperature.

Data recording is set for one measurement each ten seconds.

Sensor Calibration

This is an activity where it is good to have accurately calibrated Temperature Sensors, since an actual freezing and melting point is being measured and not just a change in temperature.

Calibrate the Temperature Sensor using two samples of water at known temperatures (e.g., ice-cold water and boiling-hot water).

> **Hint: Refer to the instruction sheet for the Temperature Sensor, the On-Line Help file for *DataStudio*, or the User's Guides for *ScienceWorkshop*.**

PART IIA: Equipment Setup – Add Hot Water to Ice

1.   Set up a Styrofoam cup, beaker, and Temperature Sensor as shown.

2.   Crush several cubes of ice and put approximately 50 or 60 grams of crushed ice into the cup.

Add 50 to 60 g of crushed ice to the cup.

Styrofoam cup

Beaker
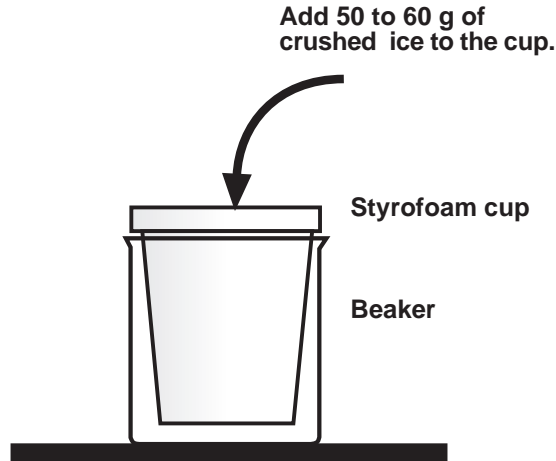
What do you think the temperature of the ice will be?

PART IIIA: Data Recording – Add Hot Water to Ice

1.   Use the Temperature Sensor to measure the initial temperature of the ice. Measure and record the temperature.

🖊   **Hint: Use a Digits display and 'Monitor Data' in *DataStudio* or 'Monitor' in *ScienceWorkshop* to see the temperature of the ice.**

What do think the temperature of the ice will be?

2.   Prepare a container of hot water. Use the Temperature Sensor to measure the initial temperature of the hot water. Measure and record the temperature.

Hot water at 40 'C will work just fine. Cooler temperature water may lack the heat necessary to melt the entire ice sample.

3.   Add 30 mL of hot water (40' C or above) to the ice while stirring the ice/water mixture. Measure and record the temperature.

Is the ice/water mixture warmer, cooler or the same temperature as the initial temperature of the hot water?

The mixture of ice and water should be at 0'C, the normal melting point for ice.

If the hot water cooled down, where did its heat energy go?

The heat from the hot water brought about the phase change (solid – liquid).

4.   Add another 30 mL of hot water while stirring. Measure and record the temperature.

Carefully observe the mixture and note if there is any remaining ice in the container.

5.   Continue to add 30-mL quantities of hot water until *all* of the ice is melted. Measure and record the temperature of the final mixture.

Once all of the ice is gone from the container, what happens to the temperature of the mixture?

PART IIB: Equipment Setup – Add Ice to Water

1.   Set up the cup, beaker, and the Temperature Sensor as shown.
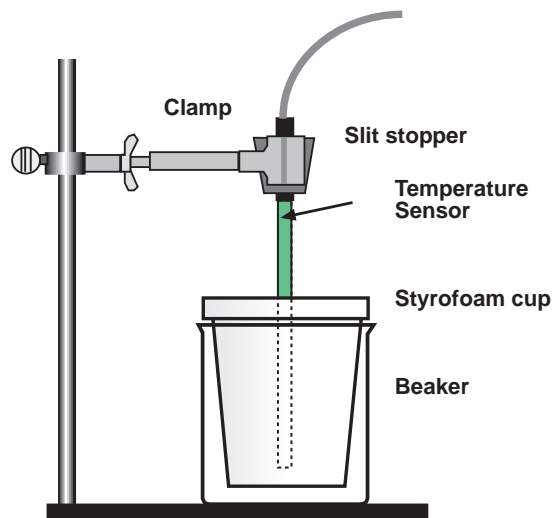
2.   Pour 100.0 mL of water at about 60° C into the Styrofoam cup.

3.   Obtain 7 or 8 large ice cubes.

4.   Lower the Temperature Sensor into the warm water (to about 1 cm from the bottom).

PART IIIB: Data Recording – Add Ice to Water

1.   Start recording temperature data.

2.   Watch the Digits display. Wait until the temperature reaches a maximum. This maximum
        will determine the initial temperature, T_1, of the water.

        **Prepare to add ice cubes to the Styrofoam cup. Shake excess water from the ice cubes
        (or dry them with a paper towel).**

3.   As soon as this maximum temperature is reached, put ice cubes into the Styrofoam cup.

4.   Record the maximum temperature, T_1, in your data table.

1.   Use a stirring rod to stir the mixture as the temperature approaches 0° C.

Important: As the ice melts, add ice cubes to keep the mixture cold.

6.   When the temperature reaches about 0° C, use tongs to quickly remove the unmelted ice
        cubes.

7.   Continue stirring until the temperature reaches a minimum (and begins to rise again). This
        minimum temperature is the final temperature, T_2, of the water.

8.   Record T_2 in your data table.

9.   Stop the data recording.

10.   Use the 100-mL graduated cylinder to measure the volume of water remaining in the
        Styrofoam cup to the nearest 0.1 mL. Record this as V_2.

Analyzing the Data for PART B – Add Ice to Water

1. Use the Statistics tool in the Table display to check your minimum and maximum temperature values.

2. Subtract T_2 - T_1 to determine ΔT, the change in water temperature.

3. Calculate the volume of ice that was melted ($V_2 - V_1$).

4. Find the mass of ice melted (use 1.00 g/mL as the density of water).

5. Calculate the energy (in joules) released by the 100 g of liquid water as it cooled ($q = C_p \cdot m \cdot \Delta T$).

6. Now calculate the heat of fusion, the energy required to melt one gram of ice (in J/g H_2O).

7. Use your answer to Step 6 and the molar mass of water to calculate the molar heat of fusion for ice (in kJ/mol H_2O).

Record your results in the Lab Report section.

© 19 99 *PASCO scientific* **SL07**

Lab Report - Activity SL07: Heat of Fusion for Ice

What do you think?

How does water in the solid phase (ice) become water in the liquid phase, in terms of energy transfer? Does this phase change require energy and does it occur at various temperatures or at a *fixed* temperature for a pure crystalline solid?

Data Table: Heat of Fusion

Initial water temperature, T_1 (˚C)	
Final water temperature, T_2 (˚C)	
Change in water temperature, ΔT (˚C)	
Final water volume, V_2, (mL)	
Initial water volume, V_1, (mL)	
Volume of melt, (mL)	

Mass of ice melted	**g**
Heat released by cooling water ($q = C_p \bullet m \bullet \Delta T$)	**J**
J/g ice melted (Heat of Fusion)	**J/g**
Accepted Heat of Fusion	330.24 **J/g**
Percent difference	**%**

Questions

1. What is your percent error for the heat of fusion value?

2. What is your percent error for the molar heat of fusion value (see below)? (The accepted value for molar heat of fusion for ice is 6.01 kJ/mol.)

Equations

$$\Delta T = T_2 - T_1$$

$$\Delta V = \text{Volume ice melted} = V_2 - V_1$$

$$\text{mass ice melted} = \Delta V \times 1.00 \text{ g/mL}$$

$$q \text{ released by water} = -q \text{ absorbed by ice} = 4.18 \text{J/g°C} \times 100.0 \text{ g} \times \Delta T$$

$$\text{heat of fusion} = \frac{q \text{ released by water}}{\text{mass ice melted}}$$

$$\text{molar heat of fusion} = \text{heat of fusion} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \times 18.0 \text{ g/mol}$$

$$\% \text{ error} = \left|\frac{\text{Actual} - \text{Experimental}}{\text{Actual}}\right| \times 100 = \left|\frac{6.01 \text{ kJ/mol} - \text{molar heat of fusion}}{6.01 \text{ kJ/mol}}\right| \times 100$$

Activity SL08: Heat of Vaporization of a Liquid
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Phase change	C04 Vaporization.DS	C04 Heat of Vaporization	C04_HVAP.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Acetone	10 mL
Graduated cylinder, 10 mL	3	Isopropyl alcohol (or ethanol)	10 mL
Protective gear	PS	Water, distilled or de-ionized	10 mL

What do you think?

Which liquid is more efficient (alcohol, acetone, or water) at cooling down an object as a result of evaporation? Is there a relationship between the rate of evaporation and the cooling effect that a liquid exhibits? Is there a relationship between the boiling point of these liquids and their rate of evaporation?

Take time to write answers to the questions in the Lab Report section.

Background

Have you ever heard of a person that has a high fever getting a "sponge" bath? A common home remedy for bringing down a fever is to use a sponge to apply either water or rubbing alcohol to the skin of the person with the fever. The water or alcohol is normally at room temperature to start. The method takes advantage of basic physical science theory: evaporation follows from the distribution of molecular speeds in a liquid. The faster molecules have enough energy to escape through the liquid surface tension despite the attractive forces of the other molecules. The molecules left behind redistribute the available energy in collisions among themselves. Since the most energetic molecules have escaped, the average energy of the system is less than before and the liquid is now at a lower temperature. In the case of the sick patient this has the effect of reducing the temperature of the body.

You may have already observed this cooling as a result of evaporation in everyday experiences. Here are some examples:

- Rubbing alcohol feels "cold" to the touch even if it is at room temperature. Rubbing alcohol is often used to "sponge bath" a patient who is suffering from a high fever.

- Acetone, the main component of many fingernail polish removers, also feels "cold" to the touch, even when it is at room temperature. (* Acetone is a toxic substance and should not be placed on the skin and it should only be used in a chemical fume hood)

- Your body uses water (a coating of sweat on your skin) to cool down the body when it is overheating.

What do you think about how the above phenomena takes place?

SAFETY REMINDERS
- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

Allow equal measures of various liquids to evaporate from the end of a Temperature Sensor and observe the change in temperature using *DataStudio* or *ScienceWorkshop*. Use the software to determine the rate of cooling of the three liquids.

> **Hint: Use the *DataStudio* "slope" feature or the *ScienceWorkshop* "linear fit" feature.**

Compare the rate of evaporation of the three liquids.

Pre-Lab

Acetone, rubbing alcohol (isopropyl alcohol). and water are three liquids that have different physical and chemical properties. Differences in physical and chemical properties of these particular solvents make each useful for particular purposes. One of these properties is volatility. A volatile liquid is one that evaporates quickly. Variation in volatility is one of several physical and chemical properties that separate one liquid from another.

Refer to resources such as the Handbook of Chemistry and Physics and find the Boiling Points and Heat of Vaporization values of the liquids. Predict the cooling effects of the various liquids based on this information.

> **Can you rank the liquids in order from "fastest cooling" to "slowest cooling"?**

Fill in the table below with data obtained from a reference resource (such as the Handbook of Chemistry and Physics).

Property	Acetone	Isopropyl alcohol	Water
Molecular mass (g/mole)	58	60	18
Freezing point (˚C)	-94	-79	0
Boiling point (˚C)	57	70	100
Heat of vaporization (cal/g)	134.7	235.3	540

In general, the lower the Heat of Vaporization, the lower the Boiling Point of the liquid, and the more volatile the liquid.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor into Analog Channel A of the interface.

3. Open the file titled as shown;
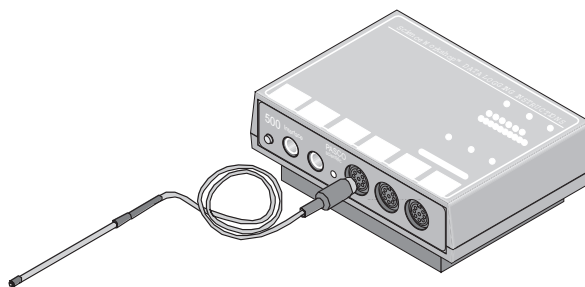
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C04 Vaporization.DS	C04 Heat of Vaporization	C04_HVAP.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook

- The *ScienceWorkshop* file has a Graph display of Temperature versus Time.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

1. Put 10 mL of acetone, isopropyl alcohol, and water into separate 10-mL graduated cylinders.

PART IIIA: Data Recording for Acetone

The liquid and the sensor should be at room temperature at the start of the activity.

1. Place the Temperature Sensor into the cylinder with the acetone until the sensor touches the bottom of the cylinder. When everything is ready, start recording data. Leave the sensor in the liquid for 10 seconds.

2. After 10 seconds, remove the sensor from the liquid. Hold the sensor vertically. The liquid will evaporate and the evaporation will take about 2 minutes.

3. Continue collecting data until the liquid on the sensor appears to be completely evaporated and then stop recording data.

4. Rinse the Temperature Sensor.
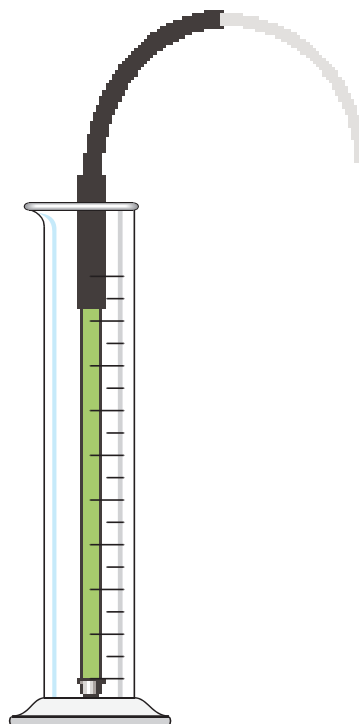
PART IIIB: Data Recording for Isopropyl Alcohol

5. Repeat the procedure of cooling the Temperature Sensor with alcohol instead of acetone.

6. Rinse the Temperature Sensor.

PART IIIB: Data Recording for Isopropyl Alcohol

7. Repeat the procedure of cooling the Temperature Sensor with water instead of alcohol.

8. Rinse the Temperature Sensor.

9. Dispose of the liquids in the graduated cylinders as directed.

Analyzing the Data

1.   Set up your Graph display so it shows the data for the first liquid (acetone).

     Hint: Rescale the Graph to fit the data.

2.   Use the 'slope' feature in the Graph in *DataStudio* or the 'Curve fit –linear fit' feature of
     ScienceWorkshop to determine the rate at which the liquid cools.

     Hint: One way to determine the rate is to compare the change in temperature to the amount of time.

     **Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*. Click and drag the
     cursor from the beginning point to the minimum temperature.**
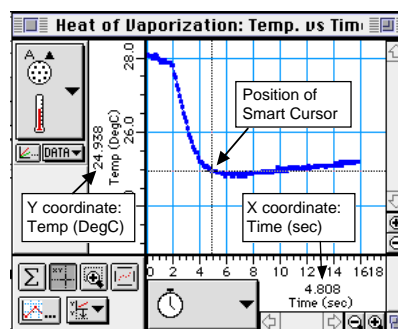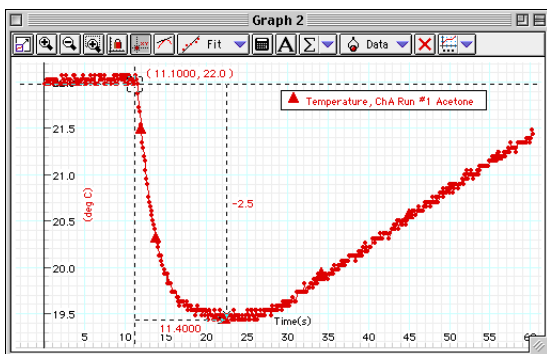
3.   Repeat the data gathering process for the other two liquids: alcohol and water.

     **Hint: Drag the data run to the Graph in DataStudio, or click on the DATA menu button and select "Run
     #2" from the data menu in ScienceWorkshop.**

Record your results in the Lab Report section.

Lab Report - Activity SL08: Heat of Vaporization of a Liquid

What Do You Think?

Which liquid is more efficient (alcohol, acetone, or water) at cooling down an object as a result of evaporation? Is there a relationship between the rate of evaporation and the cooling effect that a liquid exhibits? Is there a relationship between the boiling point of these liquids and their rate of evaporation?

Data Table: Heat of Vaporization – Liquid

Liquid	Slope (rate of cooling)
Acetone	
Alcohol	
Water	

$$\text{Slope} = \frac{\text{Change in Temperature}}{\text{Change in Time}}$$

Questions

1. Rank the three solvents, from low slope to high slope, by the slope of their Temperature vs. Time curve.

2. How does your ranking compare to their boiling points?

3. How does your ranking compare to their Heats of Vaporization?

4. What is the relationship of Heat of Vaporization to the rate of evaporation of these solvents?

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Activity SL09: Charles' Law – Volume versus Temperature (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	C08 Charles' Law.DS	C08 Charles' Law	C08_CHAR.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Temperature Sensor (CI-6505A)	1	Tongs	1
Beaker, heat proof,1000 mL	1	Protective gear	PS
Graduated cylinder, 100 mL	1	**Chemicals and Consumables**	**Qty**
Heat Engine/Gas Law Apparatus	1	Glycerin	1 mL
Hot plate	1	Water	750 mL

What Do You Think?

What is the relationship between the volume of a gas and the temperature of the gas?

Take time to write an answer to the question in the Lab Report section.

Background

Charles' Law states that the volume of a gas is directly proportional to its absolute (Kelvin) temperature, assuming all other factors such as pressure remain constant. If the two parameters are directly proportional, the plot of volume (V) versus temperature (T) is a straight line. For an ideal gas, if this line is extrapolated for temperatures below which the substance is no longer a gas, the line always intersects the temperature axis at Absolute Zero, corresponding to a volume of zero.

SAFETY REMINDERS

- Wear protective gear during this acivity.
- Follow directions for using the equipment.
- Be very careful using a burner or hot plate to heat water.

For You To Do

Use the Temperature Sensor to measure the temperature of a water bath. Use the cylinder of the Heat Engine/Gas Law Apparatus to measure the change in volume of the gas in a metal can immersed in the water bath. Use *DataStudio* or *ScienceWorkshop* to record the temperature and the volume, and display and analyze the data.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor to Analog Channel A on the interface.

3. Open the file titled as shown;
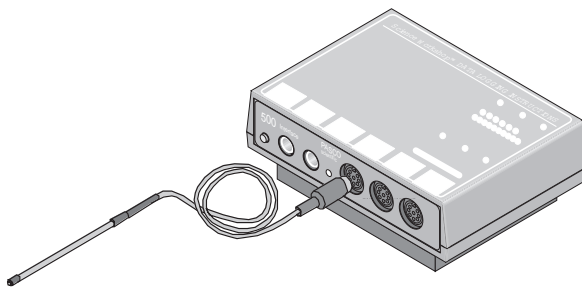
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
C08 Charles' Law.DS	C08 Charles' Law	C08_CHAR.SWS

• The *DataStudio* file has a Workbook display. Read the instructions in the Workbook

• The *ScienceWorkshop* file has a Digits, Table, and Graph display of Temperature versus Time.

• Data recording is set so there is one measurement of temperature per second. You will use the default data for the volume measurements in the *DataStudio* Table or "Keyboard" sampling in *ScienceWorkshop* using Parameter = Volume and Units = mm.

• The 'Default Data' numbers under 'Volume' in the *DataStudio* Table actually represent the position of the piston in the Heat Engine/Gas Law Apparatus.
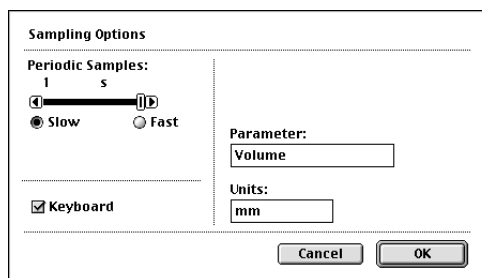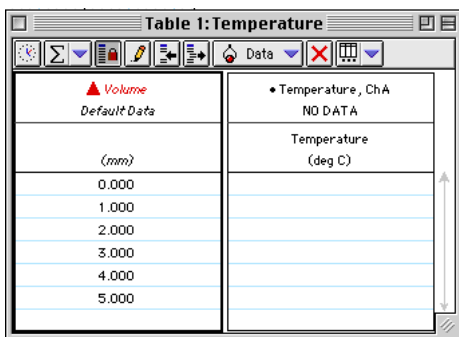
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

1. Fill a 1000-mL beaker about three fourths full of water. Place the Temperature Sensor in the water. Put the beaker onto the hot plate, but don't start heating the water yet.

2. Set up the Heat Engine/Gas Law Apparatus. Close the clamp on the tubing to one of the pressure ports. Place the Heat Engine/Gas Law Apparatus on its side so the cylinder is horizontal. Set the piston at the zero millimeter mark.

3. Set up the tubing that will connect the Heat Engine/Gas Law Apparatus to the metal can. You will need a quick-release coupling, a connector, a piece of plastic tubing about 12" (30 cm) long, and glycerin. Put a drop of glycerin on the barb of the quick-release coupling and insert the barb into one end of the plastic tubing. Put a drop of glycerin on the barb end of the connector and put the barb into the other end of the tubing.

Barb

Plastic Tubing

Quick-Release Coupling

4. Set up the metal can. You will need a one-hole rubber stopper. Put a drop of glycerin on the end of the connector and insert the connector into the rubber stopper. Put the rubber stopper tightly into the can.

5. Connect the quick-release coupling to the open pressure port on the base of the Heat Engine/Gas Law Apparatus.

6. Put the metal can into the beaker of water. Use tongs to hold the can in the water.

CONNECTOR (640-030)

RUBBER STOPPER

Plastic Tubing

Beaker

Piston

Metal Can

Heat Engine/Gas Law Apparatus
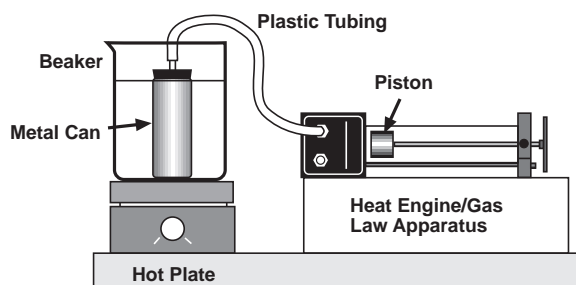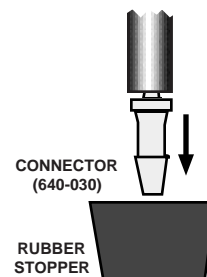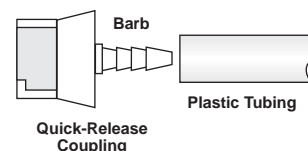
Hot Plate

7. Turn on the hot plate to start heating the water in the beaker.

PART III: Data Recording

1.   Start recording data. In *DataStudio*, the 'Start' button changes to a 'Keep'
        button [✔ Keep] [■] .
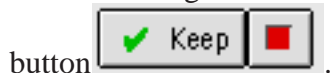
        Note: For *ScienceWorkshop* instructions, see the appendix at the end of the activity.

2.   Since the piston of the Heat Engine/Gas Law Apparatus is at the 0 millimeter mark, click
        'Keep' to record the value of temperature.

·   The first temperature value is displayed in the data Table next to "0" in the Volume
        column.

·   Stir the water in the beaker with the sensor.

3.   Watch the piston closely. When it reaches the 1 millimeter mark, click 'Keep' to record the
        value of temperature.

·   Continue to stir the water with the sensor during the time that you record data.

4.   When the piston reaches the 2 millimeter mark, click 'Keep' to record the value of
        temperature.

5.   Repeat the data recording procedure at each millimeter mark until the piston reaches the 5
        millimeter mark and you have 5 data points. Do not go above 95 ˚C. When you are done,
        stop data recording.

Analyzing the Data

Determine the relationship between volume and temperature.

1.   In the Graph display of Volume versus Temperature, rescale the graph to fit the data.

2.   Use the Graph's analysis tools to determine whether the plot of Volume versus
        Temperature is linear or not.

·   Hint: In *DataStudio*, use **Fit ->Linear**.

·   Hint: In *ScienceWorkshop*, use **Statistics ->Curve Fit ->Linear Fit**.

Record your results in the Lab Report section.

Lab Report - Activity SL09: Charles' Law – Volume vs. Temperature

What Do You Think?

What is the relationship between the volume of a gas and the temperature of the gas?

Question

How well did your results correspond to Charles' Law?

Optional:

- Measure the volume of the metal can. First, fill the metal can to the brim with water. Hold the can over a beaker and put the rubber stopper back into the top of the can. (NOTE: Some of the water will be pushed out by the rubber stopper.) Carefully remove the rubber stopper. Pour the water from the can into a graduated cylinder. Measure the volume of the plastic tubing that connected the metal can to the Heat Engine/Gas Law Apparatus. Pour water into the tubing until it is completely filled. Then add the water from the tubing to the water in the graduated cylinder.

- Record the volume of water in the graduated cylinder as the total volume of the metal can and tubing:

    Volume of can + tubing = _____ mL

Find a value for Absolute Zero based on your data.

- To determine the value for Absolute Zero, plot *total* volume versus temperature.

- Hint: Use the software's calculator to determine the total volume. Remember, the volume of a cylinder is the area of its base multiplied by its height. The area of the piston in the Heat Engine/Gas Law Apparatus is 8.29 square centimeters.

- Hint: The height is the piston position. Convert the piston position from millimeters to centimeters.

- Hint: The value for Absolute Zero is the temperature where the plot on the Graph intersects the X-axis.

Data

Experimental value for Absolute Zero (°C)	

Starter Labs with Computers
SL09: Charles' Law – Volume vs. Temperature

Student Workbook
012-06997

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Appendix (*ScienceWorkshop*)

1. When you are ready, start recording data. In *ScienceWorkshop,* the Keyboard Sampling window will open. Adjust its position on your screen so you can also see the Digits display of temperature.

2. Stir the water in the beaker with the sensor.

3. Since the piston of the Heat Engine/Gas Law Apparatus is at the 0 millimeter mark, type in "0" and click the "Enter" button in the Keyboard Sampling window.

4. Watch the piston closely. When it reaches the 1 millimeter mark, type in "1" and click the "Enter" button in the Keyboard Sampling window.

5. Continue to stir the water with the sensor during the time that you record data.

6. When the piston reaches the 2 millimeter mark, click the "Enter" button in the Keyboard Sampling window.

7. Repeat the data recording procedure until you have at least 5 data points. Do not go above 95 ˚C. When you are done, click the "Stop Sampling" button to stop data recording.
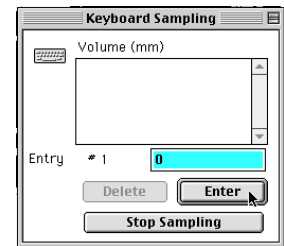
Create a Calculation (*ScienceWorkshop*)

1. Click the Calculator icon or select Calculator Window from the Experiment menu to open the Experiment Calculator.

2. Create a formula for the total volume. First, click on the INPUT menu button and select "Volume (mm)".
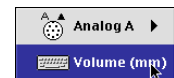
3. Use the cursor to click the "divide" button (/) in the calculator keypad. Then type in "10" (to convert from millimeters to centimeters).

4. Use the cursor to click the "multiply" button (*) in the calculator keypad. Then type in "8.29"(the surface area of the piston in square centimeters).

5. Use the cursor to click the "addition" button (+) in the calculator keypad. Then type in *your* number for the volume of the metal can plus the plastic tubing.

6. Fill in the Calculation Name, Short Name, and Units as indicated. Finally click the "equals" button (=) on the calculator.

7. You now have a formula for determining the total volume of air. Your formula should have your volume for the metal can plus tubing.
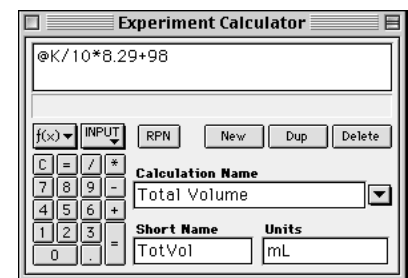
8. Change the Graph to show "Total Volume" on the vertical axis. Click the "Plot Input" menu button and select the Total Volume calculation for the vertical axis.

9. Click on the axis labels to adjust the maximum and minimum values for the vertical and horizontal axes.
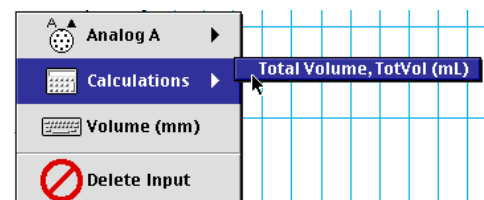
10.   For the vertical axis set the minimum volume to 0 and the maximum to a value slightly bigger than your largest volume.

11.   For the horizontal axis start with -400 and 100. Later you can fine tune it when you know where your V vs. T line intersects the temperature axis.)

12.   To determine your estimate of Absolute Zero, find the point on the horizontal axis where the "best fit" line for Linear Fit intersects the horizontal Temperature axis.

13.   If needed, can either change the minimum value for that axis or click on the Zoom Out button in the lower right corner (a circle with a minus sign in it) .

14.   Click the "Smart Cursor" button ( ). Move the Smart Cursor to the point at which the V vs. T line intersects the Temperature axis. This temperature that corresponds to a volume of zero is your experimental value for Absolute Zero. Record your experimental value for Absolute Zero.
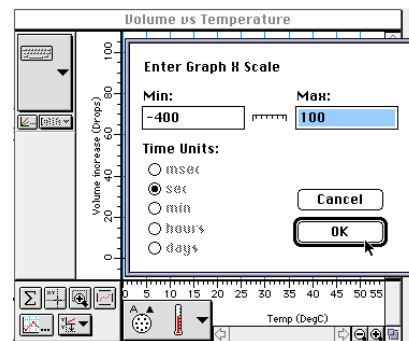
Activity SL10: Endothermic and Exothermic Reactions (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Reactions	C20 Endo and E xo React.DS	C20 Endo-Exo Reactions	C20_ENDO.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Citric acid ($H_3C_6H_5O_7$), 1.5 Molar	30 mL
Balance (SE-8723)	1	Hydrochloric acid (HCl), 0.5 Molar	30 mL
Beaker, 250 mL	1	Baking soda ($NaHCO_3$)	10.0 g
Graduated cylinder, 50 mL	1	Magnesium ribbon (Mg)	20.0 cm
		Styrofoam cup	1
Protective gear	PS	Weighing paper	1

What Do You Think?

Many familiar chemical reactions involve the release of energy, such as combustion. Are there any chemical reactions that involve the absorption of energy?

Take time to write an answer to the question in the Lab Report section.

Background

Many chemical reactions give off energy. Chemical reactions that release energy are called exothermic reactions. Some chemical reactions absorb energy and are called endothermic reactions. You will study one exothermic and one endothermic reaction in this experiment.

First, you will study the reaction between citric acid solution and baking soda. An equation for the reaction is:

$$H_3C_6H_5O_7(aq) \ + \ 3 \ NaHCO_3(s) \ ---> \ 3 \ CO_2(g) \ + \ 3 \ H_2O(l) \ + \ Na_3C_6H_5O_7(aq)$$
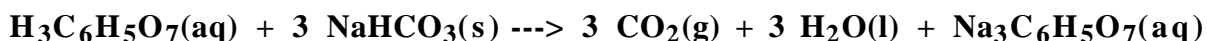
Next, you will study the reaction between magnesium metal and hydrochloric acid. An equation for this reaction is:
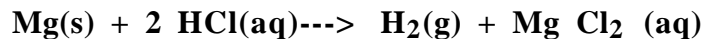
$$Mg(s) \ + \ 2 \ HCl(aq) ---> \ H_2(g) \ + \ Mg \ Cl_2 \ (aq)$$

SAFETY REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

Use the Temperature Sensor to measure the change in temperature of a chemical reaction that releases energy. Then measure the change in temperature of a chemical reaction that absorbs energy. Use *DataStudio* or *ScienceWorkshop* to record and analyze the data.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Temperature sensor's DIN plug into Analog Channel A on the interface.

3. Open the file titled as shown:
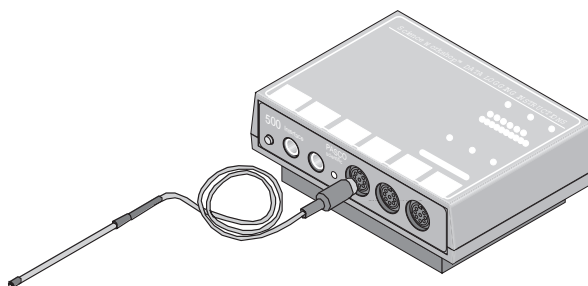
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
C20 Endo and E xo React.DS	C20 Endo-Exo Reactions	C20_ENDO.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document has a Graph display of Temperature versus Time.

- Data recording is set for one measurement per second. Data recording stops automatically at 250 seconds (about 4 minutes).

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

1. Place a Styrofoam cup into the 250 mL beaker as shown in the diagram. Put 30 mL of 1.5 Molar citric acid into the cup. Place the Temperature Sensor into the citric acid solution.

2. Weigh out 10.0 g of solid baking soda on a piece of weighing paper.
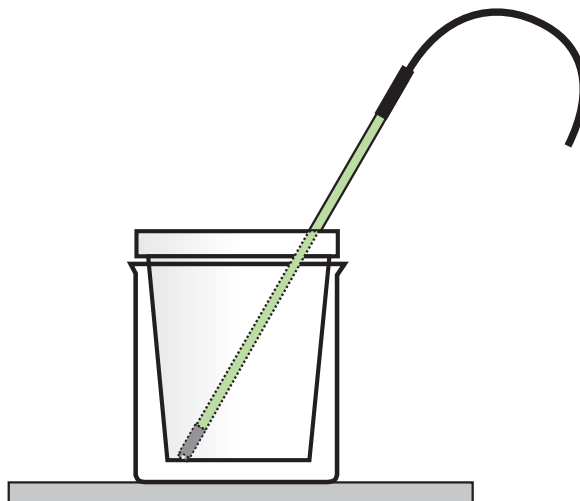
PART IIIA: Data Recording - Reacting Citric Acid and Baking Soda

1. Get ready to record data. The Temperature Sensor must be in the citric acid solution for a few seconds before you begin recording data.

2. When everything is ready, start recording data.

3. After about 20 seconds, add the baking soda to the citric acid solution.

4. Gently stir the solution with the Temperature Sensor to ensure good mixing.

5. Record data until a minimum temperature has been reached and temperature readings begin to increase or let the computer automatically end it after 250 seconds.

6. Dispose of the reaction products as directed by your teacher. Rinse the cup.

PART IIIB: Data Recording - Reacting Magnesium and Hydrochloric Acid

1. Measure out 30 mL of HCl solution into the Styrofoam cup. Place the Temperature Sensor into the HCl solution.

2. Obtain a 20.0 cm piece of shiny magnesium metal from the teacher.

3. Get ready to record data. Note: The Temperature Sensor must be in the HCl solution for a few seconds before you begin recording data.

4. When everything is ready, begin data recording.

5. After about 20 seconds, add the magnesium ribbon to the acid solution.

6. Gently stir the solution with the Temperature Sensor to ensure good mixing.

7. Record data until a maximum temperature has been reached and temperature readings begin to decrease or let the computer automatically end it after 250 seconds.

8. Dispose of the reaction products as directed by your teacher. Rinse the cup.

Analyzing the Data

1.   Set up your Table display so it shows both runs of data (that is, Run #1 for Citric Acid and Baking Soda and Run #2 for Magnesium and Hydrochloric Acid).

2.   Use the Table's analysis tools to find the minimum and maximum values for temperature for Run #1. Hint: Look at the graph to determine if the minimum or maximum occurred first. Record the initial temperature. Record the other as the final temperature.

3.   Find the minimum and maximum values for temperature for Run #2. Look at the graph to determine if the minimum or maximum occurred first. Record this value as the initial temperature in the Data Table. Record the other as the final temperature.

4.   Calculate the temperature change for each reaction by subtracting the initial temperature from the final temperature.

Record your results in the Lab Report section.

Lab Report - Activity SL10: Endothermic and Exothermic Reactions

What Do You Think?

Many familiar chemical reactions involve the release of energy, such as combustion. Are there any chemical reactions that involve the absorption of energy?

Data Table

	Run #1: Citric Acid - Baking Soda	Run #2: Hydrochloric Acid - Magnesium
Final temperature (°C)		
Initial temperature (°C)		
Temperature change (°C)		

Questions

1. Which reaction had a negative temperature change (ΔT)? Is the reaction endothermic or exothermic? Explain.

2. For each reaction, describe three ways you could tell a chemical reaction was taking place.

3. Which reaction took place at a greater rate? Explain your answer.

Activity SL11: Heat of Solution
(Temperature Sensor)

Concept	DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
Reactions & energy	C21 Heat of Solution.DS	C21 Heat of Solution	C21_HEAT.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Ammonium chloride (NH_4Cl), anhydrous	1 g
Balance (SE-8723)	1	Sodium carbonate (Na_2CO_3), anhydrous	1 g
Calorimeter*, 25 mL	1	Water, distilled	40 mL
Graduated cylinder, 100 mL	1	Weighing paper	2
Rubber band	1	Cup, plastic (condiment)	2
Protective gear	PS	Lid, plastic (to fit plastic cup)	1

(*The calorimeter is made from two small plastic cups nested one inside the other. Please see the diagram.)

What Do You Think?

In this activity, you will dissolve two solids, ammonium chloride and sodium carbonate, to determine if the solution process for each is exothermic, $\Delta H = (-)$, or endothermic, $\Delta H = (+)$. What do you predict?

Take time to write an answer to the question in the Lab Report section.

Background

When an ionic compound dissolves in water, the ions that make up the crystalline structure break into individual charged particles. These charged particles are then surrounded by water molecules. In fact, the polar covalent water molecules are responsible for the crystal's breakdown. The solution process requires an increase in entropy. Entropy, S, a measure of disorder, is positive. Crystals, which are orderly arrangement of molecules, break down to individual ions. The ions become scattered throughout the solution. The change in entropy (ΔS) is positive.
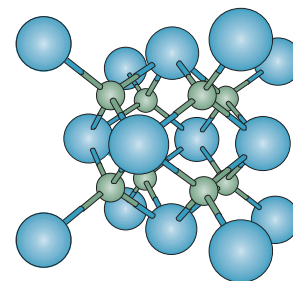
Beside the increase in disorder, the process of dissolving a solid may give off or require heat. If the solution of the solid crystal gets warm, the reaction is exothermic and the Heat of Solution (ΔH) is negative. If the solution of the solid crystal gets cool, the reaction is endothermic and the Heat of Solution (ΔH) is positive.

The combination of attaining maximum disorder and lowest energy can be reconciled by the Gibb's Free Energy equation which says:

$$\Delta G = \Delta H - T\Delta S$$

If the substance dissolves, the reaction is spontaneous and ΔG is negative (-).

Since a solution is always more disordered than the two components separately, ΔS is always positve (+). The value of $(-T\Delta S)$ is always negative. If the solution gets cold, the value of ΔH is positive but the tendency of the reaction to maximum disorder over rides the ΔH value and the solid dissolves.

If the solution gets warm, the values of ΔH and ΔS are additive and the solid still dissolves. Once the solid is dissolved, the system reaches equilibrium and no further energy is lost or gained.

SAFETY REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

Use the Temperature Sensor to measure the change in temperature as two different solids dissolve in distilled water. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor to Analog Channel A on the interface.

3. Open the file titled as shown;
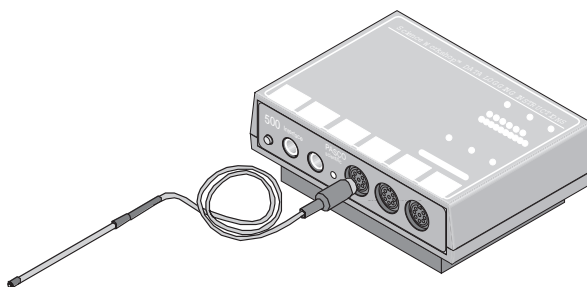
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C21 Heat of Solution.DS	C21 Heat of Solution	C21_HEAT.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document has a Graph display with a plot of the Temperature versus Time and a Table display of Temperature.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

Heat of Solution

1. Make a calorimeter by placing a rubber band about the middle of a plastic condiment cup. Nest this cup inside another cup of the same dimension.

2. Use a 1/4" paper punch to make a hole in the lid of the inside cup.

3. Put 20 mL of distilled water in the inside cup.

4. Measure 1.0 g of ammonium chloride on a piece of weighing paper. DON'T add the solid to the liquid yet.

5. Put the lid on the cup. Place the Temperature Sensor in the hole in the lid.
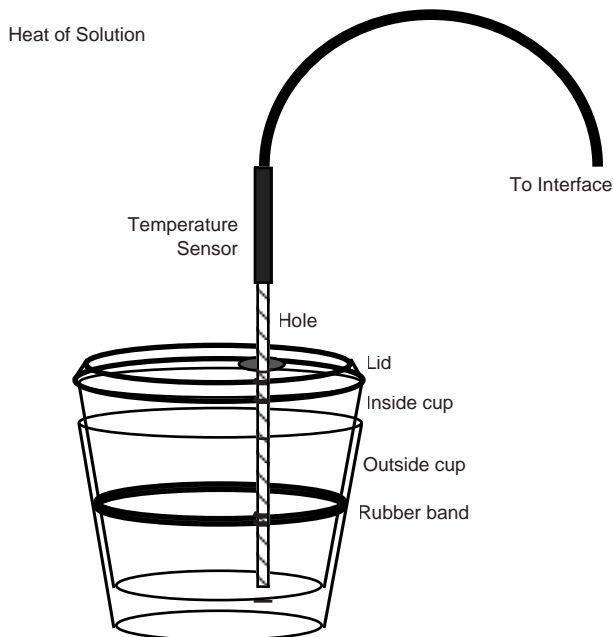
PART IIIA: Data Recording – Ammonium Chloride

1. When everything is ready, start recording data.

2. After about five seconds, remove the Temperature Sensor and add the ammonium chloride solid through the hole. QUICKLY put the sensor back into the cup.

3. Swirl the cup as you allow the reaction to continue until it is complete.

4. Continue until the temperature does not change any further, and then stop recording data.

5. Remove the Temperature Sensor from the cup and rinse the end of the sensor.

6. Discard the solution and rinse the cup.

PART IIIB: Data Recording – Sodium Carbonate

Repeat the procedure with 1.0 g of sodium carbonate solid in place of the ammonium chloride.

1. Put 20 mL of distilled water in the inside cup.

2. Measure 1.0 g of sodium carbonate on a piece of weighing paper. DON'T add the solid to the liquid yet.

3. Put the lid on the cup. Place the Temperature Sensor in the hole in the lid.

4. When everything is ready, start recording data.

5. After about five seconds, remove the Temperature Sensor and add the sodium carbonate solid through the hole. QUICKLY put the sensor back into the cup.

6. Swirl the cup as you allow the reaction to continue until it is complete.

7. Continue until the temperature does not change any further, and then stop recording data.

8. Remove the Temperature Sensor from the cup and rinse the end of the sensor.

9. Discard the solution and rinse the cup.

• You will have two runs of data at the end of the data recording.

Analyzing the Data

1. Set up the Table so it has two columns: one for the first data run (ammonium chloride - Run #1) and one for the second data run (sodium carbonate - Run #2).

2. Use the Table or Graph display to find the starting and ending values for temperature for the solution of ammonium chloride (Run #1). Record these values.

3. Find the starting and ending values for temperature for the solution of sodium carbonate (Run #2). Record these values.

Record your results in the Lab Report section.

Lab Report - Activity SL11: Heat of Solution

What Do You Think?

In this activity, you will dissolve two solids, ammonium chloride and sodium carbonate, to determine if the solution process for each is exothermic, ΔH = (-), or endothermic, ΔH = (+). What do you predict?

Data Table: Ammonium Chloride

Data	Item	Value
1	**Mass of ammonium chloride used**	**g**
2	**Moles of ammonium chloride used** $(Data\ 1\ x\dfrac{1\ mole}{53g})$	**moles**
3	**Starting temperature of water**	**˚C**
4	**Ending temperature of water**	**˚C**
5	**Change in temperature (Data 3 - Data 4)**	**˚C**
6	**Heat generated or gained (mass of liquid x Data 5 x 4.18)**	**J**
7	**Molar Heat of Solution (Data 6÷ Data 2)**	**J/mole**

Data Table: Sodium Carbonate

Data	Item	Value
1	**Mass of sodium carbonate used**	**g**
2	**Moles of sodium carbonate used** $(Data\ 1\ x\dfrac{1\ mole}{106g})$	**moles**
3	**Starting temperature of water**	**˚C**
4	**Ending temperature of water**	**˚C**
5	**Change in temperature (Data 3 - Data 4)**	**˚C**
6	**Heat generated or gained (mass of liquid x Data 5 x 4.18)**	**J**
7	**Molar Heat of Solution (Data 6÷ Data 2)**	**J/mole**

Questions

1. Which substance undergoes an exothermic reaction (ΔH = (-) negative)?

2. Which substance undergoes an endothermic reaction (ΔH = (+) positive)?

3. Complete the summary table below by marking "-" or "+" for each substance:

Summary	Ammonium chloride	Sodium carbonate
ΔG		
ΔH		
ΔS		

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Activity SL12: Hess's Law – Additivity of Heats of Reaction (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Reactions & energy	C23 Hess's Law.DS	C23 Hess's Law	C23_HESS.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Hydrochloric acid (HCl), 1.00 Molar	50 mL
Balance (SE-8723)	1	Hydrochloric acid (HCl), 0.50 Molar	100 mL
Base and Support Rod (ME-9355)	1	Sodium hydroxide (NaOH), 1 Molar	50 mL
Beaker, 250 mL	1	Sodium hydroxide (NaOH), solid	4 g
Clamp, Buret (SE-9446)	1	Styrofoam cup	1
Graduated cylinder, 100 mL	1	Water, distilled	100 mL
Slit stopper	1	Weighing paper	2
Spatula and/or tweezers	1		
Stirring rod	1		
Protective gear	PS		

What Do You Think?

Heats of Reaction are listed for various reactions in resources such as The Handbook of Chemistry and Physics. When the heat of reaction for a specific chemical reaction is not listed, what method could you use to determine the unknown heat of reaction?

Take time to write an answer to this question in the Lab Report section.

Background

The purpose of this activity is to verify Hess's Law. This law, referred to as the additivity of heats of reaction, states that the heat of reaction for a reaction is equal to the sum of the heats of formation of the individual components of the reaction.

$$A + B \rightarrow C \qquad \Delta H_C = \,?$$
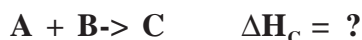
$$\Delta H_C = \Delta H_A + \Delta H_B$$

The reactions you will use in this activity are:

Solid sodium hydroxide dissolves in water to form an aqueous solution of ions.

I. NaOH (s) $\rightarrow$ Na$^+$ (aq) + OH$^-$ (aq)
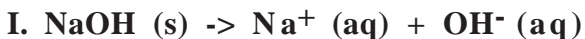
Solid sodium hydroxide reacts with aqueous hydrochloric acid to form water and an aqueous solution of sodium chloride.

II. NaOH (s) + H$^+$ (aq) + Cl$^-$ (aq) $\rightarrow$ H$_2$O (l) + Na$^+$ (aq) + Cl$^-$ (aq)
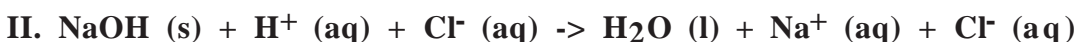
Solutions of aqueous sodium hydroxide and hydrochloric acid react to form water and aqueous sodium chloride.

III. Na$^+$ (aq) + OH$^-$(aq) + H$^+$(aq) + Cl$^-$ (aq) $\rightarrow$ H$_2$O (l) + Na$^+$ (aq) + Cl$^-$ (aq)

SAFETY REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

Pre-Lab

In the Lab Report section, combine two of the above equations algebraically to obtain the third equation. Indicate the number of each reaction to the left of the reaction equation.

For You To Do

Use the Temperature Sensor to measure the change in temperature during each reaction. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor to Analog Channel A on the interface.

3. Open the file titled as shown;
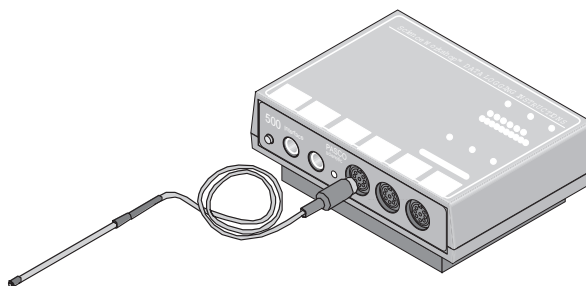
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
C23 Hess's Law.DS	C23 Hess's Law	C23_HESS.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook

- The *ScienceWorkshop* document has a Digits display and a Table display of Temperature.

- Data recording is set so there is one measurement per second. Data recording stops automatically at 200 seconds.

PART II: Sensor Calibration and Equipment Setup

- **You do not need to calibrate the Temperature Sensor.**

1. Use a base and support rod, a clamp, and a slit stopper to support a Temperature Sensor as shown.
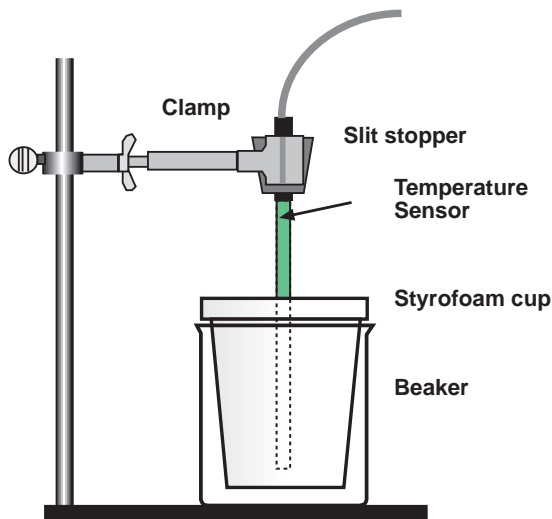
2. Place a Styrofoam cup into a 250-mL beaker as shown in the diagram. Measure out 100.0 mL of water into the Styrofoam cup.

3. Tare the balance to the weight of the weighing paper. Weigh out about 2 grams of solid sodium hydroxide, NaOH, and record the mass to the nearest 0.01 g.

NOTE: Since sodium hydroxide absorbs moisture from the air, weigh it and proceed to the next step without delay. Caution: Handle the NaOH and resulting solution with care.

PART IIIA: Data Recording - Solid NaOH and Water

1. When everything is ready, start recording data.

2. After about two seconds, add the solid sodium hydroxide to the water.

- Observe the change in temperature on the Digits display.

3. Use the stirring rod to stir the contents continuously for 200 seconds or until a maximum temperature has been reached and the temperature starts to drop.

4. As soon as the temperature begins to drop after reaching a maximum, stop recording data.

5. Remove the Temperature Sensor from the cup and rinse and dry the sensor.

6. Dispose of the solution as directed. Rinse and dry the cup and stirring rod.

PART IIIB: Data Recording - Solid NaOH and 0.50 Molar Hydrochloric Acid

1. Put 100.0 mL of 0.50 Molar hydrochloric acid into the Styrofoam cup. Put the Temperature Sensor into the cup.

2. Weigh out about 2 grams of solid sodium hydroxide, and record the mass to the nearest 0.01.

- CAUTION: Handle the HCl solution and NaOH solid with care.

3. Repeat the procedure described in Part IIIA to record the temperature as the solid sodium hydroxide reacts with the hydrochloric acid.

4. Remove the Temperature Sensor from the cup and rinse and dry the sensor.

5. Dispose of the solution as directed and rinse and dry the cup and stirring rod.

PART IIIC: Data Recording - Sodium Hydroxide Solution and Hydrochloric Acid

1. Put 50.0 mL of 1.00 Molar hydrochloric acid into the Styrofoam cup. Put the Temperature Sensor into the acid.

2. Measure out 50.0 mL of 1.00 Molar sodium hydroxide into a graduated cylinder.

- CAUTION: Make sure that both solutions are at approximately the same temperature. Handle the HCl solution and NaOH solution with care.

3. When everything is ready, start recording data.

4. After about two seconds, add the sodium hydroxide solution to the acid.

- Observe the change in temperature on the Digits display.

5. Use the stirring rod to stir the contents continuously for 200 seconds or until a maximum temperature has been reached and the temperature starts to drop.

6. As soon as the temperature begins to drop after reaching a maximum, stop recording data.

7. Remove the Temperature Sensor from the cup and rinse and dry the sensor.

8. Dispose of the solution as directed and rinse and dry the cup and stirring rod.

Analyzing the Data

1. Determine the mass of 100 mL of solution for each reaction (assume the density of each solution is 1.00 g/mL). Record the values in the Data Table.

2. Set up the Table display so there is one column for each run of data: one for Run #1 (solid NaOH and water), a second for Run #2 (solid NaOH and 0.5 Molar HCl), and a third for Run #3 (NaOH solution and 1 Molar HCl).

3. Use the Table to determine the initial temperature, T_1 for each reaction. Record the temperature, T_1.

4. Use the Tables data analysis tools to determine the maximum temperature, T_2, for each reaction. Record the temperatures.

Calculations

1. Determine the temperature change, ΔT, for each reaction.

2. Calculate the heat released by each reaction, q, by using the formula:

$$q = Cp \bullet m \bullet \Delta T \quad (Cp = 4.18 \text{ J/g}°\text{C})$$

    Convert joules to kiloJoules in your final answer.

3. Find the heat of reaction, ΔH ($\Delta H = -q$).

4. Calculate moles of NaOH used for reactions I, II, and III.

5. Use the heat of reaction and the number of moles to determine ΔH/mol NaOH in each of the three reactions.

6. To verify the results of the experiment, combine the heat of reaction (ΔH/mol) for Reaction I and Reaction III.

•   This sum should be similar to the heat of reaction (ΔH/mol) for Reaction 2.

7. Using the value in Reaction II as the accepted value and the sum of Reactions I and III as the experimental value, find the percent difference for the experiment.

Formulas

$$Mass\ of\ solution = 100.0\ mL \times 1.00\ g\,/\,mL$$

$$\Delta T = T_2 - T_1$$

$$q = 4.18\ J\,/\,g^{\circ}C \times 100.0\ g \times \Delta T$$

$$\Delta H = -q$$

$$\#\ moles\ NaOH = \frac{mass\ NaOH}{40.00\ g\,/\,mol}$$

$$\#\ moles\ NaOH = Volume \times Molarity$$

$$\Delta H\,/\,mol\ NaOH = \frac{\Delta H}{\#\ moles\ NaOH}$$

$$Percent\ difference = \left|\frac{(\Delta H_1 + \Delta H_3) - \Delta H_2}{\Delta H_2}\right| \times 100$$

Record your results in the Lab Report section.

Lab Report - Activity SL13: Hess's Law – Additivity of Heats of Reaction

What Do You Think?

Heats of Reaction are listed for various reactions in resources such as The Handbook of Chemistry and Physics. When the heat of reaction for a specific chemical reaction is not listed, what method could you use to determine the unknown heat of reaction?

Pre-Lab

Combine two of the above equations algebraically to obtain the third equation. Indicate the number of each reaction to the left of the reaction equation.

Data Table: Hess' Law

Data	Item	Reaction I	Reaction II	Reaction III
1	Mass of solid NaOH	g	g	*
2	Mass (total) of solution	g	g	g
3	Final temperature, T_2	˚C	˚C	˚C
4	Initial temperature, T_1	˚C	˚C	˚C
5	Change in temp., ΔT	˚C	˚C	˚C
6	Heat, q	kJ	kJ	kJ
7	ΔH	kJ	kJ	kJ
8	Moles of NaOH			
9	ΔH/mol	kJ/mol	kJ/mol	kJ/mol

(*No solid NaOH mass.)

Heat of Reaction I plus Heat of Reaction III:

Heat of Reaction II:

Percent difference(%):

Question

1.   According to your data, is the heat of reaction for the reaction equal to the sum of the heats of formation of the individual components of the reaction?

Activity SL13: Heat of Combustion - Magnesium
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Reactions & energy	C22 Combustion.ds	C22 Heat of Combustion	C22_COMB.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Temperature Sensor (CI-6505A)	1	Stirring rod	1
Balance (SE-8723)	1	Protective gear	PS
Base and Support Rod (ME-9355)	1	Chemicals and Consumables	Qty
Beaker, 250 ml	1	Hydrochloric acid (HCl), 1.00 Molar	200 ml
Clamp, Buret (SE-9446)	1	Magnesium oxide (MgO)	1 g
Graduated cylinder, 100 ml	1	Magnesium ribbon (Mg)	0.5 g
Slit stopper	1	Styrofoam cup	1
		Weighing paper	2

Purpose

The Heat of Combustion of a substance is a piece of information that chemists and chemistry students need to know when conducting chemical reactions. The amount of heat given off by one substance may be different than the amount of heat given off by a similar substance. In this activity you will calculate the Heat of Combustion of magnesium ribbon.

Background - Calorimetry

Calorimetery is the measure and study of heat transfer. In calorimetry, a substance is burned, usually in air or in pure oxygen. For example, you could "burn" a strip of magnesium metal and use the energy given off to heat a known quantity of water in a calorimeter cup. (This is a traditional method for measuring the heat of a reaction in many chemistry labs.)
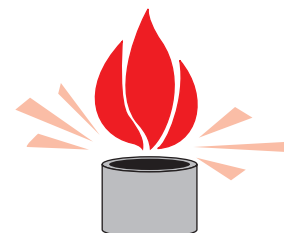
What Do You Think?

Based on your experiences, what do you think are some possible sources of error in the calorimeter method? How might these sources of error effect the measurement of the Heat of Combustion of a substance?

Take time to write an answer to these questions in the Lab Report section.

(Note: See the 'Optional' section of this activity for more information about the calorimetry method.)

Background – Heat of Reaction

A second method to determine the Heat of Combustion is also a traditional method, but it does not directly "burn" the substance. Instead, this method uses the energy released or absorbed during simple chemical reactions to calculate – indirectly – the Heat of Combustion.

For example, when magnesium combines with oxygen during combustion, the reaction is represented by the equation:

IV.   Mg (s) + 1/2 O_2 (g) -> MgO (s)
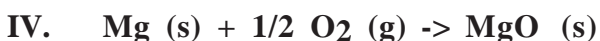
(Magnesium and oxygen form magnesium oxide.)

If other reactions have the same overall outcome, then you can combine the energy released or absorbed by each of the other reactions to calculate the energy produced by the first reaction. Combining equations is a valid method for calculating the Heat of Combustion.

Here are three reactions that are equivalent to the combustion of magnesium.

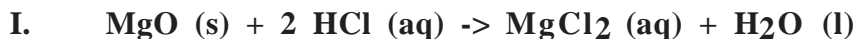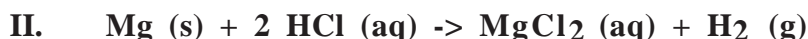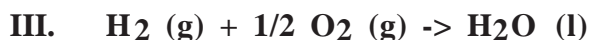Note: You will be asked to confirm that equations **I**, **II**, and **III** are equivalent to equation **IV**.

I. $MgO \ (s) \ + \ 2 \ HCl \ (aq) \ -> \ MgCl_2 \ (aq) \ + \ H_2O \ (l)$

(Magnesium oxide and hydrochloric acid form magnesium chloride and water.)

II. $Mg \ (s) \ + \ 2 \ HCl \ (aq) \ -> \ MgCl_2 \ (aq) \ + \ H_2 \ (g)$

(Magnesium and hydrochloric acid form magnesium chloride and hydrogen gas.)

III. $H_2 \ (g) \ + \ 1/2 \ O_2 \ (g) \ -> \ H_2O \ (l)$

(Hydrogen and oxygen form water.)

Pre-Lab

In the space provided in the Lab Report section, combine equations **I**, **II**, and **III** to obtain equation **IV**.

SAFETY REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

Use the Temperature Sensor to measure the change in temperature during two chemical reactions of magnesium and hydrochloric acid. Use *ScienceWorkshop* or *DataStuidio* to record, display, and analyze the data.

Use the data to calculate the heat of reaction for magnesium oxide and hydrochloric acid (equation **I**) and the heat of reaction for magnesium and hydrochloric acid (equation **II**).

Use the heats of reaction for **I**, **II**, and **III** to determine the heat of reaction for **IV** – the Heat of Combustion for magnesium.

The heat of reaction for equation **III** above is $\Delta H = -285.8$ kJ/mol.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor to Analog Channel A on the interface.

3. Open the file titled as shown:
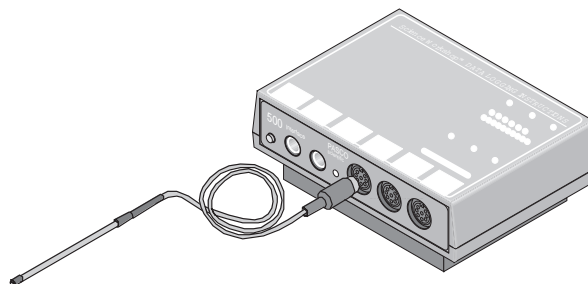
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
C22 Combustion.ds	C22 Heat of Combustion	C22_COMB.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook

- The *ScienceWorkshop* document has a Digits display and a Table display of Temperature.

- Data recording is set for one measurement per second.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

Method #2 Combining Chemical Equations:

1. Use a base and support rod, a clamp, and a slit stopper to support a Temperature Sensor as shown.

2. Place a Styrofoam cup into a 250-mL beaker as shown in the diagram. Measure out 100.0 ml of 1.00 Molar HCl into the Styrofoam cup.

3. Lower the Temperature Sensor into the solution.
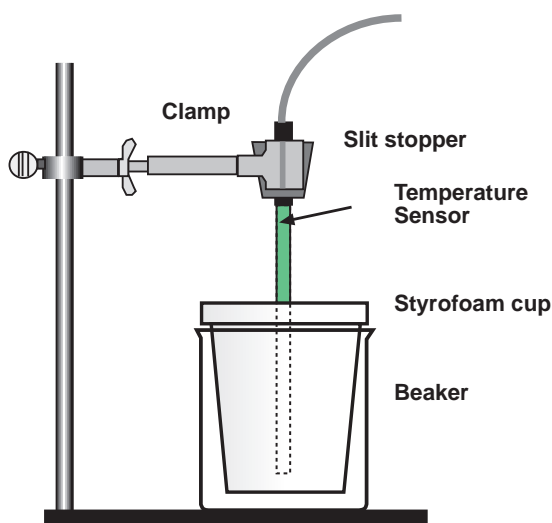
4. Tare your balance to the weight of the weighing paper. Weigh out about 1.00 g of magnesium oxide, MgO, on a piece of weighing paper. Record the exact mass used in your data table.

Safety Alert!

Magnesium oxide dust is mildly toxic by ingestion. DO NOT INHALE the dust!

PART IIIA: Data Recording - Magnesium Oxide and Hydrochloric Acid

1.   When everything is ready, start recording data.

2.   After about five seconds, add the white magnesium oxide powder to the solution.

•   Observe the change in temperature on the Digits display.

3.   Use the stirring rod to stir the contents of the cup until a maximum temperature has been reached and the temperature starts to drop. Then stop recording data.

4.   Remove the Temperature Sensor from the cup and rinse the end of the sensor.

5.   Discard of the solution as directed and rinse the cup.

PART IIIB: Data Recording - Magnesium Ribbon and Hydrochloric Acid

6.   Repeat the procedure with 0.50 g of magnesium ribbon rather than magnesium oxide powder. Be sure to measure and record the mass of the magnesium ribbon.

7.   When everything is ready, start recording data.

8.   After about five seconds, add the white magnesium oxide powder to the solution.

•   Observe the change in temperature on the Digits display.

9.   Use the stirring rod to stir the contents of the cup until a maximum temperature has been reached and the temperature starts to drop. Then stop recording data.

10.   Remove the Temperature Sensor from the cup and rinse the end of the sensor.

11.   Discard of the solution as directed and rinse the cup.

•   You will have two runs of data at the end of the data recording.

Analyzing the Data

1.   Set up the Table display so it has two columns: one for the first run of data (magnesium oxide and hydrochloric acid) and one for the second run of data (magnesium ribbon and hydrochloric acid).

2.   Use the Table data analysis tools to find the initial temperature T_1 and maximum temperature T_2 for Run #1 (magnesium oxide and hydrochloric acid). Record these values.

3.   Find the initial temperature T_1 and maximum temperature T_2 for Run #2 (magnesium ribbon and hydrochloric acid). Record these values.

Calculations

1.   Calculate the change in temperature, ΔT, for both reactions.

2.   Calculate the energy released by both reactions, q, using the formula

$$q = C_p \cdot m \cdot \Delta T$$

• $C_p = 4.18$ J/g°C, and m = 100.0 g of HCl solution. Convert joules to kJ in your final answer.

3.   Determine the heat of reaction, ΔH, for both magnesium oxide and magnesium ribbon. (Remember, $\Delta H = -q$.)

4.   Determine the moles of magnesium oxide (MgO) and magnesium ribbon (Mg) used.

5.   Use your calculation of the heats of reaction and the number of moles to calculate ΔH/mol for magnesium oxide (MgO) and magnesium ribbon (Mg).

6.   Determine ΔH/mol for magnesium (Mg) based on the heats of reaction for magnesium oxide and hydrochloric acid (Reaction I), magnesium ribbon and hydrochloric acid (Reaction II), and hydrogen and oxygen. (Reaction III.)

•   Remember, ΔH for Reaction **III** is –285.8 kJ/mol

7.   Determine the percent difference between your calculation and the accepted value for the Heat of Combustion. The accepted value for this reaction can be found in a table of standard heats of formation.

Formulas

$$\Delta T = T_f - T_i$$

$$q = (4.18 \ J/g°C) \times 100.0 \ g \times \Delta T$$

$$\Delta H = -q$$

$$\# moles \ MgO = \frac{mass \ MgO}{40.3 \ g/mol}$$

$$\# moles \ Mg = \frac{mass \ Mg}{24.3 \ g/mol}$$

$$\Delta H/mol = \frac{\Delta H}{\# moles}$$

$$\% \ difference = \left| \frac{Actual - Experimental}{Actual} \right| \times 100$$

Record your results in the Lab Report section.

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Lab Report - Activity SL12: Heat of Combustion - Magnesium

What Do You Think?

Based on your experiences, what do you think are some possible sources of error in the calorimeter method? How might these sources of error effect the measurement of the Heat of Combustion of a substance?

Data Table

Data	Item	Reaction I (MgO)	Reaction II (Mg)
1	Volume of 1.00 M HCl	mL	mL
2	Final temperature, T_2	˚C	˚C
3	Initial temperature, T_1	˚C	˚C
4	Change in temperature, ΔT	˚C	˚C
5	Mass of solid	g	g
6	Heat, q	kJ	kJ
7	ΔH = -q	kJ	kJ
8	Moles	mol	mol
9	ΔH/mol	kJ/mol	kJ/mol

Determine the Heat of Combustion (Reaction **IV**) based on the heats of reaction for **I**, **II**, and **III**:

Eqn.	Reactants	Results	Heat of Reaction
I.	$MgCl_2$ (aq) + H_2O (l) ->	MgO (s) + 2 HCl (aq)	ΔH_1 = kJ/mol
II.	Mg (s) + 2 HCl (aq) ->	$MgCl_2$ (aq) + H_2 (g)	ΔH_2 = kJ/mol
III.	H_2 (g) + 1/2 O_2 (g) ->	H_2O (l)	ΔH_3 = -286 kJ/mol
IV.	Mg (s) + 1/2 O_2 (g) ->	MgO (s)	ΔH_4 = kJ/mol

Determine the percent difference between your calculation and the accepted value (-602 kJ/mol).

Percent difference =

Optional – Calorimeter Method

In this method, use the heat given off by a piece of burning magnesium to heat up a known volume of water. Use the mass of water heated, its specific heat (the specific heat for water is c = 1.0 cal/g ˚C or 4.18 J/g˚C, and the change in the temperature of the water to calculate the heat of combustion of the magnesium.

This method is often used to calculate the caloric content of many foods such as peanuts or sugar. (Refer to the "Food Energy Content" activity.)

Follow the procedure in the "Food Energy Content" activity. Modify the equipment set-up so that a magnesium ribbon can be burned instead of a food sample. Use a crucible to hold the burning magnesium. Use extreme caution when working with burning magnesium.

Safety Alert!

Never look into the flame produced by the burning magnesium or directly at the light given off from the combustion. The light energy is very intense and contains UV radiation that could possibly damage your eyes and vision.

Follow the same calculation method as in the "Food Energy Content" activity. Note any and all possible sources of error that may result using this method.

Questions:

1. What is the Heat of Combustion of magnesium based on your data from the calorimeter method?

2. What is the percent difference between your calculation and the accepted value?

3. Which method do you think was more reliable?

Activity SL14: Molar Mass Determination by Freezing Point Depression (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Molar mass	C25 Molar Mass.DS	C25 Molar Mass	C25_MOLA.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Temperature Sensor (CI-6505A)	1	Test tube, Pyrex, 25 x 150 mm	1
Balance (SE-8723)	1	Protective gear	PS
Base and Support Rod (ME-9355)	1	**Chemicals and Consumables**	**Qty**
Beaker, 250 mL (for water bath)	1	Para-dichlorobenzene (PDB)	15 g
Clamp, Buret (SE-9446)	1	"unknown"	2 g
Hot plate (for water bath)	1	Water	200 mL
Slit stopper	1	Weighing paper	3
Spatula	1		

What do you think?

The temperature of a mixture of pure water and pure ice is 0 ˚C. What happens to the temperature of the water/ice mixture if you add sodium chloride (table salt) to the mixture? Is the change in temperature determined by the amount of salt that you add? Are there any other substances that can have a similar effect on the freezing point of water? Will this change in the freezing point temperature happen for substances other than water?

Take time to write an answer to these questions in the Lab Report section.

Background

Freezing point depression is an example of a *colligative* property. Colligative properties depend on the concentration of solute particles (total number of moles per liter) and not on their size or specific properties. A pure substance has a specific freezing point temperature. The freezing point of the substance is lowered when another substance is dissolved in the pure substance. The freezing point *depression* (i.e., drop in freezing point temperature) depends on the total number of solute particles. For example, because sodium chloride molecules dissociate into Na^+ and Cl^- ions in solution, one mole of 'salt' becomes two moles of ions. The freezing point temperature drops twice as much as it would if the solute does not dissociate into ions. Using salt on icy roads during the winter in snowy areas is an example of freezing point depression.

Chemists use the following concept and equation. The freezing point depression, ΔT_f, of a solvent is given by:

$$\Delta T_f = -K_f\ m$$

where K_f is the molal freezing point depression constant for the solvent and m is the molality of the total solute particles.

The *molality* is ratio of the number of moles per solute and the mass of the solvent. Therefore, you can determine the number of moles of the unknown solute from its molality, m, and the mass of the solute. Since the *molar mass* of the unknown is the ratio of the mass of the solute to the number of moles, you can determine the molar mass of an *unknown* compound by means of the freezing point depression of para-dichlorobenzene (PDB).

How to Determine the Freezing Point

As a pure substance cools in its liquid state, the temperature drops at a constant rate until it begins to solidify. While freezing, its temperature levels off at a temperature known as its freezing point. Occasionally the temperature drops a little below the actual freezing point before

Temperature

supercooling (not to scale)

Extrapolate to find the
freezing point temperature.

Time
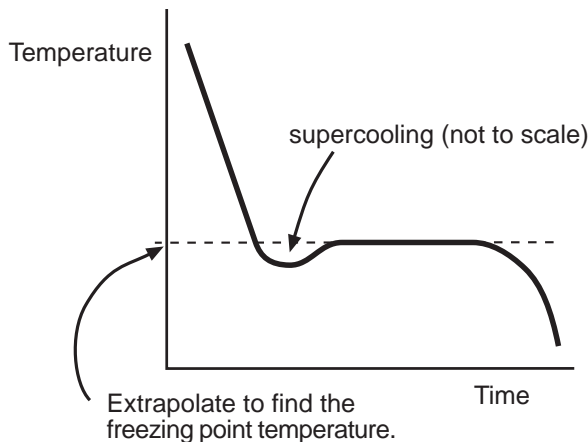
leveling off at the actual freezing point. This is known as super cooling. See the diagram below.

A solution may continue freezing over a broad temperature range. To get an good value for its freezing point draw a line through the original cooling curve of the liquid and a second through the area where it has tapered off slightly. The temperature at the point at which they intersect can be considered to be the freezing point. See the diagram below.
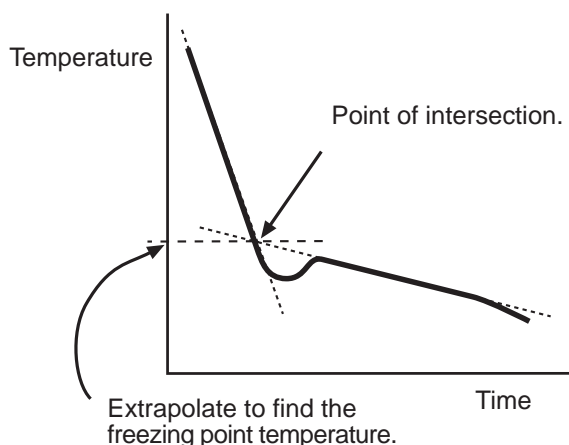
Temperature

Point of intersection.

Extrapolate to find the
freezing point temperature.

Time

SAFETY   REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Make sure the room is well ventilated.
- Dispose of all chemicals and solutions properly.

For You To Do

In this activity, measure the freezing point temperature of a pure organic substance, para-dichlorobenzene (PDB).Then measure the freezing point temperature of a solution of PDB and a measured amount of an unknown compound. The para-dichlorobenzene acts as the solvent and the unknown compound is the solute.

Use the Temperature Sensor to measure the change in temperature as melted PDB solidifies. Compare the freezing point temperature for pure PDB with the freezing point temperature of PDB mixed with an unknown substance. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data. Use the data to calculate the molar mass of the unknown compound.

Pre-Lab

Fill the 250 -mL beaker a little over half full with water. Begin to heat the water to 65 or 70 ˚C. As the water is heating, continue with the rest of the setup.

PART I: Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the DIN plug of the Temperature Sensor to Analog Channel A on the interface.

3.   Open the file titled as shown;
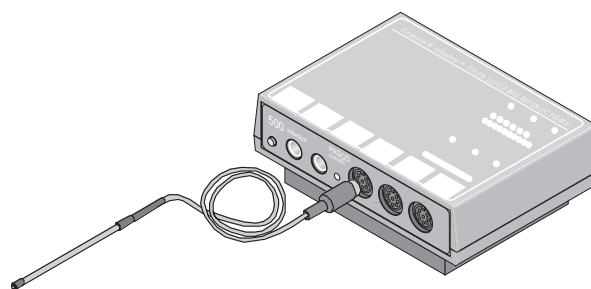
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
C25 Molar Mass.DS	C25 Molar Mass	C25_MOLA.SWS

•   The *DataStudio* file has a Workbook display. Read the instructions in the Workbook

•   The *ScienceWorkshop* document has a Digits display and a Table display of Temperature and a Graph display with a plot of the Temperature versus Time.

•   Data recording is set so there is one measurement per 15 seconds.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

1. Measure 15.00 gram of para-dichlorobenzene (p-dichlorobenzene or PDB). Record the exact mass to 0.01 g. Put the PDB into a clean dry 25 by 150-mm Pyrex test tube.

2. Use a base and support rod, clamp, and slit stopper to set up the test tube with the PDB as shown.
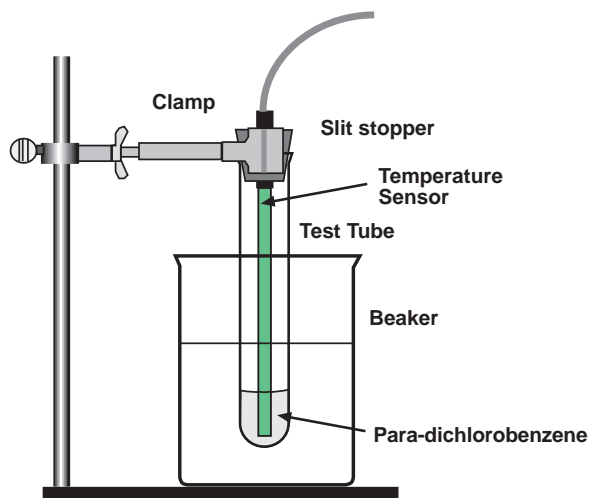
3. When the water bath is hot enough, turn off the heat source and lower the test tube and the Temperature Sensor into the hot water bath.

• NOTE: Never heat p-dichlorobenzene over an open flame.

• As the material melts, you can stir it gently with the Temperature Sensor.

4. Start to monitor the temperature of the PDB. Every fifteen seconds the Digits display will show the temperature.

5. When the melting is complete and the temperature is between 60 and 65 ˚C, stop monitoring the temperature (Hint: Click the STOP button.)

PART IIIA: Data Recording - Pure PDB

1. Raise the test tube. Immediately start recording data for determining the freezing point of the pure PDB.

2. Stir gently with the sensor throughout the entire run.

3. Continue recording data until all the material seems completely frozen.

4. Make a note of the apparent freezing point of the PDB.

5. When the PDB is solid, stop the data recording for Run #1.

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PART IIIB: Data Recording - PDB and 1 gram Unknown

1. Again heat your hot water bath. Return the test tube with the PDB to the water bath. This time stop heating the test tube when the temperature is 10 degrees above the apparent freezing point of the pure PDB.

2. Carefully weigh out 1.00 g of unknown and pour it into the test tube with the PDB. Record the mass of unknown in your data table under Run #2.

3. Do Run #2 in the same manner as you did Run #1. The material may not get as hard this time.

4. Make a note of the apparent freezing point temperature of the PDB/unknown mixture.

PART IIIC: Data Recording - PDB and 1 gram Unknown

1. Again heat your hot water bath. Return the test tube with the mixture from Part IIIB to the water bath. This time stop heating the test tube when the temperature is 10 degrees above the apparent freezing point of the last mixture.

2. Carefully weigh out a second 1.00 g of unknown and pour it into the bottom of the test tube with the mixture. Record the <u>combined</u> mass of unknown in your data table under Run #3.

•   Note: This should be about 2.00 g.

3. Do Run #3 in the same manner as you did the last two runs. The material may appear like a solid slush at the end.

4. Clean up and dispose of your chemicals as directed.

Analyzing the Data

1. Click the Graph display to make it active. The Graph display will show all three runs of data.

2. Rescale the graph to fit the data.

•   NOTE: Drag-and-drop data runs from the Summary list to the Graph display in *DataStudio*. Select each run of data separately by clicking on the DATA menu button in the Graph display in *ScienceWorkshop*.

3. Use a printed copy of your Graph display to determine the freezing point for each run as discussed in the 'How to Determine the Freezing Point' section.

4. Use the Graph's data analysis tools to determine the freezing point depression, ΔT_f, for Run #2 (PDB plus 1 g of unknown) and Run #3 (PDB plus 2 g of unknown).

•   Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*.

Calculations

1.   Use the freezing point depression and the value of K_f for PDB to calculate the molality, **m**, of the solutions for Run #2 and Run #3.

2.   Use the molality and the mass of the unknown to calculate the number of moles of unknown ("solute") used in Run #2 and Run #3. (Remember that the molality of a solution equals the number of moles of solute per kilogram of solvent.)

3.   Use the mass of the unknown and the number of moles of unknown ("solute") to determine the experimental value for the molar mass of the unknown for Run #2 and Run #3.

4.   Calculate the average experimental molar mass for the unknown.

5.   If your teacher gives you the actual value for the molar mass, then determine your percent difference.

Formulas

$$\Delta T_f = T_{pure} - T_{mixture}$$

$$Molality = \frac{\Delta T_f}{K_f} \quad \text{where } K_f = 7.10 \ °C \ kg/mol \text{ for PDB}$$

$$\# \, moles \, solute = molality \, x \, \# \, kg \, solute$$

$$Molar \, mass \, of \, solute = \frac{mass \, of \, solute}{\# \, moles \, solute}$$

$$Average \, molar \, mass = \frac{Molar \, mass \, 1 + Molar \, mass \, 2}{2}$$

$$\% difference = \left| \frac{Actual - Experimental}{Actual} \right| \times 100$$

Record your results in the Lab Report section.

Lab Report - Activity SL14: Molar Mass Determination by Freezing Point Depression

What Do You Think?

The temperature of a mixture of pure water and pure ice is 0 ˚C. What happens to the temperature of the water/ice mixture if you add sodium chloride (table salt) to the mixture? Is the change in temperature determined by the amount of salt that you add? Are there any other substances that can have a similar effect on the freezing point of water? Will this change in the freezing point temperature happen for substances other than water?

Data Table and Calculations

	Run #1	Run #2	Run #
	PDB	1 g of unknown	2 g of unknown
Mass PDB (solvent)	kg	kg	kg
Mass unknown (solute)	--	kg	kg
Freezing point, T	˚C	˚C	˚C
Freezing point depression, ΔT_f	--	˚C	˚C
Molality, m, of solute	--	mol/kg	mol/kg
Moles of unknown (solute)	--	mol	mol
Molar mass of unknown	--	kg/mol	kg/mod

Average molar mass	kg/mol
Actual molar mass of unknown*	kg/mol
Percent difference	

*lauric acid in this example

Question

1.   What is the percent difference between your measured value and the accepted value for the molar mass of the unknown substance?

Activity SL15: Molal Freezing Point Depression Constant, K_f (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop (Mac)*	*ScienceWorkshop* (Win)
Freezing point	C26 Freeze Point.DS	C26 Depression Constant	C26_DEPR.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Ice, crushed (from deionized water)	150 g
Balance (SE-8723)	1	Lid (for Styrofoam cup)	1
Beaker, 500 mL	1	Rubber band	1
Calorimeter *	1	Sodium chloride, NaCl, solid	100 g
Graduated cylinder, 100 mL	1	Styrofoam cup	2
Stir rod	1	Water	100 mL
Test tube	1	Water, deionized	50 mL
Protective gear	PS	Weighing paper	1

(*The calorimeter is made from two small Styrofoam cups nested one inside the other. Please see the diagram.)

What do you think?

Freezing a milk/cream mixture makes ice cream. The freezing usually takes place in an ice cream maker that has an inner and outer lining. The milk/cream mixture is placed into the inner container and ice, water and salt are placed in the outer container. The ice used in the outer container is initially at zero degrees Celsius. Water and salt are then added to this ice and the resulting mixture is used to "freeze" the milk/cream into ice cream. Milk and cream require a temperature colder than zero degrees Celsius to be turned into ice cream. Just how does this "freezing" temperature come about?
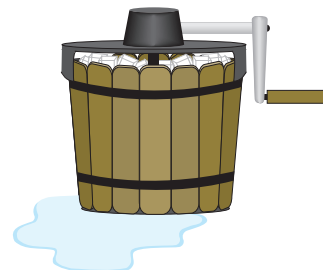
Take time to write an answer to this question in the Lab Report section.

Background

Pure substances have characteristic boiling point temperatures and freezing point temperatures if the atmospheric pressure is constant. If a pure substance is contaminated with another, the boiling and freezing point temperatures are changed.

Changes in the physical properties of a substance are referred to as *colligative* properties. Each substance changes to a different degree. For every mole of contaminating substance, the dissolving substance's melting point will be depressed by a specific amount. This amount is known as the Molal Freezing Point Depression Constant or K_f. The presence of a non-volatile solute in a solution lowers the freezing point of a substance. A non-volatile substance is one, which is not boiled away when a solution is heated.

For example, when sodium chloride is dissolved in ice water, the molecule of the salt dissolves to form two ions for every molecule of salt.

$$NaCl_{(s)} \implies Na^+_{(aq)} + Cl^-_{(aq)}$$

The effect on the freezing point of water with sodium chloride is double what it would be if the molecule stayed together and acted as a single unit. The number of particles influences the freezing point of a solid, not just the mass of material, dissolved.

SAFETY   REMINDERS

- Wear protective gear while handling chemicals.

- Follow directions for using the equipment.

- Dispose of all chemicals and solutions properly.

For You To Do

This activity has two parts:

Part A - Observation

Place a test tube of water into a beaker containing ice, water and salt. Stir the ice/water/salt mixture and observe what happens to the ice in the test tube. Use a Temperature Sensor and either *DataStudio* or *ScienceWorkshop* to record the temperature of the water in the test tube.

Part B – Measurement

Use a Temperature Sensor to measure the change in the freezing point of a common substance, water, and to use these measurements to determine the value of the Molal Freezing Point Depression Constant K_f.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor to Analog Channel A on the interface.

3. Open the file titled as shown;
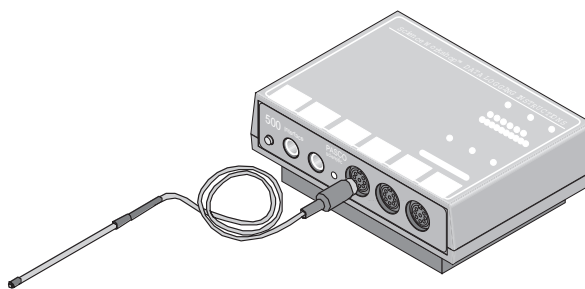
DataStudio	*ScienceWorkshop (Mac)*	*ScienceWorkshop* (Win)
C26 Freeze Point.DS	C26 Depression Constant	C26_DEPR.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook

- The *ScienceWorkshop* document has a Graph display of the Temperature versus Time.

- Data recording is set so there is one measurement per second.

PART II: Sensor Calibration

This is an activity where it is good to calibrate the Temperature Sensor, since an actual freezing point is being measured and not just a change in temperature. The calibration procedure is simple. (Refer to the Temperature Sensor instruction sheet or the *DataStudio* On-Line Help file or the *ScienceWorkshop* User's Guide.)

PART IIA: Equipment Setup - Observation

- Put about 100 grams of ice, 50 mL of water, and a couple of teaspoons of table salt into a beaker. Stir the mixture to dissolve the ice.
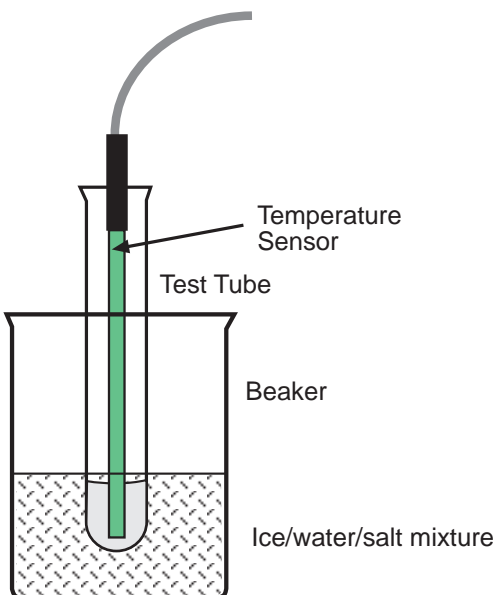

- Put water into a test tube. Place a Temperature Sensor into the water.

- Place the test tube into the ice/water/salt mixture in the beaker.

- Start recording the temperature of the water in the test tube.

- Continue to measure the temperature of the water in the test tube until it stops decreasing.

- Observe the contents of the test tube throughout the activity.

Questions About The Observation (Optional)

- Does a phase change occur for the water in the test tube?

- Can you determine the freezing point of water in this activity?

- Can ice be colder than zero degrees Celsius?

PART IIB: Equipment Setup - Measurement

1.   Weigh one Styrofoam cup and record the weight of the cup.

2.   Make a calorimeter by placing a rubber band about the middle of the Styrofoam cup. Nest this cup inside another cup of the same dimension.

3.   Use a 1/4" paper punch to make a hole in the lid of the inside cup.

4.   Put 50 mL of water and 50 g of ice in the inside cup.

5.   Carefully measure 2.9 g of sodium chloride. Add the salt to the ice/water mixture.

6.   Put the lid on the cup. Place the Temperature Sensor in the hole in the lid.
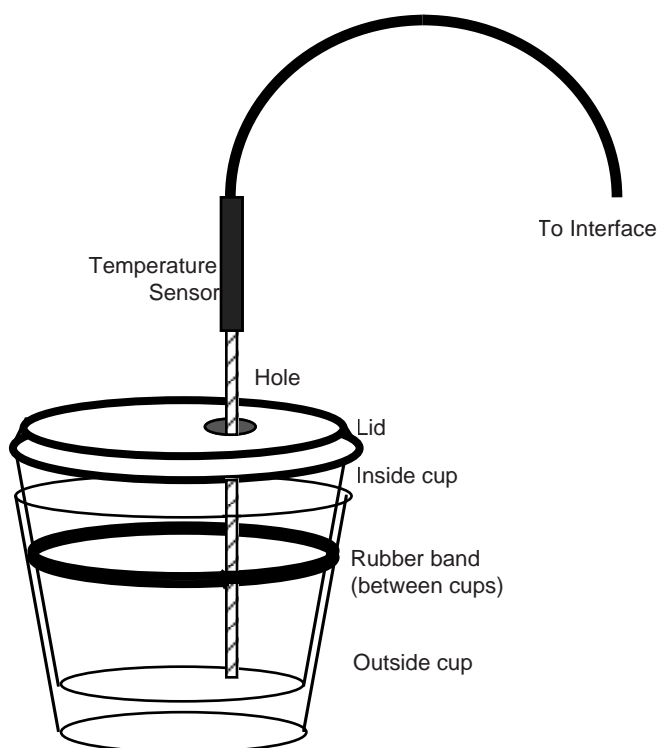
Molal Freezing Point Depression Constant (kf)

PART III: Data Recording

1.   Start recording data.

2.   Gently swirl the calorimeter to help the salt dissolve until the reaction is complete.

3.   Stop the data recording after approximately 90 seconds (1.5 minutes).

4.   Remove any remaining chunks of ice from the inner cup. Weigh the inner cup with the remaining water and record the total weight of the cup plus water.

Analyzing the Data

1.   Use the Graph analysis tools to determine the maximum temperature (maximum 'y') and minimum temperature (minimum 'y').

•   Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*.

2.   Record the maximum temperature and the minimum temperature.

Calculations

1.   Calculate the change in temperature and record it.

2.   Calculate the mass of the water remaining in the cup after the salt dissolved.

3.   Calculate the number of moles of solute (salt).

4.   Determine the molality of the ice/water/salt mixture.

5.   Calculate the Molal Freezing Point Depression Constant, K_f.

6.   Compare your value for the Molal Freezing Point Depression Constant, K_f, to the accepted value.

•   Note: A mass of 2.9 g sodium chloride is equal to 0.05 moles of sodium chloride, or 0.1 moles of dissolved ions.

•   The molality of a solution is equal to the moles of solute divided by the weight (in kg) of solvent.

$$m \ (molality) = \frac{moles \ of \ solute}{weight \ of \ solvent}$$

•   The Molal Freezing Point Depression Constant formula is:

Δ freezing temperature of water = m (molality) x K_f

$$K_f = \frac{\Delta \ temperature}{m \ (molality)}$$

Record your results in the Lab Report section.

Lab Report - Activity SL15: Molal Freezing Point Depression Constant, K_f

What do you think?

Freezing a milk/cream mixture makes ice cream. The freezing usually takes place in an ice cream maker that has an inner and outer lining. The milk/cream mixture is placed into the inner container and ice, water and salt are placed in the outer container. The ice used in the outer container is initially at zero degrees Celsius. Water and salt are then added to this ice and the resulting mixture is used to "freeze" the milk/cream into ice cream. Milk and cream require a temperature colder than zero degrees Celsius to be turned into ice cream. Just how does this "freezing" temperature come about?

Data Table

Mass of empty cup	**kg**
Mass of cup plus water	**kg**
Mass of water used	**kg**
Minimum Temperature	**˚C**
Maximum Temperature	**˚C**
Change in Temperature	**˚C**

1. Calculate the number of moles of solute (salt).

2. Determine the molality of the ice/water/salt mixture.

3. Calculate the Molal Freezing Point Depression Constant, K_f.

Questions

1.   If ionic solutions, like sodium chloride, form ions and effect the freezing point so much more than non-ionic solutions, like ethylene glycol (Zerex^{TM}), why are non-ionic materials used in cars?

2.   Why is calcium chloride ($CaCl_2$) more effective as an anti-icing material than sodium chloride (NaCl)?

3.   What is your value of Kf? How does this compare with the accepted value for Kf? (The accepted value of Kf for water is 1.86 ˚C kg/mol.)

Questions About the Observation (Optional)

•   Does a phase change occur for the water in the test tube?

•   Can you determine the freezing point of water in this activity?

•   Can ice be colder than zero degrees Celsius?

Activity SL16: Reduction Potentials in Micro-Voltaic Cells (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electrochemistry	C28 Reduction Potentials. DS	C28 Reduction Potentials	C28_REDU.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Voltage Sensor (CI-6503)	1	Filter paper, 11 cm diameter	1 sheet
Eyedropper or pipette	1	Sand paper	1 sheet
Forceps	1 pair	Sodium nitrate, $NaNO_3$, 1.0 Molar	10 mL
Glass plate, 15 cm x 15 cm	1	Solutions of M_1^{2+}, M_2^{2+}, … M_5^{2+}, 1 Molar	2 ml ea.
Metal samples, 1 cm x 1 cm, M_1 … M_5	5		
Scissors	1 pair		
Protective gear	PS		

What Do You Think?

The purpose of this activity is to establish the reduction potentials of five metals relative to an arbitrarily chosen metal. Measure the voltage, or potential difference, between various pairs of 'half-cells'. Which pair of metals will have the largest reduction potential?

Take time to write an answer to this question in the Lab Report section.

Background

A voltaic cell uses a spontaneous oxidation-reduction reaction to produce electrical energy. Placing a piece of metal into a solution containing a cation of the metal produces half-cells. For example, a piece of copper metal in a solution of copper sulfate ($CuSO_4$ or Cu^{2+}) is a half-cell.

In this micro-version of a voltaic cell, the half cell is a small piece of metal placed into three drops of corresponding cation solution on a piece of filter paper. The next figure shows the arrangement of half-cells on a piece of filter paper. A porous barrier or a salt bridge normally separates the two half-reactions. Here, the salt bridge is made from several drops of aqueous sodium nitrate ($NaNO_3$) placed on the filter paper linking the two half-cells. Using the computer as a voltmeter, the red (positive) end of the Voltage Sensor makes contact with one metal and the black (negative) end of the Voltage Sensor makes contact with another metal.
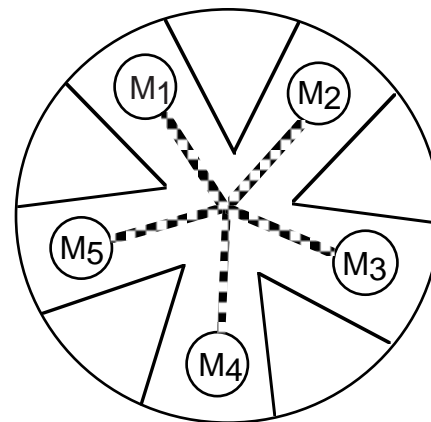
By comparing the voltage values obtained for several pairs of half-cells, and by recording which metal made contact with the red (+) and black (–) ends, you can establish the reduction potential sequence for the metals in this lab.

SAFETY REMINDERS

- Wear protective gear while handling chemicals.

- Follow directions for using the equipment.

- Dispose of all chemicals and solutions properly.

For You To Do

Use the Voltage Sensor to measure the potential difference (voltage) between pieces of different metals that are arranged in a voltaic cell. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Voltage Sensor to Analog Channel A on the interface.

3. Open the file titled as shown:
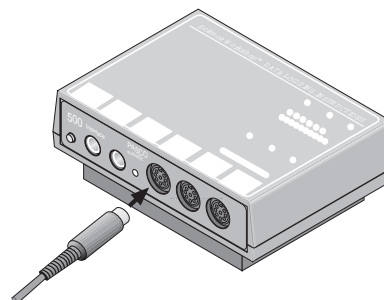
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C28 Reduction Potentials. DS	C28 Reduction Potentials	C28_REDU.SWS

- The *DataStudio* file has a Table display with the numbers for each metal-to-metal combination already entered and a Workbook display. Read the instructions in the Workbook display.

- The *ScienceWorkshop* document has a Table display of the voltage with the number of the metal in the half-cell and a Digits display of voltage.

- Data recording is set so there is one measurement per second.

- You will enter the number of each metal-to-metal combination using Manual Sampling in *DataStudio* or Keyboard Sampling in *ScienceWorkshop*.

Note: See the appendix of this activity for instructions on using Keyboard Sampling in *ScienceWorkshop*.
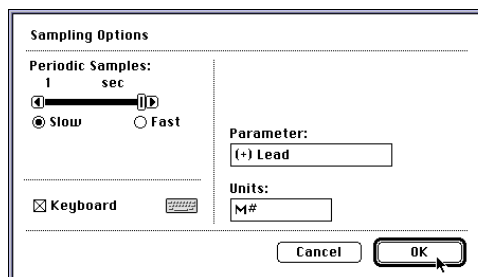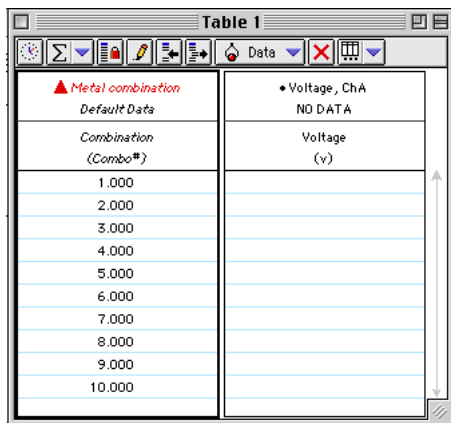
PART II: Sensor Calibration and Equipment Setup

• You do not need to calibrate the Voltage Sensor.

1. Draw five small circles with connecting lines on a piece of circular filter paper, as shown in the diagram.

2. Using a pair of scissors cut wedges between the circles as shown.

3. Label the circles M_1, M_2, M_3, M_4, and M_5. Place the filter paper on top of the glass plate.
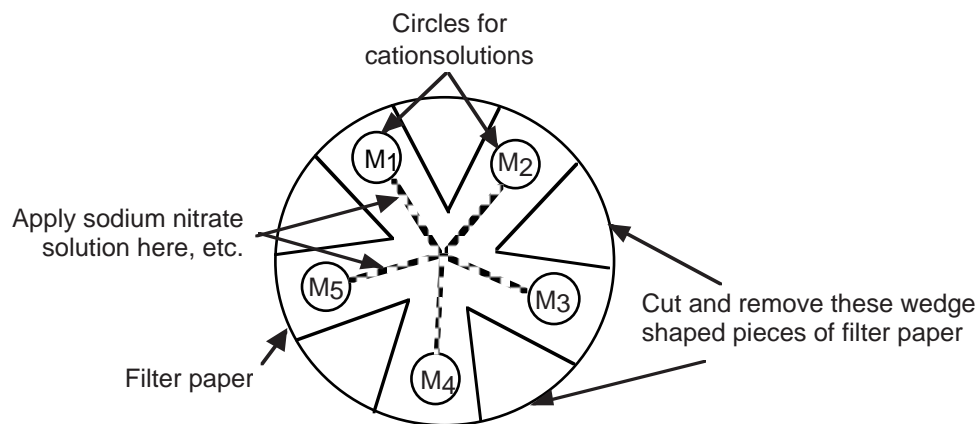
Reduction Potentials – Micro-Voltaic Cells

4. Get small pieces of the five metals designated as follows:

Number	M_1	M_2	M_3	M_4	M_5
Metal	Copper	Zinc	Lead	Silver	Iron

5. Sand each piece of metal on both sides. Place each metal near the circle on the filter paper that has the same number.

6. Place three drops of each solution on the appropriate circle (M_1^{2+} on M_1, etc.). Then place the piece of metal on the wet spot with its respective cation.
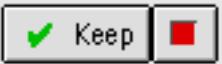
Caution!

Handle these solutions with care. Some are toxic and others cause hard-to-remove stains. If a spill occurs, inform your instructor.

Number	M_1^{2+}	M_2^{2+}	M_3^{2+}	M_4^{2+}	M_5^{2+}
Solution	Copper sulfate	Zinc sulfate	Lead nitrate	Silver nitrate	Iron sulfate
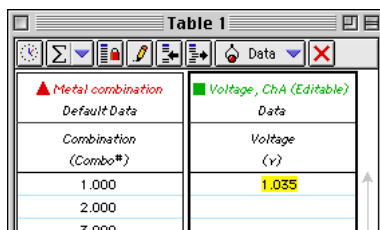
7. The top side of the metal should be kept dry.

8. Add enough 1 Molar sodium nitrate ($NaNO_3$) solution to make a continuous trail along a line drawn between each circle and the center of the filter paper.

9. You may have to dampen the filter paper with more NaNO3 during the experiment.

PART IIIA: Data Recording – Copper (M₁) as the Reference Metal

1.   Click on the Digits display to make it active. Move it so you can see it while recording data.

2.   Use M1 (copper) as the reference metal.

•   You will measure the potential of four cells by connecting M1 to M2 (copper to zinc), M1 to M3 (copper to lead), M1 to M4 (copper to silver), and M1 to M5 (copper to iron).

3.   When everything is ready, start recording data. In *DataStudio*, the 'Start' button changes to

a 'Keep' button [✔ Keep ■] .

> Note: For *ScienceWorkshop* instructions, see the appendix at the end of the activity.

4.   Touch the tip of the red (+) end of the Voltage Sensor to one metal sample (for example, M₁) and the tip of the black (-) end to the other metal sample (for example, M₂).

•   If the voltage drops to 0.00 V, reverse the ends of the Voltage Sensor, that is, switch the red (+) end of the sensor with the black (-) end of the sensor.

5.   Wait about 5 seconds. Record which metal (copper, M₁, or zinc, M₂) is touched by the red (+) end of the Voltage Sensor and which is touched by the black (–) end of the Voltage Sensor. Click 'Keep' to record the voltage in the Table display.

•   The voltage value will appear in the cell in the Table next to *"1"* in the Combination (Combo #) column.

6.   Use the same procedure to measure the potential of the other three 'cells' (pieces of metal) using copper, M₁, as the reference electrode.

•   In other words, measure the potential between copper, M₁, and lead, M₃, then between copper, M₁, and silver, M₄, and finally between copper, M₁, and iron, M₅.

7.   Touch the ends of the Voltage Sensor to the next pair of metal samples (M₁ and M₃).

•   Remember to switch the ends of the sensor if the voltage drops to 0.00 V.

8.   Click 'Keep', to record the voltage in the Table.

9.   Record which metal was touched by the tip of the red (+) end of the Voltage Sensor and which metal was touched by the black (-) end of the sensor.

10.   Analyze your data for copper and *make predictions* about the rest of the half-cell combinations before you make any measurements of voltage for the other half-cell combinations.

Record your data in the Lab Report section.

Analyzing the Data: PART IIIA - Copper (M₁) as the Reference Metal

1. After finishing Part IIIA of the procedure, use the measured voltages from your Table to arrange the five metals (including copper, M_1) in Data Table 2 from the <u>lowest</u> reduction potential at the top (most negative) to the <u>highest</u> reduction potential at the bottom (most positive).

- **Give copper, M_1, the reference metal, an arbitrary value of 0.000 V.**

- **If the other metal (e.g., zinc, M_2, lead, M_3, silver, M_4, or iron, M_5) was touched by the *negative* (black) end of the Voltage Sensor, place it *above* copper, M_1, in the chart (with a <u>negative</u> E° value).**

- **If the other metal was touched by the *positive* (red) end of the Voltage Sensor, place it *below* copper, M_1, in the chart (with a <u>positive</u> E° value).**

2. Also in Data Table 2, record the numerical value of the Reduction Potential (voltage) relative to copper, M_1, for each of the other metals (zinc, M_2, lead, M_3, silver, M_4, and iron M_5).

- **The Reduction Potential is the value that is recorded in the *DataStudio* Table display.**

- **Remember: If the metal is *above* copper in the list in Data Table 2, the Reduction Potential is negative. If the metal is *below* copper in the list in Data Table 2, the Reduction Potential is positive.**

Predictions

1. Calculate a <u>predicted</u> potential difference for each of the remaining half-cell combinations shown in Data Table 3 (M_2/M_3, M_2/M_4, M_3/M_5 and M_3/M_4, M_3/M_5 and M_4/M_5) using the reduction potentials you just determined (in Data Table 2).

2. Record the predicted cell potential differences in Data Table 3.

Record your predictions in the Lab Report section.

3. Go on to Part IIIB and finish the activity.

PART IIIB: Data Recording – Non-copper Reference Metals

1. Go back to data recording.

2. Measure the potential differences of the six remaining half-cell combinations using the same procedure as in Part IIIA.

- If the NaNO3 salt bridge solution has dried, you may re-moisten it.

3. Click 'Keep' to record each measured Reduction Potential (voltage) in the *DataStudio* Table display.

4. When you have finished your measurements, stop recording data.

Clean-Up

1. Use forceps to remove each of the pieces of metal from the filter paper. Remember to avoid getting the solutions on your hands.

2. Rinse each piece of metal with tap water, dry, and return it to the correct container.

3. Remove the filter paper from the glass plate using the forceps, and discard it as directed by your teacher. Rinse the glass plate with tap water, making sure that your hands do not come in contact with wet spots on the glass.

4. Clean and dry the ends of the Voltage Sensor. (Do not wash them. Instead, wipe the ends with a slightly damp paper towel and then dry them.)

Analyzing the Data: PART IIIB - Non-copper Reference Metals

1. Compare the measured half-cell reduction potentials with your *predicted* half-cell reduction potentials in Data Table 3.

2. Calculate the percent difference between your prediction and the measured value for each of the potentials you measured in Part IIIB.

•   **Optional:** Find the reduction potential chart in your textbook and identity of metals M_2 through M_5. If your book has an oxidation potential chart, all the reactions will be reversed and the signs will be switched on all the potentials. Reminder: H_2 has a reduction potential of 0.00 V on the textbook chart. Locate copper, M_1, on the chart, and then determine possible identities of the other metals using your experimental reduction potential sequence in Data Table 2. You must add the difference in potential between H_2 and copper to all values in Table 2. Note: One of the metals has a 1^+ oxidation state; the remainder of the metals have 2^+ oxidation states.

Record your data in the Lab Report section.

Lab Report - Activity SL16: Reduction Potentials in Micro-voltaic Cells

What do you think?

The purpose of this activity is to establish the reduction potentials of five metals relative to an arbitrarily chosen metal. Measure the voltage, or potential difference, between various pairs of 'half-cells'. Which pair of metals will have the largest reduction potential?

Data Table 1: Copper as the Reference Metal

Number	Combination	Potential	Metal For Red (+) Tip	Metal For Black (-) Tip
1	Copper/Zinc	V		
2	Copper/Lead	V		
3	Copper/Silver	V		
4	Copper/Iron	V		

Data Table 2: Rank the Metals

Metal	Lowest (-) Reduction Potential, E°
Zinc (Zn/Zn2+)	V
Iron (Fe/Fe2+)	V
Lead (Pb/Pb2+)	V
Copper (Cu/Cu2+)	0.000 V
Silver (Ag/Ag+)	V
	Highest (+) Reduction Potential, E°

Data Table 3: Predictions and Results

Number	Half-Cell Combination	Predicted Potential	Measured Potential	Percent Difference (%)
5	Zinc/Lead			
6	Zinc/Silver			
7	Zinc/Iron			
8	Lead/Silver			
9	Lead/Iron			
10	Iron/Silver			

Question

1.   How well did your predictions match the measured values for the potential differences
      measured using non-copper reference metals?

Appendix: Using Keyboard Sampling in ScienceWorkshop

- Do the following to record voltage data and the metal-to-metal combination using Keyboard Sampling in ScienceWorkshop.

1. Click on the Digits display to make it active. Move it so you can see it while recording data.

2. Use M1 (copper) as the reference metal.

- You will measure the potential of four cells by connecting M1 to M2 (copper to zinc), M1 to M3 (copper to lead), M1 to M4 (copper to silver), and M1 to M5 (copper to iron).

3. When everything is ready, start recording data.

- **The Keyboard Sampling window will appear.**

4. Touch the red (+) end of the Voltage Sensor to one metal sample (copper, M_1) and the black (-) end to the other metal sample (zinc, M_2).

- **If the voltage drops to 0.00 V, reverse the leads, that is, switch the red (+) lead and the black (-) lead.**

5. Wait about 5 seconds. Read the voltage in the Digits display and record the value in Data Table 1. Also record which metal (M_1 or M_2) is touched by the red (+) end of the Voltage Sensor and which is touched by the black (–) end of the Voltage Sensor.

6. Once you have recorded the voltage of the half-cell and which metal was touched by the red end of the sensor in your Data Table, go the Keyboard Sampling window.

7. In the Keyboard Sampling window, enter the <u>number</u> of the metal sample (either 1 or 2) that was touched by the red (+) lead of the Voltage Sensor. Click "Enter".

- **Your number will replace the default value in the Keyboard Sampling window. (NOTE: In this example, the number is "1".)**

- **This process creates the Table of Voltage (V) and [+] Lead (M#) and makes a record of the potentials measured.**

8. Use the same procedure and measure the potential of the other three cells, continuing to use M_1 as the reference electrode. (In other words, measure the potential between M_1 and M_3, then between M_1 and M_4, and finally between M_1 and M_5).

9. Touch the ends of the sensor to the next pair of metal samples (M_1 and M_3). Remember; switch the ends of the sensor if the voltage drops to 0.00 V.

10. Read and record the voltage in Data Table 1.

11. Also record the label (e.g., M_1 or M_3, etc.) of the metal that was touched by the red (+) end in the Data Table.

12. Go to the Keyboard Sampling window and enter the <u>number</u> of the metal (e.g., 1 or 3) that was touched by the red (+) end of the sensor. Click "Enter".

13. When you have recorded data for the half-cells using M1 (copper) as the reference metal, click the "Pause" button to temporarily halt data recording while you analyze your data for Part IIIA.

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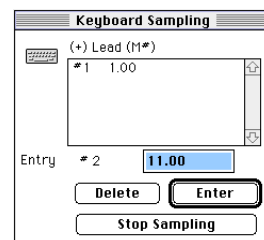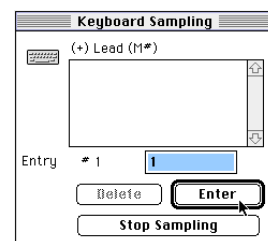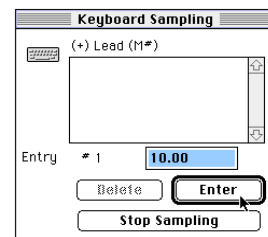
Activity SL17: Fruit Battery – Electricity
(Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electricity	GS01 Fruit Battery.ds	G01 Fruit Battery	G01_BATT.SWS

Equipment Needed	Qty	Consumables	Qty
Voltage Sensor (CI-6503)	1	Apple or other medium size fruit	1
Copper wire, 2 or 3 inches long	1		
Zinc (galvanized) nail	1		
Protective gear	PS		

What Do You Think?

In this activity you will measure the **voltage** of a "fruit battery*" using a Voltage Sensor. What type of fruit will produce the most voltage? (*In this activity, the word 'battery' will be used in place of 'cell'.)

Take time to write an answer to this question in the Lab Report section.

Background

One form of energy can be converted into another. For example, the energy stored in a piece of food can be converted into energy that helps you grow and move. The energy stored in certain kinds of food can also be converted into electricity. A piece of fruit such as an apple or orange can produce a **voltage** when **electrodes** made of different metals are placed into the fruit.

An electrode is made from a material that can conduct electricity.

For You To Do

The Voltage Sensor has a pair of flexible insulated wires joined by a type of plug called a **DIN plug**. The plugs at each end of the wires are called **banana plugs**. The Voltage Sensor comes with a pair of clips called **alligator clips** that can be slipped onto the end of the banana plugs.
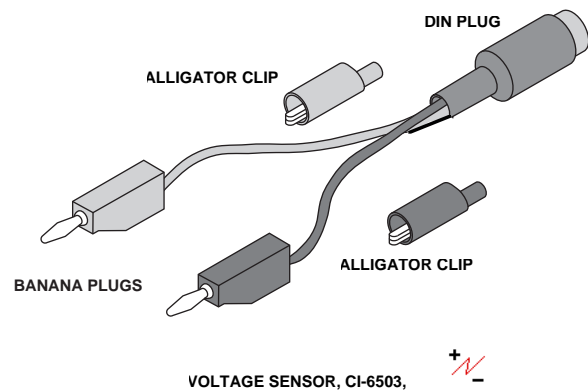
For this activity, use the Voltage Sensor to measure the voltage (or potential difference) produced by a piece of fruit that has a copper electrode (copper wire) and a zinc electrode (galvanized nail) in it. Use *DataStudio* or *ScienceWorkshop* to record and display the measured voltages.

SAFETY REMINDERS	
• Follow directions carefully when using the equipment for this activity.	THINK SAFETY ACT SAFELY BE SAFE!
• Wear protective gear (e.g., goggles, gloves, apron).	

Prediction

Will the voltage from a piece of fruit be as much as the voltage from a D size dry cell battery (about 1.5 volts)? Predict what the voltage will be from the piece of fruit. Record your prediction and the type of fruit you are going to use.

Type of fruit	Predicted voltage (V)

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and then turn on the computer.

2. Connect the Voltage Sensor DIN plug into Analog Channel A on the interface.

3. Open the file as shown:
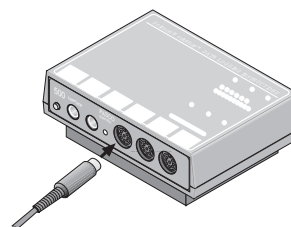
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
GS01 Fruit Battery.ds	G01 Fruit Battery	G01_BATT.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document has an Experiment Setup window and an Experiment Notes window. It also has a Table display, a Digits display, and a Meter display, all showing voltage.

- Data recording is set for ten measurements per second, or 10 Hz.

Experiment Setup window:

The window shows an icon for the kind of sensor. For this activity, the window shows the icon for the Voltage Sensor below Analog Channel A.
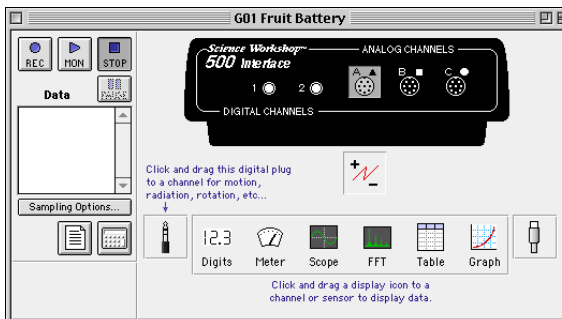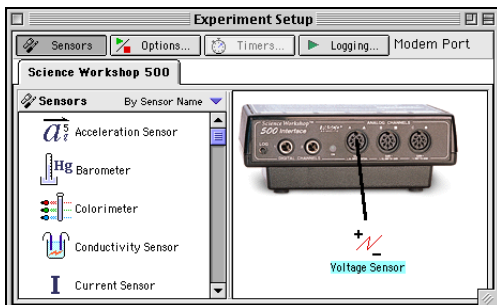
Digits display:
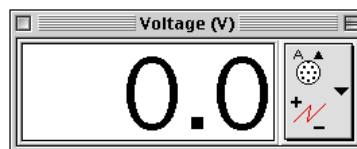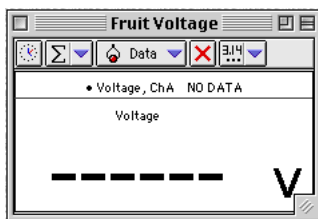
Meter display:
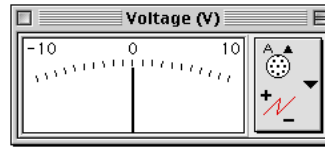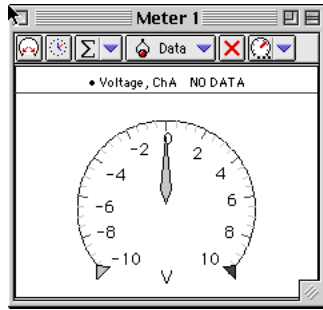
Table display:

The Table display has a display area that is similar to columns in a spreadsheet.

PART II: Equipment Setup

1. Stick the piece of copper wire and the galvanized nail into the piece of fruit to turn it into a battery.

Galvanized nail

Copper wire

Alligator clip
(included with
Voltage
Sensor)

Fruit

Voltage Sensor

To Interface

Fruit Battery
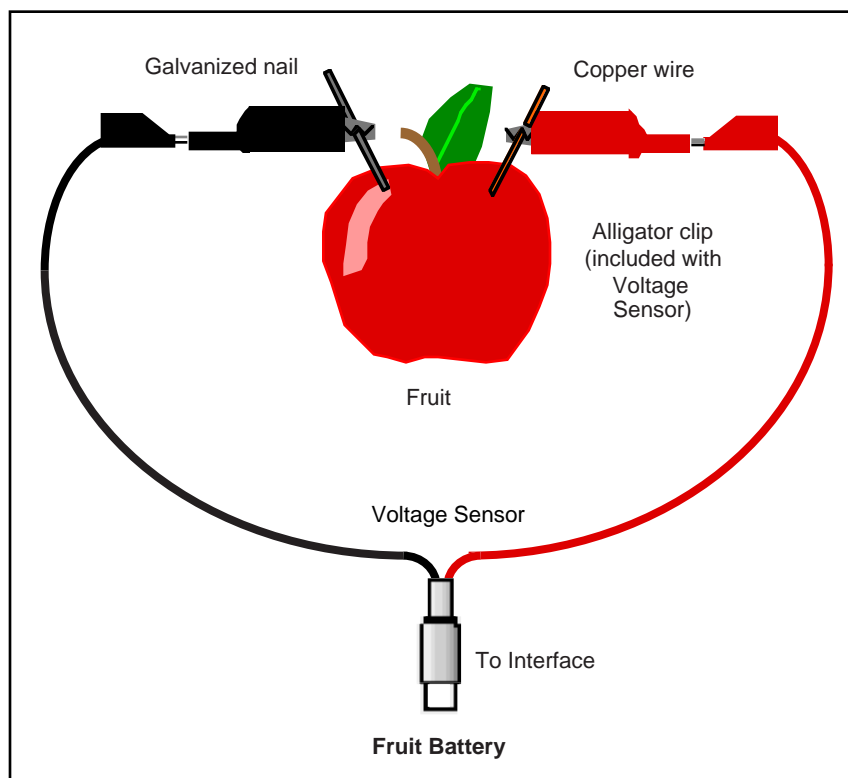
2. Put alligator clips on the ends of the Voltage Sensor leads. Connect the red end of the Voltage Sensor to the copper wire and the black end of the Voltage Sensor to the nail.

PART III: Data Recording

1. Start recording data.

•   Watch the values of voltage in the Digits display and Meter display.

2. Record data for about 10 seconds.

3. Stop recording data.

Analyzing the Data

1. Set up the Table to show statistics.

2. Record the Max (maximum) value of voltage in the Data Table.

Record your results in the Lab Report section.

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Lab Report - Activity SL17: Fruit Battery

What Do You Think?

In this activity you will measure the **voltage** of a "fruit battery*" using a Voltage Sensor. What type of fruit will produce the most voltage? (*In this activity, the word 'battery' will be used in place of 'cell'.)

Data Table

Type of Fruit	Maximum Voltage (V)

Optional

- Try inserting the electrodes to different depths.
- Try inserting the electrodes closer to each other or farther away from each other.
- Try different kinds of fruit.
- Try different <u>sizes</u> of the same kind of fruit.

Questions

1. How does your prediction compare to the actual value of maximum voltage? (Was your prediction lower, higher, or very close?)

2. If you tried any of the optional activities, what were the results?

a. Did changing how far in the electrodes were make the voltage go up, go down, or stay the same?

b. Did putting the electrodes closer together make the voltage go up, go down, or stay the same?

c. Did putting the electrodes farther apart make the voltage go up, go down, or stay the same?

d. Did a different kind of fruit make any difference? If so, what was the kind of fruit, and was its voltage higher or lower than your first piece of fruit?

e. Did a different size of your kind of fruit make a difference? If so, did the voltage go up or go down?

Ending the Activity

•   **Check with your instructor about putting away the equipment for this activity.**

•   **Check with your instructor about disposing of the pieces of fruit after you are done with them.**

Activity SL18: Mixing Hot and Cold Water – Thermodynamics (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Thermodynamics	GS03 Mix Hot and Cold.DS	G03 Hot and Cold	G03_HOT.SWS

Equipment Needed	Qty	Consumables	Qty
Temperature Sensor (CI-6505A)	1	Water, hot	150 mL
Beaker, 250 mL	2	Water, ice	200 mL
Graduated cylinder, 100 mL	1		
Protective gear	PS		

What Do You Think?

When masses of substances at different temperatures are mixed together, the hotter substance heats the cooler substance and the resulting final temperature is somewhere between the initial temperatures of the two substances. Can you predict the final temperature of a mixture of two substances?

Take time to write an answer to this question in the Lab Report section.

Background

Temperature is a measure of the average **kinetic energy** (energy of motion) of the particles in a substance. The **thermal energy** in the substance is the total of all the kinetic energy of all the particles in the substance. The thermal energy in a substance depends on the mass of the substance, the **specific heat capacity** of the substance, and the temperature of the substance.

HOT WATER   **COLD WATER**

ICE

WHAT WILL THE TEMPERATURE OF THE MIXTURE BE COMPARED TO THE TEMPERATURE OF THE HOT WATER AND THE COLD WATER?

Heat is the name given to thermal energy when it moves from a substance with a high temperature to a substance with a lower temperature. Heat is energy in transit.

When substances of different temperatures are mixed, the hotter one heats the cooler one until the temperature of the mixture reaches a balance called **thermal equilibrium**.

The thermal energy in an object depends on the amount of mass, the specific heat of the object, and its temperature. In equation form:

$$\Delta Q \text{ (change in thermal energy)} = m\ c\ \Delta T$$

where **m** is the mass in grams, **c** is the specific heat and ΔT is the change in temperature.

The value for the specific heat, **c**, of water is 1.0 cal/g ˚C or 4.19 J/g ˚C. This value is constant between the temperatures of 0˚ C and 100 ˚C.

When a hot substance heats a cooler one, the energy 'lost" by the hot substance equals the energy 'gained' by the cooler one, or (in equation form):

$$Q_{lost} = Q_{gained}$$

For You To Do

For this activity, use mathematical logic and algebra to predict the final temperature of a mixture of hot and cold water. Then use the Temperature Sensor to measure the temperature of a hot liquid and the temperature of a cold liquid before they are mixed. Use the Temperature Sensor to measures the temperature of the mixture. Use insulated containers so that the containers will not gain or lose thermal energy during the activity.

This activity has two parts. In PART A, the amount of hot liquid <u>is the same as</u> the amount of cold liquid. In PART B, you will use <u>different amounts</u> of each liquid. You will make predictions for the final equilibrium temperature for the mixture based on the temperature of the hot and cold liquids before they are mixed.

Use *DataStudio* or *Science Workshop* to record, display, and analyze the data on a Graph.

Prediction: PART A

Will the temperature of a mixture of hot and cold water be the same as the temperature of the hot water by itself or the cold water by itself?

- Predict what the final temperature will be for the mixture of the hot and cold water compared to the temperature of either the hot water by itself or the cold water by itself. Imagine that the hot water is at 70 ˚C and the cold water is at 10 ˚C. For PART A assume that *equal* amounts of water are mixed together.

Starting temp. of hot water	Starting temp. of cold water	Predicted temp. of mixture
70 ˚C*	10 ˚C*	

(*These temperatures are just examples.)

SAFETY REMINDERS

- Wear protective gear while handling hot water containers.

- Follow directions for using the equipment.

Name _____   Class _____   Date _____

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and then turn on the computer.

2. Connect the Temperature Sensor DIN plug into Analog Channel A on the interface.

3. Open the file as shown:
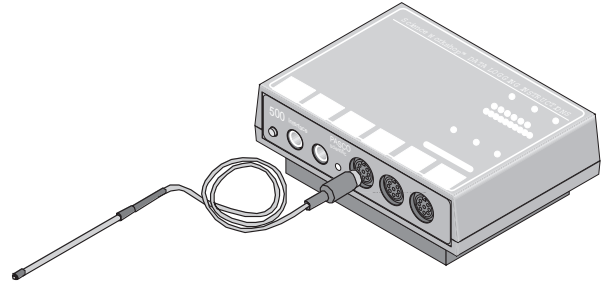
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
GS03 Mix Hot and Cold.DS	G03 Hot and Cold	G03_HOT.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document has a Graph display of temperature versus time.

- Data recording is set for ten measurements per second (or 10 Hz).

See the *DataStudio* Online Help file or the *ScienceWorkshop* User's Guide for more information about the Graph display.
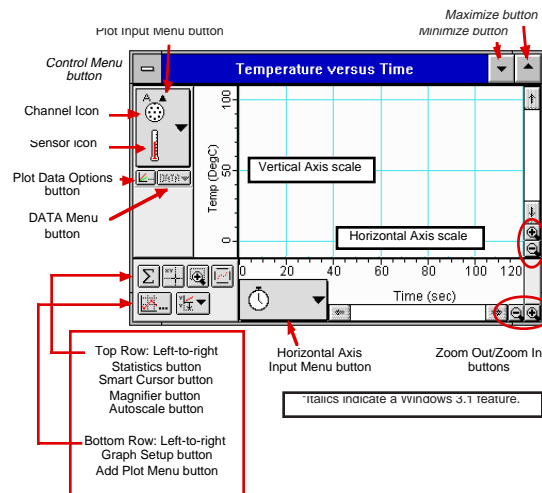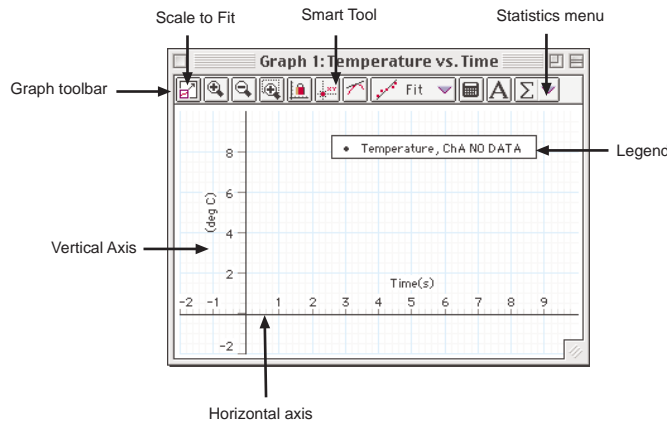
PART IIA: Equipment Setup – Equal Amounts of Hot and Cold Water

1.   Put 100 mL (milliliters) of cold water into the first container so that it is slightly less than half full.

2.   Put 100 mL of hot water into the second container so that is also slightly less than half full.

TEMPERATURE SENSOR

TO INTERFACE

COLD WATER

HOT WATER

HOT AND COLD - THERMODYNAMICS
(TEMPERATURE SENSOR)
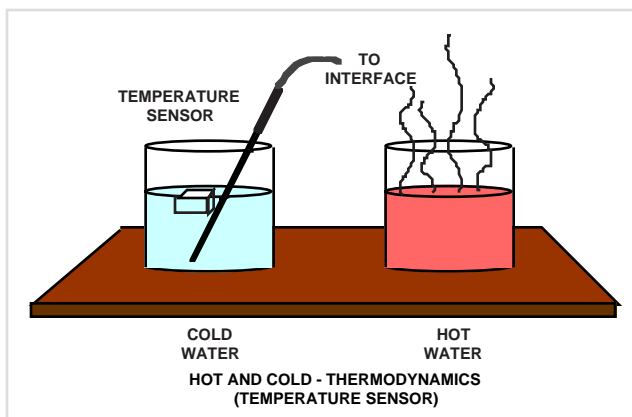
PART IIIA: Data Recording – Equal Amounts of Hot and Cold Water

1.   Place the Temperature Sensor into the cold water. Start recording data. Watch the values of temperature in the Graph display.

2.   After about 40 seconds, move the Temperature Sensor to the hot water.

3.   After a total of 80 seconds, <u>remove the Temperature Sensor from the hot water</u>. Pour the hot water into the cold water.

4.   Quickly place the Temperature Sensor into the combined liquids. Stir to thoroughly mix the two liquids.

5.   Stop data recording after 120 seconds.

STEP 1: MEASURE THE TEMPERATURE OF THE COLD WATER.

STEP 2: MEASURE THE TEMPERATURE OF THE HOT WATER.

STEP 3: POUR THE HOT WATER INTO THE COLD WATER.

STEP 4: MEASURE THE TEMPERATURE OF THE MIXTURE.

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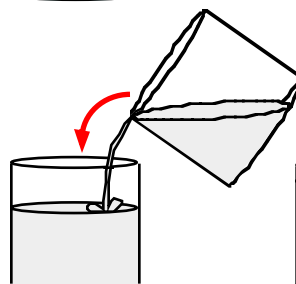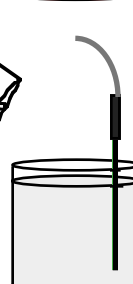
Analyzing the Data: PART A – Equal Amounts of Hot and Cold Water

1. Rescale the Graph to fit your data.

2. Find and record the LOWEST temperature in the Graph (the Y-coordinate of the lowest point in the Graph).

•   Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*.

3. Find and record the HIGHEST temperature in the Graph (the Y-coordinate of the highest point in the Graph).

4. Find and record the <u>final</u> temperature of the combined liquids (the Y-coordinate at the end of the plot).
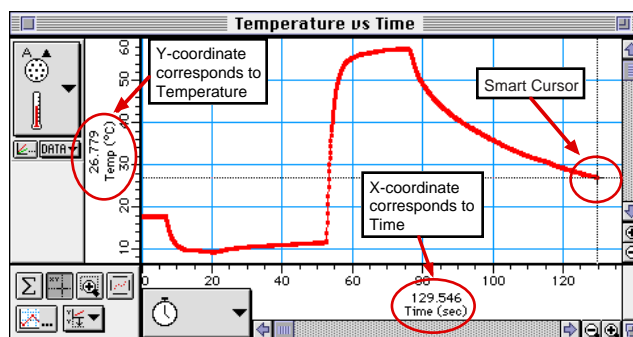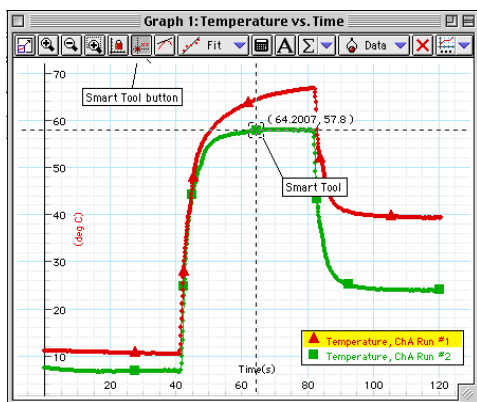
Record your results in the Lab Report section.

Procedure: PART B – Unequal Amounts of Hot and Cold Water

For this part of the activity, measure the temperature of hot water and cold water before and after they are mixed, but use unequal amounts of hot and cold water.

Prediction: PART B – Unequal Amounts of Hot and Cold Water

Will the final temperature of unequal amounts of hot and cold water be the same as the final temperature of equal amounts of hot water and cold water?

1.   Predict what the final temperature will be for the mixture of the hot and cold water compared to the temperature of either the hot water by itself or the cold water by itself. (Imagine that you have 50 mL of hot water at 70 ˚C and 100 mL of cold water at 10 ˚C.)

Temp. of hot water (50 mL)	Temp. of cold water (100 mL)	Predicted temp. of mixture
70 ˚C*	10 ˚C*	

(*These temperatures are just examples.)

PART IIB: Equipment Setup – Unequal Amounts of Hot and Cold Water

1.   Put 100 mL (milliliters) of cold water into the first container so that it is slightly less than half full.

2.   Put 50 mL of hot water into the second container.
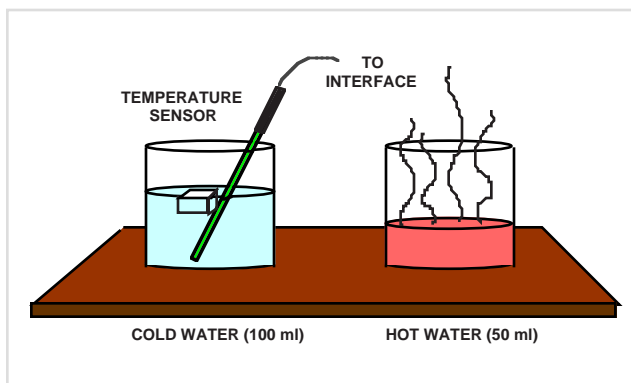
PART IIIB: Data Recording – Unequal Amounts of Hot and Cold Water

1.   Place the Temperature Sensor into the cold water. Start recording data. Watch the values of temperature in the Graph display.

2.   After about 40 seconds, move the Temperature Sensor to the hot water.

3.   After a total of 80 seconds, remove the Temperature Sensor from the hot water. Pour the hot water into the cold water.

4.   Quickly place the Temperature Sensor into the combined liquids. Stir to thoroughly mix the two liquids.

5.   Stop end data recording after 120 seconds.

TEMPERATURE SENSOR

TO INTERFACE

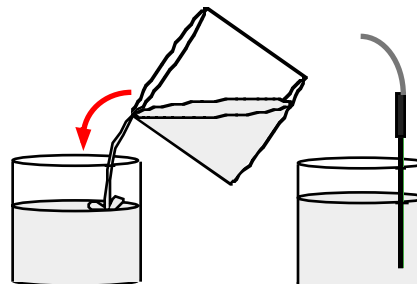COLD WATER (100 ml)   HOT WATER (50 ml)

STEP 1: MEASURE THE TEMPERATURE OF THE COLD WATER.

STEP 2: MEASURE THE TEMPERATURE OF THE HOT WATER.

STEP 3: POUR THE HOT WATER INTO THE COLD WATER.

STEP 4: MEASURE THE TEMPERATURE OF THE MIXTURE.

Name _____   Class _____   Date _____
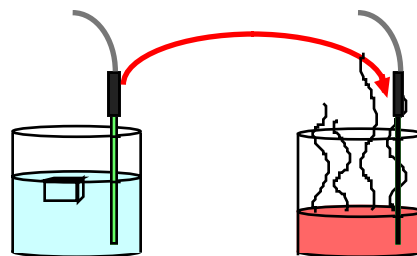
Analyzing the Data: PART B – Unequal Amounts of Hot and Cold Water

1. Rescale the Graph to fit your data.

2. Find and record the LOWEST temperature in the Graph (the Y-coordinate of the lowest point in the Graph).

3. Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*.

4. Find and record the HIGHEST temperature in the Graph (the Y-coordinate of the highest point in the Graph).

5. Find and record the <u>final</u> temperature of the combined liquids (the Y-coordinate at the end of the plot).
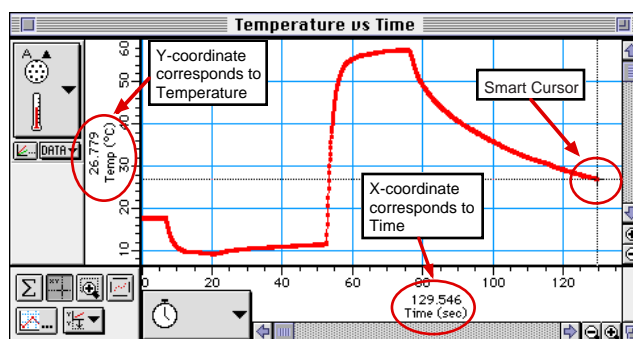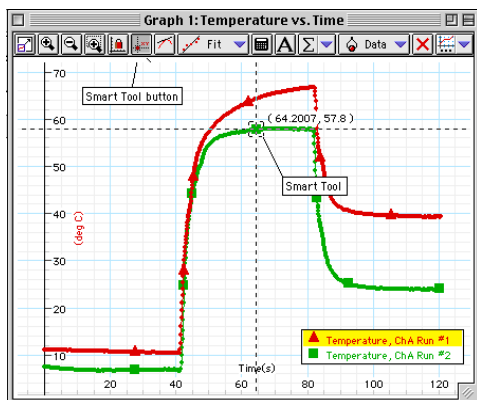
Record your results in the Lab Report section.

Lab Report - Activity SL18: Mixing Hot and Cold Water

What Do You Think?

When masses of substances at different temperatures are mixed together, the hotter substance heats the cooler substance and the resulting final temperature is somewhere between the initial temperatures of the two substances. Can you predict the final temperature of a mixture of two substances?

Prediction: PART A – Equal Amounts of Hot and Cold Water

Will the temperature of a mixture of hot and cold water be the same as the temperature of the hot water by itself or the cold water by itself?

- Predict what the final temperature will be for the mixture of the hot and cold water compared to the temperature of either the hot water by itself or the cold water by itself.

Starting temp. of hot water	Starting temp. of cold water	Predicted temp. of mixture

Data Table: PART A – Equal Amounts of Hot and Cold Water

LOWEST Temperature	HIGHEST Temperature	Final Temperature

Prediction: PART B – Unequal Amounts of Hot and Cold Water

Will the final temperature of unequal amounts of hot and cold water be the same as the final temperature of equal amounts of hot water and cold water?

- Predict what the final temperature will be for the mixture of the hot and cold water compared to the temperature of either the hot water by itself or the cold water by itself.

Temp. of hot water (50 mL)	Temp. of cold water (100 mL)	Predicted temp. of mixture

Data Table: PART B – Unequal Amounts of Hot and Cold Water

LOWEST Temperature	HIGHEST Temperature	Final Temperature

Questions

1. In PART A, how does the <u>final</u> temperature of the mixture compare to the lowest temperature of the 100 mL of cold water and the highest temperature of the 100 mL of hot water?

2.   In PART B, how does the final temperature of the mixture compare to the lowest
       temperature of the 100 mL of cold water and the highest temperature of the 50 mL of hot
       water?

3.   How does the final temperature in PART A compare to your prediction?

4.   How does the final temperature in PART B compare to your prediction?

5.   If the initial temperatures of the hot and cold water were increased by the same amount,
       how would this effect the final temperature of the new mixture?

Conclusion

•   Write a sentence that describes how to predict a final temperature for a mixture of hot and
       cold liquids based on the amount of each liquid and the starting temperature of each liquid.

Optional

Predict the final temperature of these mixtures:

100 mL of 10 ˚C water and 100 mL of 40 ˚C water.

200 mL of 10 ˚C water and 100 mL of 40 ˚C water.

100 mL of 10 ˚C water and 200 mL of 40 ˚C water.

300 mL of 10 ˚C water and 100 mL of 40 ˚C water.

100 mL of 10 ˚C water and 300 mL of 40 ˚C water.

100 mL of 0 ˚C water and 100 mL of 100 ˚C water.

100 mL of 20 ˚C water and 200 mL of 50 ˚C water.

Activity SL19: Insolation – Solar Radiation
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	GS16 Insolation.DS	G16 Insolation	G16_SUN.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Cardboard, 15 by 15 cm	1
Clock	1	Ice, cube	2 – 3
Cup	1	Paper towel	1
Lamp (100 W or 150 W) - OPTIONAL	1	Straw	1
Protractor (for measuring angles)	1	Tape	1 roll
		Water	100 mL

This activity can be done outdoors on a sunny day. The best time is at noon.

What Do You Think?

Skin doctors warn us that over exposure to the radiation from the sun is harmful to our skin and can possibly lead to skin cancer. What time of the day are the sun's rays most absorbed by our skin? What do you think? Is there a relation to the amount of radiation absorbed and the angle at which the sun's rays strike the skin?

Take time to write answers to these questions in the Lab Report section.

Background

The Sun accounts for 99.9% of the energy that Earth gets at its surface. (Heat moving upward from Earth's core makes up the small remainder). **Insolation** is solar radiation, or energy received from the Sun. Insolation is made up of **ultraviolet** and visible light and **infrared** solar radiation.

The amount of energy that the entire Earth receives from the Sun remains fairly constant from year to year, but the amount of energy that a particular spot on Earth receives may change a great deal from day to day. One thing that makes a difference is the angle of the sunlight that hits the Earth's surface.
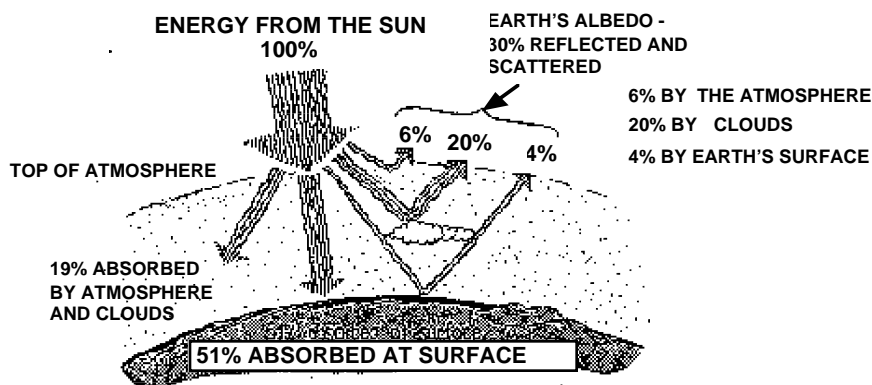
If the angle at which the sunlight hits the Earth's surface is almost vertical (90°), the amount of energy that is soaked up by a square meter of area at that part of the Earth's surface is a maximum. If the sunlight hits the Earth's surface at a smaller angle than ninety degrees, the amount of energy that is soaked up by a square meter of area is less.

At higher latitudes on the Earth's surface, the angle can be very small, so the amount of energy that is soaked up can also be very small.

If three surfaces of equal area start with the same temperature and are exposed to sunlight for the same amount of time, but the three surfaces are at <u>different</u> angles to the sunlight, the <u>change</u> in temperature for each surface should also be different.

ANGLE OF SUNLIGHT IS 30˚

ANGLE OF SUNLIGHT IS 60˚

ANGLE OF SUNLIGHT IS 90˚

(The amount of solar radiation, or insolation, received by the Earth is enormous. The amount of energy received each second over each square meter of area that is at right angles (90˚) to the Sun's rays at the top of the atmosphere is 1400 joules. In power units, this is 1400 watts per square meter, or 1.4 kilowatts per square meter.)
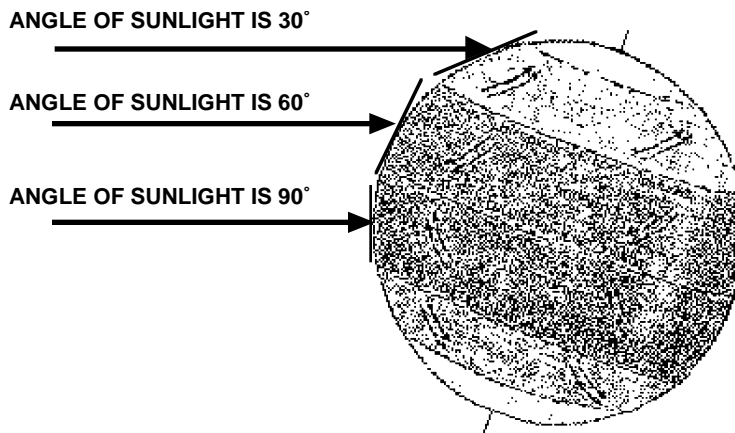
SAFETY REMINDERS

- Protect your eyes and skin from direct sunlight.

- Follow directions for using the equipment.

- If you do this activity using a lamp, be careful not to tough it when it gets hot.

**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

In this activity, measure the amount of energy from the sun's rays as it strikes a piece of paper at different angles. Use a temperature sensor to measure the temperature of the paper and compare data of angle of incidence and temperature. Use *DataStudio* or *ScienceWorkshop* to record and display your data.

NOTE: One option for this activity is to use the *ScienceWorkshop 500 Interface* out-of-doors. The *ScienceWorkshop 500 Interface* can be programmed to record data, and then disconnected from the computer. You can carry it outdoors, record the data, and then re-connect it to the computer to analyze the data.

1. PROGRAM THE INTERFACE WHILE CONNECTED TO THE COMPUTER

This procedure will describe how to use the *Science Workshop 500 Interface* and the Temperature Sensor to measure the insolation (solar radiation) outdoors. The last section of this activity will describe how to record data using a lamp as a simulation of the Sun.

2. DISCONNECT THE INTERFACE AND GO COLLECT DATA

In this activity the Temperature Sensor measures the temperature at the surface of a piece of cardboard that is exposed to solar radiation (sunlight) at three different angles.

**3. RE-CONNECT THE INTERFACE AND ANALYZE THE DATA**

You will use the protractor and straw to measure the angle that the sunlight makes with the piece of cardboard.
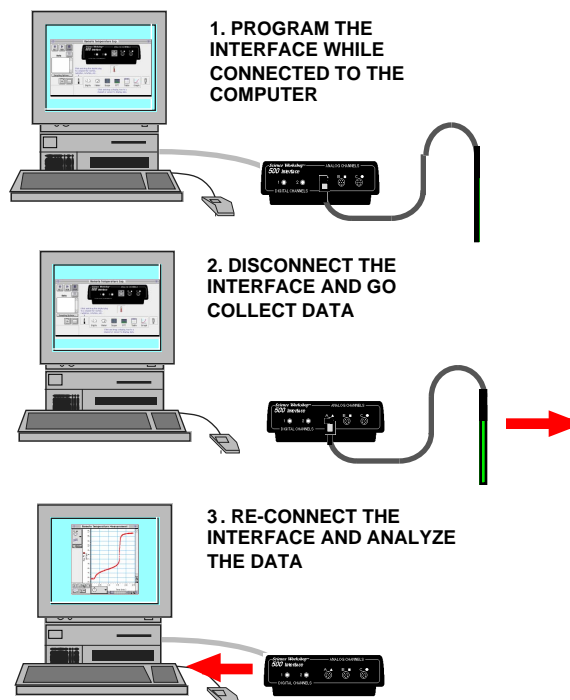
The *Science Workshop 500 Interface* records the temperature data. The program downloads the data from the interface and then displays the data for analysis.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the DIN plug of the Temperature Sensor into Analog Channel A on the interface.

3. Open the file titled as shown;
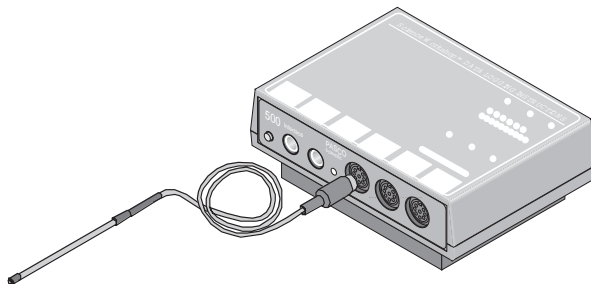
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
GS16 Insolation.DS	G16 Insolation	G16_SUN.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The ScienceWorkshop document has a Graph display of Temperature versus Time.

- Data recording is set at 1 sec (or one measurement per second).

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Temperature Sensor.

1. Use a piece of cardboard that is approximately square and about 15 x 15 cm (or 6 x 6 inches). Tape the protractor at the center of one edge of the piece of cardboard so the protractor is at right angles to the piece of cardboard.

2. Put some ice and water into the cup.

- You will use the ice water to cool the tip of the Temperature Sensor before each trial of data recording.
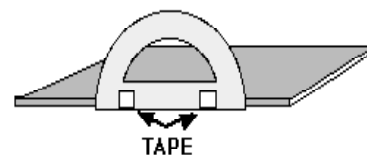
PART III: Data Recording

NOTE: Data recording for this activity has several steps:

- The first step in data recording is to get the interface ready to make measurements and disconnect it from the computer.

- The second step in data recording is to line up the Temperature Sensor and cardboard with the sunlight.

- The third step in data recording is to make measurements of the change in temperature for three different angles of sunlight. You will do this by lining up the cardboard at 90˚, 60˚, and 30˚ to the sunlight.

- The final step in data recording is to reconnect the interface to the computer.

Prepare the Interface

• Make sure that there are four AA alkaline batteries in the interface battery compartment.

• Make sure that the POWER switch on the back panel of the interface is **ON**.

1. Click the **Experiment** menu in the menu bar. Select **Disconnect for Logging...** from the **Experiment** menu.

LIGHT-EMITTING
DIODE (LED)

DATA LOGGING
BUTTON

• The Data Logging Setup window will open. If your computer is connected to a printer, click **Print Checklist**.

LED BLINK RATES:
SLEEP MODE = ONE BLINK EVERY FIVE SECONDS
WAKE UP MODE = ONE BLINK EVERY SECOND FOR ABOUT TEN SECONDS
DATA LOGGING MODE = SEVERAL BLINKS EVERY SECOND

2. Click **Begin Logging**.

• The interface goes into "sleep" mode. The green light-emitting diode (LED) on the front panel of the interface will go out, and then will blink once every five seconds.

INTERFACE
CABLE

PLUG FROM
POWER
SUPPLY

POWER SWITCH = ON

3. Disconnect the interface from the computer. Unplug the power cord and the interface cable from the back of the interface box.

INTERFACE

4. Take the interface with Temperature Sensor, a straw, the cup of ice water, tape, paper towels, the clock, and the protractor/cardboard setup outside. Find an open area next to a sunny, south-facing wall.
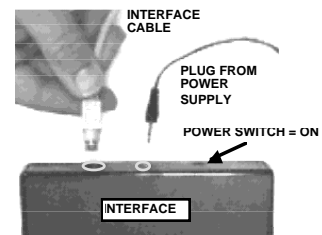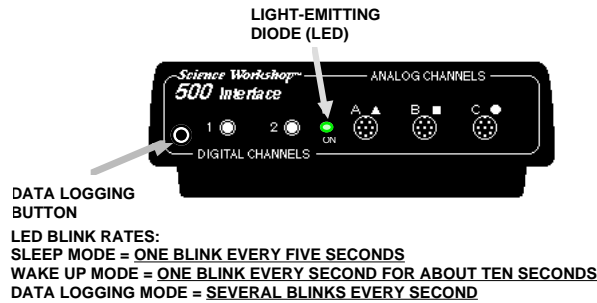
Line Up the Temperature Sensor

1. Place the protractor/cardboard setup at the base of the wall so that the cardboard is at about right angles to the sunlight.

2. Hold the straw against the side of the protractor. Put the end of the straw next to the center line of the protractor.

*   Keep a small gap between the end of the straw and the cardboard. Line up the straw with the 90 degree mark along the curved edge of the protractor. Use a piece of tape to help hold the straw in place.

3. Adjust the protractor/cardboard setup up or down along the wall until the straw makes no shadow and is <u>directly in line with the sunlight</u>.

90˚ on PROTRACTOR

SUNLIGHT

STRAW

WALL

PROTRACTOR

TEMPERATURE SENSOR & CARDBOARD SETUP

*   When the straw is directly in line with the sunlight, a spot of sunlight shows up on the cardboard below the end of the straw.

STRAW

SPOT OF SUNLIGHT BELOW THE END OF THE STRAW

PROTRACTOR
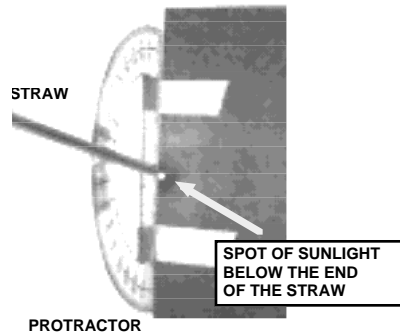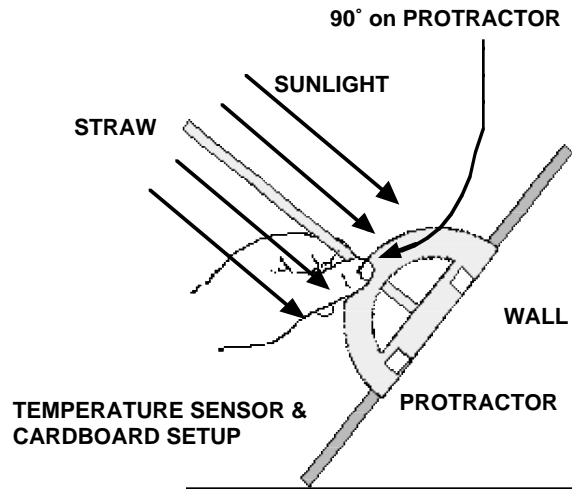
4. Put pieces of tape at the top and bottom edges of the cardboard to temporarily hold it in place against the wall.

5. Put the end of the Temperature Sensor into the cup of ice water for about ten seconds to cool it down. Remove the Temperature Sensor and dry it off.

CARDBOARD

TEMPERATURE SENSOR

TAPE

PROTRACTOR
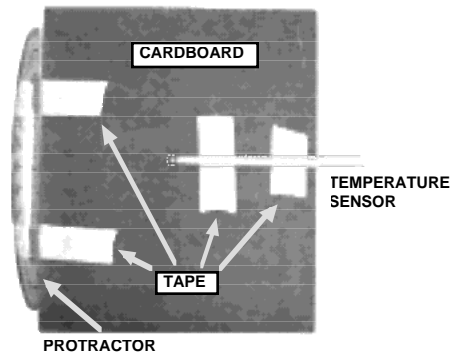
6. CAREFULLY tape the Temperature Sensor onto the cardboard so the tip of the sensor is about in the center of the piece of cardboard. (See the diagram.)

7.   Get the clock ready to keep track of the time. You will record data for ten minutes for each
      angle.

Record the Data

1.   When you are ready to record data, press the
      <u>Data Logging</u> button on the front panel of the
      interface to "wake up" the interface.

•   The green LED on the interface will blink once
   per second for <u>ten seconds</u> as the interface
      wakes up.
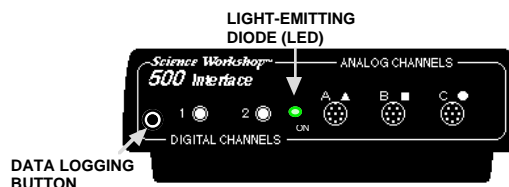
Get ready to record the time on the clock when the LED begins to blink rapidly.

•   The green LED will blink rapidly (several times per second) when the interface starts to
      record data.

2.   Record the starting time for data recording. Let the interface record data for <u>ten</u> minutes.

3.   At the end of ten minutes, press and hold the Data Logging button until the LED goes out
      to stop recording data.

•   The green LED will blink once every five seconds. The interface is in "sleep" mode.

4.   Remove the Temperature Sensor from the protractor/cardboard setup.

5.   Remove the tape from the straw. Move
      the straw so the end of the straw is next
      to the center line of the protractor, but
      the straw is lined up with 60˚ on the
      curved edge of the protractor. Re-attach
      the tape to the straw to hold the straw in
      place.

6.   Remove the tape from the top and
      bottom edges of the cardboard. Adjust
      the cardboard until the straw makes no
      shadow and a spot of sunlight shines
      through the straw onto the cardboard.
      Re-attach the tape to hold the cardboard
      in place.

7.   Put the Temperature Sensor into the ice water for about ten seconds to cool it down.
      Remove the sensor and dry it off.

8.   CAREFULLY tape the Temperature Sensor back into position on the cardboard.

9.   Get ready to record data for ten minutes.

10.   Press the Data Logging button to "wake up" the interface.

•   The green LED will blink once per second for ten seconds as the interface "wakes up".

11.   Data recording begins when the LED starts blinking rapidly. Let the interface record for
      ten minutes.

12.   At the end of ten minutes, press and hold the Data Logging button until the LED goes out
      to stop data recording.

•   The green LED will blink once every five seconds. The interface is in "sleep" mode.

13.   Remove the Temperature Sensor from the protractor/cardboard setup.
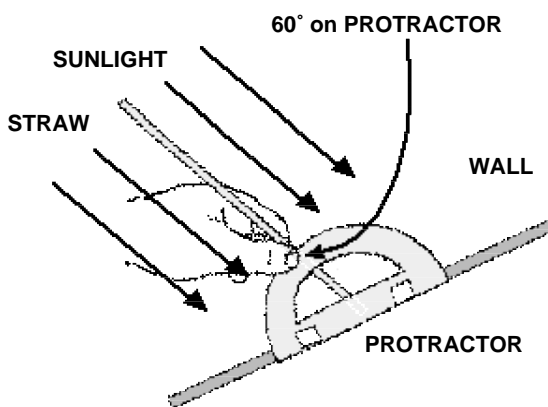
14.   Remove the tape from the straw. Move the straw so the end of the straw is next to the center line of the protractor, but the straw is lined up with 30˚ on the curved edge of the protractor. Re-attach the tape to the straw to hold the straw in place.
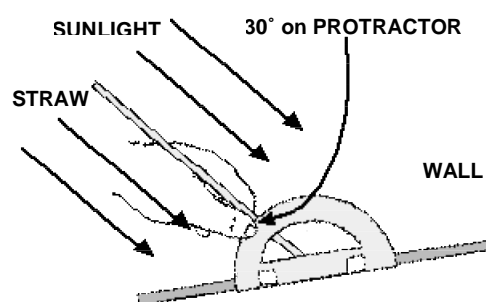
15.   Remove the tape from the top and bottom edges of the cardboard. Adjust the cardboard until the straw makes no shadow and a spot of sunlight shines through the straw onto the cardboard. Re-attach the tape to the wall to hold the cardboard in place.

16.   Put the Temperature Sensor into the ice water for about ten seconds to cool it down. Remove the sensor and dry it off.

17.   CAREFULLY tape the Temperature Sensor back into position on the cardboard.

18.   Get ready to record data for ten minutes.

19.   Press the Data Logging button to "wake up" the interface.

•   The green LED will blink once per second for ten seconds as the interface "wakes up".

20.   Data recording begins when the LED starts blinking rapidly. Let the interface record for ten minutes.

21.   At the end of ten minutes, press and hold the Data Logging button until the LED goes out to stop data recording.

•   The green LED will blink once every five seconds. The interface is in "sleep" mode.

22.   Take the interface and the rest of your equipment indoors.

Re-connect the Interface

1.   Plug the interface cable and the power cord into the back panel on the interface.

NOTE: The LED will continue to blink once every five seconds.

2.   Download the data from the interface box to your computer.

•   In the program, select **Connect To Interface** from the **Experiment** menu.

•   The green LED will stay ON.

Analyzing the Data

1. Set up you Graph display to show Statistics for the Minimum and Maximum values of temperature.

•   Hint: In *DataStudio*, click the Statistics Menu button. In *ScienceWorkshop*, click the Statistics button to open the Statistics area on the right side of the Graph. Then click the Statistics Menu button.

2. Record the Minimum y as the Initial Temperature for Run #1. Record the Maximum y as the Final Temperature for Run #1.

3. Repeat the procedure to find the initial and final temperatures for Run #2.

4. Repeat the procedure to find the initial and final temperatures for Run #3.

5. Calculate the Change in Temperature for each run by subtracting the initial temperature from the final temperature.

Record your results in the Lab Report section.

Lab Report - Activity SL19: Insolation – Solar Radiation

What Do You Think?

Skin doctors warn us that over exposure to the radiation from the sun is harmful to our skin and can possibly lead to skin cancer. What time of the day are the sun's rays most absorbed by our skin? What is the relationship between the amount of radiation absorbed and the angle at which the sun's rays strike the skin?

Data Table

The data for this activity are dependent on the location, time of year, weather conditions, etc. The following are typical changes in temperature for each angle:

Angle	Initial Temp.	Final Temp.	Change in Temp.
90˚			˚C
60˚			˚C
30˚			˚C

Questions

1. Which angle exposed the cardboard to the MOST solar radiation?

2. Which angle exposed the cardboard to the LEAST solar radiation?

3. Which angle best represents the Earth in the summer?

4. Which angle best represents the Earth in the winter?

Ending the Activity

• Check with your instructor about putting away the equipment for this activity.

Alternate   Method

- If you cannot go outdoors to record data, use a 100-watt or 150 watt lamp as a substitute for the Sun.

1. Place the protractor/cardboard setup 25 cm (or about 10 inches) from the lamp.

2. Do not select **Disconnect for Logging…** from the **Experiment** menu.

3. Record and analyze data as described before.

Activity SL20: Heat vs. Temperature
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	GS22 Heat v Temperature.DS	G22 Heat v. Temperature	G22_TEMP.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Temperature Sensor (CI-6505A)	1	Styrofoam cup with lid	1
Graduated cylinder, 100 mL	1	Water	300 mL
Heating resistor, 10 Ω, 1 W	1		
Power supply, DC, 10 W (SE-9720)	1		
Protective gear	1		

(*such as the heating resistor that is part of the PASCO CI-6514 Thermodynamics Kit)

What Do You Think?

What is the relationship between **heat**, **thermal energy**, and **temperature**?

Take time to write an answer to the question in the Lab Report section.

Background

Heat is energy in transit between two or more objects. When the energy is inside an object, it is sometimes called internal energy or thermal energy. The **thermal energy** in an object is the total kinetic energy of all the particles that make up the object.

Temperature is a measure of the average kinetic energy of all the particles in the object. The number for the temperature of an object doesn't tell you much about the actual kinetic energy of a particle inside the object. The number comes from a temperature scale such as the kind found on a common thermometer.

A thermometer measures temperature by means of the expansion and contraction of a liquid, usually mercury or colored alcohol. The reason that this works is that the liquid in a thermometer expands or contracts in a predictable, repeatable way when it gains or loses thermal energy. For example, the mercury in a thermometer always expands to the same level when the end of the thermometer is in boiling water. It always shrinks to the same level when the end of the thermometer is in ice-cold water. The number on the temperature scale is a way to make comparisons. If we say that a certain liquid has a temperature of 0˚ C, it means that the mercury in a thermometer put into this liquid would shrink to the same level as it did when the thermometer was put into ice-cold water.
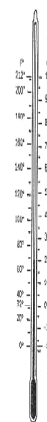
The amount of thermal energy in an object is related to temperature, but temperature by itself can't tell you have much thermal energy is in an object. For example, a bed of glowing coals in a fireplace might have a temperature of 600 ˚C while a single spark from the fire might have a temperature of 2000˚ C. The single "hot" spark gives off very little heat while the bed of relatively "cool" coals gives off a large amount of heat. The difference between the bed of coals and the single spark has to do with both the temperature and the quantity of matter.

Identical thermometers in two pots of water on a hot stove will show different temperatures even if the pots have been on the stove for the same time if the amount of water in one pot is different than the amount in the other.
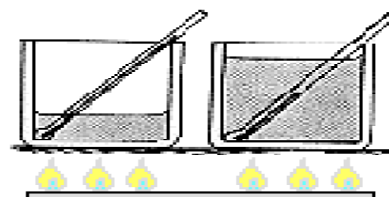
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Be sure that the heating resistor is in the water before you turn on the power supply.


For You To Do

Use the Temperature Sensor to measure the temperature of 100 mL water as a heating resistor heats it for a set amount of time. Then use the sensor to measure the temperature of 200 mL of water as the same resistor heats it for the same amount of time. Both measurements start at the same temperature.

Use *DataStudio* or*ScienceWorkshop* to record and display the data. Compare the final temperature of the 100 mL sample of water to the final temperature of the 200 mL sample of water.

PART I: Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the DIN plug of the Temperature Sensor into Analog Channel A on the interface.

3.   Open the document titled as shown:
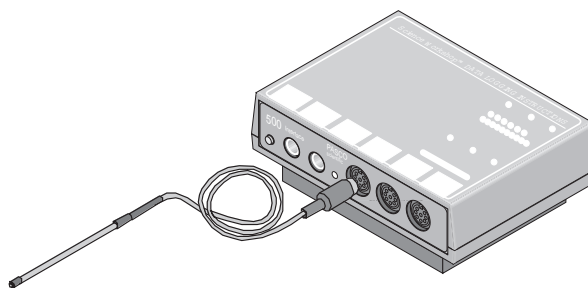
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
GS22 Heat v Temperature.DS	G22 Heat v. Temperature	G22_TEMP.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document will open with a Graph display of Temperature versus Time, a Digits display of Temperature, and a Table display of Temperature.

- Data recording is set so there is 1 second per measurement, a **Start Condition = Channel A** at 0.20 volts, and a **Stop Condition = Time** at 600 seconds (or 10 minutes).

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Temperature Sensor.

1. If you have a lid that will fit over the top of the cup, make one hole in the lid for the Temperature Sensor, and a second hole in the lid for the heating resistor.

2. Put 100 mL of water in the foam cup.

> - NOTE: Start with water that is about two degrees below 20 ˚C. The program will begin recording data when the water warms up to 20 ˚C.

3. Connect the banana plugs of the heating resistor into the output jacks of the power supply.

4. Put the heating resistor through its hole in the lid. Submerge the resistor in the water.

5. Put the Temperature Sensor through its hole in the lid of the cup.

> - CAUTION: Be sure the resistor is submerged in water when the current is flowing through it. Otherwise it can burn up!

PART III: Data Recording

1. Set the DC power supply to output 10 volts at 1 amp. Turn on the power supply.

1. Click the **REC** button. Data recording <u>begins</u> when the temperature of the water reaches 20 ˚C.

- Watch the Digits display to keep track of the temperature.

> IMPORTANT: While the power supply is ON, gently swirl the water in the cup so the water will be heated evenly.

3. Data recording stops automatically at ten minutes. When data recording stops, turn off the DC power supply.

4. Remove the sensor and heating resistor from the cup. Pour out the 100 mL of warmed water.

5. Put 200 mL of water into the cup. Use water that is about two degrees below 20 ˚C.

6. Put the sensor and heating resistor back into the cup.

7. Turn on the power supply.

8. Click the **REC** button to begin the second measurement. Data recording <u>begins</u> when the temperature of the water reaches 20 ˚C.

9. Watch the Digits display to keep track of the temperature.

> - IMPORTANT: While the power supply is ON, gently swirl the water in the cup so the water will be heated evenly.
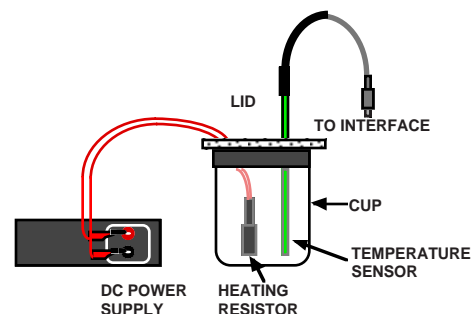
10. Data recording stops automatically at ten minutes. When data recording stops, turn off the DC power supply.

11. Remove the sensor and heating resistor from the cup. Pour out the 200 mL of warmed water.

Starter Labs with Computers
SL20: Heat vs. Temperature

Student Workbook
012-06997

Analyzing the Data

1. Set up the Graph to show statistics such as Minimum and Maximum.

•   Hint: In *DataStudio*, click the Statistics Menu button. In *ScienceWorkshop*, click the Statistics button to open the Statistics area on the right side of the Graph. Then click the Statistics Menu button.

2. Set up the Table to show statistics such as Minimum and Maximum

3. Record the Minimum and Maximum temperatures for the first run of data.

4. Record the Minimum and Maximum temperatures for the second run of data.

5. Record the amount of water used for each run.

6. Find the change in temperature for each run and record it.

Record your results in the Lab Report section.

Lab Report - Activity SL20: Heat vs. Temperature

What Do You Think?

What is the relationship between **heat**, **thermal energy**, and **temperature**?

Data Table

Item	Run #1	Run #2
Amount of Water	mL	mL
Temperature (maximum)	˚C	˚C
Temperature (minimum)	˚C	˚C
Change in Temperature (ΔT)	˚C	˚C

Questions

1. What is the change in temperature for the 100 mL of water in Run #1?

2. What is the change in temperature for the 200 mL of water in Run #2?

3. How does the change in temperature for Run #1 compare to the change in temperature for Run #2?

4. Did the 100 mL of water receive the same, more than, or less thermal energy than the 200 ml of water? Why?

5. Why is the final temperature for the 200 mL of water different than the final temperature for the 100 mL of water?

Ending the Activity

• **Check with your instructor about putting away the equipment for this activity.**

Starter Labs with Computers
SL20: Heat vs. Temperature

Student Workbook
012-06997

©1999 _PASCO scientific_ **SL20**

Activity SL21: Heat Transfer
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	GS23 Heat Transfer.DS	G23 Heat Transfer	G23_HEAT.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Temperature Sensor (CI-6505A)	2	Thermal insulation pads	2
Aluminum can, black (TD-8570A)	1	Tongs (for handling cans with hot water)	1
Aluminum can, plain (TD-8570A)	1	Protective gear	PS
Fan (optional)	1	**Consumables**	**Qty**
Heat lamp (optional)	1	Water, hot (90˚C)	800 mL

What Do You Think?

Parts of robot spacecraft are painted black while other parts are left unpainted. Part of the reason is that unpainted sections of the spacecraft hull absorb energy more slowly than sections that are painted black. Do you think the reverse is possible, will an unpainted aluminum can emit energy faster or slower than a black colored aluminum can?

Take time to write an answer to the question in the Lab Report section.

Background

Heat is energy in transit. Heat transfer happens when two objects are at different temperatures.

Heat is transferred in three ways: **conduction**, **convection**, and **radiation**. When an aluminum can full of hot water sits in a room, the water loses heat by conduction through the aluminum sides (by direct contact with cooler molecules), by convection as air molecules collide with the aluminum, and by radiation as electromagnetic waves are emitted from the can's surface.

SAFETY REMINDERS
• Wear protective gear.
• Follow directions for using the equipment.
• Wear gloves and use tongs when handling the cans with hot water in them.

For You To Do

In this activity, put hot water into two aluminum cans, one unpainted and the other painted black. Use the Temperature Sensors to measure the temperature of the water in each can as it cools. Use *DataStudio* or *ScienceWorkshop* to record and display the temperatures for each can.

Examine the plot of temperature versus time to find can transfers heat fastest.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect one Temperature Sensor to Analog Channel A. Connect the second Temperature Sensor to Analog Channel B on the interface box.

3. Open the document titled as shown:
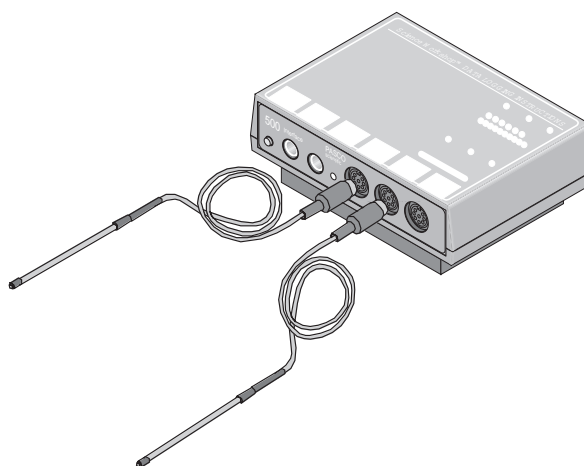
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
GS23 Heat Transfer.DS	G23 Heat Transfer	G23_HEAT.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document will open with a Graph display showing plots of Temperature vs. Time for each Temperature Sensor. .

- Data recording is set so there is one measurement each 10 seconds and **Stop Condition = Time** at 900 seconds (15 minutes).

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Temperature Sensors.

1. Prepare the two aluminum cans (one unpainted and one painted black). Heat approximately 800 milliliters of water to 90˚ C, but don't fill the cans with water yet. Place each can on an insulated pad. Keep the cans away from drafts.

2. Fill each can to the same level with hot (90 C) water (approximately 200 ml). Put Temperature Sensor A into the unpainted can and Temperature Sensor B into the black can.
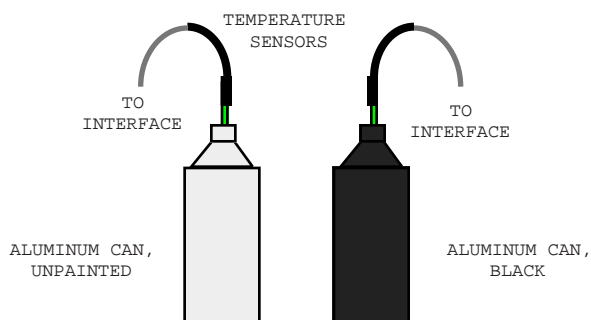
PART III: Data Recording

1. When you are ready, start recording data. Data points will begin to appear in the graph every 10 seconds.

2. Swirl the water in the cans continuously for 15 minutes. Data collecting will stop automatically at 15 minutes.

Analyzing the Data

1. Set up your Graph to show statistics

- Hint: In *DataStudio*, click the Statistics Menu button. In *ScienceWorkshop*, click the Statistics button to open the Statistics area on the right side of the Graph. Then click the Statistics Menu button.

2. Record the maximum y value as the Maximum temperature. Record the minimum y value as the Minimum temperature.

Record your results in the Lab Report section.

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Lab Report - Activity SL21: Heat Transfer

What Do You Think?

Parts of robot spacecraft are painted black while other parts are left unpainted. Part of the reason is that unpainted sections of the spacecraft hull absorb energy more slowly than sections that are painted black. Do you think the reverse is possible, will an unpainted aluminum can emit energy faster or slower than a black colored aluminum can?

Data Table

Can	Maximum temperature	Minimum temperature
Unpainted	˚C	˚C
Black	˚C	˚C

Questions

1. Which can cooled down faster?

2. When the cans are cooling, which processes transfer heat? Which process do you think is dominant?

3. When a can is cooling, does it cool faster at the beginning of the experiment or toward the end of the experiment? Why?

Optional: Save Your Data

NOTE: You may want to save the original experiment and data before beginning the optional activities.

Optional: Cooling With A Fan

Repeat the experiment but put a fan next to the cans so the air blows equally on each of the cans. Turn on the fan and begin recording data.

Optional: Heating With A Lamp

Fill the cans with room temperature water. Put the Temperature Sensors in each can as before. Place a heat lamp near the cans so that the cans are equally illuminated. Turn on the lamp and begin recording data.

Optional Questions

1.   How much faster does each can cool when the fan is on? (To compare the cooling times, find out how much time it took for each can to cool from about 85 ˚C to 80 ˚C with and without the fan. Divide the cooling time without the fan by the cooling time with the fan for each can.)

2.   When the can is cooling with the fan, what processes transfer heat? Which process is dominant?

3.   Which can heated faster?

4.   When the can is being heated with a lamp, which processes transfer heat? Which process is dominant?

Activity SL22: Induction – Magnet through a Coil
(Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electromagnetism	GS29 Induction.DS	G29 Induction - Magnet	G29_INDU.SWS

Equipment Needed	Qty
Voltage Sensor (CI-6503)	1
Coil	1
Bar magnet, alnico (EM-8620)	2

(*such as on the AC/DC Electronics Lab (EM-8656) board, or the Basic Electricity Board (EM-8622) or the Coils and Core Set (SF-8616)

What Do You Think?

The purpose of this activity is to measure the **voltage** created in a coil by a magnet dropping through the center of the coil. Will the voltage be different if the magnet falls faster through the same coil?

Take time to write an answer to the question in the Lab Report section.

Background

Connect a coil of wire to a sensitive meter that can measure tiny amounts of electric current. Set the coil so you can move a bar magnet back and forth through the center of the coil. When the bar magnet moves through the coil, the sensitive meter will show that a current is flowing through the coil. The current flows through the wire of the coil because the magnet caused (induced) a **voltage**.

The amount of voltage depends on how many turns of wire are in the coil, and the rate at which the magnet is moved back-and-forth through the coil of wire. In other words, the more turns of wire in the coil, the more voltage it puts out. The faster the magnet moves through the coil, the more voltage the coil puts out.

The direction of the voltage (positive or negative) depends on which end of the magnet (called the magnetic **pole**) is going through the coil of wire, and in which direction. A bar magnet has both a north magnetic pole and a south magnetic pole. If the bar magnet falls through the coil of wire, the voltage will be positive when one end of the bar magnet moves through the coil, and negative when the other end of the bar magnet moves through the pole.

Both ends of a magnet usually have the same magnetic strength. If you put the north end of the magnet into the coil, it should create the same voltage as when you put the south end of the magnet into the coil, assuming that you put both ends into the coil with the same speed. If one end of the magnet moves faster, it produces more voltage. However, because the magnet moves faster, the amount of time that it is in the coil is shorter.

The amount of voltage multiplied by the amount of time that the voltage lasts is called the **flux**. If a magnet moves slowly, the voltage is low, but the amount of time is longer. If the magnet moves quickly, the voltage is higher, but the amount of time is shorter.

Theoretically, the amount of flux produced by a magnet moving slowly is the same as the amount of flux produced by the same magnet when it moves quickly.
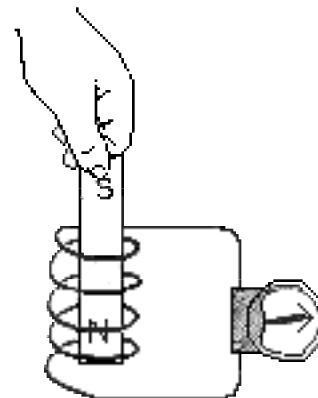
SAFETY   REMINDERS

•   Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Voltage Sensor to measure the voltage induced in the coil by a magnet as the magnet falls through the coil. Use *DataStudio* or *ScienceWorkshop* to record and display the induced voltage. Use the plot of voltage versus time to find out whether the flux created by one end of the magnet is the same as the flux created by the other end of the magnet.

PART I: Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

•   Connect the Voltage Sensor DIN plug into Analog Channel A.

3.   Open the document titled as shown:
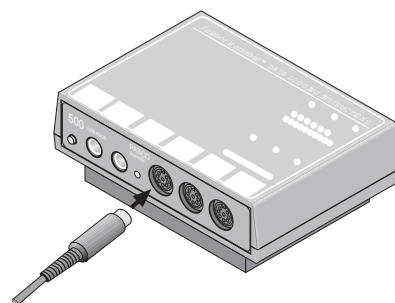
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
GS29 Induction.DS	G29 Induction - Magnet	G29_INDU.SWS

•   The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

•   The *ScienceWorkshop* document opens with a Graph display of Voltage vs. Time and a Meter display of Voltage.

•   Data recording is set at 200 Hz (200 measurements per second), **Start   Condition   =   Channel A = 0.05 V,** and **Stop Condition = Time** at 0.5 seconds.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.

1. Put alligator clips on the ends of the voltage sensor leads.

2. Attach a voltage sensor lead to one component spring next to the inductor coil on the circuit board. Attach the other lead to the other component spring next to the coil.

3. Arrange the circuit board so the corner with the coil is beyond the edge of the table and a magnet dropped through the coil can fall freely.

- The bar magnet will be dropped through the coil. Make sure that the magnet does not strike the floor, or it may break.

Part III: Data Recording

1. Hold the magnet so that the south end is about 2 cm above the coil.

2. Start recording data. Let the magnet drop through the coil.

- Data recording begins when the magnet falls through the coil and the induced voltage reaches 0.05 volts.

- Data recording ends automatically after 0.5 seconds.

3. Repeat data recording, but release the magnet from about 5 cm above the coil so the magnet falls through the coil faster.

Analyzing the Data

1. Set up your Graph so it shows the area between the curve of voltage and the X-axis.

*   Hint: In *DataStudio*, select **Area** from the Statistics menu in the Graph toolbar.

*   Hint: In *ScienceWorkshop*, click the Statistics button to open the Statistics area on the right side of the graph. In the Statistics area, click the Statistics Menu button. Select **Integration** from the menu.

2. In the Graph display, use the cursor to click-and-draw a rectangle around the <u>first peak</u> of the voltage plot.

*   The Statistics will show the area under the curve for the first peak.

3. Record the value of Integration for the first peak.

4. Repeat the process to find the area under the <u>second peak</u>. Record the value.

5. Repeat the data analysis for the second run of data (magnet falling faster).

Record your results in the Lab Report section.

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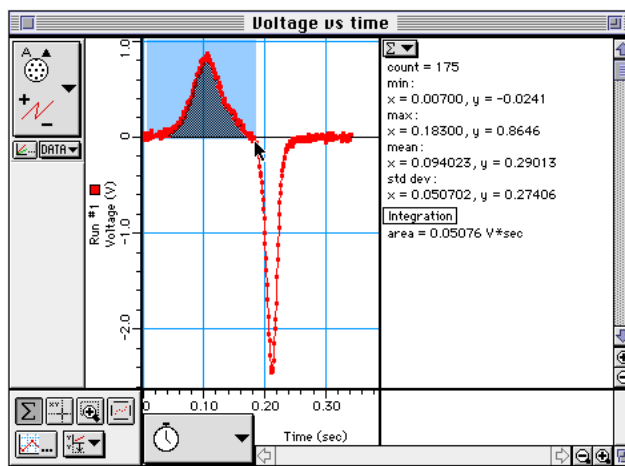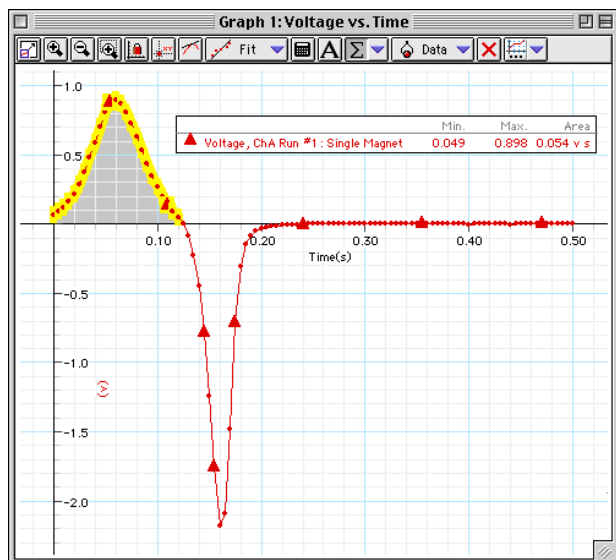
Lab Report - Activity SL22: Induction - Magnet through a Coil

What Do You Think?

The purpose of this activity is to measure the **voltage** created in a coil by a magnet dropping through the center of the coil. Will the voltage be different if the magnet falls faster through the same coil?

Data Table – Run #1

Peak	Integration
First	V*s
Second	V*s

Data Table – Run #2

Peak	Integration
First	V*s
Second	V*s

Questions

1. Is the first peak of flux (V*s) equal to the second peak of flux?

2. Why is the second peak taller than the first peak?

3. Why are the peaks in opposite directions?

4. How does the voltage in the second run compare to the voltage in the first run?

Optional

Repeat the data recording and data analysis procedures for the following optional setups:

- Tape two bar magnets together so both south ends are together.

- Re-arrange the two bar magnets so that the south end of one is with the north end of the other.

Activity SL23: Photoelectric Effect
(Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Nature of light	GS30 Photoelectric Effect.DS	G30 Photoelectric Effect	G30_PHOT.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Voltage Sensor (CI-6503)	1	Optics & Alignment Kit (AP-9369)	1
Photoelectric Head (AP-9368)	1	Mercury Vapor Light (OS-9286)	1

What Do You Think?

The purpose of this activity is to measure the **voltage** produced when different colors of light fall on a photoelectric tube and to find out the relationship between the wavelength of light and the amount of voltage it produces. What do you think is the relationship between the wavelength (color) of light and the amount of voltage it produces?

Take time to write an answer to the question in the Lab Report section.

Background

White light (such as sunlight) is a mixture of all the colors of light in a rainbow. You can see the colors of light in a rainbow by shining white light through a prism. Each color of light travels in a slightly different path through the prism, so the colors spread away from each other when they come out of the prism.

WHITE LIGHT

RED LIGHT
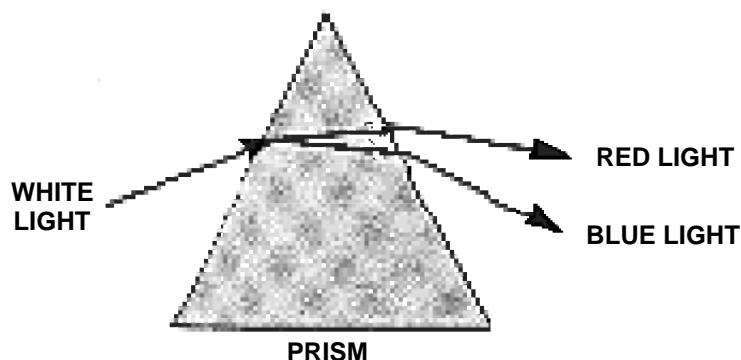
BLUE LIGHT

PRISM

Red light travels through the prism with the least amount of change in its direction. Blue light travels through the prism and changes its direction by a greater angle. This change in direction of the different colors of light is called **dispersion**. It is caused by **refraction**.

Refraction happens when light is traveling through something and then meets something new. If the light is at an angle to the boundary between the old region and the new region, the light must change its direction as it goes through the new region.

Each color of light in the rainbow has a different amount of energy. Each color also has a certain **wavelength**. Blue light has a <u>shorter</u> wavelength than red light. If a color of light that has the right amount of energy strikes a metal surface, the light can knock electrons out of the metal.

This is called the **photoelectric effect** because the bits of energy that make up light are called photons, and photons with the right amount of energy can knock electrons out of the metal surface ("photon-electron" or photoelectric effect).

PHOTONS THAT DO NO HAVE THE RIGHT ENERGY, NO MATTER HOW BRIGHT, CANNOT KNOCK ELECTRONS OUT OF THE PLATE OF METAL.

When electrons get knocked out of the metal by photons of light, the metal can produce a **voltage**. The amount of voltage depends on the number of electrons that get knocked out of the metal. The number of

PHOTONS OF THE RIGHT ENERGY CAN KNOCK ELECTRONS OUT OF THE PLATE OF METAL.

electrons depends on the energy of the light. The energy of the light depends on the wavelength. The color of the light tells you whether the wavelength is long or short.

Albert Einstein knew the relationship between the color of light (or its wavelength) and the amount of energy in the light. He used the relationship between color and energy to explain the photoelectric effect (for which he won the Nobel Prize).

Does a short wavelength color like blue light have more energy, or does a long wavelength color like red light?

SAFETY REMINDERS

* Follow directions for using the equipment.

* Be careful not to touch the mercury vapor light source after it gets hot.

**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

Use the Voltage Sensor to measure the voltage produced by the photoelectric effect.

Use *DataStudio* or *ScienceWorkshop* to record and display the voltage produced by each color of light you measure. Use a plot of voltage versus wavelength (color) to find the relationship between the voltage and the wavelength. Determine the relationship between the color of light (the wavelength) and the amount of voltage the light produces.
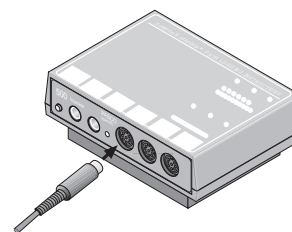
PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Voltage Sensor DIN plug into Analog Channel A.

3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
GS30 Photoelectric Effect.DS	G30 Photoelectric Effect	G30_PHOT.SWS

* The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

* The *ScienceWorkshop* document opens with a Graph display of Voltage vs. Wavelength and a Meter display of Voltage.

* Data recording is set at 10 Hz. You will enter the wavelength of each color of light into *DataStudio* using 'Manual Sampling' or into *ScienceWorkshop* using 'Keyboard Sampling' with Parameter = Wavelength (color) and Units = nm.

* The 'Default Data' numbers under 'Wavelength' in the *DataStudio* Table are the wavelengths of the colors of light from a mercury light source. The colors of are as follows: violet, blue, green, and yellow.

* This table shows the wavelength for each color:

Color	Wavelength	Color	Wavelength
violet	404.656	green	546.074
blue	435.835	yellow	576.960

PART II: Sensor Calibration and Equipment Setup

•   You do not need to calibrate the Voltage Sensor.

> ⚠ NOTE: Read the instruction manual that comes with the PASCO Photoelectric Effect Apparatus before you do the equipment setup.

1.   Install the two 9 volt batteries that come with the Photoelectric Apparatus into the battery compartment on the apparatus.

2.   Put the Photoelectric Apparatus onto the support base assembly.

3.   Put the light block into the slot on the back of the mercury vapor light source.

4.   Put the coupling bar assembly onto the bottom of the slot on the front of the mercury vapor light source.

5.   Put the light aperture assembly in the middle of the slot on the front of the mercury vapor light source.

•   Be sure that the light aperture assembly is lined up with the opening on the front of the light source.

6.   Put the lens/grating assembly onto the ends of the horizontal rods on the light aperture assembly.

7.   Put the hole at the end of the support base assembly over the pin on the end of the coupling bar assembly.

8.   Put the Voltage Sensor banana plugs into the output jacks on the side of the Photoelectric Apparatus.
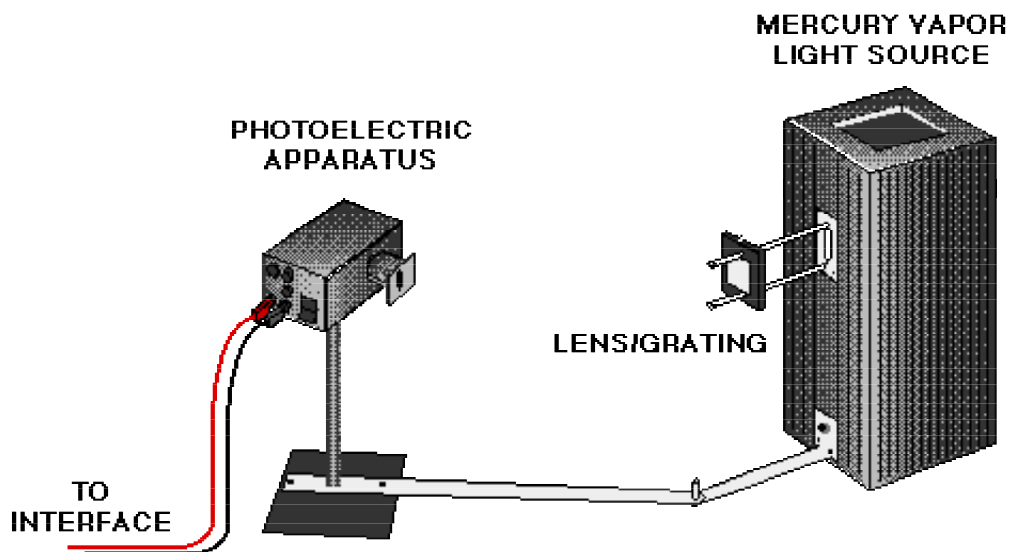
9.   Turn on the light source so it has time to warm up before you make measurements.

Part III: Data Recording
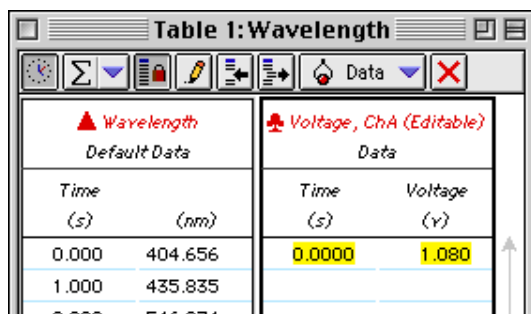
Color	Wavelength (nm)
violet	404.656
blue	435.835
green	546.074
yellow	576.960

1. Adjust the position of the Photoelectric Apparatus so that only the *violet* color light from the mercury light source goes through the slot on the front of the apparatus and shines on the photodiode tube inside.

2. Turn on the Photoelectric Effect Apparatus. Press the PUSH TO ZERO button on the side of the apparatus.

3. Start recording data. In *DataStudio*, the 'Start' button changes to a 'Keep' button [✓ Keep] [■] .

•   Note: For *ScienceWorkshop* instructions, see the appendix at the end of the activity.

4. When the voltage stops going up, click 'Keep' to record the voltage in the Table next to the wavelength of violet light.

•   The Table in DataStudio will show the value of voltage for violet light in the first row.

5. Adjust the position of the Photoelectric Apparatus so that only the blue color light goes through the slot on the front of the apparatus and shines on the photodiode tube inside.

6. Click 'Keep' to record the value of voltage for blue light.

7. Put the green filter on the front of the Photoelectric Apparatus. Adjust the apparatus so that only the green light goes through the slot and shines on the photodiode tube inside.

8. Click 'Keep' to record the value of voltage for green light.

9. Replace the green filter with the yellow filter. Adjust the Photoelectric Apparatus so that only the yellow light goes through the slot and shines on the photodiode tube inside.

10. Click 'Keep' to record the value of voltage for yellow light.

11. Stop data recording

12. Turn off the Photoelectric Effect Apparatus and the light source. Remove the yellow filter.

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> ⚠️ CAUTION! The light source can be very hot. Let it cool down before you take the apparatus apart.

Analyzing the Data

1. Set up the Graph to show a 'Linear' curve fit for the voltage and wavelength data.

2. Hint: In *DataStudio*, select 'Linear' from the Curve Fit menu. In *ScienceWorkshop*, click the 'Statistics' button to open the Statistics area on the right side of the graph. Click the 'Autoscale' button to rescale the graph to fit the data. In the Statistics area, click the 'Statistics Menu' button. Select Curve Fit, Linear Fit from the menu.

Answer the questions in the Lab Report section.

Ending the Activity

•   Check with your instructor about putting away the equipment for this activity. Remember; wait until the light source cools down before taking the apparatus apart.

©1999 *PASCO scientific* **SL23**

Lab Report - Activity SL23: Photoelectric Effect

What Do You Think?

The purpose of this activity is to measure the **voltage** produced when different colors of light fall on a photoelectric tube and to find out the relationship between the wavelength of light and the amount of voltage it produces. What do you think is the relationship between the wavelength (color) of light and the amount of voltage it produces?

Questions

1. Based on your Graph, is the relationship between voltage and wavelength direct, inverse, inverse square, or something else?

2. Which color produces the highest voltage?

3. Which color produces the lowest voltage?

4. Based on your data, what is the relationship between wavelength (color) and energy of the photons?

Appendix (*ScienceWorkshop*)

1. When you are ready, start recording data. In *ScienceWorkshop,* the Keyboard Sampling window will open. Adjust its position on your screen so you can also see the Digits display of temperature.

•   **The Keyboard Sampling window will open. Move it so you can see the Digits display of Voltage at the same time.**

•   **It may take a few moments for the voltage to reach its maximum value.**

2. When the voltage stops going up, type in the wavelength for violet light. Click **Enter** to record your typed in value.

•   **The Keyboard Sampling window will show your first value in the Data list.**

3. Adjust the position of the Photoelectric Apparatus so that only the blue color light goes through the slot on the front of the apparatus and shines on the photodiode tube inside.

4. Type in the wavelength for blue light in the **Keyboard Sampling** window. Click **Enter** to record your value.

5. Put the green filter on the front of the Photoelectric Apparatus. Adjust the apparatus so that only the green light goes through the slot and shines on the photodiode tube inside.

6. Type in the wavelength for green light and click **Enter** in the **Keyboard Sampling** window.

7. Replace the green filter with the yellow filter. Adjust the Photoelectric Apparatus so that only the yellow light goes through the slot and shines on the photodiode tube inside.

8. Type in the wavelength for yellow light and click **Enter** in the **Keyboard Sampling** window.

•   **Your Keyboard Sampling window will show four wavelengths in the data list.**

9. Click **Stop Sampling**.

•   **The Keyboard Sampling window will disappear. Run #1 will appear in the Data list in the Experiment Setup window.**

10. Turn off the Photoelectric Effect Apparatus. Remove the yellow filter.
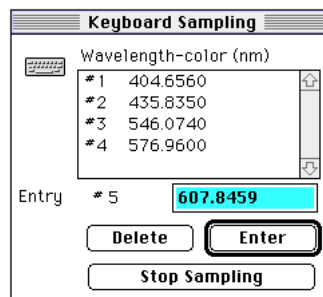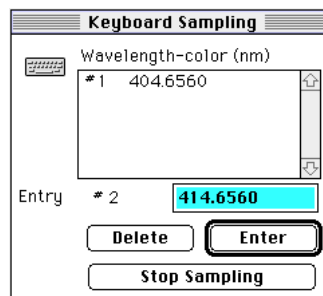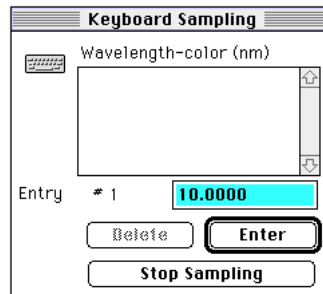
Activity SL24: Calculating Final Temperature of a Mixture – Algebraic Manipulations
(Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Algebraic manipulations	MA03.DS	MA03	MA03.SWS

Equipment Needed	Qty	Consumables	Qty
Temperature Sensor (CI-6505A)	1	Water, cold	1000 mL
Graduated cylinder, 100 mL	1	Water, hot	1000 mL
Styrofoam cup	2		
Lid for cup	2		
Protective gear	PS		

What Do You Think?

When masses of substances at different temperatures are mixed together, the hotter substance heats the cooler substance and the resulting final temperature is somewhere between the initial temperatures of the two substances. How can you use mathematical logic and algebra to predict the final temperature of a mixture of two substances?

Take time to write an answer to this question in the Lab Report section.

Background

When two substances of different temperatures are mixed, the hotter one heats the cooler one until the temperature of the mixture reaches a balance called thermal equilibrium.

The thermal energy in an object depends on the amount of mass, the specific heat of the object, and its temperature. In equation form:

$$\Delta Q \text{ (change in thermal energy)} = m \ c \ \Delta T$$

where **m** is the mass in grams, **c** is the specific heat and ΔT is the change in temperature.

The value for the specific heat, **c**, of water is 1.0 cal/g ˚C or 4.19 J/g ˚C. This value is constant between the temperatures of 0˚ C and 100 ˚C.

When a hot substance heats a cooler one, the energy 'lost" by the hot substance equals the energy 'gained' by the cooler one, or (in equation form):

$$\textit{Energy lost = Energy gained}$$

$$\Delta Q_{lost} = \Delta Q_{gained}$$

$$m_{hot\ water} \times c\ (\Delta T)_{hot\ water} = m_{cold\ water} \times c\ (\Delta T)_{cold\ water}$$

$$m_{hot\ water} \times c\ (T_i - x)_{hot\ water} = m_{cold\ water} \times c\ (x - T_i)_{cold\ water}$$

m = mass of water (assume that 1 mL of water is 1 gram)

c = specific heat for water = 1.0 cal/g °C

T_i = initial temperature

x = final temperature (unknown for this activity)

SAFETY   REMINDERS
• Wear protective gear.
• Follow directions for using the equipment.
• Wear gloves when handling the hot water.

For You To Do

Use the Temperature Sensor to measure the temperature of a known amount cold water in one cup and a known amount of hot water in a second cup.

(Based on the temperatures, you could use algebra to make a prediction about the final temperature of the mixture.)

Mix the hot and cold water and measure the temperature of the mixture. Use insulated containers so the water will not gain or lose thermal energy during the activity. Use *DataStudio* or *ScienceWorkshop* to record and display the temperatures.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Temperature Sensor to Analog Channel A.

3. Open the document titled as shown:
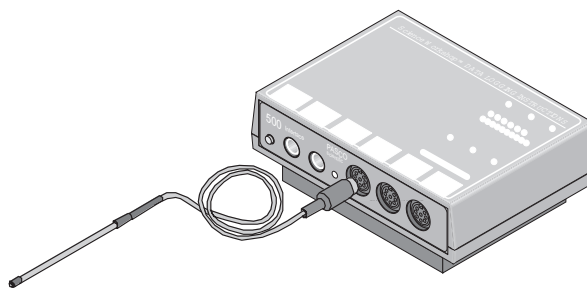
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
MA03.DS	MA03	MA03.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document has a Digits display and a Table display of temperature versus time.

- Data recording is set at 10 Hz (10 measurements per second).

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Temperature Sensors.

1. Label container #1 "Cold Water" and place the lid on it. Label container #2 "Hot Water" and place a lid on it. (Use a lid on the containers so the containers will not lose or gain energy from the environment.)
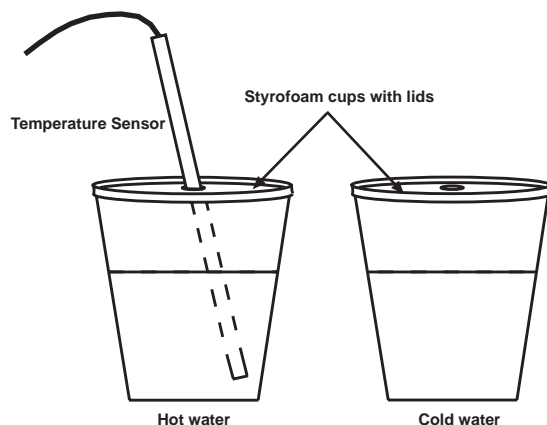
PART III: Data Recording

There are five parts:

Run #	Cold Water	Hot Water	Ratio of Cold to Hot
1	100 mL	100 mL	1:1
2	200 mL	100 mL	2:1
3	100 mL	200 mL	1:2
4	300 mL	100 mL	3:1
5	100 mL	300 mL	1:3

Each part follows the same basic procedure:

- Prepare each container: Fill each container with the amount of water needed for the run.

- Measure the Cold Water (container #1): Put the Temperature Sensor through the lid of container #1 (Cold Water). When you are ready, start recording data for container #1. Stir the water with the sensor until the temperature stabilizes, and record the temperature. Stop recording data.

- Measure the Hot Water (container #2): Put the Temperature Sensor through the lid on the container #2 (Hot Water). When you are ready, start recording data for container #1. Stir the water with the sensor until the temperature stabilizes, and record the temperature. Stop recording data.

- Combine the water: Pour the water from container #2 into #1 and put the lid on it.

- Measure the mixture: Place the Temperature Sensor through the lid. Start recording data. Stir with the sensor, and when the temperature reaches equilibrium, record the temperature of the mixture. Stop recording data.

Record your measured temperatures in the Lab Report section.

Analyzing the Data

1.   Calculate the final temperature of each mixture using the following:

$$\textbf{\textit{Energy lost = Energy gained}}$$

$$\Delta Q_{lost} = \Delta Q_{gained}$$

$$m_{hot\ water} \times c\ (\Delta T)_{hot\ water}\ =\ m_{cold\ water} \times c\ (\Delta T)_{cold\ water}$$

$$(\textbf{\textit{Eqn. 1}})\ m_{hot\ water} \times c\ (T_i - x)_{hot\ water}\ =\ m_{cold\ water} \times c\ (x - T_i)_{cold\ water}$$

m = mass of water (1 mL = 1 gram),

c = specific heat for water = 1.0 cal/g °C

T_i = initial temperature

x = final temperature (unknown for this activity)

> •   Hint: Rearrange Equation 1 to solve for "x", the final temperature of the mixture. Use the masses of water and the initial temperatures to calculate the value of "x", the final temperature.

In Run #1, for example, container #1 (cold water) contains 100 grams of water at the initial temperature you recorded. Container #2 (hot water) also contains 100 grams of water at the initial temperature you recorded.

Record your calculated temperatures in the Lab Report section.

Lab Report - Activity SL24: Calculating Final Temperature of a Mixture – Algebraic Manipulations

What Do You Think?

When masses of substances at different temperatures are mixed together, the hotter substance heats the cooler substance and the resulting final temperature is somewhere between the initial temperatures of the two substances. How can you use mathematical logic and algebra to predict the final temperature of a mixture of two substances?

Quantities

Run #	Cold Water	Hot Water	Ratio of Cold to Hot
1	100 mL	100 mL	1:1
2	200 mL	100 mL	2:1
3	100 mL	200 mL	1:2
4	300 mL	100 mL	3:1
5	100 mL	300 mL	1:3

Data Table

Temperatures	Run #1	Run #2	Run #3	Run #4	Run #5
Cold water	˚C	˚C	˚C	˚C	˚C
Hot water	˚C	˚C	˚C	˚C	˚C
Mixture: actual value	˚C	˚C	˚C	˚C	˚C
Mixture: *calculated* value	˚C	˚C	˚C	˚C	˚C

Analyzing the Data

Run #1 (100 mL cold + 100 mL hot)

1. How does the final temperature of the mixture compare to the initial temperatures of the cold and hot water?

2. What is the ratio of the amount of cold water to the amount of hot water?

3. What is an equation to calculate the final temperature using only the temperatures of the water samples and their ratio?

Run #2 (200 mL cold + 100 mL hot)

1.   How does the final temperature of the mixture compare to the initial temperatures of the cold and hot water?

2.   What is the ratio of the amount of cold water to the amount of hot water?

3.   What is an equation to calculate the final temperature using only the temperatures of the water and their ratio?

Run #3 (100 mL cold + 200 mL hot)

1.   How does the final temperature of the mixture compare to the initial temperatures of the cold and hot water?

2.   What is the ratio of the amount of cold water to the amount of hot water?

3.   What is an equation to calculate the final temperature using only the temperatures of the water and their ratio?

Run #4 (300 mL cold + 100 mL hot)

1.   How does the final temperature of the mixture compare to the initial temperatures of the cold and hot water?

2.   What is the ratio of the amount of cold water to the amount of hot water?

3.   What is an equation to calculate the final temperature using only the temperatures of the water and their ratio?

Run #5 (100 mL cold + 300 mL hot)

1. How does the final temperature of the mixture compare to the initial temperatures of the cold and hot water?

2. What is the ratio of the amount of cold water to the amount of hot water?

3. What is an equation to calculate the final temperature using only the temperatures of the water and their ratio?

Questions:

- Run #1 has equal amounts of cold and hot water mixed together.

1. How many degrees above the initial temperature of the cold water was the final temperature of the mixture?

2. How many degrees below the initial temperature of the hot water was the final temperature of the mixture?

3. If the initial temperatures of the hot and cold water were increased proportionately, how would this effect the final temperature of the new mixture?

- Run #2 and Run #3 have the amounts of hot and cold water reversed.

4. What can you say about the final temperature of the mixture in relation to the original temperatures of the hot and cold water?

- Run #4 and Run #5 have the amounts of hot and cold water reversed.

5.   What can you say about the final temperature of the mixture in relation to the original temperatures of the hot and cold water?

6.   Are your measured values of final temperature the same as the calculated values of final temperature? If not, by how much do they differ? What are possible explanations for any discrepancy?

- Predict the final temperature of these mixtures :

1.   100 mL of 10 ˚C water and 100 mL of 40 ˚C water.

2.   200 mL of 10 ˚C water and 100 mL of 40 ˚C water.

3.   100 mL of 10 ˚C water and 200 mL of 40 ˚C water.

4.   300 mL of 10 ˚C water and 100 mL of 40 ˚C water.

5.   100 mL of 10 ˚C water and 300 mL of 40 ˚C water.

6.   100 mL of 0 ˚C water and 100 mL of 100 ˚C water.

7.   100 mL of 20 ˚C water and 200 mL of 50 ˚C water.

Algebraic   Manipulation

Rearrange Equation 1 to solve for the final temperature of the mixture, x.

$$(Eqn. 1)\ m_{hot\ water} \times c\ (T_i - x)_{hot\ water}\ =\ m_{cold\ water} \times c\ (x - T_i)_{cold\ water}$$

Activity SL25: Exponential Modeling – Newton's Law of Cooling (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshp* (Win)
Exponential modeling	MA11.DS	MA11	MA11.SWS

Equipment Needed	Qty	Consumables	Qty
Temperature Sensor (CI-6505A)	1	Water	300 mL
Beaker, 1000 mL	1		
Hot plate	1		
Textbook	1		
Protective gear	PS		

What Do You Think?

From your own experience with the cooling of hot liquids (take coffee or tea for example), name some ways in which you would cause the hot liquid to reach the desired temperature before taking a sip.

Take time to write an answer to this question in the Lab Report section.

Background

The cooling of a hot beverage is a common daily occurrence. If a hot cup of your favorite brew is allowed to sit for a while, the temperature of the liquid plus the cup ultimately reaches the temperature of its surroundings (room temperature).

The graph of temperature versus time for a hot beverage is a nice example of exponential decay. At first glance, the graph of the cooling process shows a rapid decrease in temperature. A little while later, the graph levels off as it approaches room temperature. Newton observed the rate at which an object cools, $\Delta T/\Delta t$, depends on how much hotter the object is than its surroundings. This is the reason why the graph shows a greater cooling rate at first, and a leveling off as the object approaches room temperature.

This activity is a simple cooling experiment that lets you model the data using the exponential function e^x.

Newton's *Law of Cooling* states:

The rate of cooling is directly proportional to the temperature difference between the object and its surroundings, $(T_{object} - T_{room})$.

$$Rate\ of\ cooling = -k\ (T_{object} - T_{room})$$

Transforming Newton's Law of Cooling into an equation that relates the temperature of the object as a function of time requires advanced techniques. Leaving the solving to the experts (you could be that expert in future math courses), the equation is:

$$T(t) = (T(0) - T_{room})e^{-kt} + T_{room}$$

where $T(t)$ is the temperature at time "t", $T(0)$ is the initial temperature of the object, T_{room} is room temperature, and k is a constant of proportionality.

You will determine $\boldsymbol{k}$ using properties of natural logarithms and one of the data points.

SAFETY REMINDERS	
•   Wear protective gear.
•   Follow directions for using the equipment.
•   Be careful when heating the water.

For You To Do

First, use the Temperature Sensor to measure the room temperature. Then measure the temperature as the sensor cools down to room temperature from an initial temperature of about 100 ˚C. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data.

Pre-Lab

Put 300 mL of water into the 1000-mL beaker and place the beaker on the hot plate. Start heating the water to a boil. Do not leave the hot plate unattended.
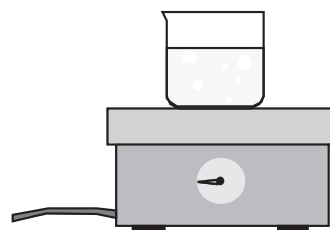
PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Temperature Sensor to Analog Channel A.

3. Open the file titled as shown:
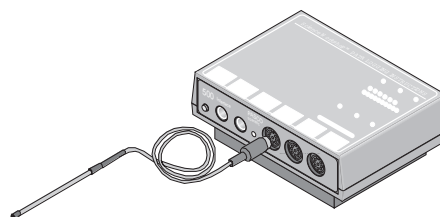
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshp (Win)
MA11.DS	MA11	MA11.SWS

• The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

• The *ScienceWorkshop* document will open with a Digits display, a Table display , and a Graph display of Temperature.

• Data recording is set so there is one measurement per 5 s and **Stop Condition** = **Time** at 600 s (10 min.).

PART II: Sensor Calibration and Equipment Setup

• You do not need to calibrate the Temperature Sensor.

PART III: Data Recording

1.   When the water in the beaker is boiling, use the Temperature Sensor and the Digits display to find the *room* temperature. Start to monitor the temperature of the room.

•   Hint: In *DataStudio*, select "Monitor Data" in the Experiment menu.

•   Hint: In *ScienceWorkshop*, click the **MON** button.

2.   Record the room temperature:
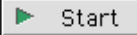
$$T_{room} \ = \ _____$$

3.   Put the Temperature Sensor into the boiling water. Watch the Digits display until the temperature reaches a maximum value and remains steady.
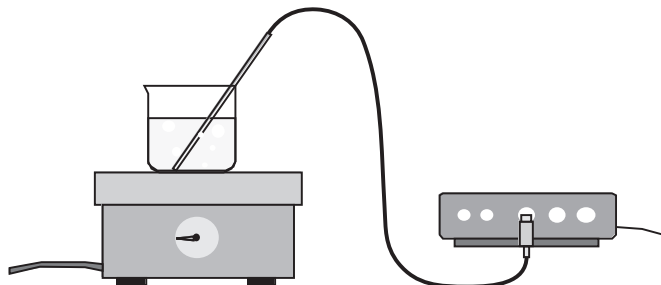
•   Once the temperature reaches a steady value, *QUICKLY* do the following:

4.   Remove the Temperature Sensor from the beaker of boiling water.

5.   Place the sensor on the textbook with the tip of the sensor extending beyond the edge of the book.

6.   Click STOP, and then immediately start recording data.

•   Hint: In *DataStudio*, click Start ► Start . In *ScienceWorkshop*, click **REC**.

7.   Turn off the hot plate.

•   Data recording stops automatically at 600 s (10 minutes).

Analyzing the Data – Rate of Cooling

1.   After the recording has stopped, click the Graph display to make it active. Set up your Graph to display statistics.

•   Hint: In *DataStudio*, click the Statistics menu button in the toolbar and select "Show All".

•   Hint: In *ScienceWorkshop*, click the Statistics button to open the statistics area on the right side of the graph. Click the Statistics menu button and select "All Of The Above".

2.   Re-scale the graph to fit the data. Refer to the graph as you answer these questions.

Write your answers in the Lab Report section.

Questions

1.   On your graph, at what point is the rate of cooling the greatest?

2.   On your graph, over what interval of time is the rate of cooling the greatest?

3.   On your graph, over what interval of time is the rate of cooling the least?

Analyzing the Data – Calculation and Curve Fit

•   Use data from your Table display and the mathematical model for Newton's Law of Cooling to calculate "k", the constant of proportionality.

The mathematical model for Newton's Law of Cooling is:

$$T(t) = (T(0) - T_{room})e^{-kt} + T_{room}$$

where $T(t)$ is the temperature at time "t", $T(0)$ is the initial temperature of the object, T_{room} is room temperature, and k is a constant of proportionality.

To determine "k" you will need the *initial* temperature, the *room* temperature, and one other temperature selected from your Table.

In this Sample Calculation below, the initial temperature of the Temperature Sensor is 94.53 ˚C. The room temperature is 21.80 ˚C. (Use your own values for these temperatures when you do the calculation.)

To get the other temperature from the Table, click the **Time** button so the Table shows both time and temperature. Then, select any data pair between t = 20 s and t = 120 s.

For the Sample Calculation below, the sample data pair is (75.0000, 33.35). In other words, at time = 75 seconds, the temperature = 33.35 ˚C.

Name _____   Class _____   Date _____

Sample Calculation

Initial temperature = 94.53 ˚C

Room temperature = 21.80 ˚C

Data pair from Table: (75, 33.35)

$$T(t) = (T(0) - T_{room})e^{-kt} + T_{room}$$

$$T(75) = (94.53 - 21.80)e^{-k(75)} + 21.80$$

$$33.35 = 72.73e^{-k(75)} + 21.80$$

$$33.35 - 21.80 = 72.73e^{-k(75)}$$

$$11.55 = 72.73e^{-k(75)}$$

$$\frac{11.55}{72.73} = e^{-k(75)}$$

$$0.159 = e^{-k(75)}$$

$$\ln(0.159) = \ln(e^{-k(75)})$$

$$-1.84 = -k(75)$$

$$\frac{-1.84}{-75} = k$$

$$0.0245 = k$$

● Use the Curve Fit feature in *DataStudio* or *ScienceWorkshop* to apply an Exponential Fit on the graph of your data.

DataStudio Curve Fit

In the *DataStudio* Graph display, click the 'Fit' menu button and select 'Natural Exponent'.

Double-click the 'Natural Exponent Fit' window to open the Curve Fit window (or click 'Curve Fit' in the main toolbar).
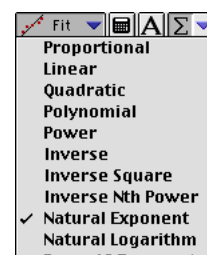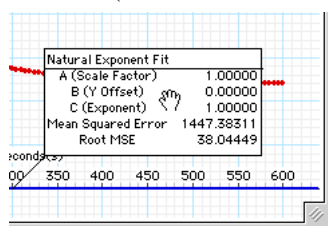
Notice the formula for 'Natural Exponent': $Ae^{-Cx} + B$

In the Curve Fit window, click 'Manual'.

In the 'Manual' Curve Fit window, type in your calculation for the proportionality constant, 'k', as the value for 'C (Exponent)'. Then type in the room temperature as 'B (Y Offset)'. Finally, type in the difference between the initial temperature and the room temperature as 'A (Scale Factor)'.

Note: The numbers shown are an example. Be sure to enter *your* numbers.

After you enter your values for the Variables, click 'Accept'.

Compare the new Curve Fit in the Graph display to your data.

Go to the 'Curve Fit' window and adjust your number for 'C (Exponent)' slightly. Click 'Accept' again to see whether your new numbers improve the Curve Fit on the Graph display.

Try the following: Click 'Automatic' in the 'Curve Fit' window and then click 'Accept'. Compare the new Curve Fit to the data in your Graph display.
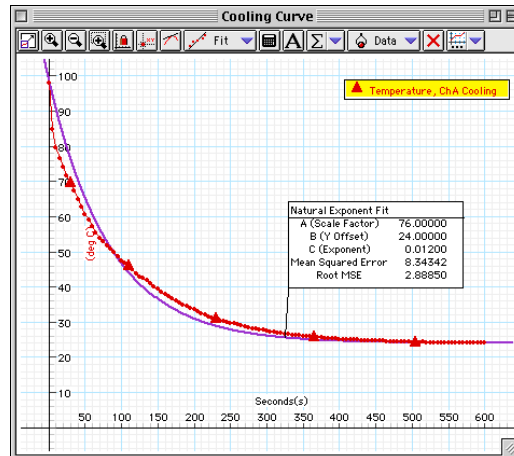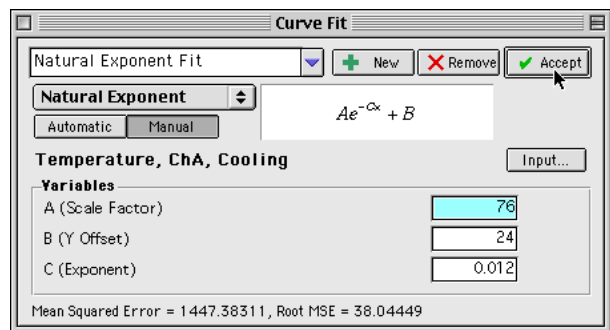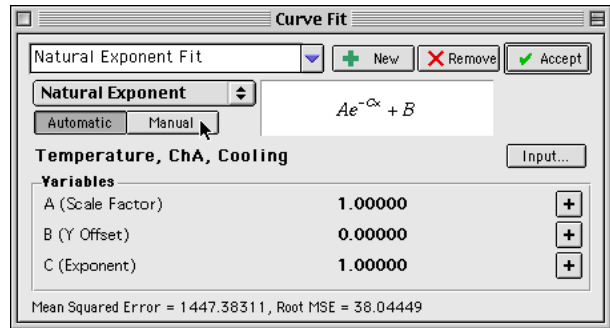
ScienceWorkshop Curve Fit

- *ScienceWorkshop* will attempt to fit the data to a mathematical formula with base "e" raised to a variable in x.
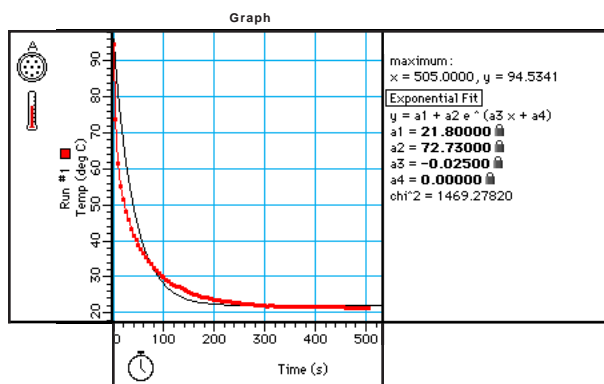
- In *ScienceWorkshop* you may see a message that says "there is no valid solution." In other words, the program needs your help to create the mathematical formula that best fits your data. Click 'OK' to continue.

- The Exponential Fit is of the form **y = a1 + a2e^(a3x + a4)**, where **a1** is the room temperature, **a2** = (initial temperature of the hot liquid) – (room temperature), **a3** = – k, and finally, **a4** has no match according to the function described in the Background. So, let a4 = 0.

ScienceWorkshop Exponential Fit Formula: $y = a2e^{(a3x + a4)} + a1$

- In the Graph statistics area, do the following:

1. Click **a1** and enter the value of the room temperature.
2. Click **a2** and enter the difference between the initial (maximum) temperature of the sensor, T(0), and the room temperature.
3. Click **a3** and enter the constant of proportionality, k, that you calculated earlier.
4. Click **a4** and enter "0" (zero).

The curve fit may not be exact, but none-the-less, that last entry really made a difference. It is important that parameters **a1**, **a2**, and **a4**, not be changed to better the fit, for they represent the actual initial and final conditions of the experiment. Try inputting different values for k (**a3**) to see if a better fit is possible.

Lab Report - Activity SL25: Exponential Modeling – Newton's Law of Cooling

What do you think?

From your own experience with the cooling of hot liquids (take coffee or tea for example), name some ways in which you would cause the hot liquid to reach the desired temperature before taking a sip.

Questions

1.   On your graph, at what point is the rate of cooling the greatest?

2.   On your graph, over what interval of time is the rate of cooling the greatest?

3.   On you graph, over what interval of time is the rate of cooling the least?

4.   How would the rate of cooling be affected if the Temperature Sensor were allowed to cool in a refrigerator?

5.   Again, if the Temperature Sensor were allowed to cool in the refrigerator, would k be greater than or smaller than if the Temperature Sensor were allowed to cool at room temperature?

6.   What would a temperature vs. time graph look like if the Temperature Sensor were allowed to warm up rather than cool down? Is this an example of an exponential function?
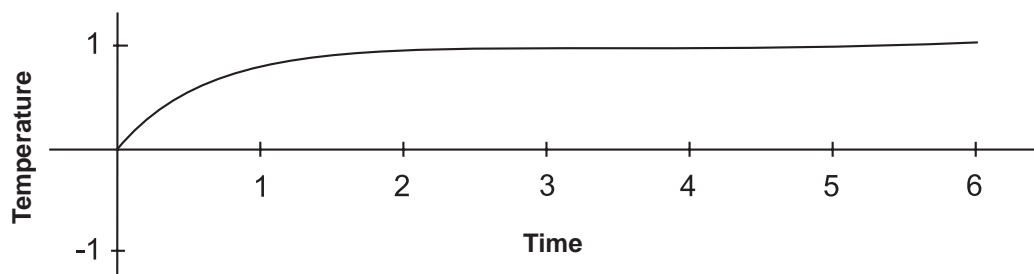
Activity SL26: Electrical Equivalent of Heat
(Temperature Sensor, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	IP18 EEH.DS	IP18 Elect. Equivalent of Heat	P45_ELEC.SWS

Equipment Needed	Qty	Consumables	Qty
Temperature Sensor (CI-6505A)	1	Styrofoam cup with lid	1
Voltage Sensor (CI-6503)	1	Water	200 mL
Balance (SE-8723)	1		
Heating resistor,10 Ω, 1 W (CI-6514A)	1	Optional	Qty
Power Supply, DC, 10 W (SE-9720)	1	Multimeter (SB-9624B)	1
Protective gear	PS		

What Do You Think?

Many households have a kitchen appliance or dispenser that delivers hot water. When operating, electrical energy is dissipated as thermal energy by a metal coil of moderate resistance. The thermal energy is then transferred to the water. How is the increase in thermal energy of the water related to the electrical energy supplied to it?

Take time to answer this question in the Lab Report section.

The purpose of this activity is show that the energy dissipated by a heating resistor in water is equal to the energy absorbed by the water. This concept is known as Joule Heating. You can find the **electrical equivalent of heat** from conservation of energy. The electrical equivalent of heat is the number of Joules of *electrical* energy that are equivalent to one calorie of *thermal* energy.

Background

When water is heated by submerging a heating resistor in the water and running a current through the resistor, the Joule heat from the resistor is transferred to the water and causes the temperature to change.

Using Conservation of Energy, if there are no energy losses to the surroundings, all the energy given off by the resistor should be absorbed by the water. The energy, *E*, dissipated by the resistor is

$$E = Pt$$

where *t* is the time during which the current flows through the resistor and *P* is the power given by

$$P = IV = \frac{V^2}{R}$$

where *V* is the voltage across the resistor and *R* is the resistance of the resistor.

The energy gained by the water is given by

$$Q = mc\Delta T$$

where *m* is the mass of the water, *c* is the specific heat of water (1 cal/g °C), and ΔT is the change in temperature of the water.

SAFETY   REMINDERS

- Wear protective gear.

- Follow directions for using the equipment.

- Be sure that the heating resistor is in the water before you turn on the power supply.

For You To Do

Use the power supply to supply electrical energy to a heating resistor at a set voltage. (The energy dissipated by the resistor warms a measured quantity of water.) Use the Temperature Sensor to measure the change in temperature of the water. Use the Voltage Sensor to measure the voltage across the heating resistor.

Use *DataStudio* or *ScienceWorkshop* to record the voltage across the heating resistor, and the change in temperature of the water. Use the program to calculate the electrical energy by integrating the electrical power (voltage squared divided by resistance) over time. Calculate the thermal energy gained by the water based on the known mass of water and its measured temperature change. Use the electrical energy (in Joules) and the energy gained by the water (in calories) to determine the electrical equivalent of heat.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Temperature Sensor DIN plug to Analog Channel A on the interface, and the Voltage Sensor DIN plug to Analog Channel B.

3. Open the document titled as shown:
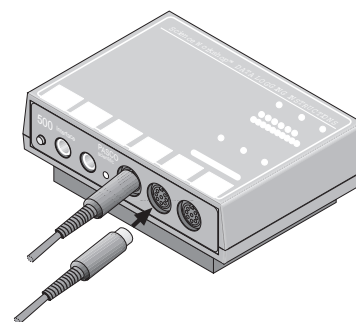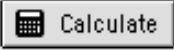
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
IP18 EEH.DS	IP18 Elect. Equivalent of Heat	P45_ELEC.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document has a Digits display of Temperature and a Graph display with Temperature vs. Time and Power Output vs. Time.

- Data recording is set at 1 second per measurement.

- The Power Output is a calculation based on the resistance of the resistor and the voltage across the resistor. The area under the Power Output vs. Time plot is the electrical energy. The calculation for electric power output assumes that the heating resistor has a resistance of 10 ohms (10 Ω).

- NOTE: If you are using a different heating resistor than the one that is included in the PASCO CI-6514A Thermodynamics Kit, use an ohmmeter to measure its resistance. Use the following procedure to modify the included calculation in *DataStudio* or in *ScienceWorkshop*.

Changing the Power Output Calculation (If Necessary)

DataStudio

1.   To change the built-in calculation for Power Output that is part of this *DataStudio*

document, click the 'Calculate' button (▦ Calculate) in the main toolbar.

•   The Calculator window will open. The window shows the calculation for Power Output
     that was created as part of this activity.
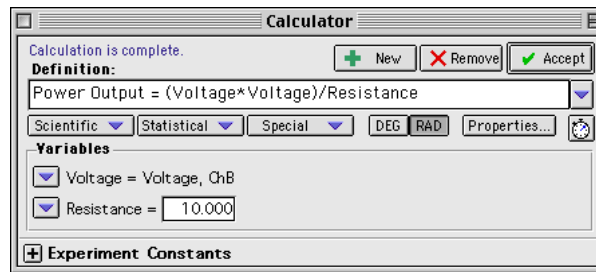
2.   If your resistor's resistance is different than 10 ohms, highlight the "10.000" in the
      'Resistance' window and type in your value for the resistance of your heating resistor.

3.   Click the 'Accept' button to save your change.

4.   Close the Experiment Calculator window.

ScienceWorkshop

1.   To change the built-in calculation for power that is part of
      this *ScienceWorkshop* document, click the **Calculator**

button (▦) in the Experiment Setup window.

•   The Experiment Calculator window will open. The window
     shows the calculation for Power Output that was created as
     part of this activity.

•   **@B.Voltage** represents the voltage measured by the Voltage
     Sensor in Analog Channel B. The calculation represents the voltage squared divided by the
     resistance, which is assumed to be 10 ohms.

2.   If your resistor's resistance is different than 10 ohms, highlight the "10" at the end of the
      calculation and type in your value for the resistance of your heating resistor.
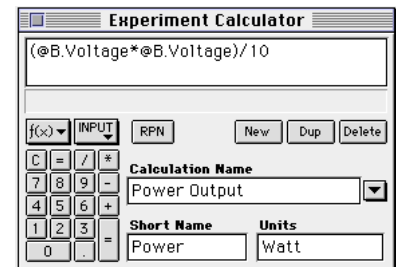
3.   Click the **equals** button (=) or press <ENTER> or <RETURN> on the keyboard to save
      your change.

4.   Close the Experiment Calculator window.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Temperature Sensor or the Voltage Sensor.

1. If you have a lid that will fit over the top of the cup, make one hole in the lid for the Temperature Sensor, and a second hole in the lid for the heating resistor. Measure the mass of the Styrofoam cup and lid. Record the mass in the Data Table.

- NOTE: Use water that is about three degrees Celsius below room temperature when data collection begins. Take data until the temperature of the water is about three degrees above room temperature. This minimizes the effect of the surroundings because the water gains energy from its surroundings for half the activity and loses energy to its surroundings for the other half of the activity.

2. Put about 200 mL of water in the cup and weigh the cup, lid and water. Measure and record the total mass. Subtract the mass of the cup and lid from the total mass of the cup with water to find the mass of the water. Record the water's mass in the Data Table.

3. Connect the banana plugs of the heating resistor into the output jacks of the power supply. Connect the banana plugs of the Voltage Sensor to the banana plugs of the heating resistor.
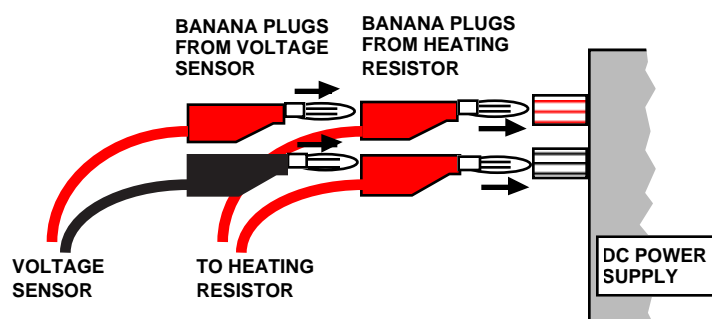
4. Put the heating resistor through its hole in the lid. Submerge the resistor in the water.

5. Put the Temperature Sensor through its hole in the lid of the cup.

CAUTION: Be sure the resistor is submerged in water when the current is flowing through it. Otherwise it can burn up!
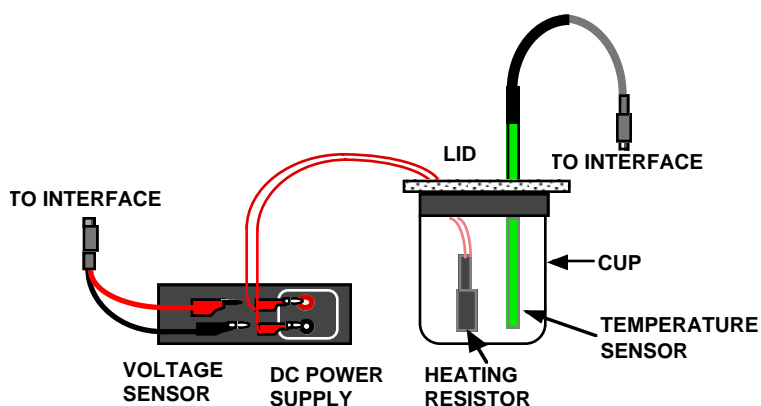
PART III: Data Recording

1. Plug in the power supply. Adjust the voltage to 10 volts and the current to 1 amp. Turn on the power supply.

2. Start recording data. Note the beginning temperature.

- IMPORTANT: During data recording, gently swirl the water in the cup so the water will be heated evenly. Watch the Digits display to keep track of the temperature.

3. When the temperature reaches three degrees <u>above</u> room temperature, turn off the DC power supply, but continue to swirl the water and collect data.

- The temperature will continue to rise as the last bit of thermal energy from the resistor is slowly given off.

4. When the water temperature begins to drop, stop recording data.

Analyzing the Data

1. Set up your Graph display so it shows statistics.

- Hint: In *DataStudio*, click the Statistics button in the Graph toolbar and select 'Show All'.

- Hint: In *ScienceWorkshop*, click the Statistics button to open the Statistics area on the right side of the graph. Click the Autoscale button to rescale the graph to fit the data. Click the Statistics Menu button in the Statistics area for the plot of *Temperature vs. Time*. Select 'All of the Above' from the Statistics menu.

2. Record the minimum and maximum temperatures (values of y) displayed in the Statistics area. Calculate and record the change in temperature of the water.

3. Set up your Graph display to show the area under the curve of Power Output versus Time.

- Hint: In *DataStudio*, click the Statistics button in the Graph toolbar and select 'Area'.

- Hint: In *ScienceWorkshop*, click the Statistics Menu button in the Statistics area for the plot of *Power Output vs. Time*. Select 'Integration' from the Statistics menu.

4. Record the 'Area' value as the electrical energy (Joules) used by the heating resistor.

- Hint: In *DataStudio*, the 'Area' value is in the Statistics.
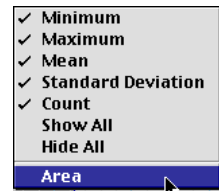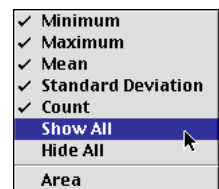
	Min.	Max.	Area
● Power Output Run #1	0.000	9.991	5250.190 s

5.   Calculate (in calories) the thermal energy (Q) absorbed by the water using $Q = mc\Delta T$,
      where m is the mass of the water, c is the specific heat of water (1cal/g°C), and ΔT is the
      change in temperature of the water. Record this value in the Data Table.

•   By the Law of Conservation of Energy, the electrical energy used by the resistor should
      equal the thermal energy gained by the water, neglecting losses to the surroundings.

      Solve for the number of Joules per calorie:

$$E.E.H. \ \ (\frac{J}{cal}) = \frac{Electrical \ Energy}{Thermal \ Energy}$$

      Calculate the percent difference between this experimental value and the accepted value
      (4.184 J/cal). Record the percent difference in the Data Table that follows.

      Record your results in the Lab Report section.

Lab Report - Activity SL26: Electrical Equivalent of Heat

What Do You Think?

Many households have a kitchen appliance or dispenser that delivers hot water. When operating, electrical energy is dissipated as thermal energy by a metal coil of moderate resistance. The thermal energy is then transferred to the water. How is the increase in thermal energy of the water related to the electrical energy supplied to it?

Data Table

Item	Amount	Item	Amount
Mass of Foam Cup	g	Temperature (max)	˚C
Mass of Foam Cup with Water	g	Temperature (min)	˚C
Mass of Water	g	Change in Temp. (ΔT)	˚C

Item	Amount
Electrical Energy, $E = Pt$	J
Thermal Energy, $\Delta Q = mc\Delta T$	calories
Electrical Equivalent of Heat	J/calorie

Accepted Value   = **4.184 J/cal**

Percent difference   = _____ %

Questions

1. Was the thermal energy gained by the water greater, the same as, or less than the electrical energy dissipated by the resistor?

2. The heating resistor is rated at 10 ohms and 1 watt. By how much was its power rating exceeded during this activity? (Remember, $P = \dfrac{V^2}{R}$.) Why didn't the resistor burn up?

3. What are some factors that could account for the percent difference between the experimental and accepted values for the electrical equivalent of heat?

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Activity SL27: Interference of Sound Waves - Beats
(Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Waves	P33 Beats.DS	P33 Interference-Beats	P33_BEAT.SWS

Equipment Needed	Qty
Voltage Sensor (CI-6503)	1
Dual Function Generator (WA-9301A)	1
Speaker (WA-9303)	1

What Do You Think?

In a typical classroom of science students, one or two people may play a guitar. They could describe to you the phenomenon they are trying to eliminate in the process of tuning. Ask a guitar player to describe what they are listening to as they tune a guitar. Write a brief description of what you hear when two slightly out-of-tune guitar strings are played at the same time.

Take time to write a brief description in the Lab Report section.

This activity examines the relationship between the beat frequency and the frequencies of the two interfering sound waves and shows beats on a Scope display.

Background

When two sound waves of slightly different frequency are produced simultaneously, they interfere with each other and the resulting sound that you hear is the superposition of the two waves. The combined sound seems to be one frequency, but the intensity varies. This loudness variation is called beats.

The beat frequency (number of beats per second) should equal the difference between the frequencies of the waves that interfere:

$$f_{beat} = |f_2 - f_1|$$

For You To Do

In this activity, use a special dual function generator to produce two sound waves of slightly different frequencies. Use the Voltage Sensor to measure the combined waveform. Use *DataStudio* or *ScienceWorkshop* to display and analyze the waveform.

Use one of the built-in analysis tools of the software to determine the beat frequency. Then use the Frequency Spectrum (FFT) display to observe the dominant frequencies of each individual wave. Then compare the beat frequency to the difference in frequency of the two interfering waves.
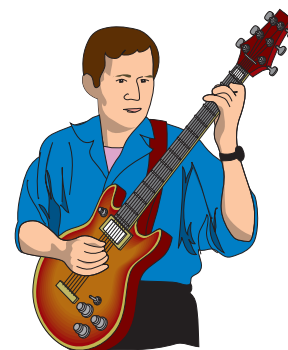
SAFETY REMINDERS
- Carefully follow the directions for using the equipment.

PART I: Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the Voltage Sensor DIN plug into Analog Channel A on the interface.
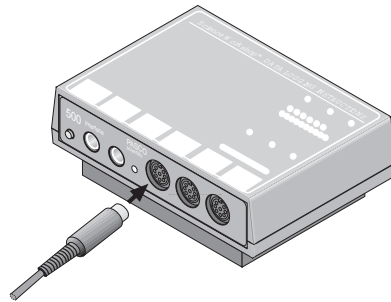
3.   Open the document titled as shown:

DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
P33 Beats.DS	P33 Interference-Beats	P33_BEAT.SWS

•   The document opens with a Scope display and a Frequency Spectrum (FFT) display.

PART II: Sensor Calibration and Equipment Setup

•   You do not need to calibrate the Voltage Sensor.

1.   Plug in power cord of the Dual Function Generator. Set the
     SUMMING AMPLIFIER found on the right hand edge of the
     Dual Function Generator so that the output from both Generator
     and Generator 2 will go into the VOLUME control at the lower
     right corner of the generator. (Put the middle 2 switches to the
     position.)

2.   Plug the Voltage Sensor banana plugs into the output jacks on
     lower right of the Generator marked 8 Ω OUT and GND.

3.   Connect the speaker plug into the top of the Voltage Sensor
     banana plugs.
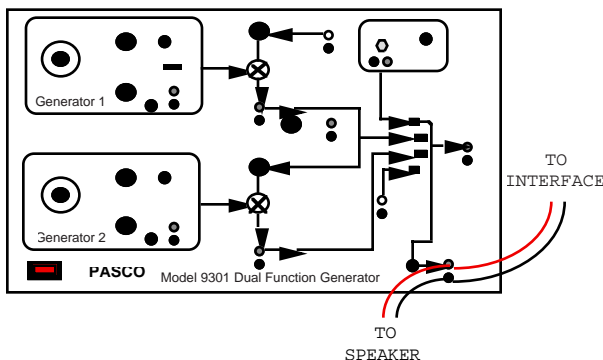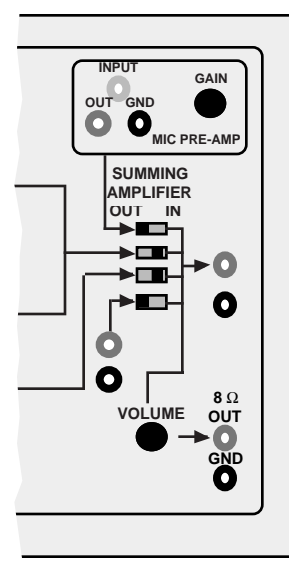
PART II: Equipment Setup - Continued

4.   Turn the MODULATION control on each of the Generators to OFF.
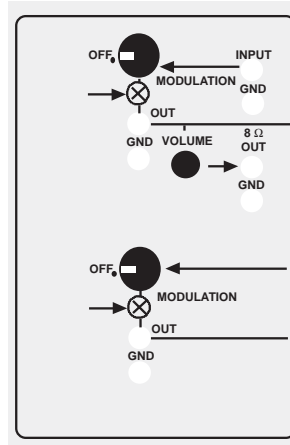
5.   Set GENERATOR 1 to a sine wave. Put the frequency range select control at 100. Put the AMPLITUDE control at the halfway point. Set the frequency at about 250 Hz.

6.   Set GENERATOR 2 to a sine wave. Put the frequency range select control at 100. Put the AMPLITUDE control at the halfway point. Set the frequency at about 230 Hz.

7.   Turn on the Dual Function Generator. Adjust the VOLUME control at the lower right corner of the generator.
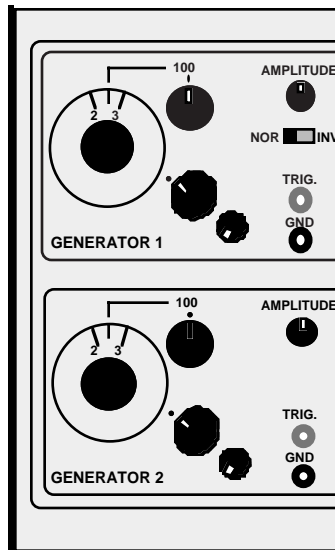
•   Note: You should be able to hear the output from both GENERATOR 1 and GENERATOR 2 of the Dual Function Generator from the speaker.

PART III: Data Recording

1.   Start monitoring data.

•   Hint: In *DataStudio*, click the Start button (▶ Start).

•   Hint: In *ScienceWorkshop*, click the MON button (▷ MON).

•   The Scope should display a waveform somewhat like the examples shown here.
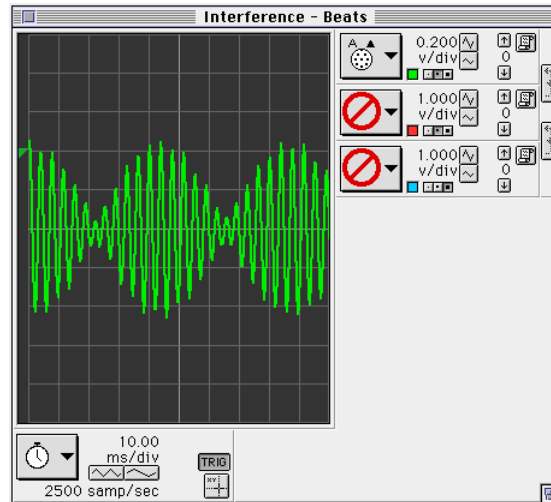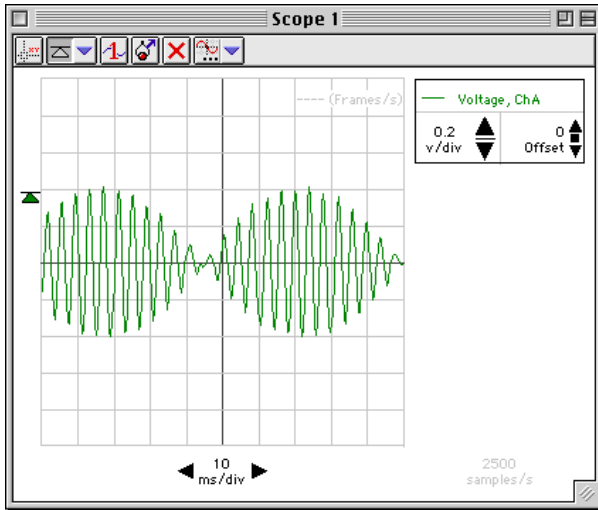
•   Notice that the sweep speed is set to 10.00 ms/div, and that the sensitivity is set to 0.200 v/div. Notice also that the trigger level is set to match the maximum amplitude of the waveform.

2.   Adjust the Scope controls as necessary in order to display your waveform.

3.   Click the STOP button to stop monitoring data.

Analyzing the Data

1.   Use the Scope display's built-in analysis tool to find the time (or period) from one maximum amplitude to the next. Record the time in the Lab Report section.

•   Hint: In *DataStudio*, click the Smart Tool button (⊞). Move the Smart Tool to the <u>first</u> point of maximum amplitude on the Scope display. Use the "delta" feature of the Smart Tool to find the time to the <u>next</u> maximum amplitude. To use the "delta" feature, move the cursor toward a corner of the Smart Tool until the cursor changes to a "Δ" shape. Move the "Δ" shaped cursor to the next maximum. Record the time.
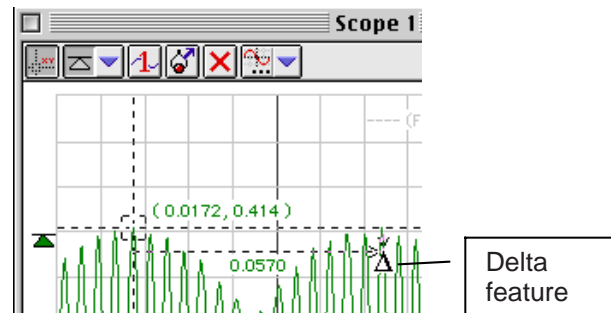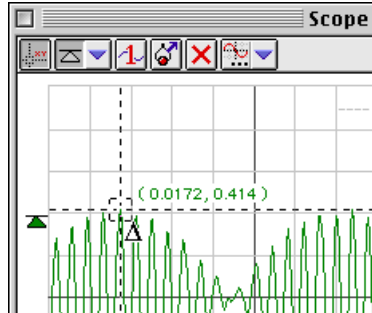
Delta feature

•   Hint: In *ScienceWorkshop*, click the Smart Cursor button (⊞) and move the cursor to the <u>first</u> point of maximum amplitude on the Scope display. Use the "delta" feature of the Smart Cursor to find the time to the next maximum amplitude. To use the "delta" feature, hold down the mouse button as you move the cursor. Record the time.

•   The next task is to find the frequency of each individual tone:

2.   Turn <u>off</u> the signal from **GENERATOR 2** on the Dual Function Generator by moving the <u>third</u> switch in the **SUMMING AMPLIFIER** from **IN** to **OUT**. The remaining tone is coming from **GENERATOR 1** alone.

3.   Set up the FFT display.

•   Hint: In *DataStudio*, click the Window menu and select FFT1 from the list.

•   Hint: In *ScienceWorkshop*, click the Display menu and select Frequency Spectrum from the end of the menu.

4.   Start monitoring data from GENERATOR 1.

5.   Hint: Click the Start button in *DataStudio* or click the MON button in *ScienceWorkshop*.

•   The FFT (Frequency Spectrum) display will show the fundamental frequency of the signal from GENERATOR 1.
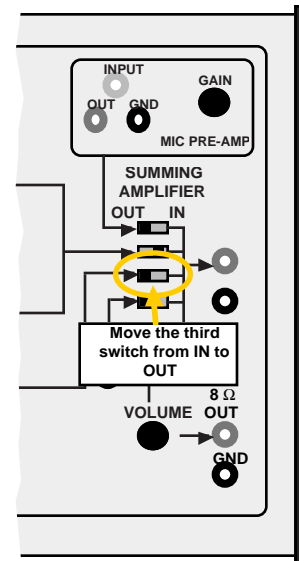
6.   Use the FFT display's analysis tools to find the principal frequency of the signal from GENERATOR 1.

•   Hint: In *DataStudio*, click the Smart Tool button. In *ScienceWorkshop*, click the Smart Cursor button. Move the cursor to the position of the maximum peak in the frequency spectrum.
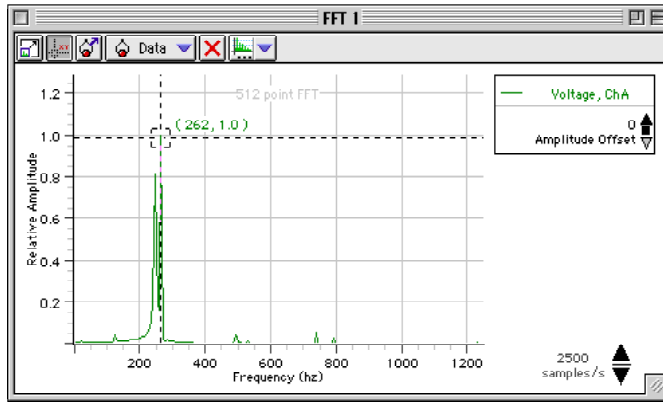
7.   Record the frequency that is displayed.

•   Hint: In *DataStudio*, the frequency is the first number in the ordered pair next to the Smart Tool. In *ScienceWorkshop*, the frequency is shown in the area just below the horizontal axis.

8.   Click the STOP button to stop monitoring data.

9.   Turn off the signal from **GENERATOR 1** on the Dual Function Generator by moving the second switch in the **SUMMING AMPLIFIER** from **IN** to **OUT**. Turn on the signal from **GENERATOR 2** by moving the third switch from **OUT** to **IN**.

•   The new tone is coming from GENERATOR 2 alone.

10. Start monitoring the data from GENERATOR 2.

•   Hint: Click the Start button in *DataStudio* or the MON button in *ScienceWorkshop*.

•   The Frequency Spectrum (FFT) display will show the fundamental frequency of the signal from GENERATOR 2.

11. Use the FFT display's analysis tools to find the principal frequency of the signal from GENERATOR 2.

•   Remember in *DataStudio*, click the Smart Tool button. In *ScienceWorkshop*, click the Smart Cursor button. Move the cursor to the position of the maximum peak in the frequency spectrum.

12. Record the frequency that is displayed.

•   Remember that in *DataStudio*, the frequency is the first number in the ordered pair next to the Smart Tool. In *ScienceWorkshop*, the frequency is shown in the area just below the horizontal axis.

13. Click the STOP button to stop monitoring data.

Record your results in the Lab Report section.

Lab Report - Activity SL27: Interference of Sound Waves - Beats

What Do You Think?

In a typical classroom of science students, one or two people may play a guitar. They could describe to you the phenomenon they are trying to eliminate in the process of tuning. Ask a guitar player to describe what they are listening to as they tune a guitar. Write a brief description of what you hear when two slightly out-of-tune guitar strings are played at the same time.

Analyzing the Data

Data Table

Time (ms)	Frequency (Hz)

Individual Frequencies for Dual Function Generator

GENERATOR 1	Hz
GENERATOR 2	Hz

1. Calculate the beat frequency: $\upsilon_{beat} = \dfrac{1}{time}$

2. Find the difference between the two individual frequencies and compare this to the beat frequency.

Beat Frequency (experimental) = _____ H z

Beat Frequency (theory) = |Frequency$_2$ - Frequency$_1$| = _____ Hz

Percent difference between experimental and theoretical values = _____ %

Question

1. What are some factors that could account for the percent difference between experimental and theoretical values?

Activity SL28: Induction – Magnet through a Coil
(Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electromagnetism	P41 Induction.DS	P41 Induction - Magnet	P41_INDU.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Voltage Sensor (CI-6503)	1	Bar Magnet, alnico (EM-8620)	2
AC/DC Electronics Lab (EM-8656)	1		

What Do You Think?

When electricity is passed through a conducting wire a magnetic field can be detected near the wire. Micheal Faraday was one of the first scientists to reverse the process. The essence of his work is decribed in the following statement:

> You can send electricity through a conducting wire to make a magnetic field. Is the reverse possible? Can you use a magnet and a conducting wire to make electricity?

Take time to write answers to these questions in the Lab Report section.

The purpose of this activity is to measure the Electromotive Force (EMF) induced in a coil by a magnet dropping through the center of a coil.

Background

When a magnet is passed through a coil there is a changing magnetic flux through the coil which induces an Electromotive Force (EMF) in the coil. According to Faraday's Law of Induction:

$$\mathcal{E} = -N \frac{\Delta \phi}{\Delta t}$$

where $\mathcal{E}$ is the induced EMF, N is the number of turns of wire in the coil, and $\frac{\Delta \phi}{\Delta t}$ is the rate of change of the flux through the coil.

In this activity, a plot of the EMF versus time is made and the area under the curve is found by integration. This area represents the flux since:

$$\mathcal{E} \Delta t = -N \Delta \phi$$
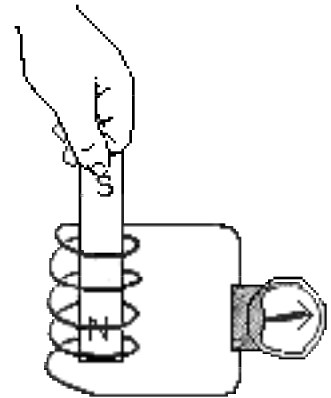
SAFETY REMINDERS

- Follow directions for using the equipment.

**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

Use the Voltage Sensor to measure the voltage (EMF) induced in a coil as a bar magnet moves through the coil. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data.

PART I: Computer Setup

1.   Connect the interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the Voltage Sensor DIN plug into Analog Channel A. Connect the Photogate stereo phone plug into Digital Channel 1.

3.   Open the document titled as shown:
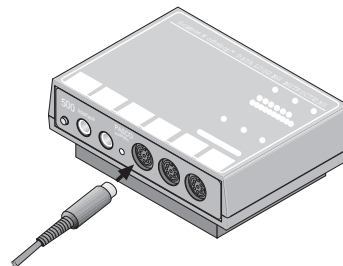
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
P41 Induction.DS	P41 Induction - Magnet	P41_INDU.SWS

• The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

• The *ScienceWorkshop* document opens with a Graph display of Voltage vs. Time and a Meter display of Voltage.

• Data recording is set at 200 Hz. The Start Condition is set to begin when voltage is at 0.05 volts. The Stop Condition is set when Time = 0.4 seconds.

• Note: In *DataStudio*, the data recorded for 0.3 seconds prior to the Start Condition are kept as well.

PART II: Sensor Calibration and Equipment Setup

• You do not need to calibrate the Voltage Sensor.

1.   Put alligator clips on the ends of the Voltage Sensor leads.

2.   Attach a Voltage Sensor lead to one component spring next to the inductor coil on the circuit board. Attach the other lead to the other component spring next to the coil.

3.   Arrange the circuit board so the corner with the coil is beyond the edge of the table, and a magnet dropped through the coil can fall freely.

• The bar magnet will be dropped through the coil. Make sure that the magnet does not strike the floor, or it may break.

Part III: Data Recording

1. Hold the magnet so that the south end is about 2 cm above the coil.

• Note: If you are using the PASCO Model EM-8620 Alnico Bar Magnet the North end is indicated by the narrow groove near one end. For the first run, hold the magnet with groove end 'up'.
---

2. Start recording data. Let the magnet drop through the coil.

• Data recording will begin when the magnet falls through the coil and the voltage from the coil reaches 0.05 V. Data recording will end automatically after 0.5 seconds.

Analyzing the Data

1. Set up your Graph to show the area under the curve of voltage versus time.

• Hint: In *DataStudio*, click the Statistics menu button ( ) and select 'Area'.
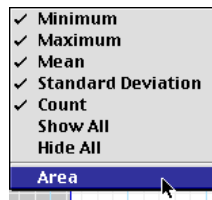
• Hint: In *ScienceWorkshop*, click the Statistics button ( ) to open the Statistics area on

the right side of the graph. Click the Autoscale button ( ) to rescale the graph to fit the

data. In the Statistics area, click the Statistics Menu button ( ). Select 'Integration'
from the menu.
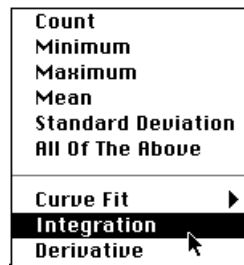
2.   In the Graph display, use the cursor to select a rectangle around the first peak of the voltage plot.

3.   In *DataStudio*, the value for 'Area' appears in the legend in the Graph. In *ScienceWorkshop*, the 'area' under the curve for the first peak appears in the statistics area under 'Integration' on the right side of the Graph.
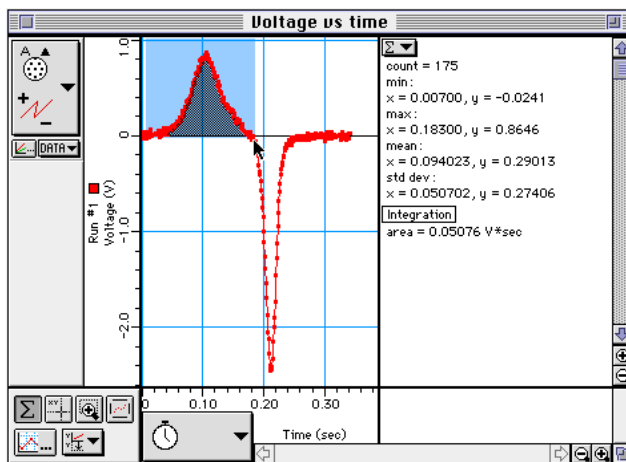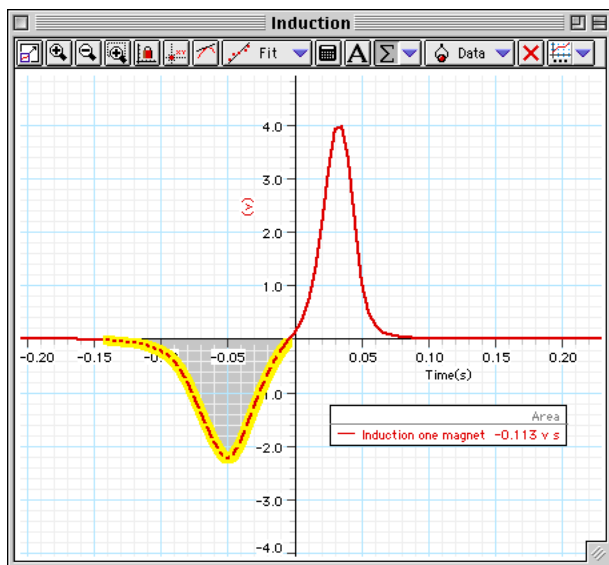
4.   Record the value of Integration for the first peak.

Integration (first peak) = _____ V*sec

5.   Repeat the process to find the area under the second peak. Record the value.

Integration (second peak) = _____ V*sec

Record your results in the Lab Report section.

Optional

Repeat the data recording and data analysis procedures for the following optional setups:

•   Tape two bar magnets together so both south ends are together.

•   Re-arrange the two bar magnets so that the south end of one is with the north end of the other.

Lab Report - Activity SL28: Induction – Magnet through a Coil

What Do You Think?

When electricity is passed through a conducting wire a magnetic field can be detected near the wire. Micheal Faraday was one of the first scientists to reverse the process. The essence of his work is decribed in the following statement:

> You can send electricity through a conducting wire to make a magnetic field. Is the reverse possible? Can you use a magnet and a conducting wire to make electricity?

Data

<div align="center">

Integration (first peak) = _____ V*sec

Integration (second peak) = _____ V*sec

</div>

Questions

1.   Is the incoming flux equal to the outgoing flux?

2.   Why is the outgoing peak higher than the incoming peak?

3.   Why are the peaks opposite in direction?

Activity SL29: LRC Circuit
(Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
AC circuits	SLP45 LRC Circuit.DS	(See appendix)	(See appendix)

Equipment Needed	Qty	From AC/DC Electronics Lab (EM-8656)	Qty
Voltage Sensor (CI-6503)	2	Capacitor, 100 microfarad (100 μF)	1
Function Generator (PI-9587C)	1	Inductor coil and iron core	1
Patch Cord (SE-9750)	2	Resistor, 10 ohm (10 Ω)	1
Graph paper (optional)	1	Wire lead, 5 inch	1
LCR Meter (SB-9754) (optional)	1		

What Do You Think?

The purpose of this activity is to study resonance in an inductor-resistor-capacitor circuit (LRC circuit) by examining the current through the circuit as a function of the frequency of the applied voltage. What will happen to the amplitude of the current in the LRC circuit when the frequency of the applied voltage is at or near the resonant frequency of the circuit?

Take time to write an answer to this question in the Lab Report section.

Background

When a vibrating mechanical system is set in motion, it vibrates at its natural frequency. However, a mechanical system can be forced to vibrate at a different frequency. The amplitude of vibration, and hence the energy transferred to the system, depends on the difference between the natural frequency and the frequency of forced vibration. The amplitude becomes very large when the difference between the natural and forced frequency becomes very small. This is known as resonance and the natural frequency of the system is sometimes called the resonant frequency. At resonance, relatively little energy is required to get a large amplitude. One example of resonance is when a singer's amplified voice is used to shatter a glass.

Electrical resonance is analogous to mechanical resonance. The energy transferred to a system is a maximum at resonance.

The amplitude of the AC current (I_o) in a series LRC circuit is dependent on the amplitude of the applied voltage (V_o) and the impedance (Z).

$$I_o = \frac{V_o}{Z}$$

Since the impedance depends on frequency, the current varies with frequency:

$$Z = \sqrt{\left(X_L - X_C\right)^2 + R^2}$$

where X_L = inductive reactance = ωL, X_C = capacitive reactance = $\frac{1}{\omega C}$, R = resistance, and ω =

angular frequency = $2\pi\nu$ (ν = linear frequency). The current will be maximum when the circuit is driven at its resonant frequency:

$$\omega_{res} = \frac{1}{\sqrt{LC}}$$

One can show that, at resonance, $X_L = X_C$ and thus the impedance (Z) is reduced to R. At resonance, the impedance is the lowest value possible and the current will be the largest value possible.

SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use a function generator to produce an alternating current through the LRC circuit. Use one Voltage Sensor to measure the voltage from the generator and a second Voltage Sensor to measure the voltage drop (potential difference) across the resistor in the circuit.

The amplitude of the current depends on the impedance in the circuit, which varies with frequency. Calculate the theoretical resonant frequency for your circuit. Use the function generator to control the frequency. If the current is a maximum at the resonant frequency and is less than maximum for greater or lesser frequencies, the current should peak at the resonant frequency. Determine the amplitude of the current through the resistor and then plot current versus frequency. The current can be determined from the ratio of the resistor voltage to the resistance. Compare the theoretical resonant frequency to your measured resonant frequency.

Also, investigate the phase relationship between the applied voltage and the resistor voltage as you vary the frequency.

Use *DataStudio* or *ScienceWorkshop* to record and display both the applied voltage and the resistor voltage.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect one Voltage Sensor to Analog Channel A. Connect the second Voltage Sensor to Analog Channel B.

3. Open the document titled as shown:
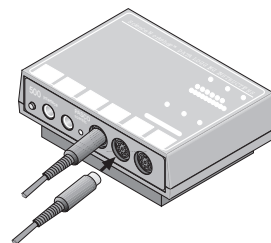
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
SLP45 LRC Circuit.DS	(See appendix)	(See appendix)

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The data sampling rate is set at 2000 Hz.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensors. The following setup shows the AC/DC Electronics Board (EM-9656).

1. Connect a 5-inch wire lead between a component spring next to the top banana jack, and the component spring at the right hand edge of the inductor coil. Put the iron core inside the inductor coil.

2. Connect the 10-Ω resistor (brown, black, black) between the component spring at the left-hand edge of the inductor coil, and the second component spring to the left of the top banana jack.

3. Connect the 100-µF capacitor between the component spring nearest to the one in which one end of the 10-Ω resistor is connected, and a component spring nearest to the bottom banana jack at the lower right corner of the AC/DC Electronics Lab circuit board.

4. Put alligator clips on the banana plugs of the Voltage Sensor connected to Analog Channel B. Connect the alligator clips of the Voltage Sensor to the wires at both ends of the 10-Ω resistor. The voltage measured at Analog Channel B is related to the current through the resistor by $I = \dfrac{V_R}{R}$.

5. Connect banana plug patch cords from the banana jacks on the edge of the AC/DC Electronics Lab Board to the output jacks of the function generator.

6. Connect the Channel A Voltage Sensor into the output jacks of the function generator.
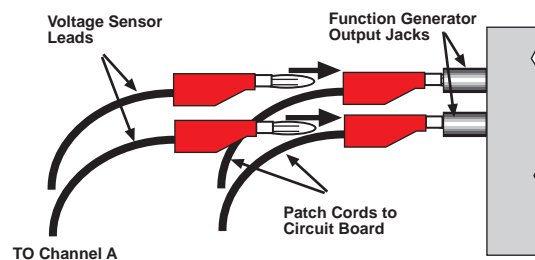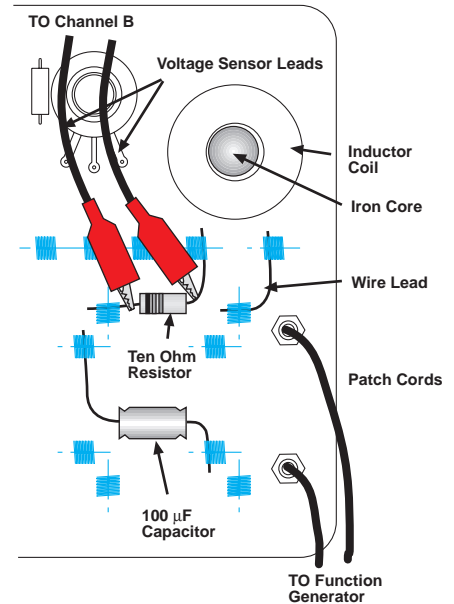
Part III: Data Recording

1.   Turn on the function generator. Set the waveform to "sine". Set the output voltage to 3
      volts. Set the output frequency to 10 Hz.

2.   Start monitoring data.

•   Hint: In *DataStudio*, click the Start button (▶ Start). In *ScienceWorkshop*, click the
      MON button. The Scope display shows the driving voltage, V, from the function generator
      (Channel A), and the voltage, V_R, across the resistor (Channel B).
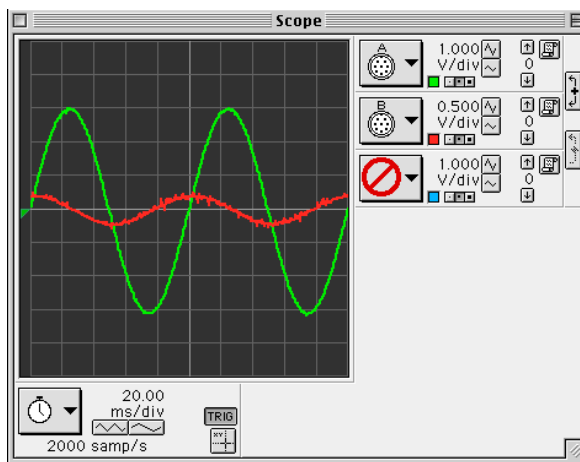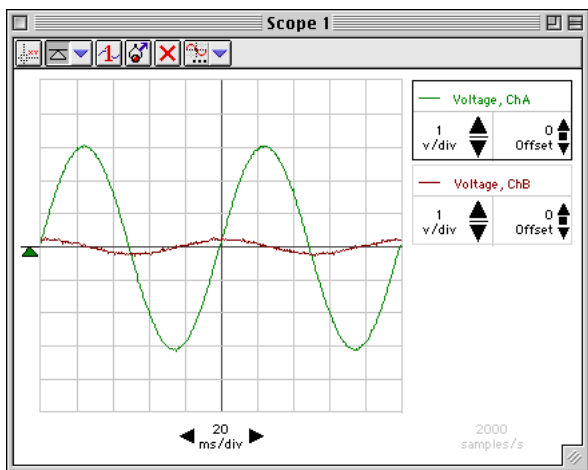
3.   In the Scope display, determine the voltage, V_R, across the resistor (i.e., voltage from
      Channel B).

•   Hint: In *DataStudio*, click the 'Smart Tool' button ( ) in the Scope display toolbar. In

      ScienceWorkshop, click the 'Smart Cursor' button ( ) along the bottom edge of the
      display. Move the cursor/cross-hair to a peak of the signal that shows the voltage across the
      resistor, V_R (Channel B).

4.   Record the voltage, V_R, in the Data Table in the Lab Report section next to 10 Hz.

•   Hint: In *DataStudio*, the voltage is the first number in the Smart Tool's ordered pair. In
      ScienceWorkshop, the voltage is displayed next to the Input Menu button for Channel B.
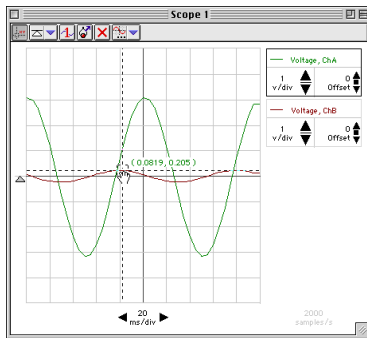
5.   Adjust the function generator to 20 Hz. Repeat the process to find the new value of voltage
      and record it in the Data Table next to 20 Hz.

6. Increase the frequency in 10 Hz increments until 150 Hz. Repeat the process of using the Smart Cursor to find each new value for the resistor voltage, V_R. Record each voltage value in the Data Table.

•   NOTE: Adjust the Sweep Speed in the Scope display using the **Sweep Speed** button as needed.

7. Look at the Data Table and estimate the approximate resonant frequency (where voltage across the resistor reaches a maximum).

8. Adjust the function generator to the value of your estimate of the resonant frequency. Make fine adjustments to the frequency until the trace of voltage from Channel B is *in phase* with the trace of voltage from Channel A.

•   Hint: Switch the Scope display to X-Y mode to check whether the trace of voltage from Channel B (resistor voltage) is *in phase* with the trace of voltage from Channel A (the function generator). See the descriptions below.

9. Record the new resonant frequency in the Data Table.

10. Click the 'STOP' button. Turn off the function generator.

Frequency Adjustment in XY Mode: *DataStudio*

1. Click Stop.

2. In the display, temporarily remove 'Voltage ChB'. (Hint: Click 'Voltage ChB' to select the input and then click the 'Remove' button (![X]) in the Scope toolbar.)

3. Click and drag 'Voltage ChB (v)' from the Summary list to the bottom edge of the Scope display. Drop 'Voltage ChB (v)' onto the Sweep Speed control panel.
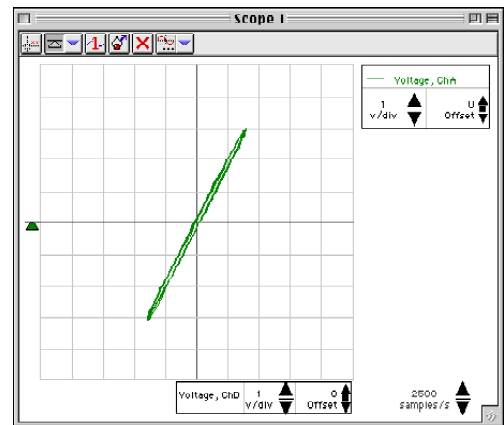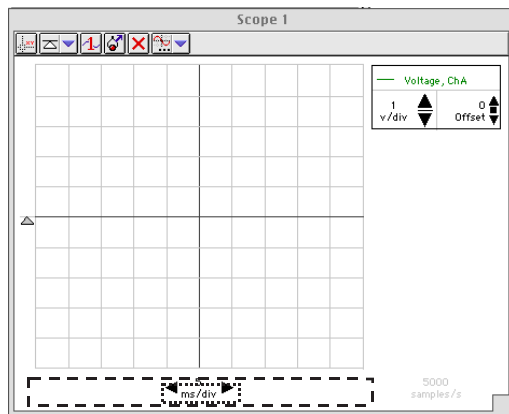
•   Note: The Sweep Speed control panel will be surrounded by a dashed rectangle when the new input ('Voltage ChB (v)') is on top of the control panel. (See the illustration.)

4. Click 'Start' to begin monitoring the data again.

5. Adjust the function generator frequency until the Scope display shows a diagonal line. An oval trace means the signals are out-of-phase.

Frequency Adjustment in XY Mode: *ScienceWorkshop*

- Click STOP.

- In the Scope display, click the 'Horizontal Axis Input' menu button ([⏱ ▾]). Select 'Analog B' from the Horizontal Axis Input menu.
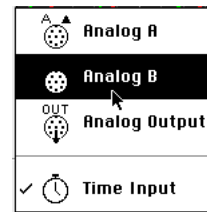
- In the Scope, click the 'Channel B Input' menu button ([B ▾]). Select 'No Input' from the Channel B Input menu.

- Click the 'MON' button to begin monitoring data again.

- Adjust the function generator frequency as needed to reach the resonant frequency. When the two inputs are in phase, the Scope display in **X‑Y** mode will show a diagonal line. An oval trace means the signals are out-of-phase.
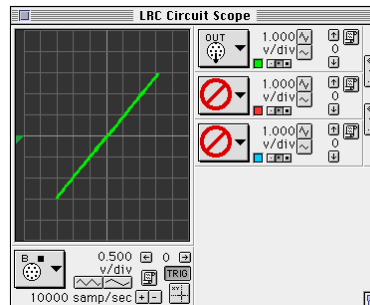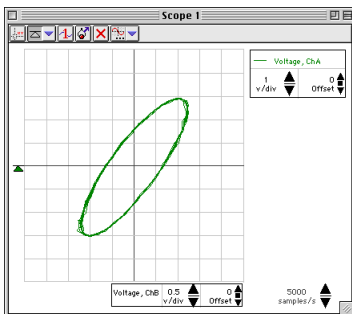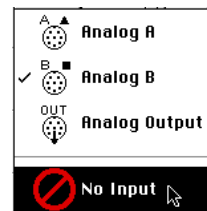
- If you have a meter that can measure inductance, resistance, and capacitance, use it to measure the inductance of the coil with the core inside, the resistance of the 10 Ohm resistor, and the capacitance of the 100 microfarad capacitor. Record your values in the Data Table.

Analyzing the Data

1. Calculate the current through the resistor for each increment of frequency and record the values in the Data Table.

2. Graph the current versus the linear frequency. You can use the software or graph paper. (NOTE: The function generator frequency is the linear frequency.)

3. Using the resonant frequency found from the Scope display, calculate the resonant angular frequency and record the value in the Data Table:

$$\omega_{res} = 2\pi v_{res}$$

4. Calculate the theoretical resonant angular frequency using the values of the inductance and capacitance:

$$\omega_{res} = \frac{1}{\sqrt{LC}}$$

Record your results in the Lab Report section.

Lab Report - Activity SL29: LRC Circuit

What Do You Think?

The purpose of this activity is to study resonance in an inductor-resistor-capacitor circuit (LRC circuit) by examining the current through the circuit as a function of the frequency of the applied voltage. What will happen to the amplitude of the current in the LRC circuit when the frequency of the applied voltage is at or near the resonant frequency of the circuit?

Data Table

Freq (Hz)	V_R	Current (V_R/R)	Freq (Hz)	V_R	Current (V_R/R)
10			90		
20			100		
30			110		
40			120		
50			130		
60			140		
70			150		
80					

Item	Value
Inductance	mH
Resistance	Ω
Capacitance	µF

Resonant frequency (linear)	Hz
Resonant angular frequency	Hz
Theoretical resonant angular frequency	Hz

Questions

1.   How does your measured value for resonant angular frequency compare to the theoretical value for resonant angular frequency?

Remember, **Percent difference** $= \left\| \dfrac{theoretical - actual}{theoretical} \right\| \times 100\%$

2.   Is the plot of current versus frequency symmetrical about the resonant frequency? Explain.

3.   At resonance, the reactances of the inductor and the capacitor cancel each other so that the impedance (Z) is equal to just the resistance (R). Calculate the resistance of the circuit by using the amplitude of the current at resonance in the equation $R = \dfrac{V}{I}$ (where V is the amplitude of the applied voltage). Is this resistance equal to 10 ohms? Why not?

Optional

1.   Use the Voltage Sensor in Analog Channel B to measure the peak voltage across each of the components of the circuit individually. The sum of these peak voltages do not equal the applied peak voltage. Why not? Draw a phasor diagram to explain this.

2.   Determine whether the resonant frequency depends on the resistance.

      (To see if the resistance makes a difference, set the Scope to the resonant frequency and then replace the 10-ohm resistor by a 100-ohm resistor. Does the resonant frequency increase, decrease, or stay the same?)

Graphing Current vs. Linear Frequency using *DataStudio*

You can enter data into a Table display and then show the data in a Graph window.

1. Select 'New Empty Data Table' from the Experiment menu.
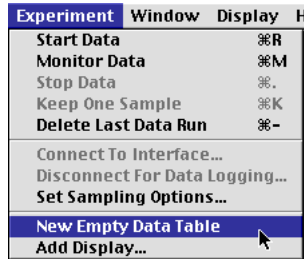
2. The Table has two columns labeled 'X' and 'Y'. The first cell under the 'X' column is ready for you to enter a number.

3. Enter the first value of frequency (Freq (Hz)), click <TAB>, and enter the first value of current (Current = V_R/R). Click <TAB> to move to the second row.

4. Continue to enter values of frequency and current. (Note: *DataStudio* anticipates the next value of frequency for you.)

5. Select 'Add Display…' from the Experiment menu.

6.   Click 'Graph' and then click 'OK' in the 'Please Choose…' window.
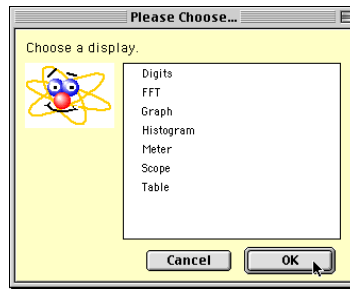
7.   From the Summary list, click and drag 'Data' (under 'Editable Data') to the new Graph.

•   The Graph shows that current peaks at about 80.
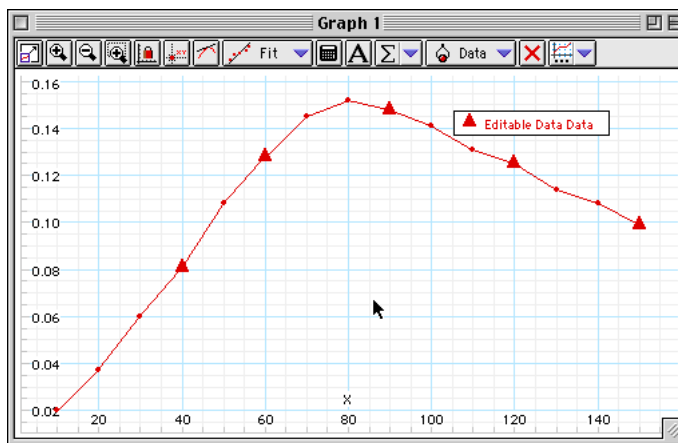
•   To add labels to the Y-axis and X-axis, double-click on 'Editable Data' in the Summary
      list to open the Data Properties window.
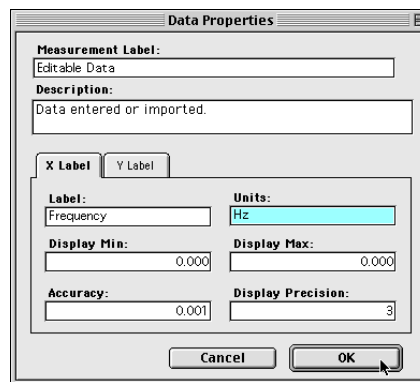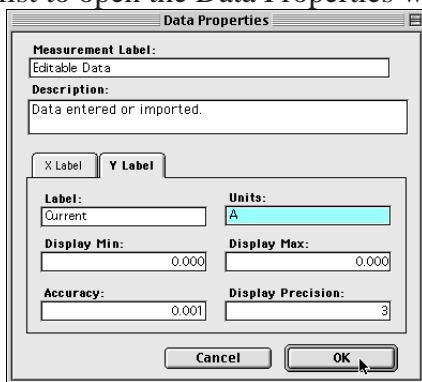
•   Enter 'Current' for the Y Label and 'A' for the Units, and enter 'Frequency' for the X
      Label and 'Hz' for the units. Click 'OK' to return to the Graph.

Graphing Current vs. Linear Frequency using *ScienceWorkshop*

You can type data into the Notes window and then display the data in a Graph window.

1. Clear the text and graphics (if any) from the Notes window.

2. Type data into the Notes window using the following procedure:

    <independent variable value #1><TAB><dependent variable value #1><return>

    <independent variable value #2><TAB><dependent variable value #2><return>, etc.

•   In this case, the independent variable is frequency, and the dependent variable value is the current.

•   For example, the figure shows two columns of numbers typed into a Notes window. The first column represents the linear **frequencies**. The second column represents hypothetical values of **current**.

3. Use the cursor to select (highlight) the two columns of numbers, or click the 'Edit' menu and pick 'Select All'**.**
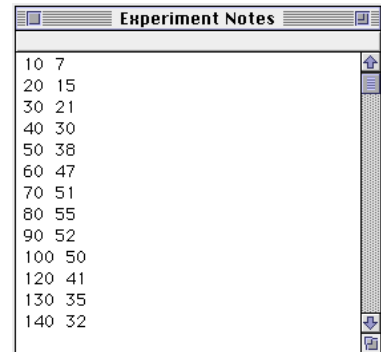
4. Copy the selection (use 'Copy' from the Edit menu).

5. Click the Display Menu and select 'New Graph'.

6. Click the **Plot Data Options** button (   ) in the new graph display. The Plot Data Options window will open.

7. Click **Paste** to paste your numbers for frequency and current into the graph. Click **O K** to return to the graph. Click the

    Autoscale button (   ) to rescale the graph to fit your data.

•   Notice that the horizontal axis shows "Time (sec)" rather than frequency, but that the range for the horizontal scale is correct.
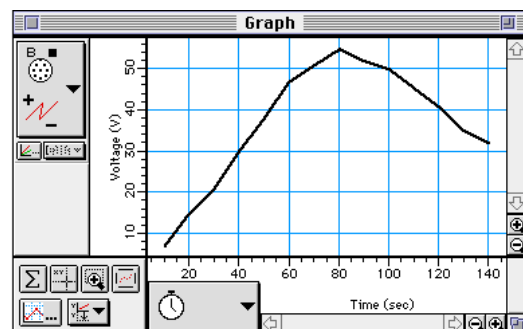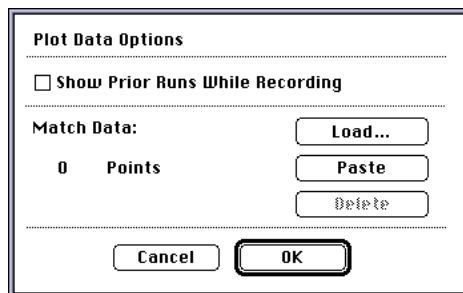
Appendix for ScienceWorkshop Experiment Setup

1.   Start the *ScienceWorkshop* program.

2.   Set up the two Voltage Sensors. In the Experiment Setup window, click and drag the analog sensor plug icon to Analog Channel A. Select **Voltage Sensor** from the list of sensors and click **OK.** Repeat the process. Click and drag the plug icon to Analog Channel B and select **Voltage Sensor**. Click **O K**.

3.   Select a Scope display. In the Experiment Setup window, click and drag the Scope display icon to the Voltage Sensor icon below Channel A.

•   Minimize the Experiment Setup window so it is out of the way.

4.   Set the input for the Scope display. Click the Input Menu button for the middle trace. Select **Analog B** from the Input Menu.

5.   Set the sweep speed. Click the left Sweep Speed button to adjust the sampling rate to 2000 samp/s.
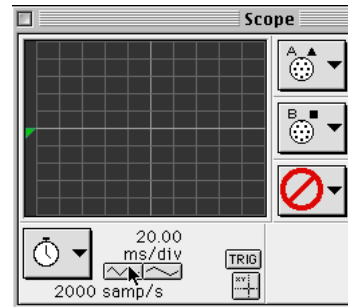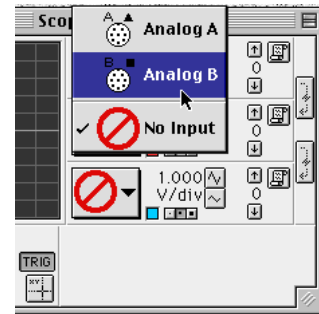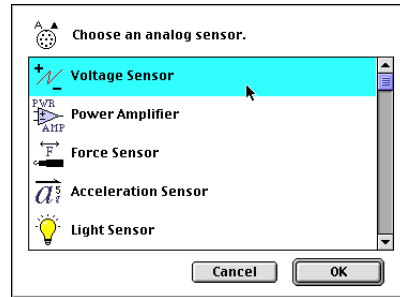
Activity SL30: Transistor Lab 1 – The NPN Transistor as a Digital Switch (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Semiconductors	SLP48 Digital Switch.DS	(See appendix)	(See appendix)

Equipment Needed	Qty	From AC/DC Electronics Lab (EM-8656)	Qty
Voltage Sensor (CI-6503)	2	Light-emitting diode (LED), red	1
Function Generator (PI-9587C)	1	Resistor, 330 Ω (orange-orange-black)	1
Patch Cord (SE-9750)	4	Resistor, 22 kΩ (red-red-orange)	1
Power Supply, 5 V DC (SE-9720)	1	Transistor, 2N 3904	1
		Wire lead, 5 inch	2

What Do You Think?

Using your library or the Internet, explore the following: What key aspects of the transistor aided in revitalizing Japan's economy after WWII?

Take time to write an answer to this question in the Lab Report section.

The purpose of this activity is to investigate how the ***npn*** **transistor** operates as a digital switch.

Background

The transistor is the essential ingredient of every electronic circuit, from the simplest amplifier or oscillator to the most elaborate digital computer. Integrated circuits (IC's) which have largely replaced circuits constructed from individual transistors, are actually arrays of transistors and other components built from a single wafer-thin piece or "chip" of semiconductor material.

The transistor is a semiconductor device that includes two p-n junctions in a sandwich configuration which may be either p-n-p or, as in this activity, n-p-n. The three regions are usually called the emitter, base, and collector.
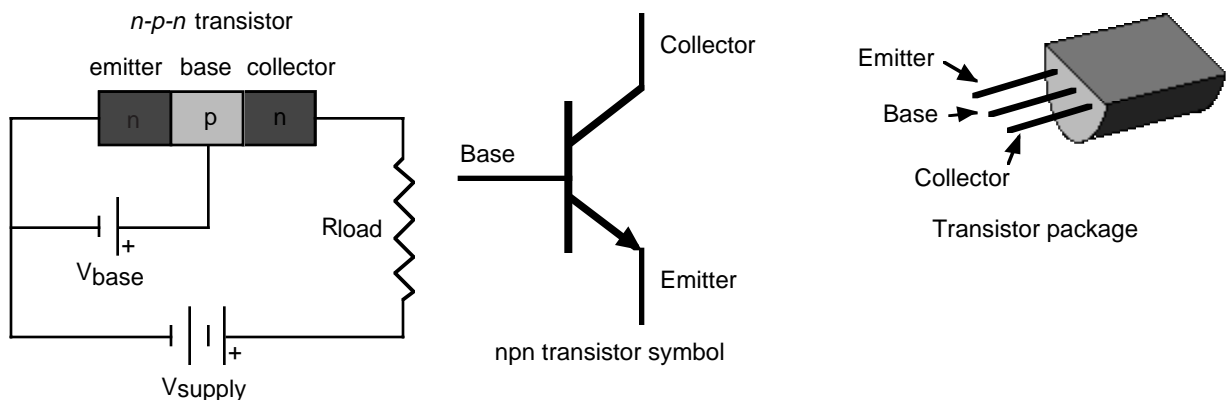
In a transistor circuit, the current to the base controls the current through the collector "loop".

The collector voltage can be considerably larger than the base voltage. Therefore, the power dissipated by the resistor may be much larger than the power supplied to the base by its voltage source. The device functions as a power amplifier (as compared to a step-up transformer, for example, which is a voltage amplifier but not a power amplifier). The output signal can have more power in it than the input signal. The extra power comes from an external source (the

power supply). A transistor circuit can amplify current or voltage. The circuit can be a constant current source or a constant voltage source.

A transistor circuit can serve as a 'digitial' electric switch. In a mechanical electric switch, a small amount of power is required to 'switch on' an electrical device (e.g., a motor) that can deliver a large amount of power. In a 'digital' transistor circuit, a small amount of power supplied to the base is used to "switch on" a much larger amount of power from the collector.

Here is some general information. A transistor is a three-terminal device. Voltage at a transistor terminal relative to ground is indicated by a single subscript. For example, V_C is the collector voltage. Voltage between two terminals is indicated by a double subscript: V_{BE} is the base-to-emitter voltage drop, for instance. If the same letter is repeated, it means a power-supply voltage: V_{CC} is the positive power-supply voltage associated with the collector.

A typical *npn* transistor follows these rules:

1.   The collector must be more positive than the emitter.

2.   The base-to-emitter and base-to-collector circuits behave like diodes. The base-emitter diode is normally conducting if the base is more positive than the emitter by 0.6 to 0.8 volts (the typical forward "turn on" voltage for a diode). The base-collector diode is reverse-biased.

3.   The transistor has maximum values of I_C, I_B, and V_{CE} and other limits such as power dissipation ($I_C V_{CE}$) and temperature.

4.   If rules 1 – 3 are obeyed, the current gain (or amplification) is the ratio of the collector current, I_C, to the base current, I_B. A small current flowing into the base controls a much larger current flowing into the collector. The ratio, called "beta", is typically around 100.

SAFETY REMINDERS

•   Follow directions for using the equipment.

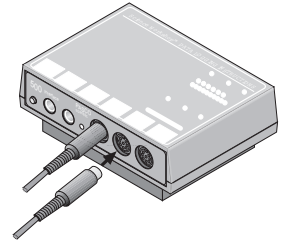**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

Use the function generator to supply an AC voltage to the base of the npn transistor. Use the DC power supply to supply a voltage to the collector of the transistor. Use one Voltage Sensor to measure the voltage drop (potential difference) across a resistor in series with the power supply and the collector of the transistor. Use the other Voltage Sensor to measure the output voltage from the function generator to the base of the transistor.

Use *DataStudio* or *ScienceWorkshop* to record and display the output voltage to the base of the transistor (Vbase) and the voltage drop across the resistor in series with the collector (Vcollector). Find the value of Vbase that causes the value of Vcollector to increase from zero. In other words, determine the voltage at which the transistor 'switches on'.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect one Voltage Sensor to Analog Channel A. Connect the other Voltage Sensor to Analog Channel B.

3. Open the document titled as shown:

DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
SLP48 Digital Switch.DS	(See appendix)	(See appendix)

• The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

• Data recording is set at 200 Hz with a Start Condition for Channel, Analog B at 0.01 V and a Stop Condition at Time equal 1 second (200 samples).

PART II: Sensor Calibration and Equipment Setup

• You do not need to calibrate the Voltage Sensors.

1. Insert the 2N3904 transistor into the socket on the AC/DC Electronics Lab circuit board. The transistor has a half-cylinder shape with one <u>flat</u> side. The socket has three holes labeled "E" (emitter), "B" (base) and "C" (collector). When held so the flat side of the transistor faces you and the wire leads point down, the <u>left</u> lead is the <u>emitter</u>, the <u>middle</u> lead is the <u>base</u>, and the <u>right</u> lead is the <u>collector</u>.
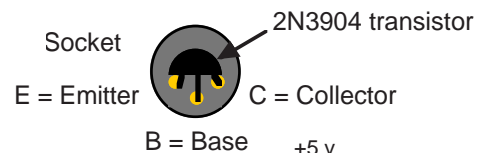
2. Connect the 22-kΩ resistor (red, red, orange) vertically between the component springs at the left edge of the component area.

3. Connect the 330-Ω resistor (orange, orange, black) horizontally between the component springs to the left of top banana jack.
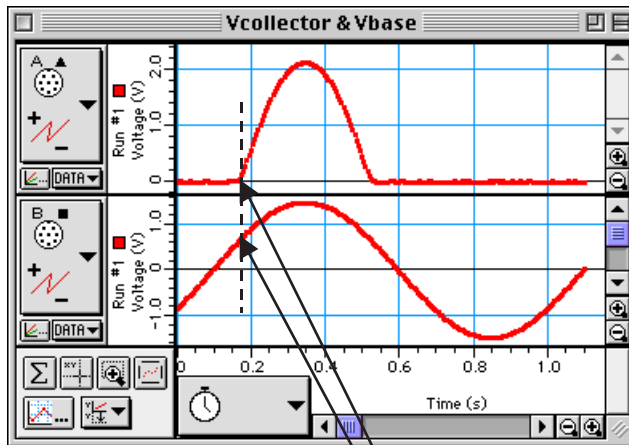

NPN transistor as a Digital Switch

4.   Carefully bend the wire leads of the red light-emitting diode (LED) so it can be mounted between component springs. Connect the LED between the component springs to the left of the 330-Ω resistor. Arrange the LED so its cathode (short lead) is to the left (away from the resistor).

5.   Connect a wire lead from the component spring at the base terminal of the transistor to the component spring at the top of the 22-kΩ resistor.

6.   Connect another wire lead from the component spring at the collector terminal of the transistor to the component spring at the left end of the LED.

7.   Connect a red banana plug patch cord from the positive (+) terminal of the DC power supply to the top input jack on the edge of the circuit board.

8.   Connect a black banana plug patch cord from the negative (-) terminal of the DC power supply to the component spring of the emitter terminal of the transistor

9.   Connect a red banana plug patch cord from the positive (+) output jack of the function generator to the component spring below the 22 kΩ resistor on the circuit board.

10.   Connect a black banana plug patch cord from the ground terminal of the function generator to the *negative* (-) terminal of the DC power supply.

11.   Put alligator clips on the banana plugs of the Channel A Voltage Sensor. Connect the red lead of the sensor to the component spring at the right end of the 330-Ω resistor and the black lead to the left end of the resistor.

12.   Connect the banana plugs of the Channel B Voltage Sensor into the output terminals of the function generator.

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PART III: Data Recording

1. Turn on the function generator and set it to output ±1.60 V, sine waveform, at 1 Hz.

2. Turn on the DC power supply and adjust its voltage output to exactly +5 Volts.

3. Start recording data.

*   Hint: In *DataStudio*, click the Start button (▶ Start). In ScienceWorkshop, click the 'REC' button

*   Observe the behavior of the LED. Write a description of what you observe. Recording will stop automatically at 1 second.

4. Turn off the function generator. Turn off the DC power supply.

Analyzing the Data

*   Optional: Save your data. If a printer is available, print the Graph display.

*   Remember, the Channel A voltage is Vcollector and the Channel B voltage (from the function generator) is Vbase.

1. Set up your Graph display so it fits the data.

*   Hint: In *DataStudio*, click the 'Scale to Fit' button in the Graph toolbar. In

    ScienceWorkshop, click the 'Autoscales button ([image]) to rescale the Graph.

2. Use the Graph's built-in analysis tool to measure the voltage to the base (Vbase) when the voltage to the collector (Vcollector) first begins to increase above zero.

*   Hint: In *DataStudio*, click the 'Smart Tool'. The Smart Tool is a large cross hair with an ordered pair of numbers that show the X-value and Y-value of its position. Place the Smart Tool at the point on Vbase (Voltage, ChB) that matches the point where Vcollector (Voltage, ChA) first increases above zero.
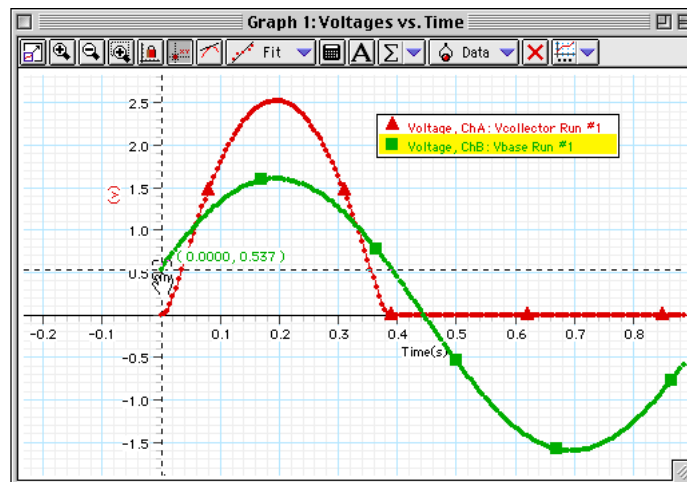
- Hint: In *ScienceWorkshop*, click the 'Smart Cursor' button. The cursor changes to a cross hair when you move it into the display area. The X-coordinate of the cursor/cross-hair is displayed under the horizontal axis. The Y-coordinate of the cursor/cross-hair is displayed next to the vertical axis. Put the cursor at the point on the plot of Vcollector (Channel A) where the voltage first begins to increase above zero. Hold down the Shift key. While holding the Shift key, move the cursor/cross-hair vertically along the dashed line until you reach the point on the plot of Vbase (Channel B) that corresponds to the same point on the plot of Vcollector.

3. Record the Y-coordinate of that point on the plot of Vbase.

<p align="center">**Voltage = _____ (V)**</p>

<p align="center">**Record your results in the Lab Report section.**</p>

Lab Report - Activity SL30: Transistor Lab 1 – The NPN Transistor as a Digital Switch

What Do You Think?

Using your library or the Internet, explore the following: What key aspects of the transistor aided in revitalizing Japan's economy after WWII?

Data

Voltage = _____V

Questions

1. What is the behavior of the LED when the circuit is active?

2. How does the general shape of the plot for the Vbase compare to the plot of Vcollector for the transistor?

3. What is the voltage on the Vbase plot when the LED turns on (that is, when the Vcollector voltage begins to rise above zero – the 'switch on' voltage)?

4. What is the relationship between the behavior of the LED and the point on the plot of Vcollector when the voltage begins to rise above zero?

Appendix for *ScienceWorkshop* Experiment Setup

1. Start the *ScienceWorkshop* program.

2. Set up the two Voltage Sensors. In the Experiment Setup window, click and drag the analog sensor plug icon to Analog Channel A. Select **Voltage Sensor** from the list of sensors and click **OK.** Repeat the process. Click and drag the plug icon to Analog Channel B and select **Voltage   Sensor**. Click **O K**.

3. Set up a Graph display. In the Experiment Setup window, click and drag the Graph display icon to the Voltage Sensor icon under Channel A. Next, click the **Add-A-Plot** menu button. Select **Analog B**, **Voltage** from the menu.
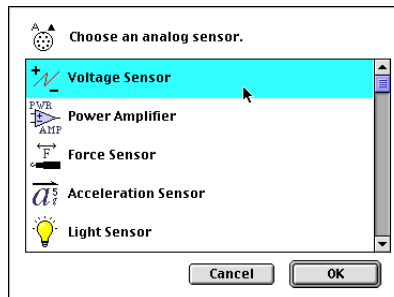
•   The Graph display should now have two plots; one for the voltage measured by the sensor in Channel A, and one for the voltage measured by the sensor in Channel B.

4. Set the Sampling Options**.** Click the Sampling Options button in the Experiment Setup window to open the Sampling Options window. Set the **Periodic Samples** to **Fast** at 200 Hz. Set up a **Start Condition** for **Channel, Analog B** at **0.01 V**. Set up a **Stop Condition** for **Samples** at **200**.

©1999 *PASCO scientific*   **SL30**
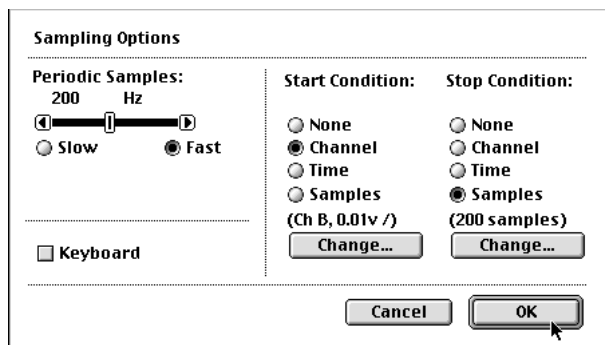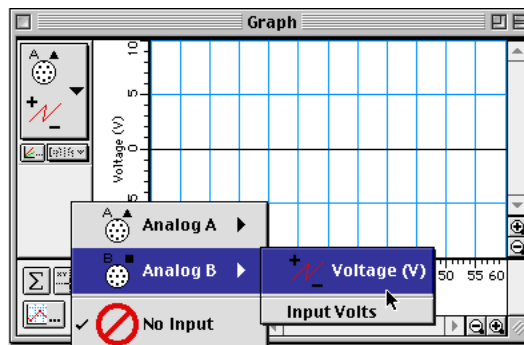
Activity SL31: Transistor Lab 3 – Common-Emitter Amplifier (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Semiconductors	SLP50 Common Emitter.DS	(See Appendix)	(See Appendix)

Equipment Needed	Qty	From AC/DC Electronics Lab (EM8656)	Qty
Voltage Sensor (CI-6503)	2	Capacitor, 1 microfarad (µF)	1
Function Generator (PI-9587C)	1	Capacitor, 10 microfarad (µF)	1
Patch Cord (SE-9750)	4	Resistor, 1 kΩ (brown-black-red)	4
Power Supply, 5 V DC, (SE-9720)	1	Resistor, 10 kΩ (brown-black-orange)	1
		Resistor, 22 kΩ (red-red-orange)	2
		Transistor, 2N 3904	1
		Wire lead, 10 inch	1
		Wire lead, 5 inch	4

What Do You Think?

Is it possible for a small semiconductor device to produce a larger output signal than the input signal supplied to it?

Take time to write an answer to this question in the Lab Report section.

The purpose of this activity is to investigate the voltage and current amplification characteristics of the *npn* transistor in a *common-emitter* amplifier circuit.

Background

In the *npn* transistor, the current flow to the base is much smaller than the current flow to the collector. This allows the transistor to be used as an amplifier. The transistor can amplify current and voltage.

If the input voltage is small enough so that it is much smaller than the forward bias on the emitter connection, the input current will encounter small impedance. The input voltage will not need to be large in order to produce sizeable currents.

Additionally, since the output voltage across the load resistor R_L is the product of the output current (collector current) and the value of R_L, the output voltage can also be made large. As a result, the output voltage can be much larger than the input voltage.

npn Common-emitter amplifier

The *common-emitter* amplifier derives its name from the fact that the base wire of the transistor and the collector wire of the transistor meet at the emitter wire; they have the emitter wire in common.
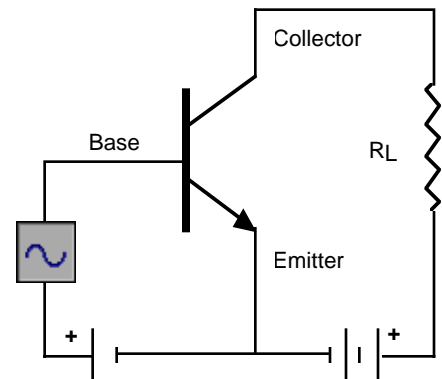
Each section of the common-emitter amplifier circuit performs a specific function. In Section 1, the Input Coupling Circuit keeps DC voltages from changing the bias circuit. The function of Section 2, the Bias Circuit, is to provide a voltage that keeps the transistor in its active region. Section 3 is the Amplifier circuit. Section 4, the Output Coupling Circuit, allows only the AC signal from the transistor to reach the load resistor so that the load resistance doesn't affect the operating voltage.
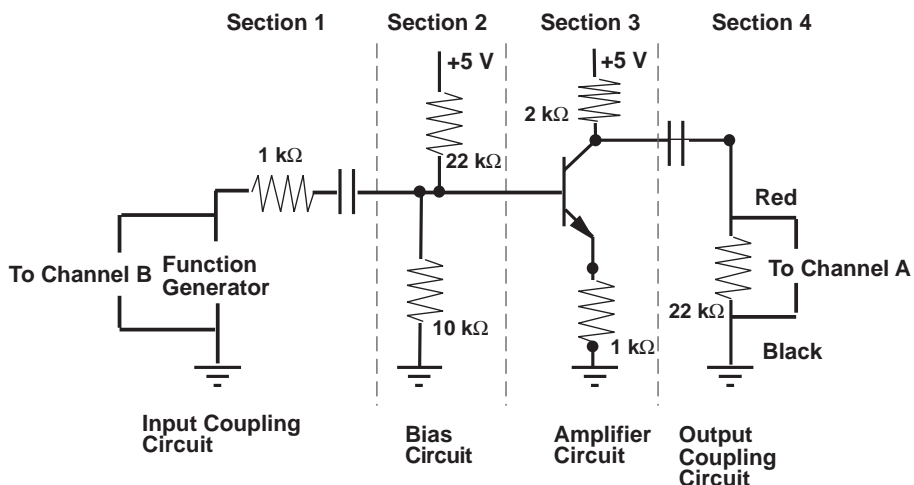
SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the function generator to supply an AC voltage to the base of the npn transistor. Use the DC power supply to supply voltage to the collector of the same transistor. Use one of the Voltage Sensors to measure the voltage drop (potential difference) across the 22 kΩ resistor in the Output Coupling Circuit, which is connected to the collector of the transistor. Use the other Voltage Sensor to measure the output voltage from the function generator.

Use *DataStudio* or *ScienceWorkshop* to record and display the voltage across the resistor in the Output Coupling Circuit as well as the output voltage from the function generator. Measure the voltage going to the base of the transistor and the voltage from the collector in order to calculate the output voltage. Compare the actual output voltage to the theoretical output voltage.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect one Voltage Sensor to Analog Channel A. Connect the other Voltage Sensor to Analog Channel B.

3. Open the document titled as shown:

DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
SLP50 Common Emitter.DS	(See appendix)	(See appendix)

*   The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

*   The data sampling rate is set to 10,000 Hz.

PART II: Sensor Calibration and Equipment Setup

*   You do not need to calibrate the Voltage Sensors. You will need the following components:

Item	Quantity	Item	Quantity
1 kΩ resistor (brown-black-red)	4	10 µF capacitor	1
10 kΩ resistor (brown-black-orange)	1	wire lead, five inch	4
22 kΩ resistor (red-red-orange)	2	wire lead, ten inch	1
1 µF capacitor	1	2N3904 transistor	1

1. Insert the 2N3904 transistor into the socket on the AC/DC Electronics Lab circuit board. The transistor has a half-cylinder shape with one flat side. The socket has three holes labeled "E" (emitter), "B" (base) and "C" (collector). When held so the flat side of the transistor faces you and the wire leads point down, the left lead is the emitter, the middle lead is the base, and the right lead is the collector.

2. Connect one five-inch wire lead from the component spring at the base terminal of the transistor to the component spring below the base terminal of the transistor.
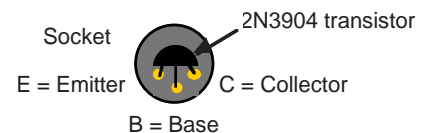
3.   Connect one 1 kΩ resistor from the component spring at the bottom end of the wire lead
      coming from the base terminal of the transistor, to the component spring directly below (at
      the bottom edge of the AC/DC lab board).
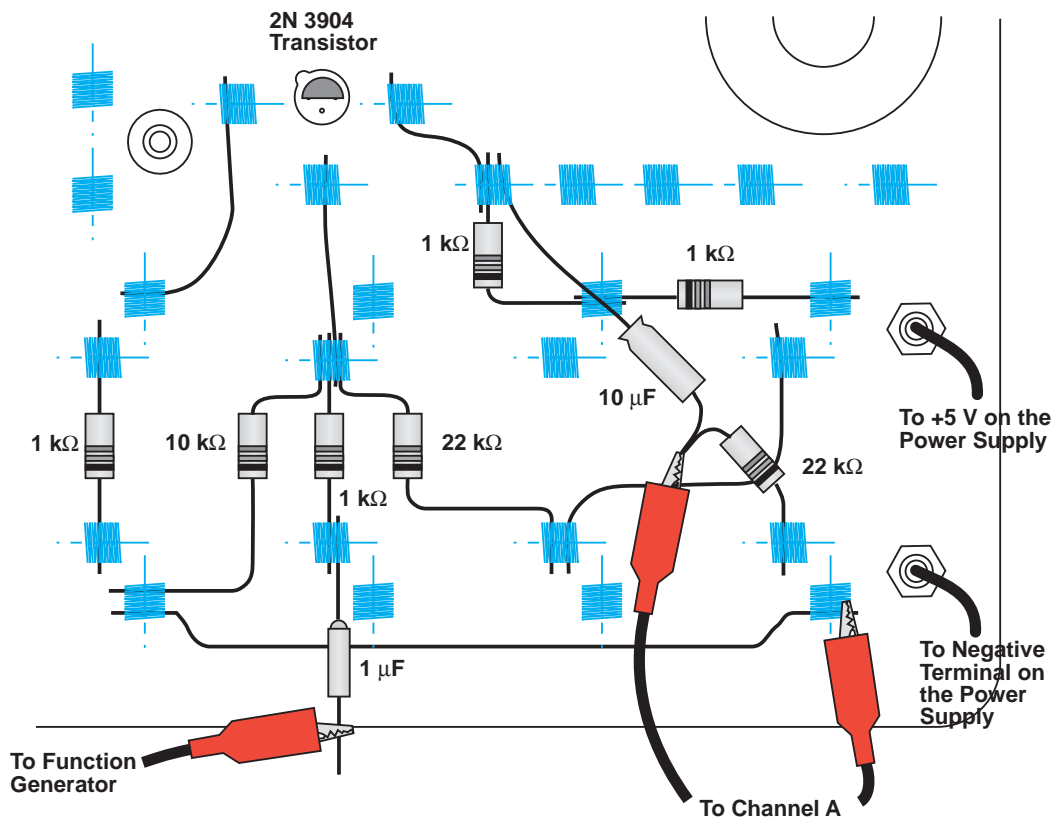
4.   Connect the wire at the negative end of the 1-µF capacitor to the same component spring at
      the bottom edge of the AC/DC lab board. Do not connect the other wire lead of the
      capacitor to anything.

•   NOTE: The negative end of the 1-µF
      capacitor has a small round bump.

5.   Connect one five inch wire lead from the component spring next to the emitter terminal of
      the transistor to the component spring at the top left corner of the component area of the
      AC/DC Electronics Lab circuit board.

6.   Connect one 1 kΩ resistor from the component spring at the top left corner of the
      component area and the component spring directly below.

7.   Connect one five-inch wire lead from the component spring next to the collector terminal
      of the transistor to the component spring to the right and slightly below.

8.   Connect one 1-kΩ resistor from the component spring at the end of the wire lead from the
      collector terminal, to the component spring below and slightly to the right of the
      component spring at the end of the wire lead from the collector terminal.

9.   Connect one 1 kΩ resistor from the component sprint to the right of the top banana jack, to
      the component spring directly to the left of the first component spring.

10.   Connect a red banana plug patch cord from the positive (+) terminal of the DC power
      supply to the top banana jack on the AC/DC lab board.

11.   Connect a black banana plug patch cord from the negative (-) terminal of the DC power supply to the bottom banana jack on the AC/DC lab board.

12.   Connect the ten inch wire lead from the component spring next to the bottom banana jack to the component spring at the bottom end of the 1 kΩ resistor that is connected to the emitter terminal of the transistor.

13.   Find the component spring at the end of the wire lead that is connected to the component spring at the base terminal of the transistor. Connect the 10-kΩ resistor from the component spring at the end of the wire lead to a component spring at the bottom left corner of the board.

•   NOTE: You can connect one end of the 10 kΩ resistor to the same component spring that holds one end of the ten inch wire lead.

14.   Return to the component spring that is at the end of the wire lead connected to the base terminal of the transistor. Connect one 22 kΩ resistor from the component spring at the end of the wire lead to the component spring that is to the right and below (at the edge of the AC/DC lab board).

15.   Connect one five-inch wire lead from the component spring at the end of the 22-kΩ resistor to a component spring next to the top banana jack.

16.   Put an alligator clip on one end of a red banana plug patch cord. Connect the alligator clip to the wire at the end of the 1 µF capacitor. Connect the other end of the patch cord to the positive (+) terminal of the function generator.

17.   Connect a black banana plug patch cord from the ground terminal of the function generator to the negative terminal of the DC power supply.

18.   Put alligator clips on the banana plugs of the Voltage Sensor. Connect the alligator clip of the black wire of the Voltage Sensor to the component spring next to the bottom banana jack at the lower right corner of the AC/DC board.

19.   Twist the wire from the negative end of the 10-µF capacitor together with the wire at one end of one 22-kΩ resistor.

•   NOTE: The negative end of the 10-µF capacitor has a slight bump. The positive end has an indentation around it. There is a band on the side of the capacitor with arrows that point to the negative end.

22 kΩ resistor

Twist wires together.

10 µF capacitor

negative end
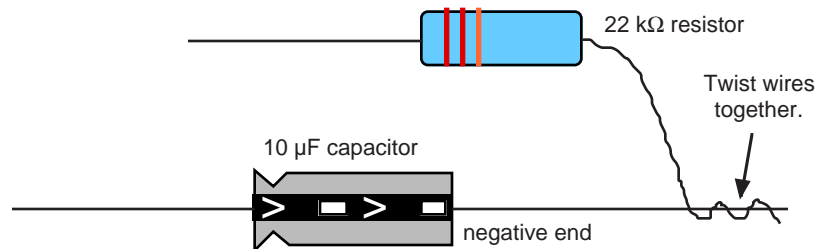
20.   Connect the wire from the positive end of the 10-µF capacitor to the component spring at one end of the wire lead connected to the collector terminal of the transistor. Connect the wire from the 22-kΩ resistor to a component spring next to the bottom banana jack at the lower right corner of the AC/DC lab board.

21.   Carefully connect the alligator clip of the red wire of the Voltage Sensor to the twisted wires of the 10-µF capacitor and the 22-kΩ resistor.

PART III: Data Recording

1. Start monitoring data. (Hint: In *DataStudio*, click the 'Start' button (▶ Start). In *ScienceWorkshop*, click the 'MON' button to begin monitoring data.)

2. Turn on the function generator. Set the frequency to 300 Hz. Set the waveform to "sine". Increase the output voltage (amplitude) until the trace of voltage on the Scope display shows an amplitude of 0.20 volts.

3. Turn on the DC power supply and adjust its voltage output to exactly +5 volts.

• Observe the trace of voltage going to the base terminal of the transistor from the function generator (the trace for Channel B). Compare this trace to the trace of voltage measured by the Voltage Sensor connected to Channel A.

4. Measure the voltages. Use the built-in analysis tools in the Scope display. (Hint: In *DataStudio*, click the 'Smart Tool' button. In *ScienceWorkshop*, click the 'Smart Cursor' button. This will stop data monitoring temporarily.)
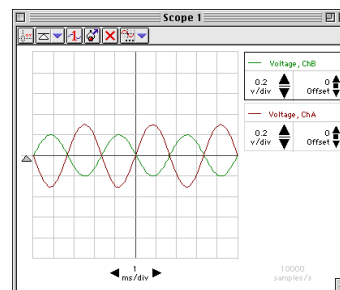
• Move the analysis tool ('Smart Tool' or 'Smart Cursor') to the first peak of the trace for the voltage from the function generator (Channel B). Record the voltage value for the peak. (Hint: In *DataStudio*, the voltage is the second number in the ordered pair. In *ScienceWorkshop*, the voltage is displayed next to the sensitivity controls (v/div)).
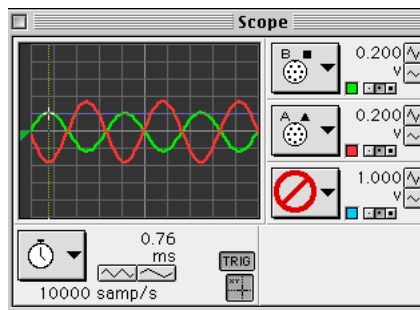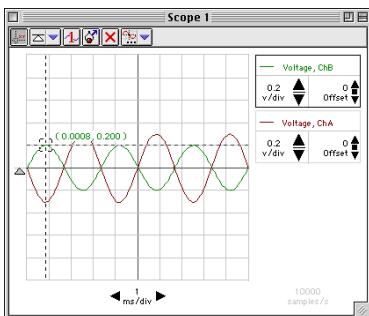
• Move the cursor/cross-hair to the first peak of the trace for the voltage for Channel A (directly below the peak of the Channel B trace). Record the voltage value for the peak.
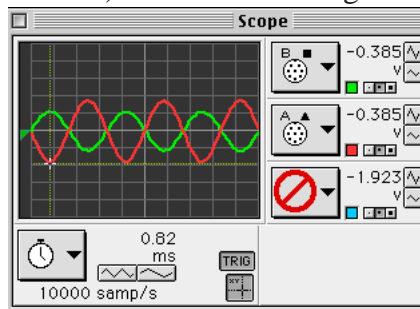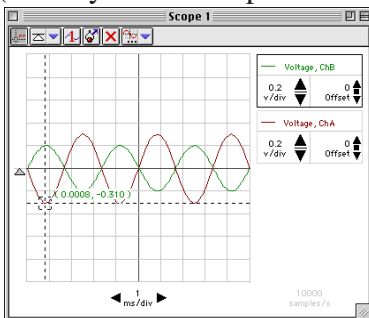
5. Click the 'STOP' button to end data monitoring.

6. Turn off the function generator. Turn off the DC power supply.

Record your results in the Lab Report section.

                           SL31

Lab Report - Activity SL31: Transistor Lab 3 – Common-Emitter Amplifier

What Do You Think?

Is it possible for a small semiconductor device to produce a larger output signal than the input signal supplied to it?

Data

$$\text{Voltage (peak) of B} \quad = \text{_____} \quad V$$

$$\text{Voltage (peak) of A} \quad = \text{_____} \quad V$$

Analyzing the Data

1. Use the values you recorded to calculate the ratio of input voltage (Voltage of B) to output voltage (Voltage of A).

$$\frac{V_{in}}{V_{out}} = \frac{Voltage\ ''B''}{Voltage\ ''A''} = \text{_____}$$

2. Calculate the theoretical output voltage as follows:

$$V_{out} = -V_{in}\frac{R_C}{R_E} = \text{_____}$$

where R_C is the value of the resistor in series with the collector terminal (2 kΩ), and R_E is the value of the resistor in series with the emitter terminal (1 kΩ). Calculate the theoretical output voltage for the common-emitter amplifier.

Questions

1. What is the phase relationship between the input signal and the output signal?

2. How does the actual output voltage compare to the theoretical value?

Appendix for *ScienceWorkshop* Experiment Setup

1.   Start the *ScienceWorkshop* program.

2.   Set up the Voltage Sensors. In the Experiment Setup
      window, click and drag the analog sensor plug icon to
      Analog Channel A. Select **Voltage Sensor** from the
      list of sensors and click **OK.** Repeat the process. Click
      and drag the plug icon to Analog Channel B and select
      Voltage   Sensor. Click **O K**.

3.   Set up a Scope display. In the Experiment Setup
      window, click and drag the Scope display icon to the Voltage Sensor icon under Channel
      B. (NOTE: This allows the Scope to "trigger" on the output
      from the function generator.)

•   Minimize the Experiment Setup window so it is out of the way.

4.   Set the second input for the Scope display. Click the Input Menu
      button for the middle trace. Select **Analog A** from the Input
      Menu.

5.   Set the sweep speed for the Scope display. Click the right Sweep Speed
      button to adjust the sweep speed to 1.00 ms/div (10000 samp/s).

•   Set the sensitivity for the Scope display. Click the top V/div button
      to adjust the sensitivity to 0.200 V/div for both Channel B and
      Channel A.
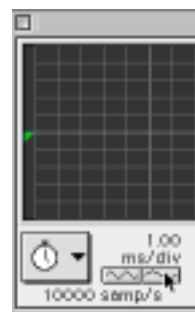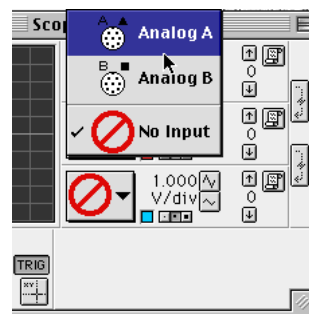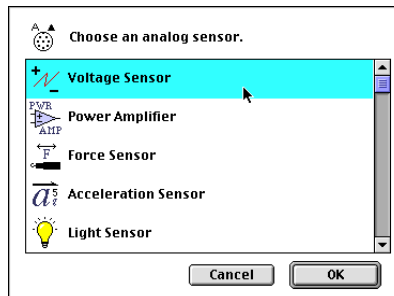
Activity SL32: Variation of Light Intensity
(Light Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Illuminance	P54 Vary Light Intensity.DS	P54 Light Bulb Intensity	P54_BULB.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	Fluorescent bulb	1
Flashlight (or other DC light source)	1	Incandescent bulb	1

What Do You Think?

The purpose of this activity is to compare the variation in intensity of light from light sources. How does the light from a DC light source compare to light from an AC light source? How does the light from a fluorescent tube compare to the light from an incandescent bulb?

Take time to write an answer to these questions in the Lab Report section.

Background

Electric light bulbs are powered by a voltage of 60 Hz (or 50 Hz in some countries) sinusoidal wave. The maximum amplitude of the voltage, and thus a maximum brightness, occurs twice per cycle because an electric bulb is excited when the voltage increases, regardless of the polarity of the voltage. An electric bulb will have maximum intensity 120 times per second (or 100 times/second). It will also have minimum intensity 120 times per second (or 100 times/second).
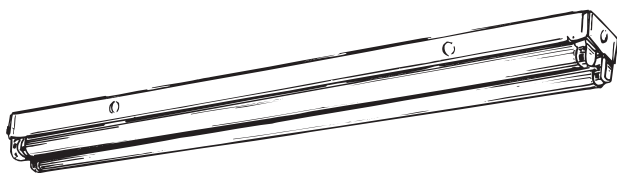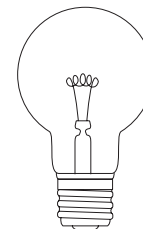
Fluorescent lights blink on and off at a particular frequency. The light intensity from incandescent bulbs powered by AC fluctuates as well. The light intensity from an incandescent bulb powered by DC should not vary.

SAFETY REMINDERS

• Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

In this activity, use the Light Sensor to measure the intensity of light from light bulbs powered by AC or DC. There are three parts to the activity: Part A = Fluorescent bulb, AC; Part B = Incandescent bulb, AC; and Part C = Incandescent bulb, DC.

Use *DataStudio* or *ScienceWorkshop* to monitor and display the variations, if any, in the light intensity. Compare the light intensity of fluorescent and incandescent lights powered by AC, and an incandescent light powered by DC.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Light Sensor cable into Analog Channel A on the interface. Connect the Light Sensor to the cable.

3. Open the document titled as shown:
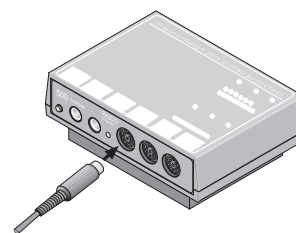
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
P54 Vary Light Intensity.DS	P54 Light Bulb Intensity	P54_BULB.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

- The *ScienceWorkshop* document opens with a Scope display of voltage from the Light Sensor in Channel A and a Frequency Spectrum (FFT) display for the same sensor. It also has a Digits display for the voltage from the Light Sensor.

- The data measurement is set at 5000 Hz (set by the Sweep Speed control in the Scope display). The Frequency Spectrum (FFT) is set to 256 data points.

PART II: Sensor Calibration & Equipment Setup

- You do not need to calibrate the Light Sensor. However, you may need to adjust the sensitivity of the sensor, depending on the brightness of the light source and how close the sensor is to the source.

Adjusting Light Sensor Sensitivity

- The Light Sensor has a GAIN switch on the top of the sensor box. The GAIN switch selects the amount of amplification for the signal that is sent to the interface. The settings are 1, 10, and 100. The setting of 10 amplifies the signal ten times and the setting of 100 amplifies the signal one hundred times.

Try the following to become more familiar with the Light Sensor:

- Place the Light Sensor on a table so the port on the sensor is below an overhead light. Set the GAIN switch to 1.

- Start monitoring data. Move the Digits display of Input Volts so you can see it clearly.

- Switch the GAIN to 10 and observe the value of Input Volts in the Digits display. Then switch to 100 and observe the value of Input Volts.

NOTE: The maximum voltage from the sensor is 4.9 V for any GAIN setting.

- Cover the Light Sensor port and observe the value of Input Volts.

- Return the GAIN setting to 10. Pick up the sensor. Observe the value of Input Volts as you move the Light Sensor closer to the overhead light source. Observe what happens when you move the Light Sensor farther from the light source.

- Click STOP to stop monitoring data.

Equipment Setup

1. Place the Light Sensor within a few feet of a fluorescent bulb that is powered by AC.

2. Turn on the fluorescent bulb.
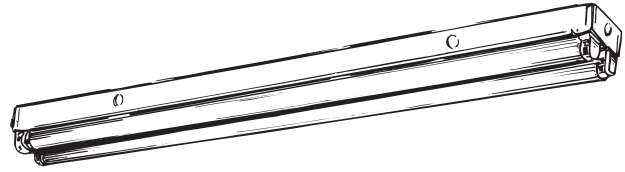
PART IIIA: Data Recording – Fluorescent Bulb, AC

1. Start monitoring data. (Hint: In *DataStudio*, click the 'Start' button (▶ Start). In *ScienceWorkshop*, click the 'MON' button.) Arrange the Scope display, the Digits display, and the Frequency Spectrum (FFT) so you can see them clearly.

• NOTE: It is likely that you will see a value in the Digits display, and a spectrum in the Frequency Spectrum display, but <u>nothing</u> in the Scope display. This is because the trigger control in the Scope is on, and the trigger level may be set too low for the voltage produced by the Light Sensor.

2. Adjust the Scope display until you see the trace of voltage from the Light Sensor:

• First, adjust the trigger level.

In *DataStudio*, move the small triangle (the 'Trigger Level' pointer) on the left side of the display up or down to the desired voltage level. In *ScienceWorkshop*, click in the space along the left edge of the Scope display that is above the Trigger Level pointer. When you click above or below the Trigger Level Pointer, it "jumps" to the spot you clicked. The value in the Digits display will indicate the <u>approximate</u> trigger level you need.
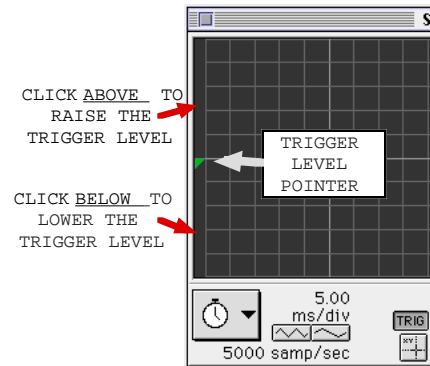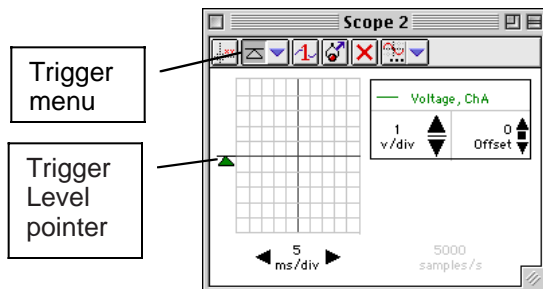
• Second, adjust the vertical position of the trace of voltage.

In *DataStudio*, click the up or down arrows next to 'Offset'. In *ScienceWorkshp*, click the 'UP/DOWN Arrows' in the right side of the Scope display.


UP Arrow: Click shift the trace voltage upward.

POSITION INDICATOR

DOWN Arrow: Click to shift the tra voltage downward

'Offset' arrows
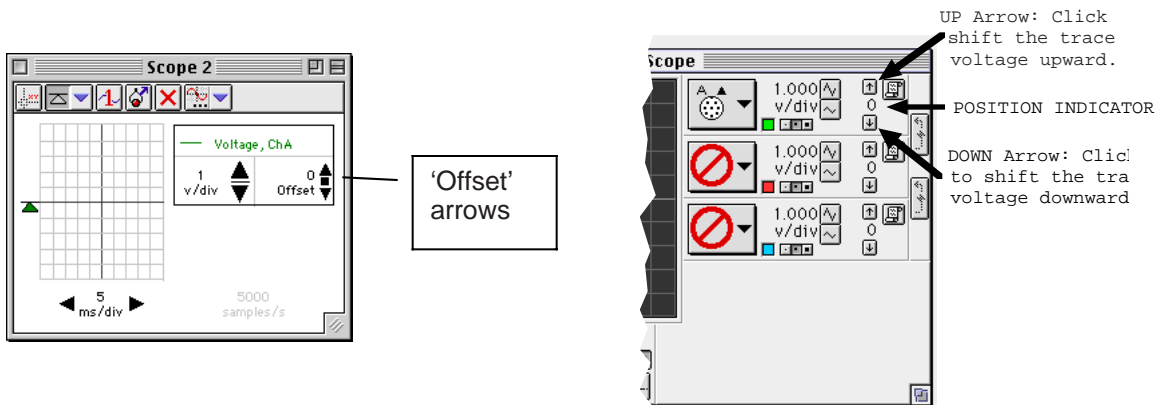
• Finally, adjust the Sensitivity (volts per division) if needed.

In *DataStudio*, click the arrows to increase or decrease the sensitivity. In *ScienceWorkshop*, click the **Vertical   Scale** buttons in the right side of the Scope display.

SENSITIVITY (VERTICAL SCALE)

INCREASE Sensitivity: Cli increase the hei of the trace.

DECREASE Sensitivity: Cli decrease the hei of the trace.

Sensitivity controls
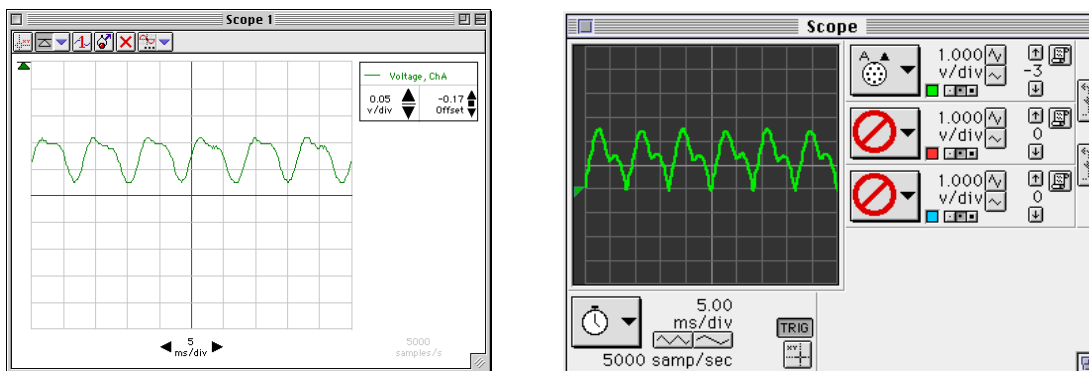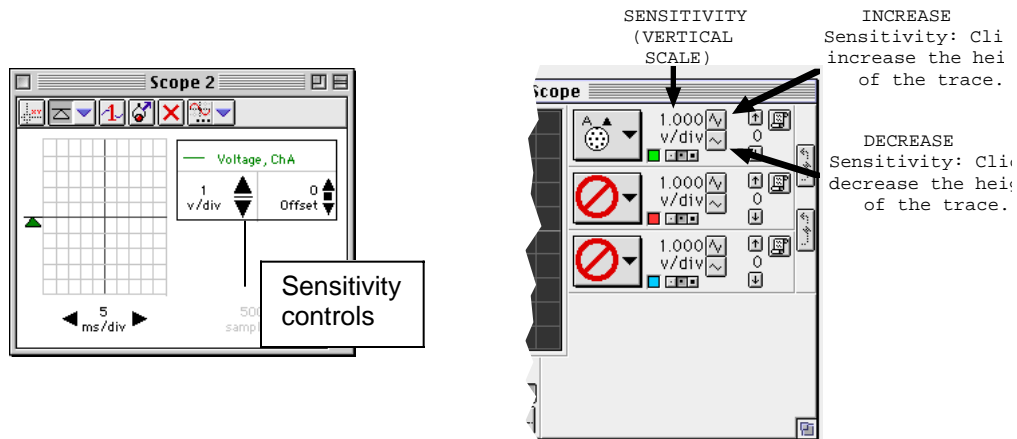
3.   Use the Frequency Spectrum to measure the frequency of the signal from the Light Sensor. Record the value of the frequency in the Lab Report section.

•   Make the FFT display (Frequency Spectrum) active. In *DataStudio*, click the 'Smart Tool' button. In *ScienceWorkshop*, click the 'Smart Cursor' button. Move the cursor/cross-hair to the top of the first peak in the display area. In *DataStudio*, the frequency is the first number in the ordered pair. In *ScienceWorkshop*, the frequency is shown below the horizontal axis.

4.   Click the STOP button to stop monitoring data.
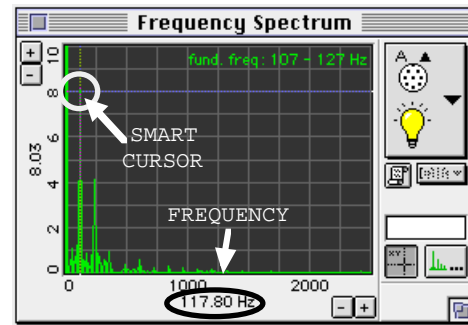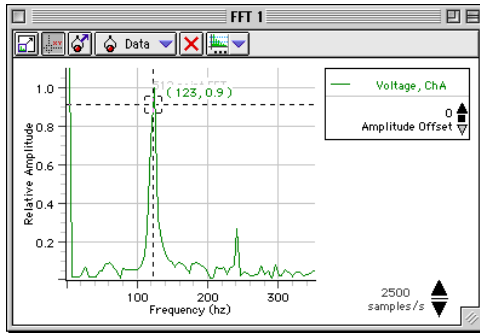
5.   Save the trace that is displayed on the Scope. Click the Scope to make it active.

•   In *DataStudio*, click the 'Transfer' button (⬀). The data in the Scope is automatically added to the data list.

•   In *ScienceWorkshop*, click the 'Data Snapshot' button (▦) in the right side of the Scope display. The **Data Cache Information** window will open. Enter appropriate information for the **Long Name**, **Short Name**, and **Units**. Click **O K** to return to the Scope.
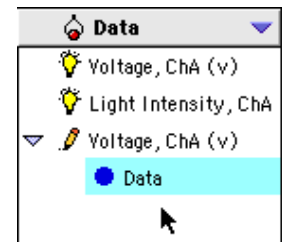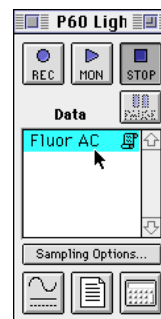
•   The **Short Name** for the Data Cache will appear in the Data List in the Experiment Setup window. (NOTE: You can display and analyze the Data Cache in any display that can show recorded data such as the Graph, Table, or FFT.)

PART IIIB: Incandescent Light, AC

Repeat the activity using an incandescent light connected to an AC power supply.

**PART IIIC: Incandescent Light – DC**

Repeat the activity using a battery operated flashlight.

Analyzing the Data

1. Set up a Graph display to show data for the AC fluorescent light, AC incandescent light, and DC incandescent light.

•   Hint: In *DataStudio*, do the following:

•   Click 'Add Display…' from the Experiment menu.

•   Select 'Graph' from the 'Please Choose…' window. Click 'OK'.

•   Click and drag 'Data' from the Data list to the new Graph display.

Drag and drop 'Data' onto the Graph.
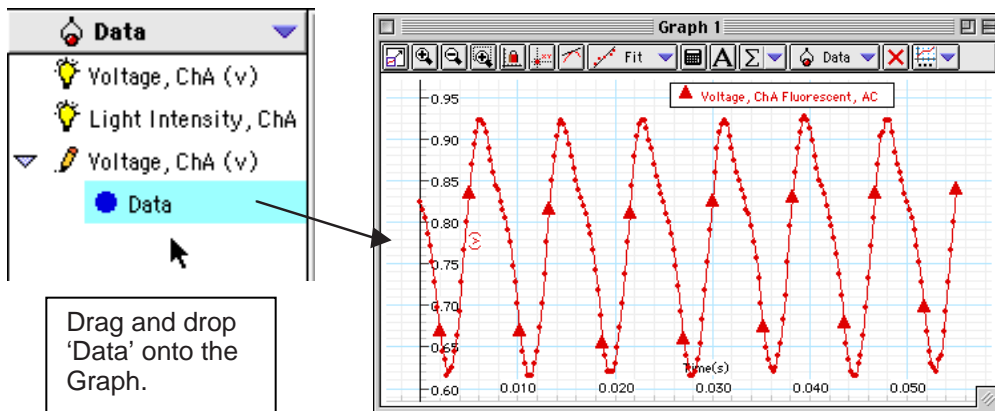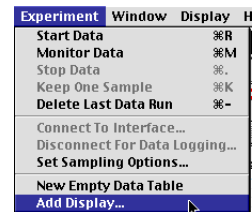
•   The Graph automatically rescales to fit the data. Repeat the process for the other runs of data.

•   Hint: In *ScienceWorkshop*, do the following:

•   Click the **Display Menu**. Select **New Graph** from the Display Menu.

•   In the new Graph display, click the **Vertical Axis Input**

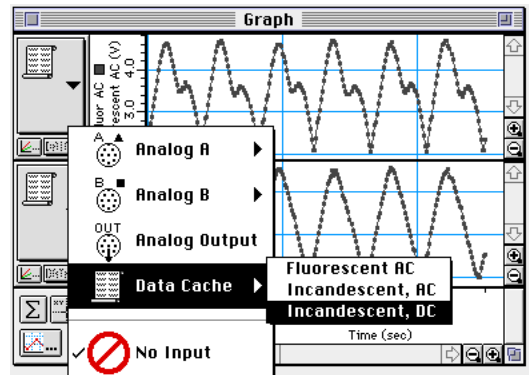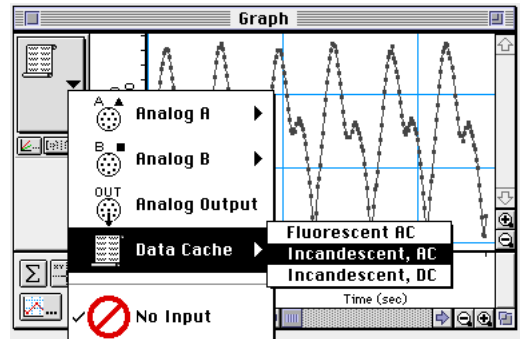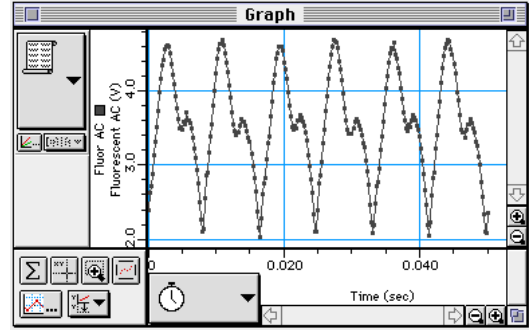   **Menu** button (). Select **Data Cache, Fluorescent AC** from the Input Menu.
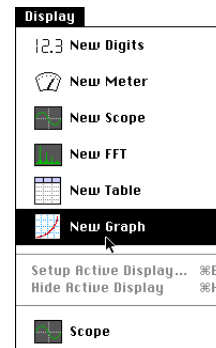
•   The Graph will show the data seen in the Scope display for the fluorescent bulb powered by AC.

•   Click the **Add Plot Menu** button () in the lower left corner of the Graph. Select **Data Cache, Incandescent AC** from the Add Plot Menu.
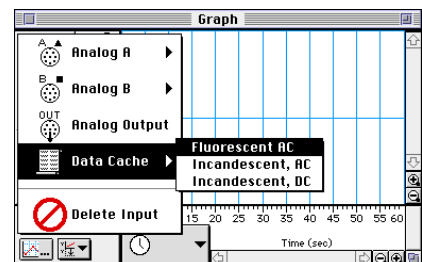
- A new plot will be added to the Graph. It will show the data seen in the Scope display for the incandescent bulb powered by AC.

- Click the **Add Plot Menu** button again. Select **Data Cache, Incandescent DC** from the Add Plot Menu.

- A third plot will be added to the Graph.

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Lab Report - Activity SL32: Variation of Light Intensity

What Do You Think?

The purpose of this activity is to compare the variation in intensity of light from light sources. How does the light from a DC light source compare to light from an AC light source? How does the light from a fluorescent tube compare to the light from an incandescent bulb?

Data Table

Light Source	Frequency
Fluorescent, AC	Hz
Incandescent, AC	Hz
Incandescent, DC	Hz

Questions

1. How does the frequency of light intensity variation for the fluorescent AC bulb and the incandescent AC bulb compare to the accepted value for AC frequency?

2. How does the fluctuation of an incandescent bulb run on 60 Hz (or 50 Hz) AC differ from the fluorescent bulb?

3. How does the fluctuation of a light bulb run on 60 Hz (or 50 Hz) AC differ from the incandescent bulb powered by DC?

©1999 _PASCO scientific_   **SL32**

Activity SL33: Light Intensity vs. Distance – Keyboard Method (Light Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Inverse Square Law	P56 Light vs Distance.DS	P56 Light vs. Distance	P56_LTVD.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	Meter stick	1
Light Source (OS-8517)	1		

What Do You Think?

Does the total light energy that passes through an imaginary spherical boundary change as distance from the point light source increases?

Does the light intensity on the surface of an imaginary spherical boundary change as the distance from the point light source increases?

How does the change in light intensity with distance for a 'real' light source compare to the change in light intensity with distance for an ideal 'point' light source?

Take time to write an answer to these questions in the Lab Report section.

The purpose of this activity is to investigate the relationship between light intensity and the distance from a light source.

Background

The light from a point light source spreads out uniformly in all directions. The intensity at a given distance **r** from the light will be equal to the power output of the light divided by the surface area of the sphere through which the light has spread. Since the area of the sphere varies as the square of its radius, **r**, the intensity will vary as $1/r^2$.
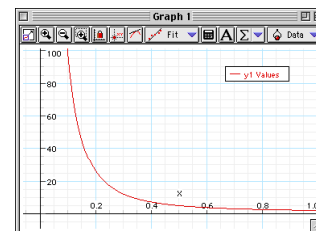
SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

In this activity, use the Light Sensor to measure the light intensity as the sensor moves away from a stationary light source powered by DC. Use the meter stick to measure the distance between the light source and the light sensor. Use Manual Sampling in *DataStudio* or use Keyboard Sampling in *ScienceWorkshop* to enter the distance between them.

Use *DataStudio* or *ScienceWorkshop* to record and display the light intensity and the typed in values of distance. Use a graph of light intensity versus distance to determine the relationship between them.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Light Sensor cable into Analog Channel A on the interface. Connect the Light Sensor to the cable.

3. Open the document titled as shown:
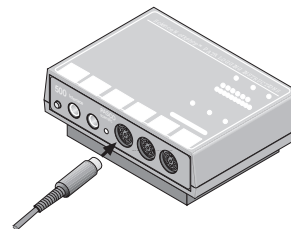
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
P56 Light vs Distance.DS	P56 Light vs. Distance	P56_LTVD.SWS

-   The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

-   The *ScienceWorkshop* document opens with a Digits display of light intensity from the Light Sensor and a Graph display of light intensity vs. distance.

-   Data recording is set at 10 Hz. You will enter the distance from the light source to the Light Sensor using 'Manual Sampling' in *DataStudio*, or 'Keyboard Sampling' in *ScienceWorkshop* with Parameter = Distance and Units = m.

PART II: Equipment Setup and Sensor Calibration

Equipment Setup

1. Arrange the light source so that it is at the same height as the Light Sensor port on the front of the light sensor box, and the light source faces the port.

2. Place the meter stick with the Light Sensor so you can measure the Light Sensor's position relative to the light source.

Light Source

Light Sensor   **Meter Stick**
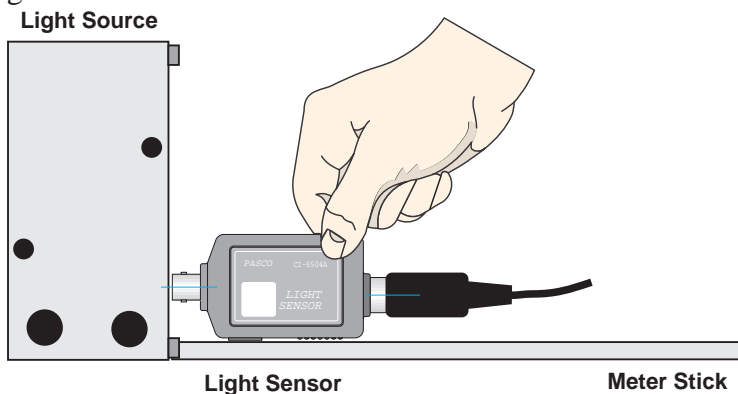
3. Turn on the light source.

Sensor   Calibration

- Calibrate the Light Sensor so that it produces its maximum voltage when the sensor is as close as possible to the light source.

1. Place the light source and Light Sensor so the port on the Light Sensor is at the same height as and is aligned with the light source.

2. Set the GAIN select switch on the top of the sensor to 1. Move the Light Sensor so its port is as close as possible to the light source.

3. In the Experiment Setup window, double-click the Light Sensor icon. (The Sensor Properties window opens in *DataStudio*. The Light Sensor setup window opens in *ScienceWorkshop*. In *DataStudio* click the 'Calibration' tab.)

4. Check the voltage from the Light Sensor.

- Hint: In the *DataStudio* 'Calibration' window, the Current Reading of the voltage from the Light Sensor appears in the upper left corner. In the *ScienceWorkshop* Sensor Setup window, the current value of the voltage from the Light Sensor appears at the bottom of the column labeled Volts.
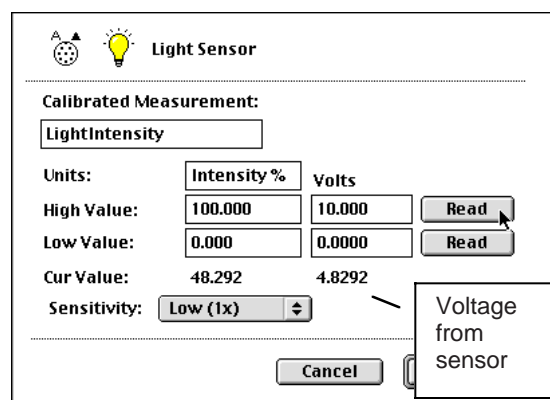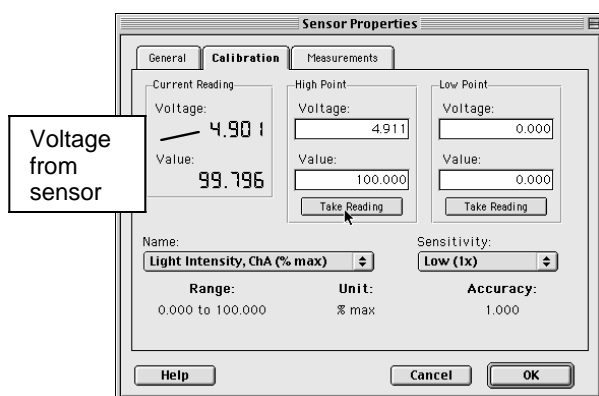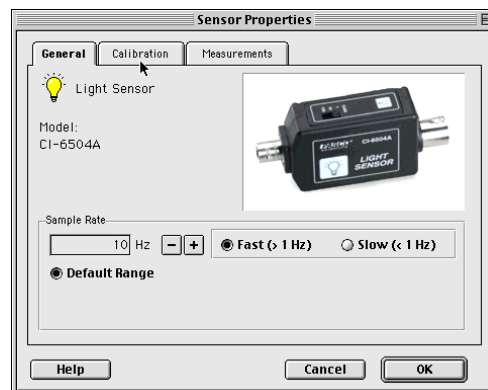
- If the value of voltage from the sensor is slight higher than 4.9 V, slowly move the sensor away from the light source until the value is 4.9 V (or slightly lower). Make a note of the position of the sensor relative to the light source.

- If the value of voltage from the Light Sensor is less than 4.9 V but more than 0.49 V go to step #5.

- If the voltage value is below 0.49 V set the GAIN switch to 10. If the value is still below 0.49 V, set the GAIN switch to 100.

5. Keep this value of voltage as the maximum value (corresponding to 100% intensity). In *DataStudio* click 'Take Reading' below the 'High Point' column. In *ScienceWorkshop*, click the top Read button. Click 'OK' to return to the Experiment Setup window.

PART III: Data Recording

(See the Appendix for specific instructions regarding *ScienceWorkshop*)

1.   In *DataStudio*, arrange the Table display so you can see it clearly.

2.   When you are ready, start recording data. (Note: The 'Start' button changes to 'Keep'
      (✔ Keep ■). The light intensity will appear in the first cell in the Table display. Click
   the 'Keep' button to record the light intensity.
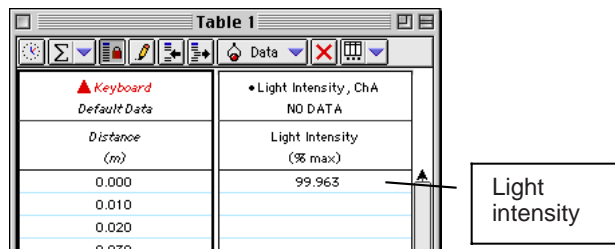
Light intensity

3.   Move the Light Sensor one centimeter farther away from the light source. The light
      intensity will appear in the second cell in the Table display. Click the 'Keep' button.

4.   Continue to move the Light Sensor away from the Light Source in one centimeter
      increments. At each new position, click the 'Keep' button to record the light intensity.

5.   When you reach the 25 centimeter (0.25 m) distance, stop recording data.

6.   Turn off the light source.

Analyzing the Data

Click the Graph to make it active. Use the built-in analysis tools to fit the data to a mathematical
formula.

1.   In *DataStudio*, click the 'Fit' menu button (Fit). Select
      'Inverse Nth Power'. Use the cursor to click-and-draw a rectangle
      around the region of smoothest data in the Graph. The *DataStudio*
      program will attempt to fit the data to a mathematical formula.
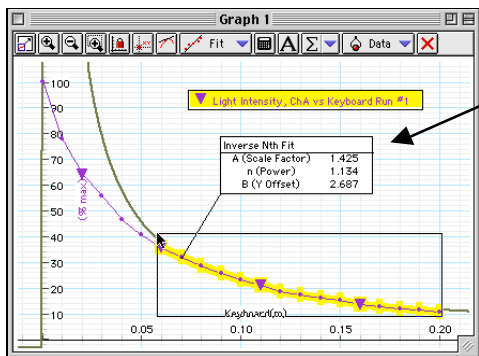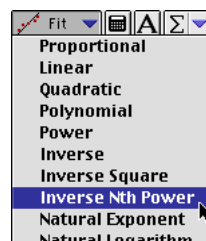

Double-click to open
Curve Fit window
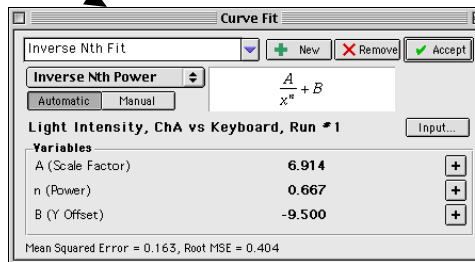
- Note: To see the mathematical formula and its parameters, double-click the curve fit text
  box in the Graph.

- In *ScienceWorkshop* click the 'Statistics' button to open the Statistics area on the right side of the Graph. Click the 'Autoscale' button to automatically rescale the Graph to fit the data.

- Use the cursor to click-and-draw a rectangle around the region of smoothest data in the Graph.

- In the Statistics area, click the **Statistics Menu** button (⬛▼). Select **Curve Fit, Power Fit** from the Statistics Menu.
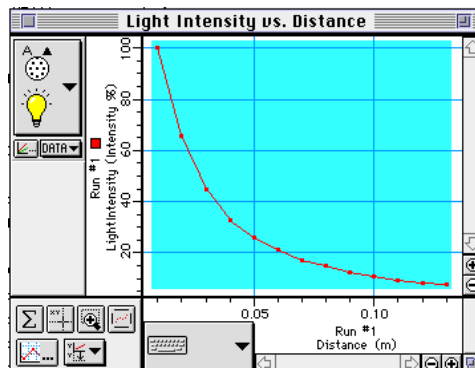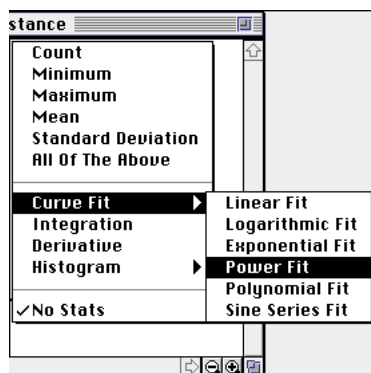
- The *ScienceWorkshop* program will attempt to fit the data to a mathematical formula based on the variable (distance) raised to a <u>power</u>.

- NOTE: You may see a message that says there is no valid solution. In other words, the program needs your help to create the mathematical formula that best fits your data. In the Statistics area, click the a4 coefficient to make it active. Type in -2 as the parameter value. Press <enter> or <return> on the keyboard to record your value.

- Examine the value of **chi^2**, the measure of closeness of fit. The closer the value is to "0.000", the better the data fit the mathematical formula shown in the Statistics area.

**Answer the questions in the Lab Report section.**

Appendix: *ScienceWorkshop* Data Recording

1. When you are ready, click the **REC** button to begin collecting data. The **Keyboard   Sampling** window will open. Move it so you can also see the Digits display. The default value for **Entry #1** is 10.0000. The Parameter and Units appear at the top of the Data list.

2. As accurately as possible, measure the distance from the light source to the port on the Light Sensor. Type in the value of distance as **Entry #1** in the **Keyboard   Sampling** window. Click **Enter** to record your value.
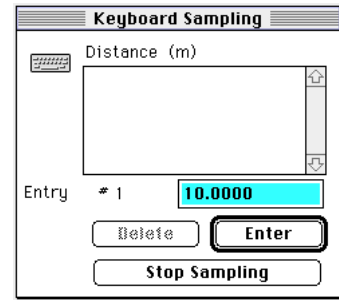
NOTE: Type in the measured distance in <u>meters</u>.

•   Your typed in value will appear in the Data list in the **Keyboard Sampling** window. The default value will change for **Entry #2**.

3. Move the Light Sensor <u>one</u> centimeter away from the original position. Type in the new distance as **Entry #2**. Click **Enter** to record your value.

•   Your typed in value will appear in the Data list, and the default value for Entry #3 will reflect the pattern of your first two entries.

4. Continue to move the Light Sensor away from the light source in one centimeter increments. Type in the distance at each new position of the sensor. Click **Enter** each time to record your value.

5. When the value of light intensity in the Digits display stops decreasing, click the **Stop Sampling** button in the **Keyboard Sampling** window to stop collecting data.

•   The **Keyboard   Sampling** window will disappear. **Run #1** will appear in the Data List in the Experiment Setup window.

6. Turn off the light source.
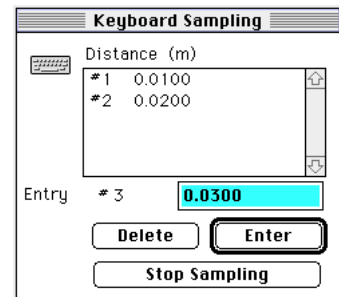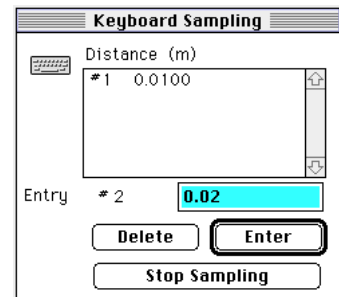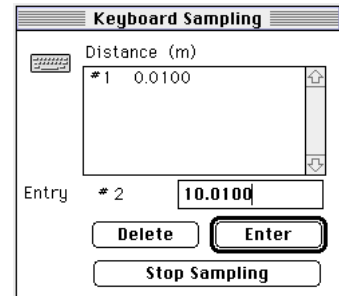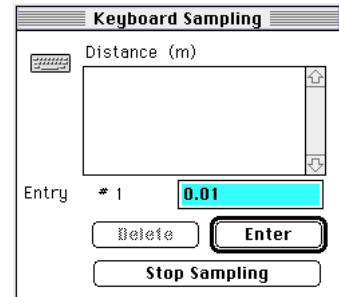
Lab Report - Activity SL33: Light Intensity vs. Distance – Keyboard Method

What Do You Think?

Does the total light energy that passes through an imaginary spherical boundary change as distance from the point light source increases?

Does the light intensity on the surface of an imaginary spherical boundary change as the distance from the point light source increases?

How does the change in light intensity with distance for a 'real' light source compare to the change in light intensity with distance for an ideal 'point' light source?

Questions

1.   What is the relationship of light intensity to distance?

2.   The light bulb is not really a point source. How does this affect the experiment (and what can be done to minimize this error)?

Starter Labs with Computers
SL33: Light Intensity vs. Distance

Student Workbook
012-06997

©1999 *PASCO scientific* **SL33**

Activity SL34: Polarization - Verify Malus' Law
(Light Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Polarization	P57 Malus' Law.DS	P57 Polarization	P57_POLA.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	Basic Optics System (OS-8515)	1
Aperture Bracket (OS-8534)	1	Polarization Analyzer (OS-8533)	1

What Do You Think?

If the transmitted light is at maximum intensity when the two polarizers are parallel, and minimum intensity when the two polarizers are perpendicular, what is the relationship of the intensity of transmitted light to the angle of the polarizers between 0 and 90 degrees?

Take time to write an answer to this question in the Lab Report section.

The purpose of this activity is to determine the relationship between the intensity of the transmitted light through two polarizers and the angle, Ø, of the axes of the two polarizers.

Background

A polarizer only allows light that is vibrating in a particular plane to pass through it. This plane forms the "axis" of polarization. Unpolarized light vibrates in all planes perpendicular to the direction of propagation. If unpolarized light is incident upon an "ideal" polarizer, only half will be transmitted through the polarizer. Since in reality no polarizer is "ideal", less than half the light will be transmitted.

The transmitted light is polarized in one plane. If this polarized light is incident upon a second polarizer, the axis of which is oriented such that it is perpendicular to the plane of polarization of the incident light, no light will be transmitted through the second polarizer (see the top figure).

POLARIZER 1   POLARIZER 2

ANGLE = 90˚

ANGLE = ø

UNPOLARIZED LIGHT   POLARIZED LIGHT, I_0

$I = I_0 \cos^2 ø$
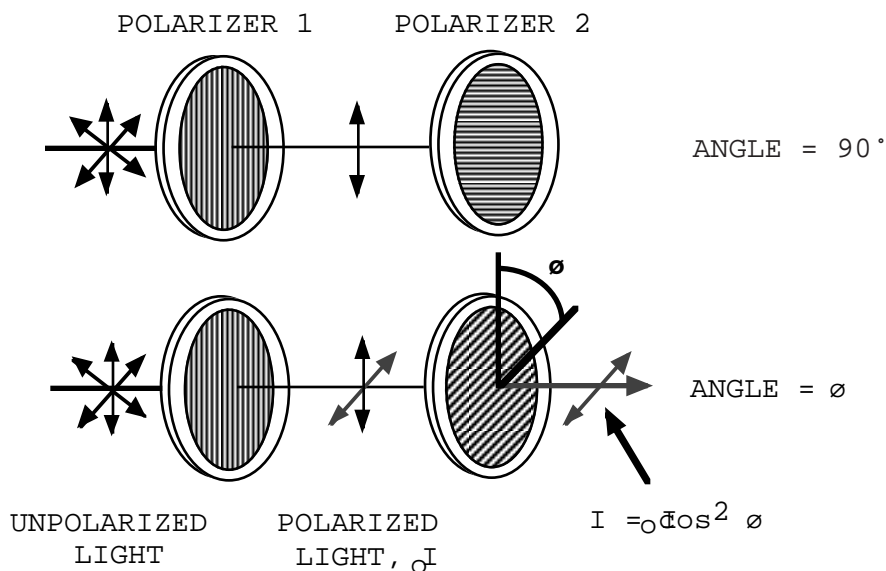
However, if the second polarizer is oriented at an angle so that it is not perpendicular to the first polarizer, there will be some component of the electric field of the polarized light that lies in the same direction as the axis of the second polarizer, thus some light will be transmitted through the second polarizer (see the bottom figure).

The component, E, of the polarized electric field, E_o, is found by:

$$E = E_o \cos \phi$$

Since the intensity of the light varies as the square of the electric field, the light intensity transmitted through the second filter is given by:

$$I = I_o \cos^2 \phi$$

where I_0 is the <u>intensity of the light passing through the first filter</u> and $\emptyset$ is the angle between the polarization axes of the two filters.

Consider the two extreme cases illustrated by this equation:

- If $\emptyset$ is zero, the second polarizer is aligned with the first polarizer, and the value of $\cos^2\emptyset$ is one. Thus the intensity transmitted by the second filter is equal to the light intensity that passes through the first filter. This case will allow maximum intensity to pass through.

- If $\emptyset$ is 90°, the second polarizer is oriented perpendicular to the plane of polarization of the first filter, and the $\cos^2(90°)$ gives zero. Thus no light is transmitted through the second filter. This case will allow minimum intensity to pass through.

- These results assume that the only absorption of light is due to polarizer effects. In fact most polarizing films are not clear and thus there is also some absorption of light due to the coloring of the Polaroid filters.

SAFETY REMINDERS

- Follow directions for using the equipment.

**THINK SAFETY**
ACT SAFELY
BE SAFE!

For You To Do

In this activity, use the Light Sensor to measure the relative intensity of light that passes through two polarizers. Change the angle of the second polarizer relative to the first polarizer.

Use *DataStudio* or *ScienceWorkshop* to record and display the light intensity and the angle between the axes of the polarizers. Use 'Manual Sampling' in *DataStudio* or 'Keyboard Sampling' in *ScienceWorkshop* to enter the angle. Use the program's built-in calculator to compare the relative intensity to the angle, the cosine of the angle, and the cosine^2 of the angle.

PART I: Computer Setup

1. Connect the interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Light Sensor cable into Analog Channel A on the interface. Connect the Light Sensor to the cable.

3. Open the document titled as shown:
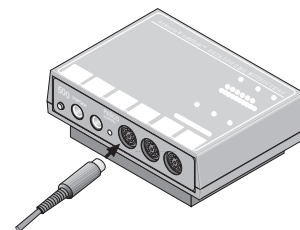
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
P57 Malus' Law.DS	P57 Polarization	P57_POLA.SWS

- The document opens with a Digits display of light intensity from the Light Sensor, a Digits display of the voltage from the Light Sensor, and a Graph display of light intensity vs. angle.

- Data recording is set at 10 Hz. You will enter the distance from the light source to the Light Sensor using 'Manual Sampling' in *DataStudio*, or 'Keyboard Sampling' in *ScienceWorkshop* with Parameter = Distance and Units = m.

PART II: Equipment Setup and Sensor Calibration

Equipment Setup

1. Place each polarizer on an accessory holder. Place the holders on an optics bench.

2. Mount the Light Sensor on an aperture bracket.

3. Put the light source and Light Sensor on opposite sides of the polarizers so the port on the Light Sensor is at the same height as the light source and is aligned with the light source. Arrange the Light Sensor and light source so that an imaginary line between the light source and the port on the Light Sensor passes through the <u>center</u> of the polarizers.
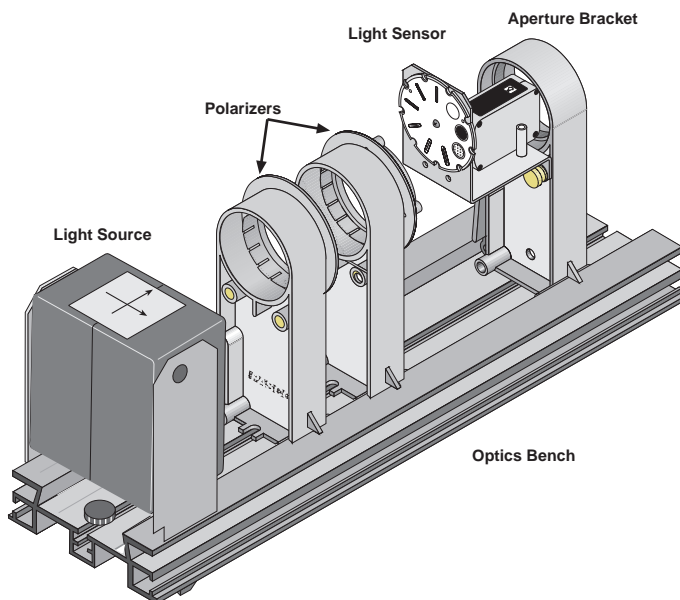

4. Turn on the light source. Move the light source and the Light Sensor so they are as close as possible to the polarizers.

Sensor   Calibration

• Calibrate the Light Sensor so that it produces its maximum voltage when axes of the two polarizers are parallel ($\emptyset = 0°$).

1. Set the GAIN select switch on the top of the sensor to 1. Move the Light Sensor so its port is as close as possible to the light source.

2. In the Experiment Setup window, double-click the Light Sensor icon. (The Sensor Properties window opens in *DataStudio*. The Light Sensor setup window opens in *ScienceWorkshop*. In *DataStudio* click the 'Calibration' tab.)
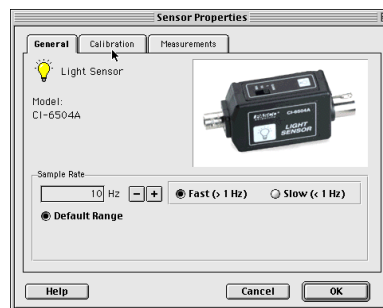
3. Check the voltage from the Light Sensor.

• Hint: In the *DataStudio* 'Calibration' window, the Current Reading of the voltage from the Light Sensor appears in the upper left corner. In the *ScienceWorkshop* Sensor Setup window, the current value of the voltage from the Light Sensor appears at the bottom of the column labeled Volts.
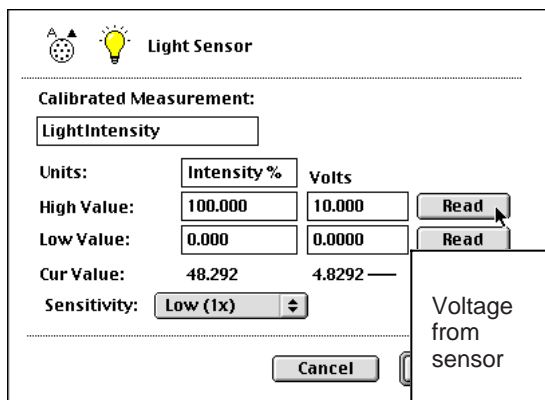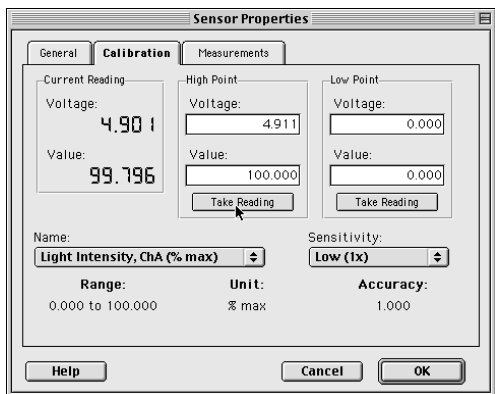
4. Now adjust the polarizers so the light source shines as brightly as possible into the Light Sensor. For example, turn one polarizer so the zero degree mark is next to the reference peg on the accessory holder. Turn the second polarizer so it is parallel with the first polarizer (i.e., also at zero degrees). Adjust the second polarizer until the transmission is maximum as indicated by the voltage in the calibration window.

• If the value of voltage from the sensor is slight higher than 4.9 V, slowly move the sensor away from the light source until the value is 4.9 V (or slightly lower).

• If the voltage value is below 0.49 V set the GAIN switch to 10. If the value is still below 0.49 V set the GAIN switch to 100.

5. Keep this value of voltage as the maximum value (corresponding to 100% intensity). In *DataStudio* click 'Take Reading' below the 'High Point' column. In *ScienceWorkshop*, click the top Read button.

6. Now adjust the polarizers so the light transmission is as dim as possible. Turn the second polarizer to 90 degrees. Adjust the second polarizer so the transmission is minimum as indicated by the voltage in the calibration window.

7. Keep this value of voltage as the minimum value (corresponding to 0% intensity). In DataStudio click 'Take Reading' below the 'Low Point' column. In ScienceWorkshop, click the bottom Read button. Click 'OK' to return to the Experiment Setup window.

PART III: Data Recording

(See the Appendix for specific instructions regarding *ScienceWorkshop*)

1.   Adjust the polarizers for *maximum* transmission of light.

2.   In *DataStudio*, arrange the Table display so you can see it clearly.

3.   When you are ready, start recording data. (Note: The 'Start' button changes to 'Keep'
      (✔ Keep ■). The light intensity will appear in the first cell in the Table display. Click
      the 'Keep' button to record the light intensity.

| Light Intensity, ChA NO DATA	Keyboard Run #1
Light Intensity (% max)	Angle (degrees)
	0.0
	10.0
	20.0
	30.0
	40.0
	50.0
	60.0
	70.0
	80.0
	90.0
	100.0
	110.0
	120.0
	130.0

4.   Turn the second polarizer by 10 degrees. The light intensity will appear in the second cell
      in the Table display. Click the 'Keep' button.

5.   Continue to turn the second polarizer in 10-degree increments up to 180 degrees. At each
      new angle, click the 'Keep' button to record the light intensity.

6.   When you reach the 180-degree mark, stop recording data.

7.   Turn off the light source.

Analyzing the Data (*DataStudio*)

• The DataStudio file has two built-in calculations. The first calculation is 'cos(x)' (cosine of the angle). The second calculation is 'cos(x)^2' (cosine squared of the angle). It computes the square of the cosine of each angle.

1. Click the Graph display to make it active. Analyze your data with the calculations.

2. In *DataStudio*, drag the first calculation, y1 = cos (x), to the horizontal axis of the Graph display.
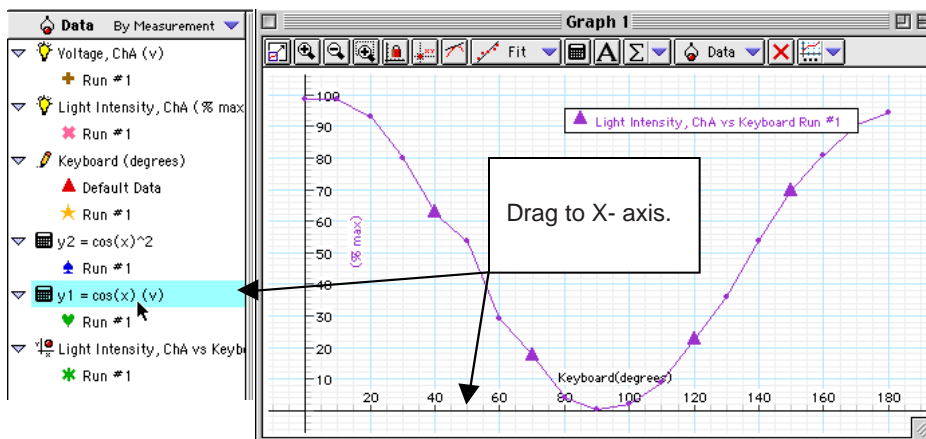
3. The Graph displays 'Light Intensity versus y1' (in other words, Light Intensity versus the cosine of the angle).

4. Fit the data to a mathematical model. Click the 'Fit' menu button and select 'Polynomial'. Note whether or not the 'Polynomial' model is a 'good fit'. Then click the 'Fit' menu button and de-select 'Polynomial'.

5. Next, drag the second calculation, y2 = cos (x)^2, to the horizontal axis of the Graph display.
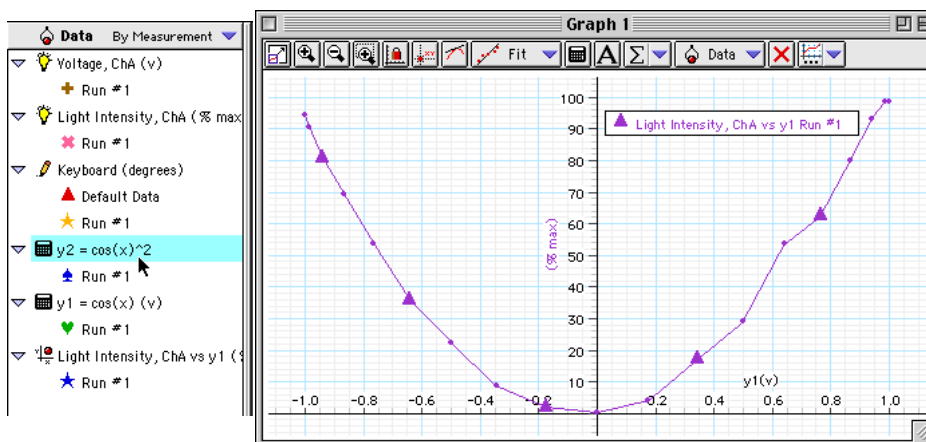
6. Fit the data to a mathematical model. Click the 'Fit' menu button and select 'Linear'. Note whether or not the 'Linear' model is a good fit.

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Analyzing the Data (*ScienceWorkshop*)

- The ScienceWorkshop file has two calculations. The first calculation is 'Cosine of Angle'. This calculation converts the angles from degrees to radians and then computes the cosine. The second calculation is 'Cosine Squared'. It computes the square of the cosine.

1. In ScienceWorkshop, click the 'Statistics' button to open the Statistics area on the right side of the Graph. Click the 'Autoscale' button to rescale the Graph to fit the data.
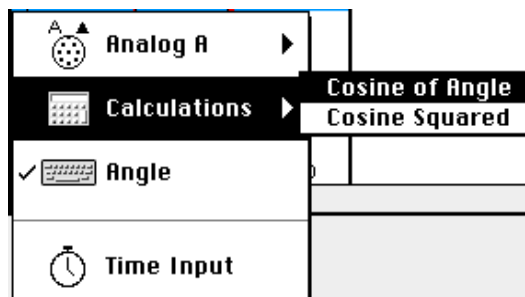
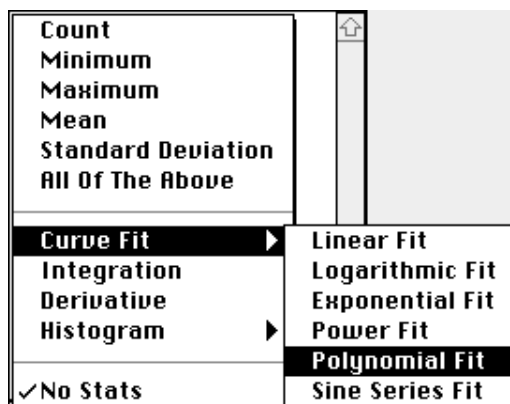2. Click the **Horizontal Axis Input Menu** button ( ). Select **Calculations, Cosine of Angle** from the Input Menu.

- The Graph will change to Intensity vs. Cosine of Angle.

3. Click the **Statistics Menu** button (Σ) in the Statistics area. Select **Curve Fit, Polynomial Fit** from the Statistics Menu.

- The *Science Workshop* program will try to fit the data to a mathematical formula that is a polynomial. The degree of the polynomial and its coefficients are displayed in the Statistics area. The chi^2 value is a measure of the closeness of fit between the data and the mathematical formula.
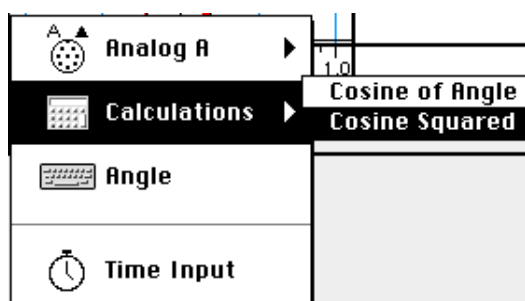
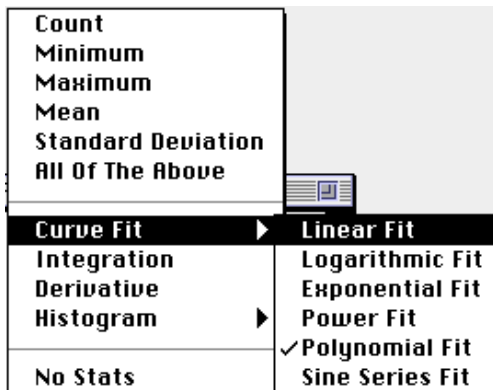4. Click the **Horizontal Axis Input Menu** button ( ) again. Select **Calculations, Cosine Squared** from the Input Menu.

- The Graph will change to Intensity vs. Cosine Squared.

5. Click the **Statistics   Menu** button (⟨Σ▼⟩)
    in the Statistics area. Select **Curve   Fit,
    Linear Fit** from the Statistics Menu.

•   The *ScienceWorkshop* program will try to fit
    the data to a mathematical formula that is a
    linear function. The chi^2 value is a measure
    of the closeness of fit between the data and
    the mathematical formula.

Count	
Minimum	
Maximum	
Mean	
Standard Deviation	
All Of The Above	
Curve Fit ▶	**Linear Fit**
Integration	Logarithmic Fit
Derivative	Exponential Fit
Histogram ▶	Power Fit
	✓Polynomial Fit
No Stats	Sine Series Fit

Answer the questions in the Lab Report section.

Appendix: *ScienceWorkshop* **Data Recording**

1. When you are ready, click the **REC** button to begin
    collecting data. The **Keyboard   Sampling** window will
    open. Arrange the Keyboard Sampling window and the two
    Digits displays so you can see all of them.

•   The Parameter and Units are displayed above the Data list
    and the default value for **Entry #1** is 10.0000.

2. Type in **0** in the Keyboard Sampling window as the value for
    Entry   #1. Click **Enter** to record your value.

•   Your typed in value will appear in the Data list. The default value for Entry #2 will still be
    10.0000.

3. Turn the second polarizer (the one closest to the Light
    Sensor) to an angle of 10 degrees. Since the default value in
    the **Keyboard   Sampling** window is correct, click **Enter**
    to record the value.

•   The new value will appear in the Data list. The default value
    will reflect the pattern of your first two entries.

4. Turn the second polarizer to an angle of 20 degrees. Click
    Enter in the **Keyboard   Sampling** window to record the
    new angle.

5. Continue to turn the second polarizer by increments of 10
    degrees until you reach 180. Click **Enter** in the **Keyboard
    Sampling** window for each new angle (including 180
    degrees).

6. When you have recorded the value at 180 degrees, click the
    Stop   Sampling button in the **Keyboard   Sampling**
    window to stop collecting data.

•   The **Keyboard   Sampling** window will disappear. **Run
    #1** will appear in the Data List in the Experiment Setup window.
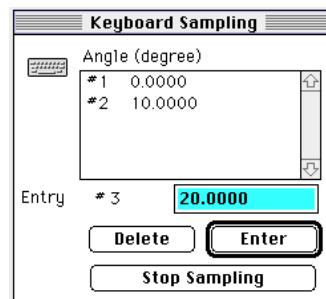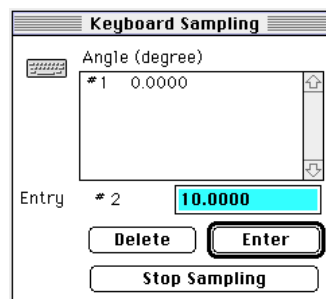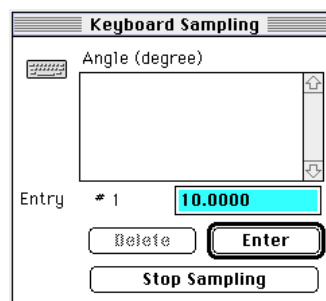
Lab Report - Activity SL34: Polarization – Verify Malus' Law

What Do You Think?

If the transmitted light is at maximum intensity when the two polarizers are parallel, and minimum intensity when the two polarizers are perpendicular, what is the relationship of the intensity of transmitted light to the angle of the polarizers between 0 and 90 degrees?

Questions

1.   What is the shape of the graph of the intensity versus the angle?

2.   What is the shape of the graph of the intensity versus the cosine of the angle?

3.   What is the shape of the graph of the intensity versus the square of the cosine of the angle?

4.   Theoretically, what percentage of incident plane polarized light would be transmitted through three polarizers which each have their axes rotated 17 degrees from each other? Assume ideal polarizers and assume that the first polarizer's axis is 17 degrees from the axis of the second polarizer.