ScienceWorkshop®

Physics Labs with Computers

Student Workbook

Volume 2

Physics activities using the *ScienceWorkshop*® program and interfaces from PASCO scientific

PASCO® scientific

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Edited by David A. Griffith.

Contents

Preface

I. Overview of Physics Labs with Computers, Volume 2: Student Workbook (CI-7016)

This manual has twenty-five activities in the following areas: motion, mechanics, thermodynamics, sound and waves, electricity and magnetism, and radioactivity. Most of these activities can be done with the sensors that are included in the Physics Bundles for the *ScienceWorkshop* 750 Interface. Many of these activities take advantage of the power output feature of the 750 Interface.

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, consumables (if any), and quantities.

Purpose (What Do You Think?)

The purpose includes a question for the student 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 and wearing protective gear (e.g., goggles).

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 students can record their data and answer the questions. The Student Workbook pages are perforated so the student can easily remove the Lab Report pages.

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 all 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 the equipment.
- Be sure to wear protective gear such as goggles or safety glasses to protect your eyes and face.
- Be careful around open flames and when using a hot plate.
- Use tongs when handling anything hot. Before touching something that you think might be hot, place the back of your hand near the object to sensor its temperature.
- If you have a question, please ask for help.

SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.

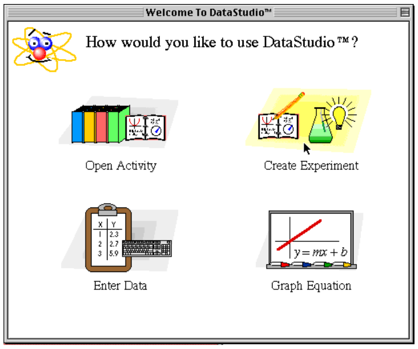
III. Acknowledgements

The editor thanks all of the people who helped in writing, revising or editing the activities in this manual.

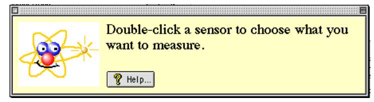
September 2, 1999.

Quick Reference Guide for *DataStudio*

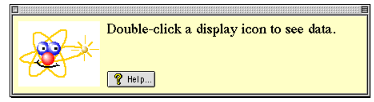
Create an Experiment



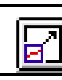
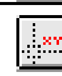
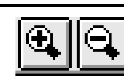
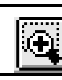
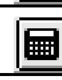
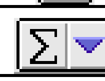
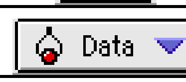
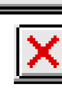
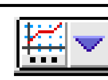
(1) Double-click a sensor.



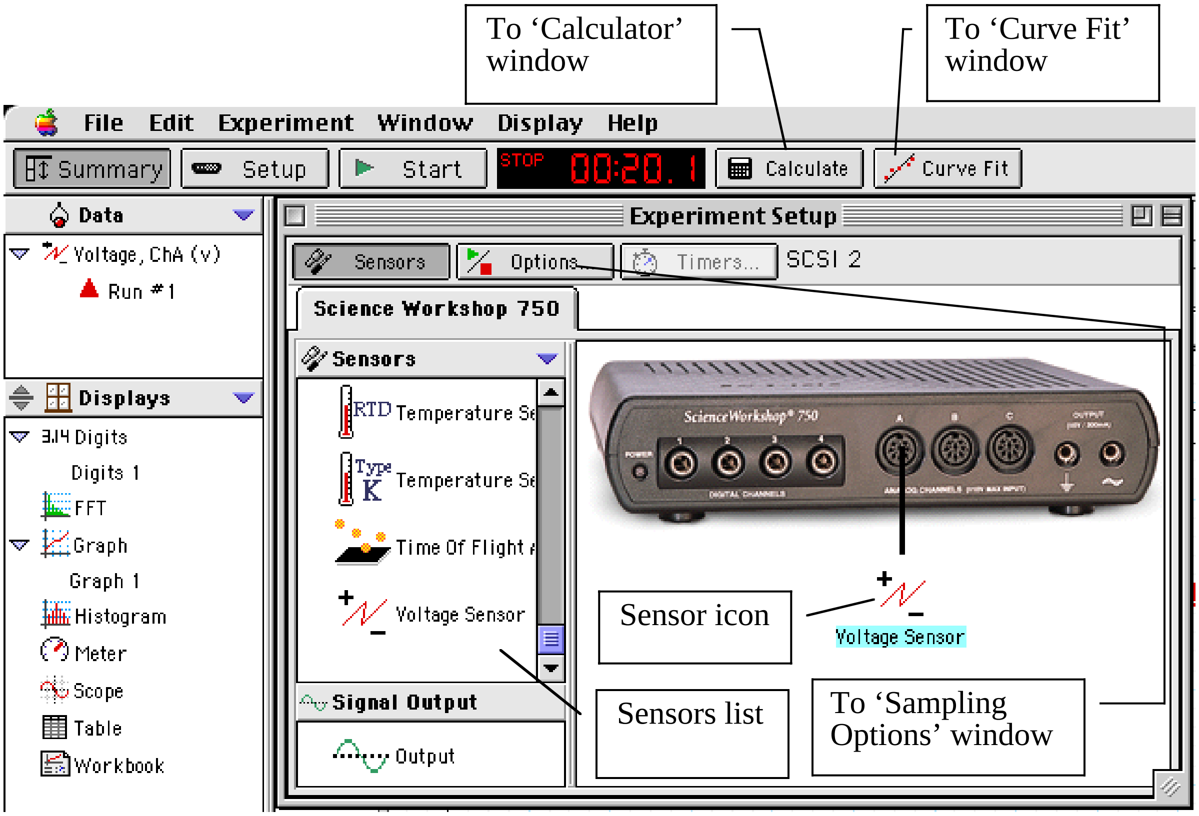
(2) Double-click a display.



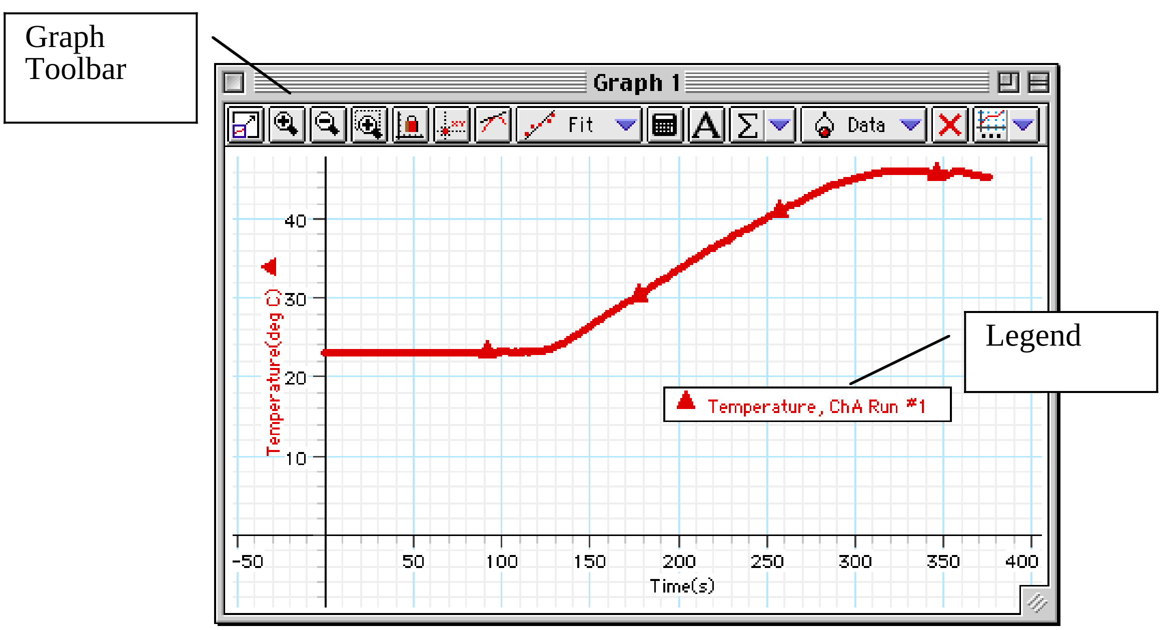
What You Want To Do	How You Do It	Button
Start recording data	Click the 'Start' button or select 'Start Data' on the Experiment menu (or on the keyboard press CTRL - R (Windows) or Command - R (Mac))	
Stop recording (or monitoring) data	Click the 'Stop' button or select 'Stop Data' on the Experiment menu (or on the keyboard press CTRL - . (period) (Win) or Command - . (Mac))	
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



Graph Display



Instructions – Using the Interface and *DataStudio*

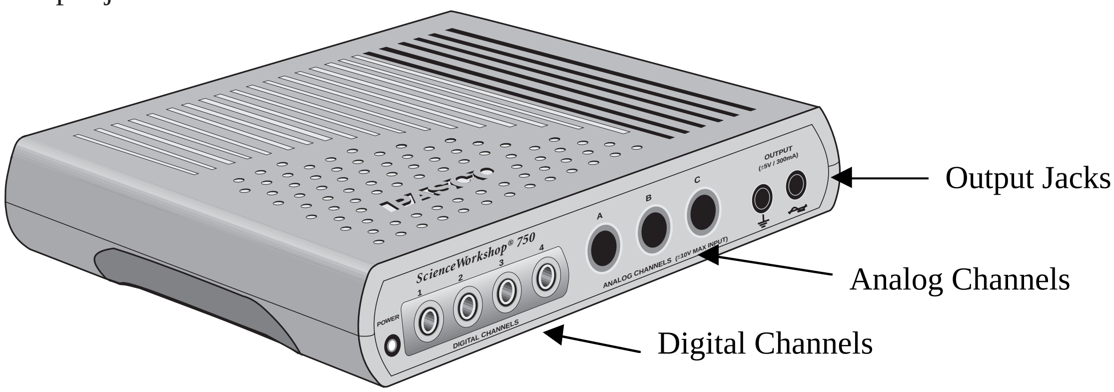
There are several features that make *DataStudio* a unique and powerful teaching tool for science and math. Section #1 covers the mechanics of the interface. Section #2 covers setting up an experiment with the software. Section #3 covers data analysis in more detail.

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 750 Interface

Setting Up the *ScienceWorkshop* 750 Interface Box

The *ScienceWorkshop* 750 Interface has four digital channels, three analog channels and a pair of output jacks.



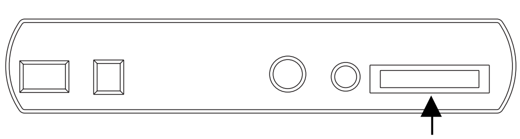
The **green LED (light-emitting diode)** on the front of the interface box indicates the mode of the interface box. A green light indicates that the power is ON.

The **Analog Channels** allow up to three analog sensors to be plugged into the *750* interface. You can plug in an analog sensor's DIN plug in only one way. The Force Sensor is an example of an analog sensor. You can connect the **Power Amplifier** into any Analog Channel.

The **Digital Channels** allow up to four digital sensors to be plugged into the *750* interface. The Photogate and Motion Sensor are examples of digital sensors. For example, you can connect four Photogates or two Motion Sensors to a *750* interface.

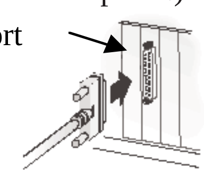
The **Output Jacks** allow you to use the *750* interface as a 1.5 watt power supply (±5 volts AC or DC at up to 300 milliamps).

The interface connects to a SCSI port on the computer. Connect one end of the SCSI cable (included with the interface) to the SCSI connector on the back of the interface box. Connect the other end of the cable to the computer's SCSI port. (Note: Refer to the *DataStudio* Getting Started Guide for information about installing a SCSI card inside your computer.)



SCSI connector

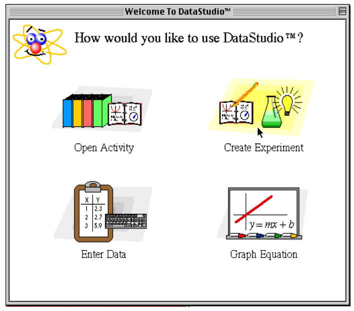
SCSI port



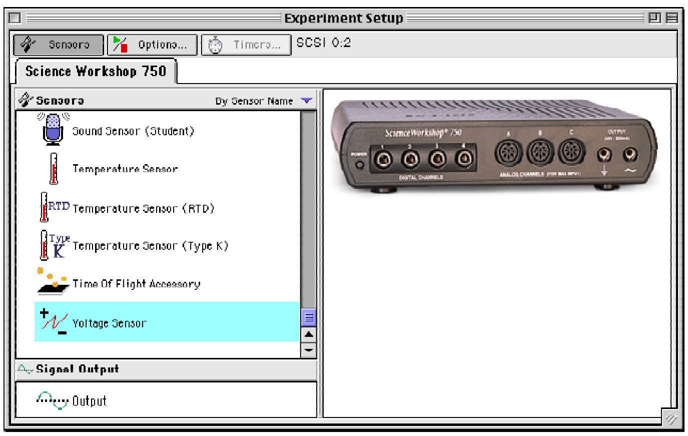
Section #2: Setting Up Your Own Experiment in DataStudio

The Summary List and the Setup Window

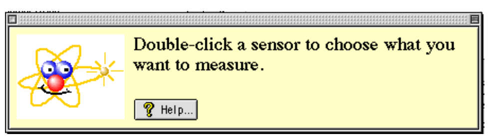
Start *DataStudio*. In the 'Welcome to DataStudio™' window, click 'Create Experiment'.



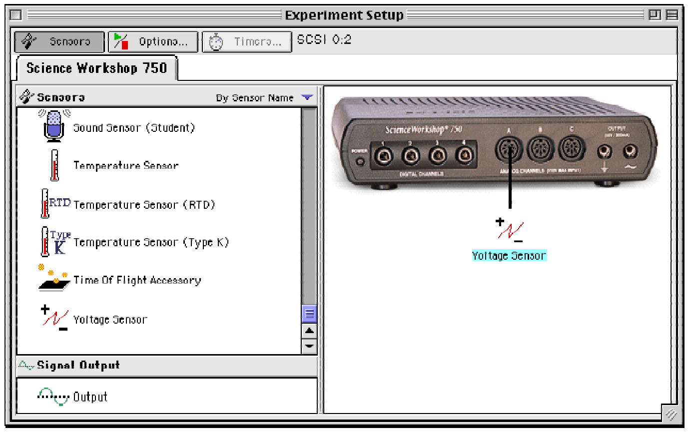
The first step to becoming proficient with *DataStudio* is to understand the Summary List and the Experiment Setup window. The Summary List shows runs of data (under 'Data') and the available displays (under 'Displays'). The Experiment Setup window shows the list of sensors (under 'Sensors') and the interface that is connected (e.g., the 750 interface).



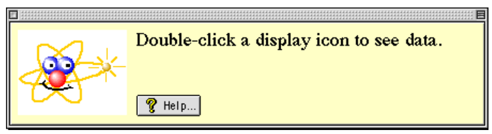
Select a sensor. The sensors are listed by name. Scroll through the list to find the 'Voltage Sensor', and then double-click the sensor to select it.



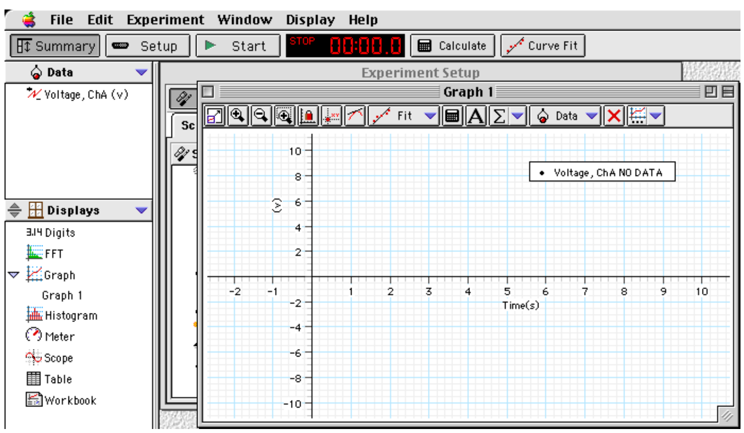
The Voltage Sensor icon appears below Channel A of the interface, and 'Voltage, ChA (v)' appears in the Data list.



Now, select a display. Double-click 'Graph' in the Displays list.

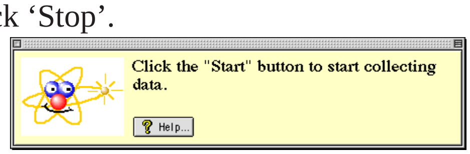


Graph 1 opens, and 'Graph 1' appears in the Displays list. Also, 'Voltage, ChA NO DATA' appears in the Graph's legend box.



Finally, click the 'Start' button () to begin recording data.

When you are finished, click 'Stop'.

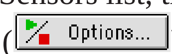


The Menu Bar 

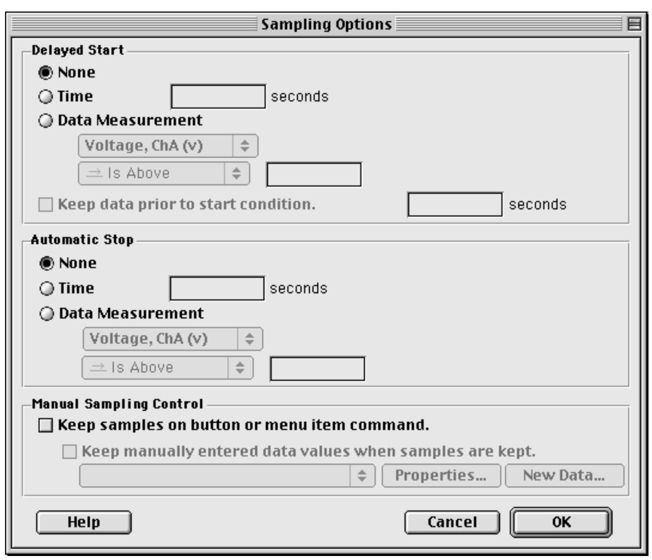
The **menu bar** at the top of the Experiment Setup window is very similar to menus bars found in Macintosh® and Windows® programs.

- 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, 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 (
), and a button to open the 'Timers' window (
) (for use with Photogates).

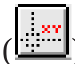
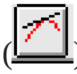
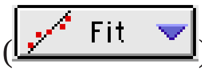
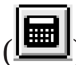
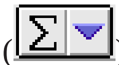
Use the 'Sampling Options' window to set a 'Delayed Start', an 'Automatic Stop' or to set the 'Manual Sampling Control'.

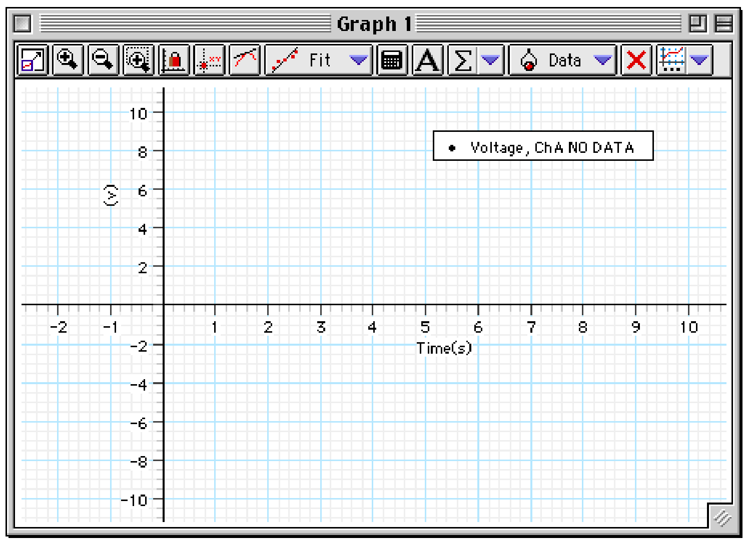


Section #3: Data Analysis

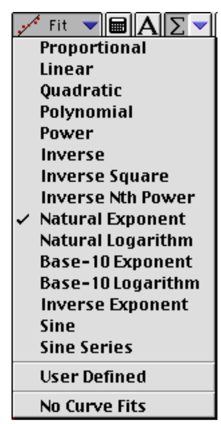
DataStudio offers several ways to analyze data:

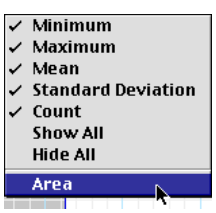
- Use the built-in analysis tools in the Graph display toolbar
- Use the 'Calculator' to create calculations based on your measured data or on a range of numbers that you select.
- Use the 'Curve Fit' to compare your data to mathematical models.

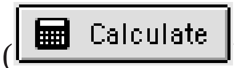
In the **Graph display toolbar**, the built-in analysis tools include the 'Smart Tool' button (), the 'Slope Tool' button (), the 'Fit' menu button (
), the 'Calculate' button (), and the 'Statistics' menu button ().



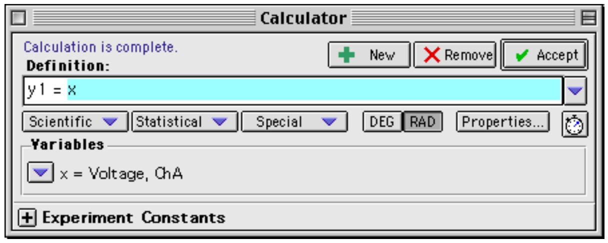
- Use the 'Smart Tool' to see the coordinates of any point.
- Use the 'Slope Tool' to see the slope of a line tangent to a point on a curve.
- Use the 'Fit' menu button to select a mathematical model.
- Use the 'Calculate' button to create a calculation on the data in your Graph.
- Use the 'Statistics' menu button to select basic statistics such as 'Minimum' or 'Maximum' or to find the area under a curve.



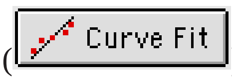


Click the ‘Calculate’ button in the main toolbar (

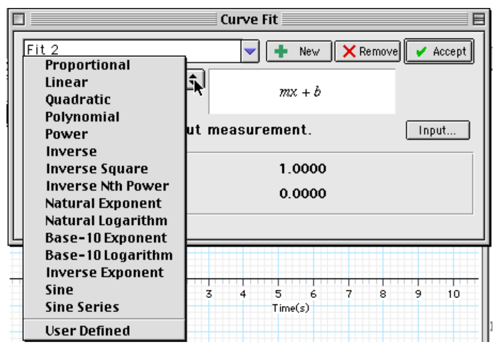
) to open the ‘**Calculator**’ window:



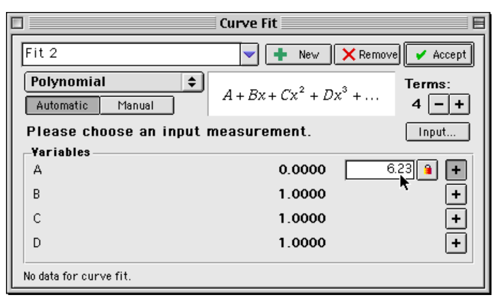
Use the ‘Definition:’ area to create your own calculation, or use the ‘Scientific’, ‘Statistical’, or ‘Special’ menus to select a specific calculation to apply to your data. After you have created the calculation, click ‘Accept’. Your calculation will appear in the Data list. You can drag your calculation to a Graph display, for example

Click the ‘Curve Fit’ button in the main toolbar (

) to open the **‘Curve Fit’** window. Click the ‘New’ button.



Select a mathematical model, or select ‘User Defined’ to create your own.



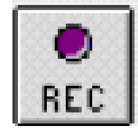
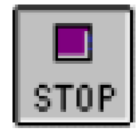
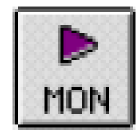
You can enter values for the coefficients or ‘lock’ a coefficient. After you have created the mathematical model, click ‘Accept’. Your curve fit will appear in the Data list. You can drag your curve fit to a Graph display, for example.

Online Help

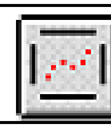
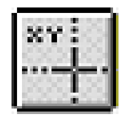
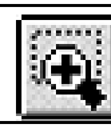
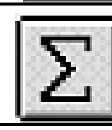
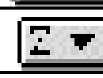
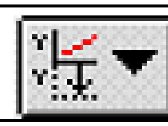
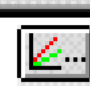
Click ‘Contents’ or ‘Search…’ in the Help menu to open the online help file. You can use the online help file to learn about any button, icon, menu, control, function or feature of the program.

Quick Reference Guide for *ScienceWorkshop*

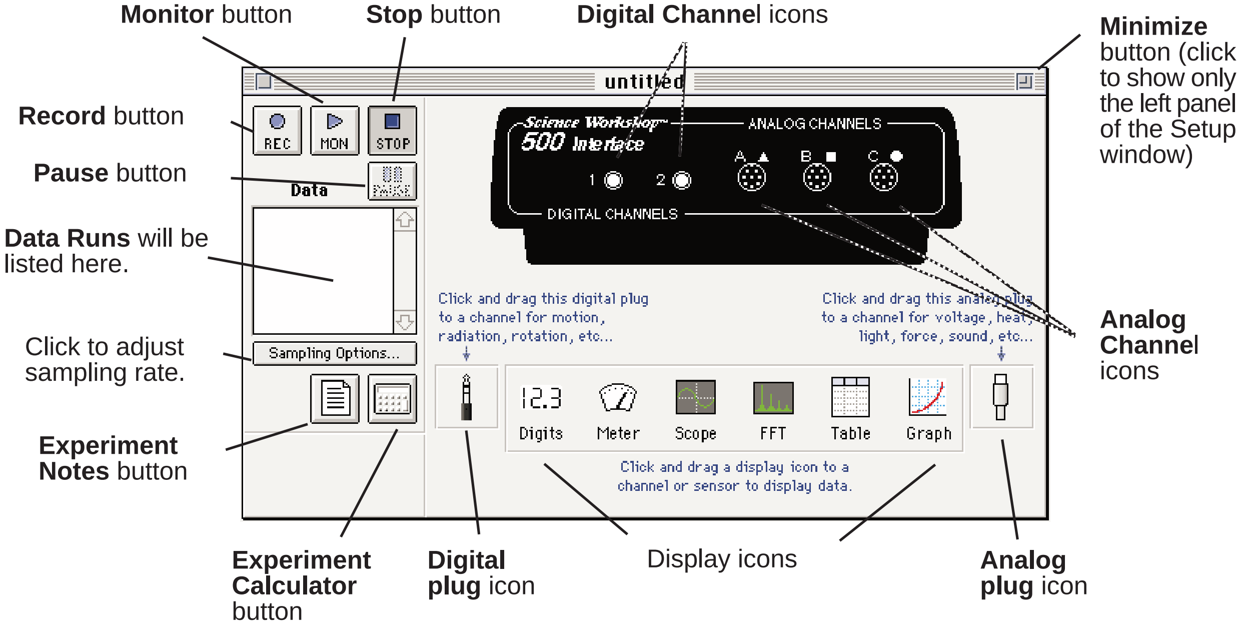
In the Experiment Setup Window:

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))	

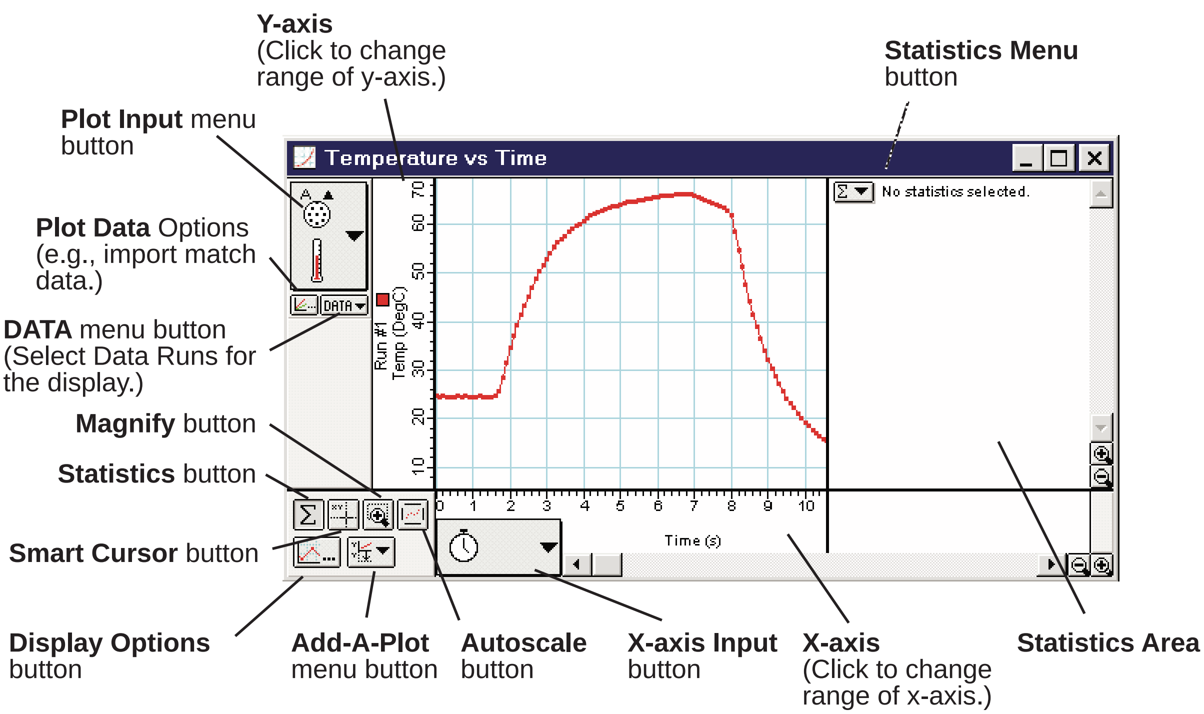
On the Graph Display:

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	

Experiment Setup Window



Graph Display



Instructions – Using *ScienceWorkshop®*

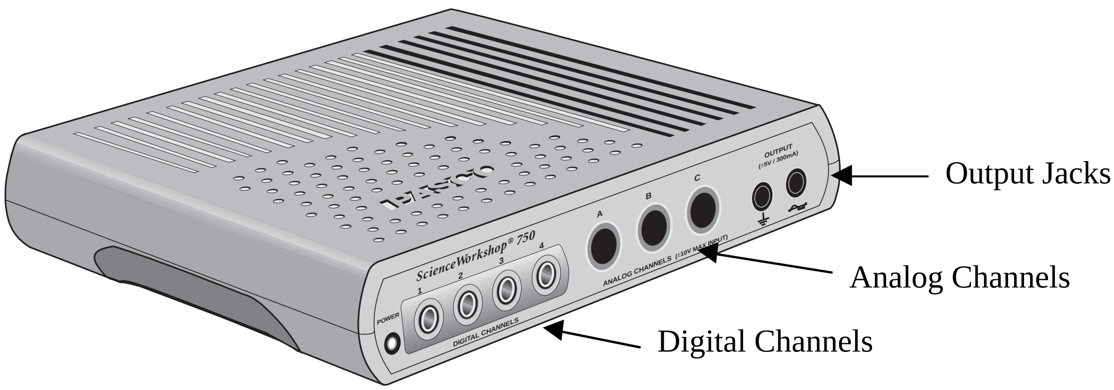
There are several features that make *ScienceWorkshop* a unique and powerful teaching tool for science and math. Section #1 covers the mechanics of the software and hardware. Section #2 covers the data analysis tools in more detail.

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: ScienceWorkshop 750 Interface

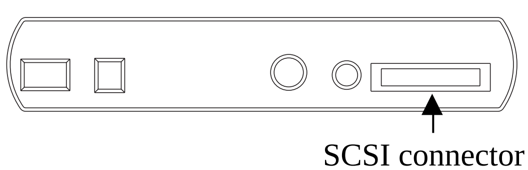
Setting Up the *ScienceWorkshop* 750 Interface Box

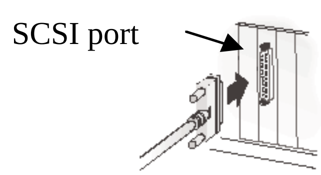
The *ScienceWorkshop* 750 Interface has four digital channels, three analog channels and a pair of output jacks.



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.
The **Analog Channels** allow up to three analog sensors to be plugged into the *750* interface. You can plug in an analog sensor’s DIN plug in only one way. The Force Sensor is an example of an analog sensor. You can connect the **Power Amplifier** into any Analog Channel.
The **Digital Channels** allow up to four digital sensors to be plugged into the *750* interface. The Photogate and Motion Sensor are examples of digital sensors. For example, you can connect four Photogates or two Motion Sensors to a *750* interface.
The **Output Jacks** allow you to use the *750* interface as a 1.5 watt power supply (±5 volts AC or DC at up to 300 milliamps).

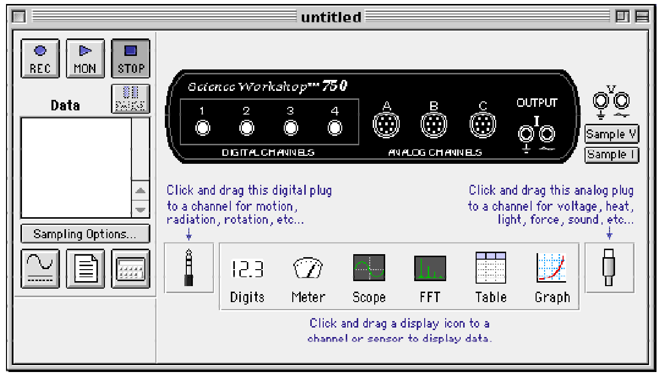
The interface connects to a SCSI port on the computer. Connect one end of the SCSI cable (included with the interface) to the SCSI connector on the back of the interface box. Connect the other end of the cable to the computer’s SCSI port. (Note: Refer to the *DataStudio* Getting Started Guide for information about installing a SCSI card inside your computer.)





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

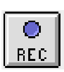
The **menu bar** at the top of the Experiment Setup window is very similar to menus bars found in Macintosh® and Windows® programs.

- 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.

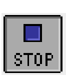
- Use the **Display** menu to select any of the six display windows (either to set up a new display or toggle to a display already in use).

Features of the Experiment Setup Window

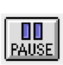


The **Record button** is in the top left corner of the Experiment Setup window. Press this button to collect data and store the data in memory. The flashing bar below the button shows when *ScienceWorkshop* is collecting data.

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.

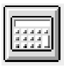


Press the **Pause button** to temporarily interrupt data collection. Press it again when you want to continue collecting data.

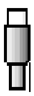
Press the **Sampling Option button** to open a window where you can select the Periodic Samples rate, the Start and Stop Conditions, and Keyboard Sampling. The default Periodic Samples rate is 10 samples per second (10 Hz) for an analog sensor and 10,000 samples per second for a digital sensor. You can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

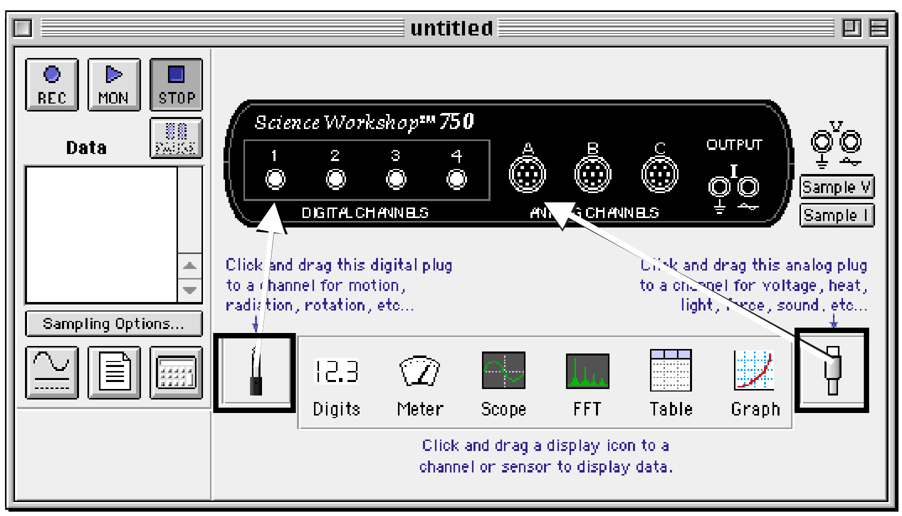

Press the **Experiment Calculator button** to open the Experiment Calculator window that allows you to do mathematical operations on collected data. You can also use it as a stand-alone calculator.


Drag the **digital plug icon** to a Digital Channel 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.

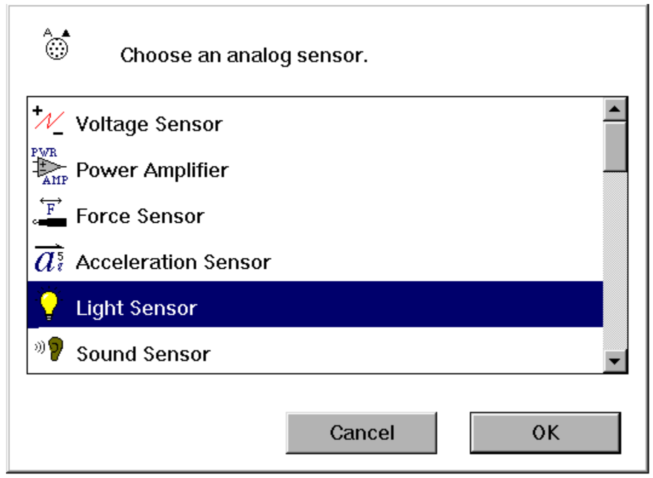

Drag the **analog plug icon** to Analog Channel A, B, or C to add an analog sensor to the Experiment Setup window. Then select the correct analog sensor from the list of sensors than opens. Click **OK** to return to the Experiment Setup window.

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 *750* Interface box that you plugged the sensor into.

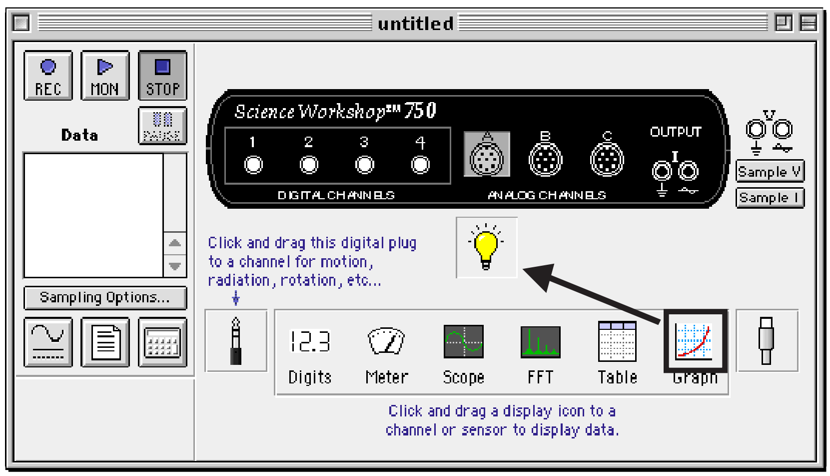


2. Choose the sensor from the sensor list that pops up. Click **OK** to return to the Experiment Setup window.



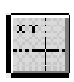
3. Drag a display icon to the Sensor icon.

You are ready to collect data!



Note: *ScienceWorkshop* has many advanced features. Refer to the *ScienceWorkshop* User's Guide for more information.

Section #2: Data Analysis

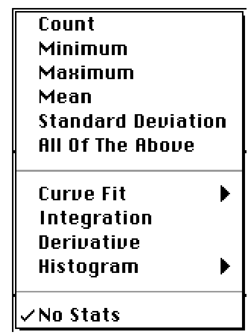
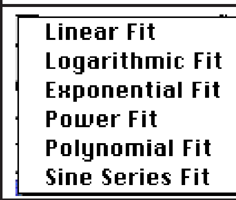
Analysis: The Smart Cursor 

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.)

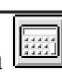
The Statistics Tool 

The Table and Graph displays have built-in statistics. Click the S**tatistics button** to open the statistics area at the bottom of a Table or on the right side of a Graph.

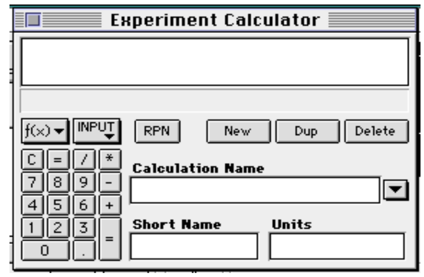
Statistics menu for a Table display	
In the Graph display, click the Statistics Menu button to see the statistics options.	
Statistics menu for a Graph display	
Curve Fit submenu	
Linear Fit will generate a basic slope equation with the slope of the best-fit line being the **a2** value in the display.	

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



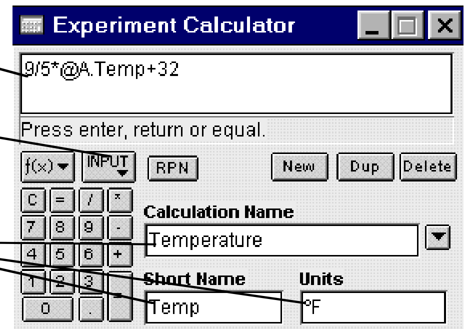
Example:
Converting the temperature data from degrees Celsius to degrees Fahrenheit for plotting on the Graph display.

1. Type the formula here

(Select the variable to be modified from the Input Menu)

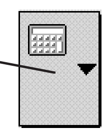
2. Fill in these dialog boxes

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 ºF)

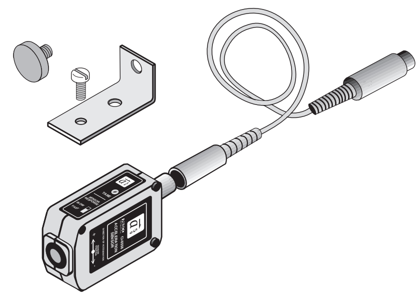
Note: The values for this calculation can also be displayed in any Table, Digits, or Meter display. To do this, select **Calculations, Temperature, (Temp ˚F)** from the **Input** menu of the display.

Tutorial Activities – Exploration of Sensors

Practice using the sensors included in the Physics Bundles for the *ScienceWorkshop* 750 interface.

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

Acceleration Sensor



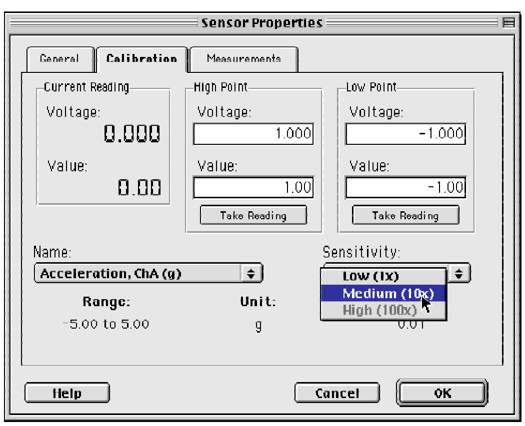
The Acceleration Sensor measures accelerations up to five times the acceleration due to Earth's gravity or ±5 g's (where 'g' is the acceleration due to gravity, or 9.8 m/s^2). The sensor's accuracy is 0.01 g and the sensor's output ranges from +5 g to –5 g depending on the direction of the acceleration. You can also use the software to display acceleration in units of m/s^2. The sensor includes a cable for connecting to the interface and hardware for mounting the sensor on a PASCO cart.

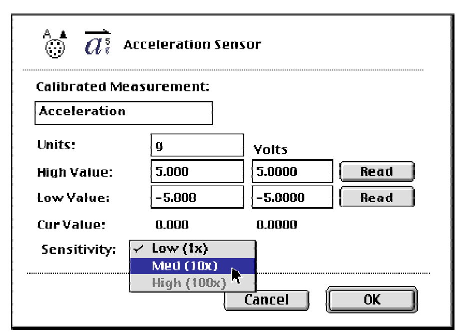
The sensor has two built-in controls located on the top of the sensor:

Tare Button: Use the tare button to zero the sensor before making a measurement. You can use this feature to nullify the effect of the Earth's gravity.

Sensor Response Switch: The sensor response switch has two settings – "slow" and "fast". The 'slow' setting reduces errors due to high frequency vibrations. Use the 'slow' setting when the acceleration is not changing rapidly, such as on elevators, roller coasters, and in automobiles. Use the 'fast' setting when the acceleration is changing rapidly, such as during cart collisions.

You can use the software to measure *very* small accelerations by setting the 'Sensitivity' to 'Medium (10x)' under 'Calibration' in the Sensor Properties window.





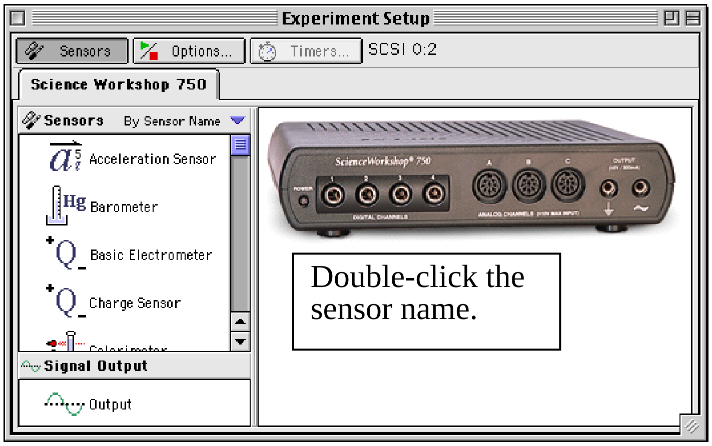
The sensing unit inside the sensor is oriented so that the greatest sensitivity is along the direction of the two arrows on the label.

Set up the sensor with the interface

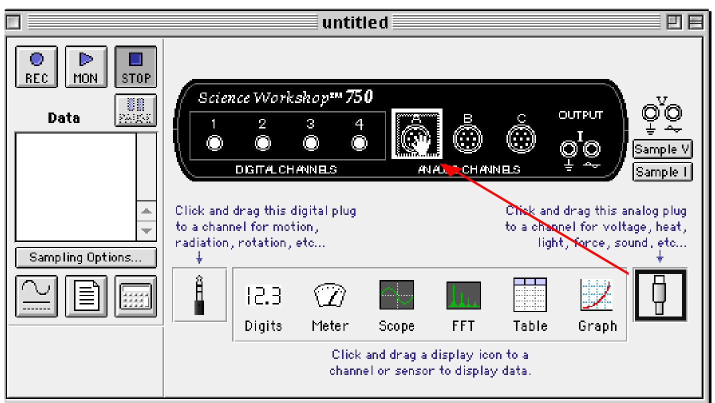
- Plug one end of the DIN-to-DIN cable into the sensor and then connect the other end of the cable into **Analog Channel A** on the interface.
- Note: You can connect the sensor directly into the interface if needed.

Set up the sensor in the software

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameter (e.g., Acceleration (g)) appears in the Data list.



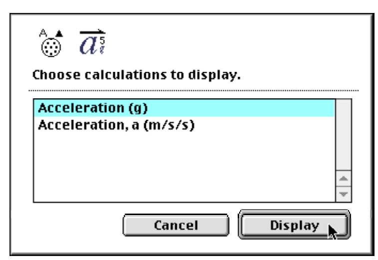
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.



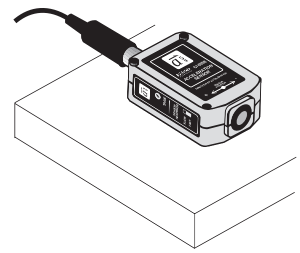
Set up a display

- In *DataStudio*, double-click the 'Graph' icon in the Displays list. **Result**: The display automatically shows acceleration versus time.

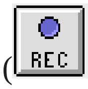
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window. Select 'Acceleration (g)' from the 'Choose…display' window and click 'Display'.



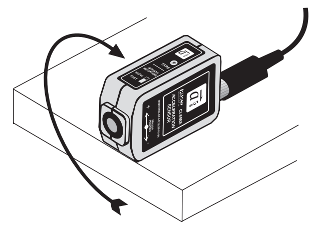
Start recording data



- Place the sensor flat on a level surface with the direction arrows parallel to the ground.
- Press the tare button to 'zero' the sensor.
- In *DataStudio*, click the 'Start' button (

). In *ScienceWorkshop*, click the 'REC' button (

).
- Rotate the sensor 90 ˚ so the arrows point up-and-down. Move the sensor up-and-down and watch the results in the Graph display.



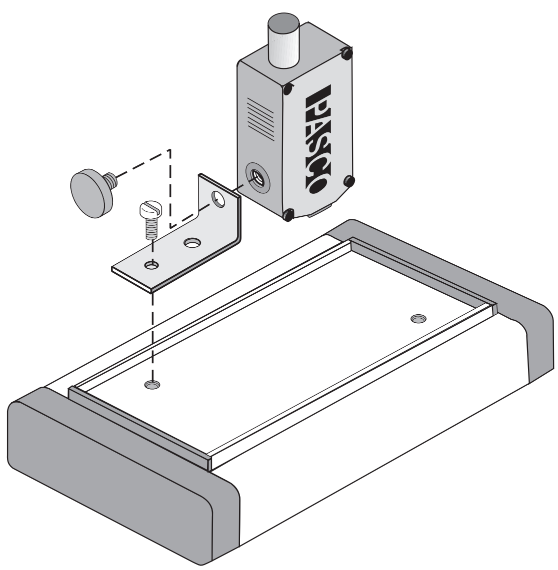
Stop recording data.

- Click 'Stop' to end data recording.

Mounting on a PASCO Cart

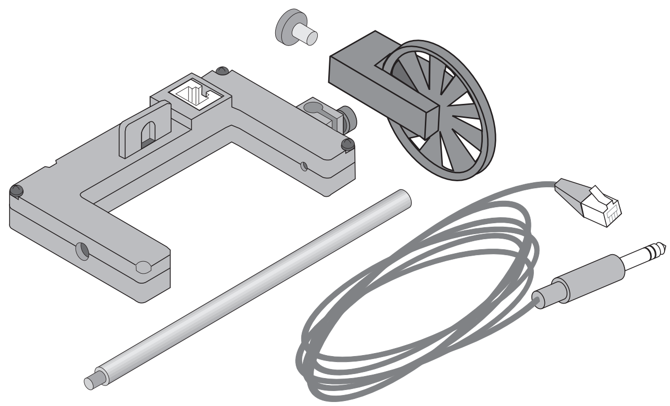
You can use the hardware that comes with the sensor to mount the sensor on top of a PASCO cart.

- Use the large thumbscrew to attach the 'short' leg of the bracket to the sensor.
- Use the small thumbscrew to attach the 'long' leg of the bracket to a threaded hole in the top of the cart.



Accessory Photogate and Photogate/Pulley System

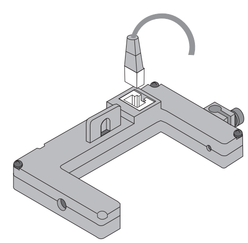
The Accessory Photogate consists of a Photogate Head and a base and support rod.



The Photogate/Pulley System includes the Photogate Head, a cable for connecting to an interface or a timer, a Pulley Mounting Rod, an attachment screw, and a Super Pulley. The Photogate Head emits an infrared beam from one side of it’s ‘U’ shape to the other. Timing begins when an object interrupts the infrared beam. A light-emitting diode (LED) on the top of the Photogate Head shows when an object blocks the beam. You can use the software to record the time that the beam is blocked or the time from when the beam is first blocked until it is blocked again or a variety of other combinations.

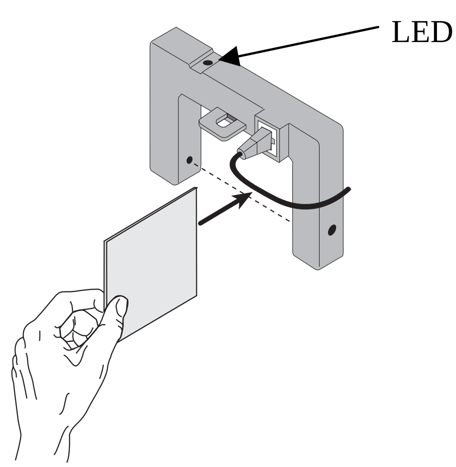
You can attach the Super Pulley to the tab on the side of the Photogate Head using the attachment screw or the Pulley Mounting Rod. The Photogate Head itself can be held in place several different ways. It has a 1/4-20 threaded hole on one side and a rod clamp on the other side.

For this activity you need a card to block the Photogate’s infrared beam.



Set up the sensor

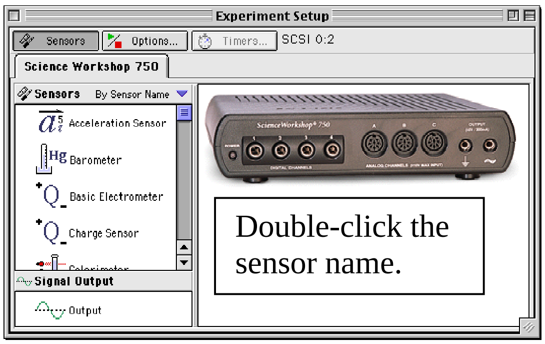
- Plug the modular connector on one end of the cable into the Photogate Head and plug the other end of the cable into **Digital Channel 1** on the interface.
- Watch the LED (light-emitting diode) on top of the Photogate Head as you pass a card back-and-forth through the opening.

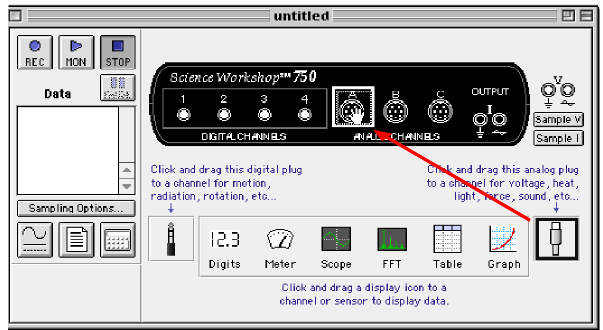


Set up the sensor in the *DataStudio* software

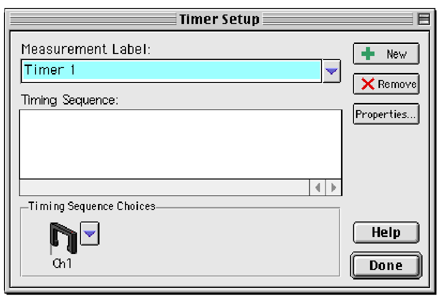
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Digital Channel 1 of the interface. The 'Timers' button (

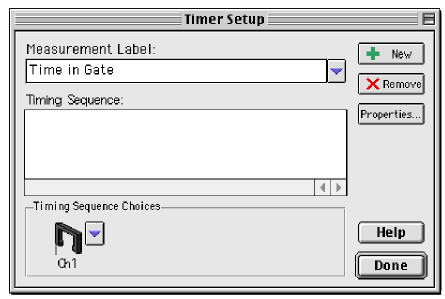
) becomes active in the Experiment Setup window toolbar.



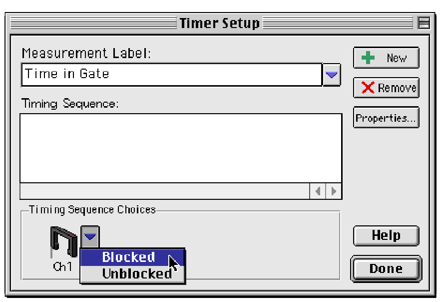


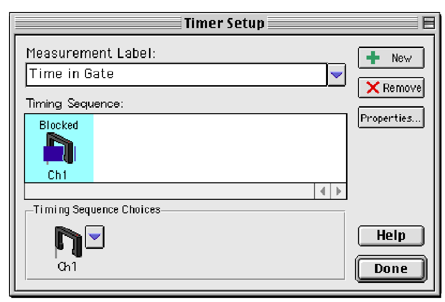
- Click the 'Timers' button in the setup window toolbar. **Result**: The Timer Setup window opens. For this activity you will measure the amount of time that a card interrupts the Photogate's infrared beam, so enter 'Time in Gate' as the Measurement Label.



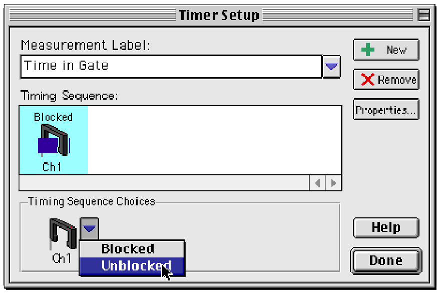


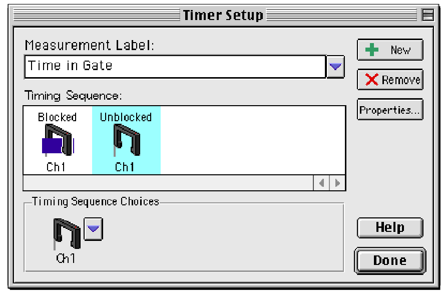
- The 'Timing Sequence' for this activity is 'blocked-to- unblocked'. Click the 'Timing Sequence Choices' menu button and select 'Blocked'. **Result**: The 'Blocked Photogate' icon appears in the Timing Sequence area.





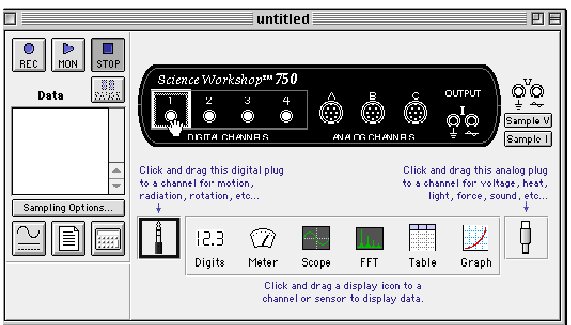
- Click the ‘Timing Sequence Choices’ menu button again and select ‘Unblocked’. **Result**: The ‘Unblocked Photogate’ icon appears next to the ‘Blocked Photogate’ icon in the Timing Sequence area. Click ‘Done’ to return to the setup window.

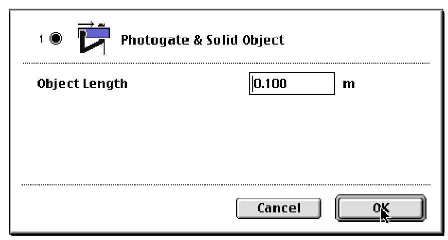




Set up the sensor in the *ScienceWorkshop* software

- In *ScienceWorkshop*, click-and-drag the ‘digital sensor plug’ icon to the Channel 1 icon in the Experiment Setup window, select ‘Photogate & Solid Object’ from the list of sensors and click ‘OK’. **Result**: The sensor’s parameter window opens and shows the default value for the ‘Object Length’ as 10 cm (0.100 m). Click ‘OK’ to return to the Experiment Setup window. **Result**: The sensor’s icon appears below Channel 1 of the interface.





Set up a display

- In *DataStudio*, double click ‘Digits’ icon from the Displays list. **Result**: The Digits display automatically shows ‘Time in Gate’. Repeat the process to create a ‘Table’ display.
- In *ScienceWorkshop*, click-and-drag the ‘Digits’ display icon to the sensor’s icon in the Experiment Setup window. Select ‘Time in Gate’ from the list and click ‘Display’. Repeat the process to create a ‘Table’ display.

Start recording data

- In *DataStudio*, click the ‘Start’ button (

). In *ScienceWorkshop*, click the ‘REC’ button (

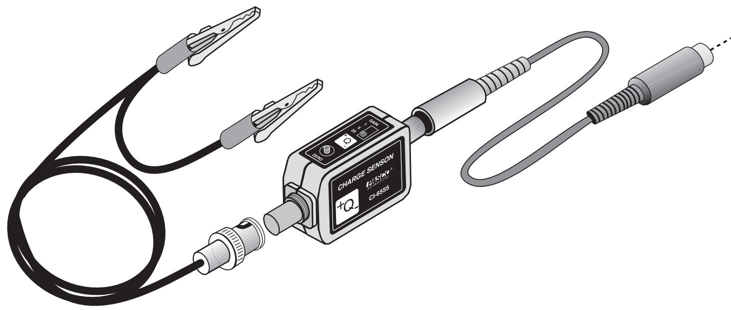
).
- Block and then unblock the Photogate’s beam several times. Watch the results in the Digits and Table displays. Find out how quickly you can move the card through the beam.

Stop recording data

- Click ‘Stop’ to end data recording.

Charge Sensor

The Charge Sensor measures voltages from sources where the total mount of charge is very small. The sensor is a voltage amplifier with a very high input resistance. The sensor can make quantitative measurements as well as show charge polarity. The sensor includes a cable for connecting to the interface and a special cable assembly with a BNC connector on one end and alligator clips on the other end.



The sensor has two built-in controls located on the top of the sensor:

Zero Button: Use the zero button to discharge the input capacitor inside the sensor.

Gain Select Switch: Use the gain select switch to set the full-scale input range of the sensor. The three settings are as follows.

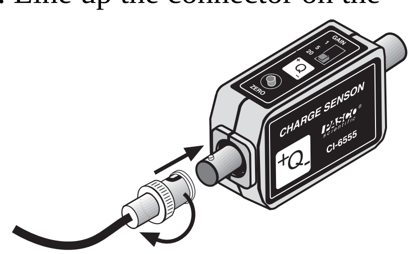
Gain Select setting	Full Scale Range (±volts)
1	10
5	2.0
20	0.5

(Note: When the sensor is on the 20x Gain Switch setting, pressing the zero button may not cause the voltage to go exactly to zero. The residual voltage is usually very small – less than 0.1 volts – and can be subtracted from the final measurement.)

For this activity you will need a pair of Charge Producers and a Faraday Ice Pail.

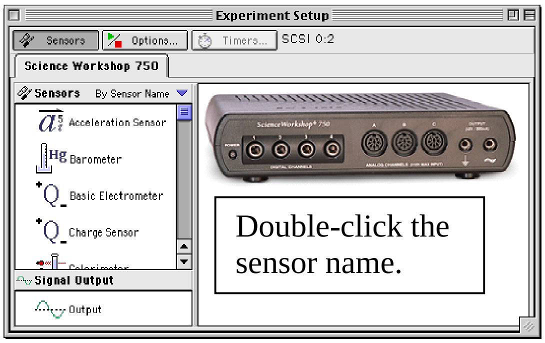
Set up the sensor with the interface

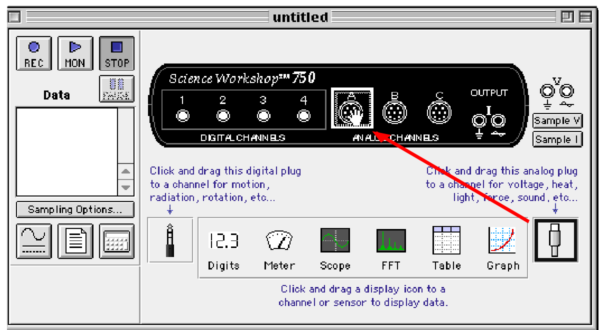
- Plug the sensor directly into **Analog Channel A** on the interface.
- Note: You can use the interface cable to connect the sensor into the interface if needed.
- Connect the cable assembly to the BNC port on the sensor. Line up the connector on the end of the cable with the pin on the BNC port. Push the connector onto the port and then twist the connector clockwise about one-quarter turn until it clicks into place.



Set up the sensor in the software

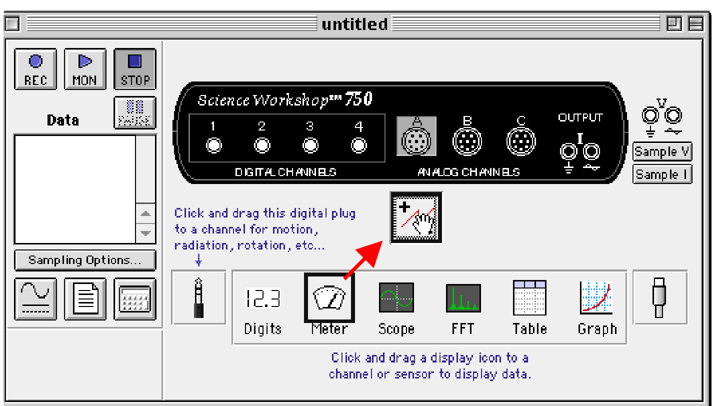
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameters (e.g., Voltage, Charge Intensity) appear in the Data list.
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.



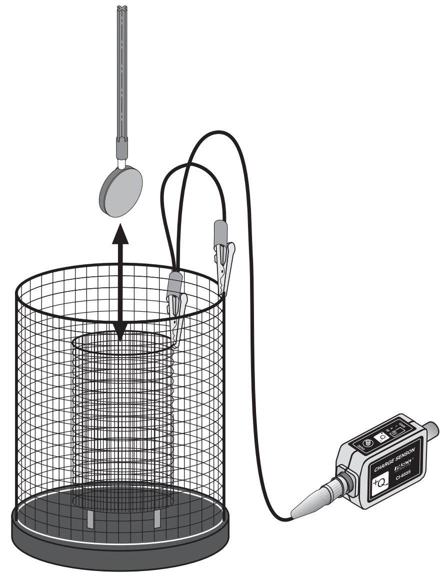


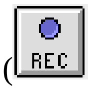
Set up a display

- In *DataStudio*, double-click the 'Meter' icon in the Displays list. **Result**: The display automatically shows voltage.
- In *ScienceWorkshop*, click-and-drag the 'Meter' display icon to the sensor's icon in the Experiment Setup window.



Start recording data



- Connect the alligator clips of the sensor's cable assembly to the inner and outer baskets of the Faraday Ice Pail.
- Press the zero button on the sensor to discharge the input capacitor.
- In *DataStudio*, click the 'Start' button (
). In *ScienceWorkshop*, click the 'REC' button (
).
- Briskly rub the two Charge Producers together. Lower one of the Charge Producers into the inner basket of the Faraday ice pail. Watch the results on the Meter display. Remove the first Charge Producer and lower the other Charge Producer into the inner basket.

Stop recording data.

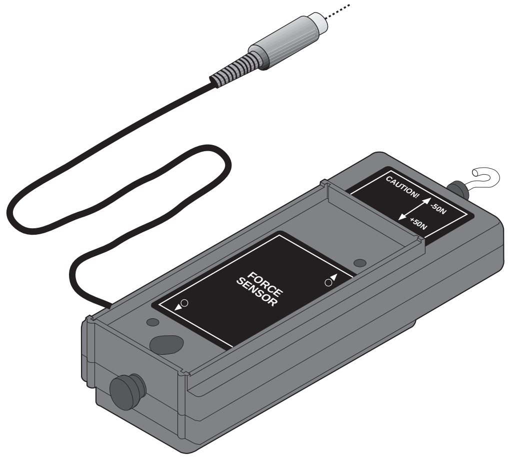
- Click 'Stop' to end data recording.

Tips for using the Charge Sensor

- Plug the Charge Sensor directly into the interface. Avoid using the interface cable if possible.
- Mount the sensor on a threaded rod (such as the SA-9242 Pulley Mounting Rod) to hold the sensor steady.
- Put the sensor and interface box as far away from the equipment as possible.
- Wrap the sensor case in aluminum foil.

Force Sensor

The Force Sensor measures forces between +50 and –50 newtons. The sensor output is +8 volts for a force of +50 newtons and –8 volts for a force of –50 newtons. Pushing on the sensor's detachable hook produces a positive voltage and pulling produces a negative voltage.



The sensor has an attached cable for connecting to the interface. It also has a built-in over-limit protector in the case so the sensor will not be damaged if a force above 50 newtons is applied. The housing has a thumbscrew for mounting the sensor on a rod, and a long thumbscrew for mounting the sensor on a PASCO cart or onto the Accessory Bracket with Bumpers.

The sensor has one built-in control.

Tare Button: Use the tare button to zero the sensor before making measurements.

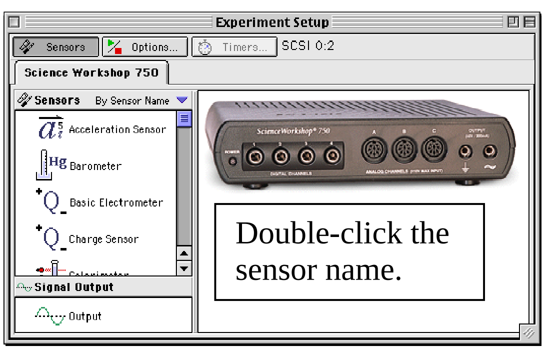
To calibrate the sensor you will need an object of known mass, such as one kilogram.

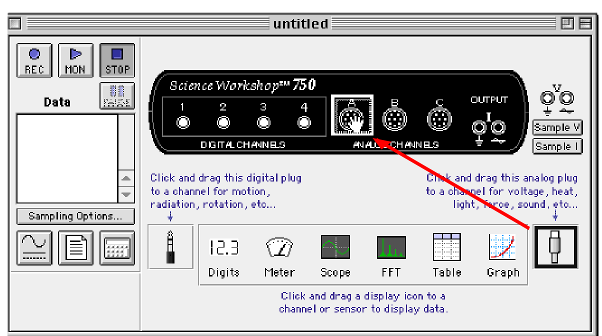
Set up the sensor with the interface

- Plug the sensor cable into **Analog Channel A** on the interface.

Set up the sensor in the software

- In *DataStudio*, double-click the 'Force Sensor" in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameters (e.g., Force) 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 the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.

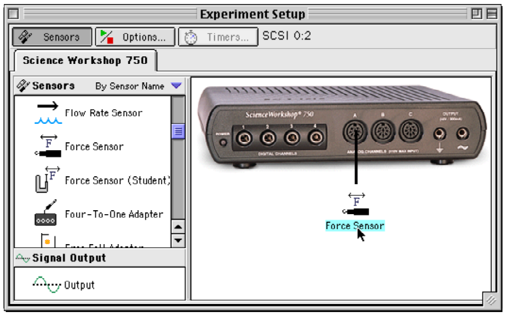


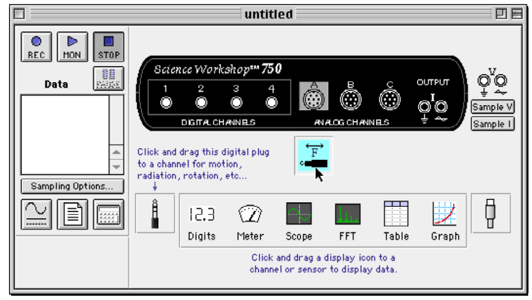


Calibrate the sensor

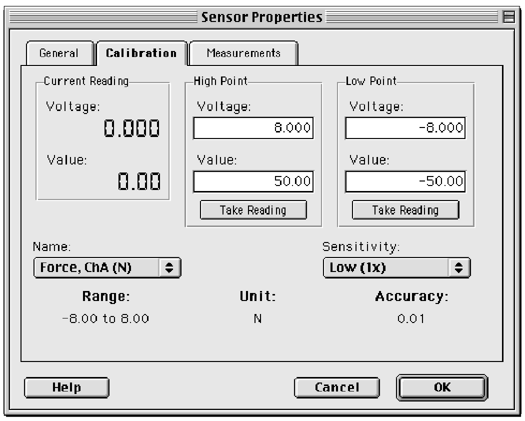
The general method for calibrating the force sensor is as follows:

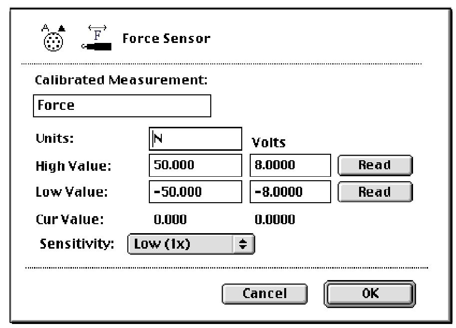
1. In the Experiment Setup window, double-click the sensor's icon.



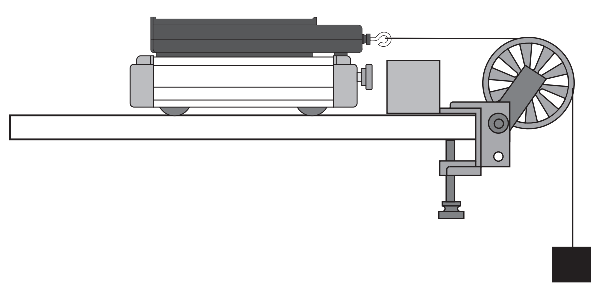


- **Result**: In *DataStudio*, the Sensor Properties window opens. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window opens.





2. Calibrate the software.



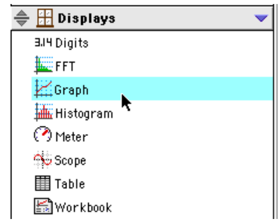
- **First**, arrange the sensor as it will used for making measurements but DO NOT apply a force to the sensor. Press the 'tare' button to zero the sensor.

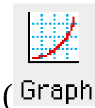
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*. When the voltage stabilizes, click the 'Take Reading' button under 'Low Point' in *DataStudio* or the 'Read' button in the row for 'Low Value:' in *ScienceWorkshop*. Enter '0' as the force value.

- **Third**, use the object of known mass to apply a pulling force on the hook. When the voltage stabilizes, click the 'Take Reading' button under 'High Point' in *DataStudio* or the 'Read' button in the row for 'High Value:' in *ScienceWorkshop*. Enter the force value. For example, enter '9.8' for a one kilogram mass.

3. Click 'OK' to return to the Experiment Setup window.

Set up a display

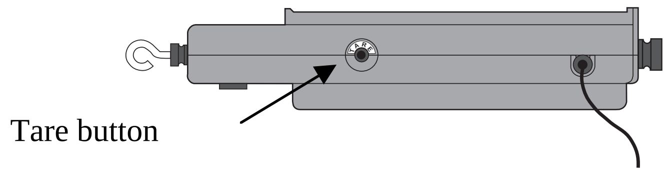


- In *DataStudio*, double-click 'Graph' in the Displays list. **Result**: The display automatically shows force.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon 

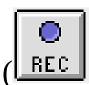
( ) to the sensor's icon in the Experiment Setup window.

Start recording data

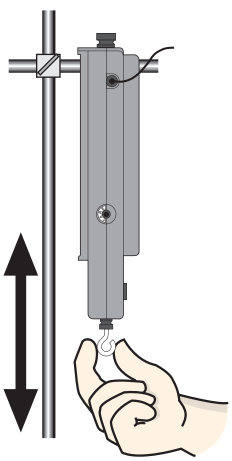
- Press the tare button on the sensor to zero it.

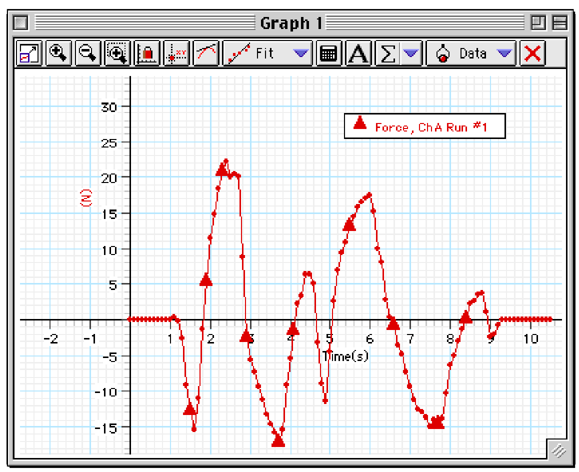


- In *DataStudio*, click the 'Start' button (

). In *ScienceWorkshop*, click the 'REC' button (

).
- Pull and push the hook on the end of the sensor and watch the results on the Graph display.

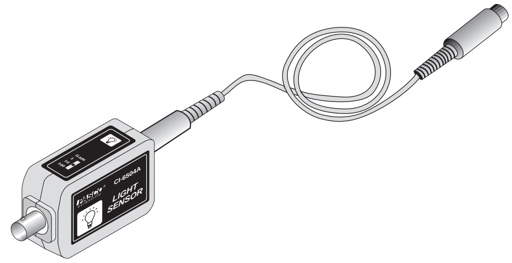




Stop recording data.

- Click 'Stop' to end data recording.

Light Sensor



The Light Sensor measures relative light intensity. The sensing element is a photodiode that produces a voltage proportional to the light intensity across a wide spectrum ranging from 350 nanometers to 100 nanometers (nm).

The sensor includes a cable for connecting to the interface. The sensor has one built-in control.

Gain Select Switch: Use the gain select switch to set the maximum input light levels of the sensor. The three settings are as follows.

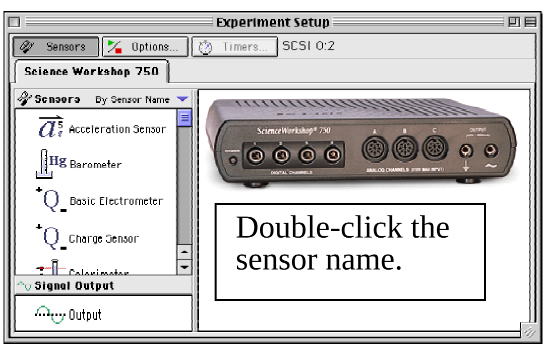
Gain Select setting	Maximum Input (lux)
1	500
10	50
100	5

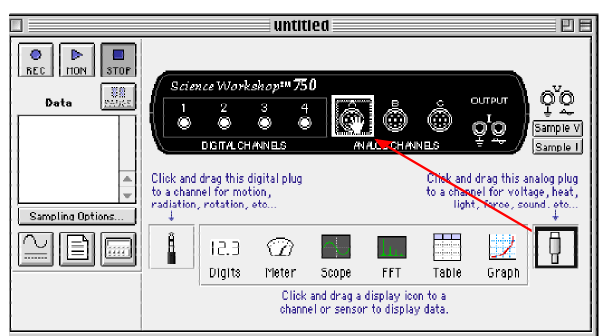
Set up the sensor with the interface

- Plug one end of the DIN-to-DIN cable into the sensor and then connect the other end of the cable into **Analog Channel A** on the interface.
- Note: You can connect the sensor directly into the interface if needed.

Set up the sensor in the software

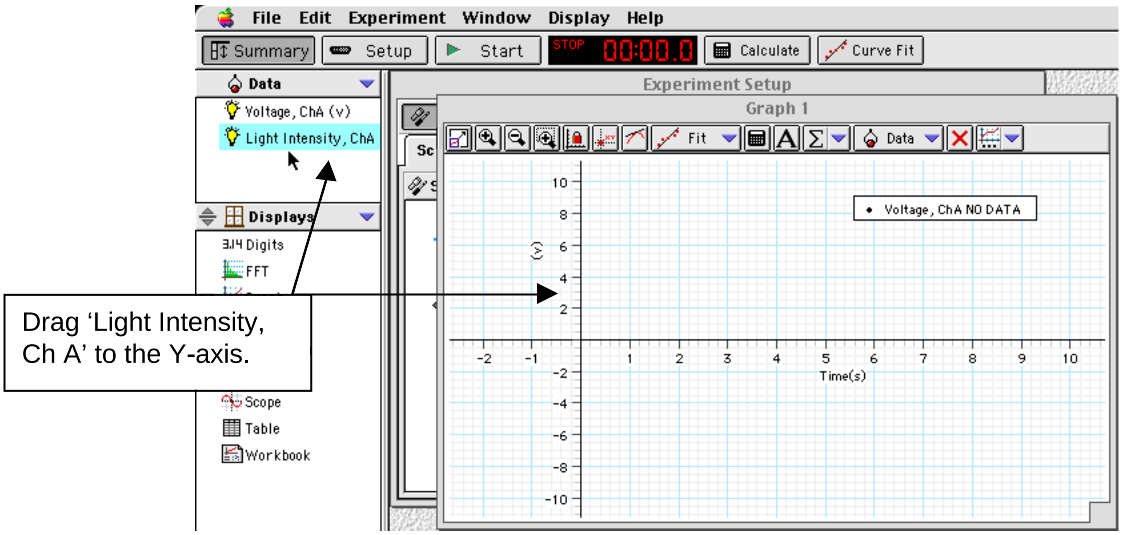
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameters appear in the Data list.
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.





Set up a display

- In *DataStudio*, double-click the 'Graph' icon in the Displays list. **Result**: The display automatically shows voltage versus time. 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.



- In *ScienceWorkshop*, click-and-drag the 'Graph display' icon to the Light Sensor icon in the Experiment Setup window. **Result**: The Graph display shows 'Intensity (% max)' versus Time (s).

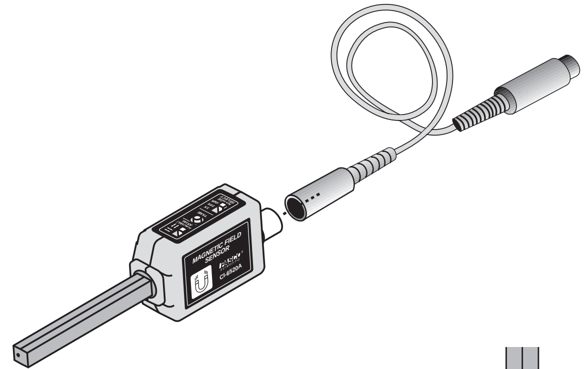
Start recording data

- Set the GAIN switch on the top of the Light Sensor to **1**.
- In *DataStudio*, click the 'Start' button (). In *ScienceWorkshop*, click the 'REC' button ().
- Move your hand over the Light Sensor, point the sensor at different light sources, and watch the results on the Graph display.

Stop recording data.

- Click 'Stop' to end data recording.

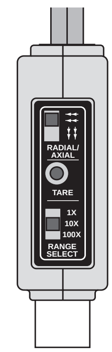
Magnetic Field Sensor



The Magnetic Field Sensor measures magnetic field strength. The sensor has two Hall Effect transducers arranged at right angles to one another in the tip of the probe. One Hall Effect device is sensitive to magnetic field lines that are parallel to the probe (axial field lines). The other is sensitive to magnetic field lines that are perpendicular to the probe (radial field lines).

The sensor includes a cable for connecting to the interface.

The sensor has three built-in controls.



Radial/Axial Select switch: Use this switch to select whether the sensor will measure the field lines that are perpendicular (radial) or that are parallel (axial) to the probe.

Tare Button: Use this button to zero the sensor.

(Note: Use the Zero Gauss Chamber – an optional extra – when you zero the sensor before measuring very weak magnetic fields.)

Range Select switch: Use this switch to select one of the three input ranges for the sensor. The ranges are as follows:

Gain	Range	Resolution	Accuracy
1X	±1000 gauss	0.5 gauss	100 gauss
10X	±100 gauss	0.05 gauss	10 gauss
100X	±10 gauss	0.005 gauss	1 gauss

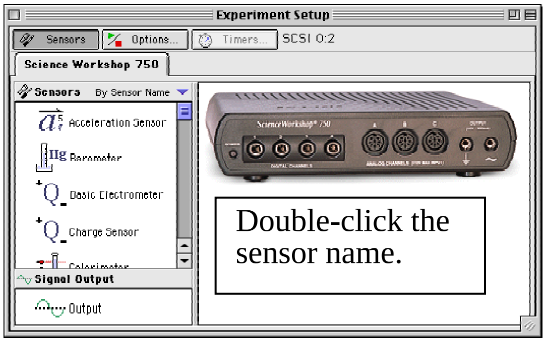
For this activity you will need a bar magnet.

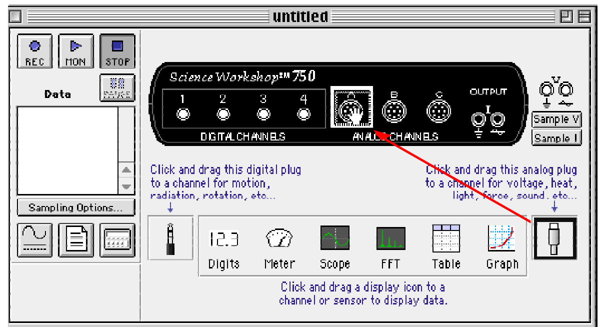
Set up the sensor with the interface

- Plug one end of the DIN-to-DIN cable into the sensor and then connect the other end of the cable into **Analog Channel A** on the interface.
- Note: You can connect the sensor directly into the interface if needed.

Set up the sensor in the software

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameters 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 the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.





Set up a display

- In *DataStudio*, double-click the 'Digits' icon in the Displays list.
- In *ScienceWorkshop*, click-and-drag the 'Digits' display icon to the sensor's icon in the Experiment Setup window.
- **Result**: The display automatically shows magnetic field strength in gauss.

Start recording data

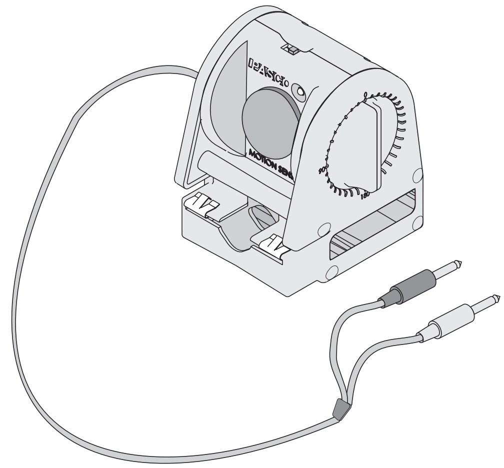
- Zero the sensor. Move the sensor away from any magnet or magnetic field source and push the 'TARE' button on the top of the sensor.
- Set the 'RANGE SELECT' switch to 1X.
- Set the 'RADIAL/AXIAL' switch to 'AXIAL'.
- In *DataStudio*, click the 'Start' button (
). In *ScienceWorkshop*, click the 'REC' button (
).

- Point the sensor's probe toward one end of the bar magnet. Move the sensor towards and away from the magnet. Measure the magnetic field at different positions around the magnet. Watch the results on the Digits display.
- Switch the 'RADIAL/AXIAL' switch to 'RADIAL' and move the sensor to different positions around the magnet.

Stop recording data

- Click 'Stop' to end data recording.

Motion Sensor II



The Motion Sensor II is a sonar ranging device. It sends out ultrasonic pulses and detects echoes of these pulses that are reflected from an object. The sensor includes a cable for connecting to the interface. One end of the cable connects to the sensor. The other end has two stereo phone plugs that connect to the interface. The yellow plug carries the ‘transmit pulse’ signal from the interface. The other plug returns the echo to the interface.

The sensor can measure objects as close as 15 cm (0.15 m) or as far as 8 m. You can use the software to set the number of pulses (the ‘trigger rate’) from as few as five per second to as many as 120 per second.

The sensor has one built-in control.

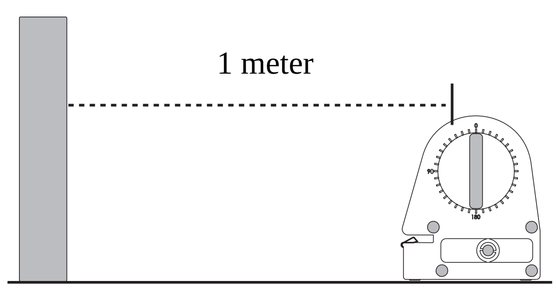
Narrow/Standard (Std.) Switch: Set the switch to *Narrow* for measuring highly reflective targets (such as a PASCO cart) at distances of 2 m or less. Set the switch to *Std* for measuring targets that are poor reflectors or for distances longer than 2 m.

Note: On the Standard setting, you may need to tilt the sensor up by five or ten degrees to avoid reflections from the front of the sensor housing or from a surface underneath the sensor.

For this activity you will need a meter stick and a highly reflective target, such as a book.

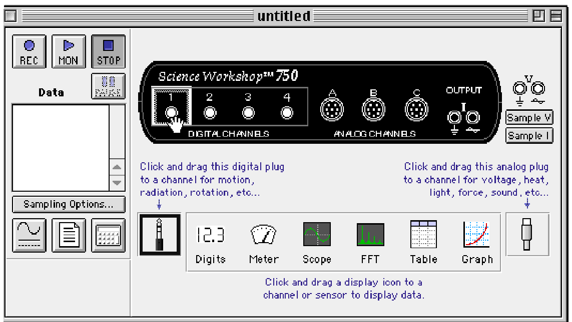
Set up the sensor

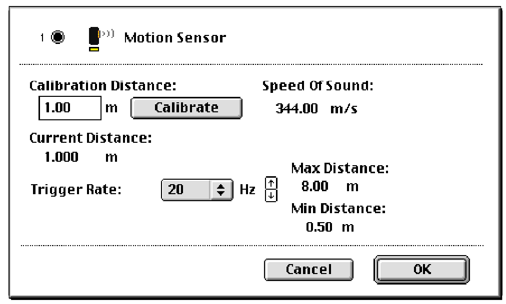
- Plug the modular connector on one end of the interface cable into the side of the Motion Sensor. Connect the yellow phone plug into **Digital Channel 1** on the interface. Connect the other phone plug into **Digital Channel 2**.
- Place the sensor exactly one meter away from a target. Arrange the sensor and target so the pulses from the sensor can reflect from the target and be detected by the sensor.



Set up the sensor in the software

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below the digital channels of the interface. The sensor's parameters (e.g., Position, etc.) appear in the Data list.
- In *ScienceWorkshop*, click-and-drag the 'digital sensor plug' icon to the Channel 1 icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's calibration window opens and the sensor begins to click a few times per second.

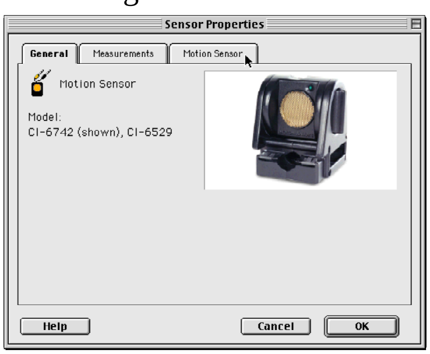


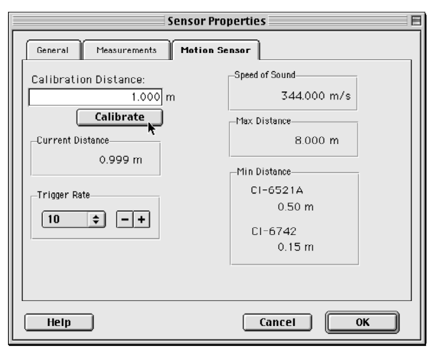


Calibrate the sensor

The general method for calibrating the motion sensor is as follows:

1. In the *DataStudio* Experiment Setup window, double-click the sensor's icon. **Result**: The Sensor Properties window opens.
2. In *DataStudio*, click the 'Motion Sensor' tab. **Result**: The calibration window opens and the sensor begins to click a few times per second.





3. Calibrate the *DataStudio* or *ScienceWorkshop* software.

- **First**, make sure that the sensor is one meter from the target.
- **Second**, click the 'Calibrate' button in the Motion Sensor window. **Result**: The software calculates the speed of sound based on the calibration distance (one meter) and the round trip time of the pulse and echo

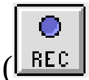
4. Click 'OK' to return to the Experiment Setup window.

Set up a display

- In *DataStudio*, double-click the 'Graph' icon from the Displays list. **Result**: The Graph display shows position versus time.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window. Select 'Position, x (m)' from the list of and click 'Display'. **Result**: The Graph display shows position versus time.

Start recording data

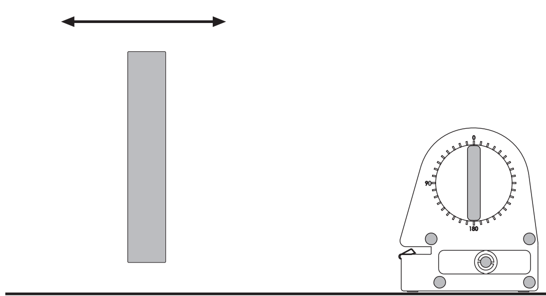
- In *DataStudio*, click the 'Start' button (

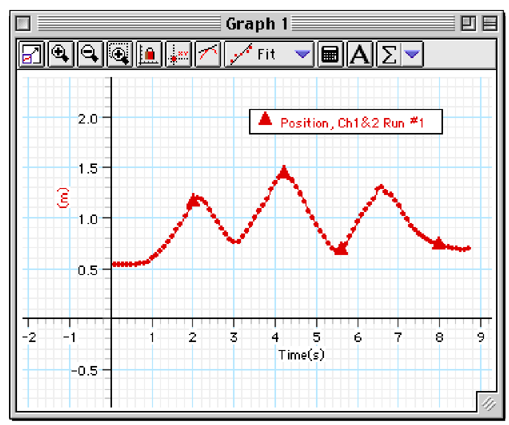
). In *ScienceWorkshop*, click the 'REC' button (

).
- Move a target (such as a book) back-and-forth in front of the sensor. Watch the results on the Graph display.

Stop recording data

- Click 'Stop' to end data recording.

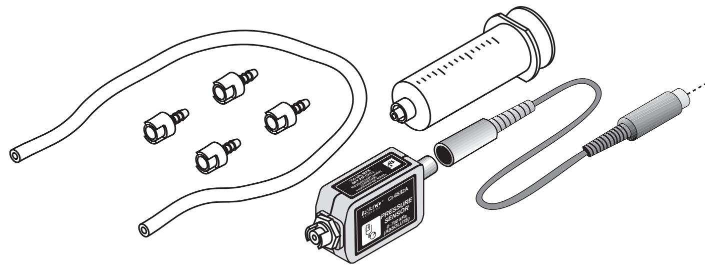




Pressure Sensor

The Pressure Sensor includes a cable, a syringe, tubing, and connectors for the tubing.

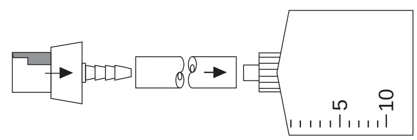
The sensor can measure pressures as high as 700 kilopascals, or about seven atmospheres. It is designed for non-corrosive gases. Do not put liquids into the sensor.



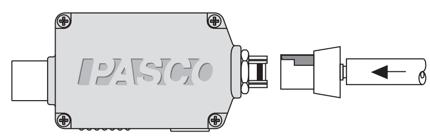
For this activity you will need two drops of glycerin, the syringe, a short piece of tubing, and a quick-release connector.

Set up the sensor

- Plug the DIN connector cable into the sensor's DIN plug and then connect the cable into **Analog Channel A** on the interface.
- Prepare the syringe. Cut a short piece of tubing (about 2 cm). Put a drop of glycerin on the barb end of a quick-release connector. Put the barb end of the connector into one end of the tubing. Put a drop of glycerin on the tip of the syringe. Put the tip of the syringe into the other end of the tubing. Pull out the piston so it is at about the 10 cc mark.

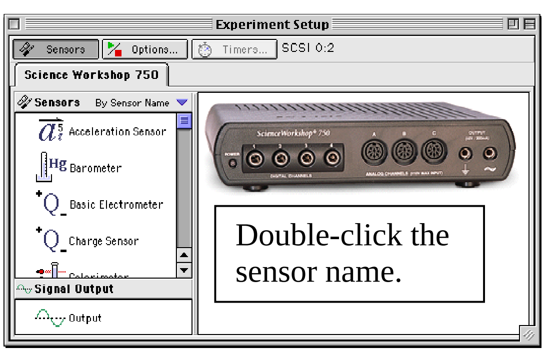


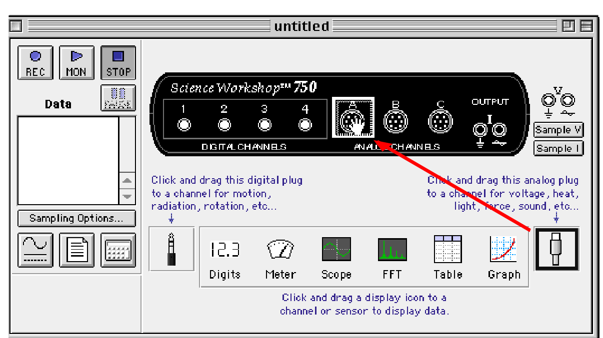
- Connect the syringe to the sensor. Line up the quick-release connector with the pressure port on the sensor. Push the connector onto the port and turn the connector clockwise until it clicks.



Set up the sensor in the software

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result:** The sensor icon appears below Channel A of the interface. The sensor's parameters (e.g., Pressure) 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 the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.

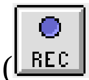


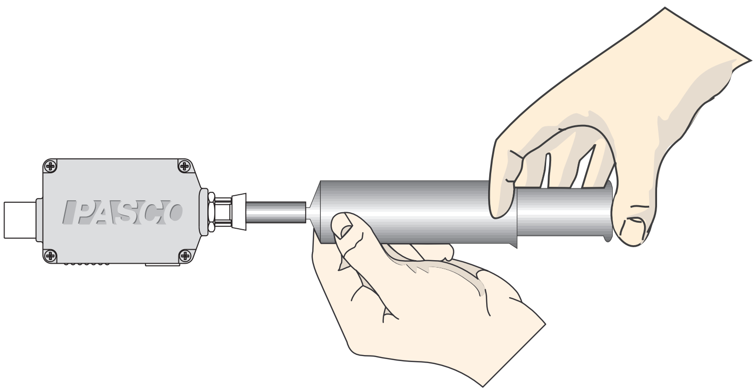


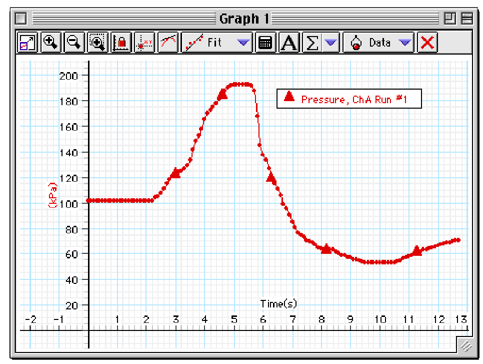
Set up a Graph display of Pressure versus Time

- In *DataStudio*, double click the 'Graph' icon in the Displays list. **Result**: The display automatically shows pressure versus time.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window. **Result**: The display automatically shows pressure versus time.

Start recording data

- In *DataStudio*, click the 'Start' button (
). In *ScienceWorkshop*, click the 'REC' button (
).
- After a few seconds, push the piston in so it is at the 5 cc mark. Then pull the piston out so it is at the 20 cc mark.
- Note the change in pressure in the Graph display.

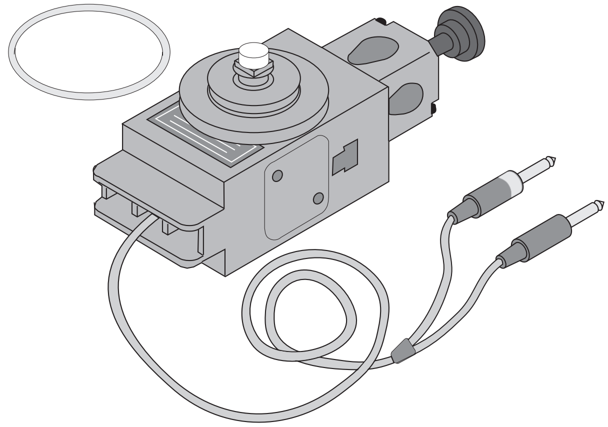




Stop recording data

- Click 'Stop' to end data recording.

Rotary Motion Sensor



The Rotary Motion Sensor measures rotational and linear motion. An optical encoder on the Rotary Motion Sensor's shaft produces up to 1440 pulses (or "counts") per rotation of the shaft. (You can use the software to set the number of counts per rotation at either 360 or 1440.) The optical encoder also produces a signal to tell which way the sensor's shaft is rotating.

The sensor has a detachable three-step pulley and comes with a rubber "O" ring that fits in the groove of the largest step on the pulley. The sensor has an attached cable for connecting to the interface and a rod clamp that can be attached to the sensor at three different places.

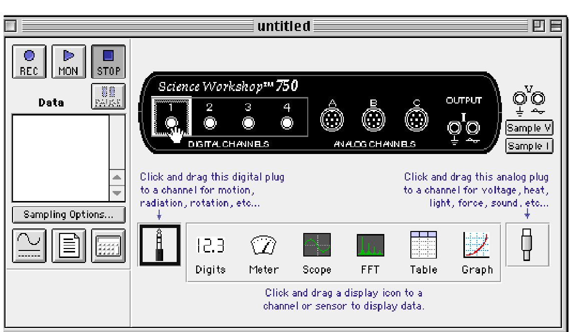
Set up the sensor

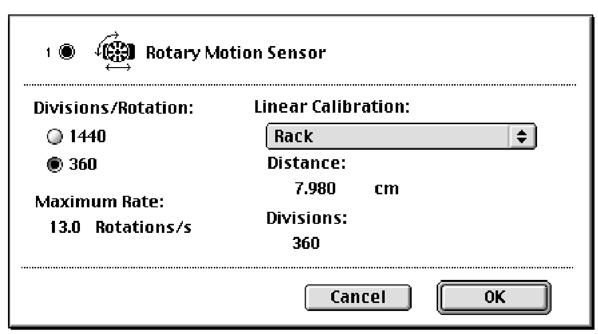
- Connect one of the phone plugs into **Digital Channel 1** on the interface. Connect the other phone plug into **Digital Channel 2**. (NOTE: The order of the plugs is not critical. If rotating the sensor's shaft produces a negative displacement when you want a positive displacement, reverse the order of the plugs.)
- Prepare the three-step pulley. Put the rubber "O" ring onto the largest step on the pulley.

Set up the sensor in the software

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channels 1 and 2 of the interface. The sensor's parameter (e.g., Angular Position) appears in the Data list.
- In *ScienceWorkshop*, click-and-drag the 'digital sensor plug' icon to the Channel 1 icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor setup window opens.

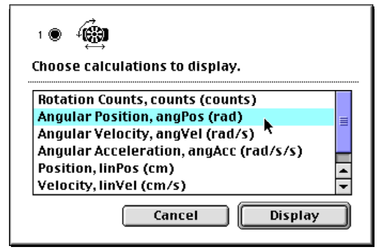
  Click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channels 1 and 2 of the interface.



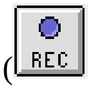


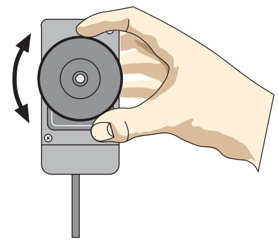
Set up a Graph display of Angular Position versus Time.

- In *DataStudio*, double-click the ‘Graph’ icon in the Displays list. **Result**: The Graph display automatically shows ‘Angular Position’ versus ‘Time’.
- In *ScienceWorkshop*, click-and-drag the ‘Graph’ display icon to the sensor’s icon in the Experiment Setup window. **Result**: A list of calculations opens. Select ‘Angular Position’ from the list and then click ‘Display’. **Result**: The Graph display shows ‘Angular Position’ versus ‘Time’.

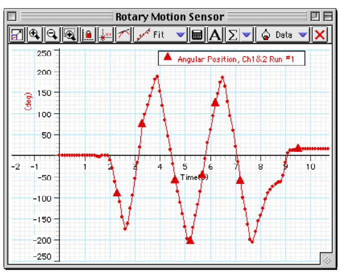


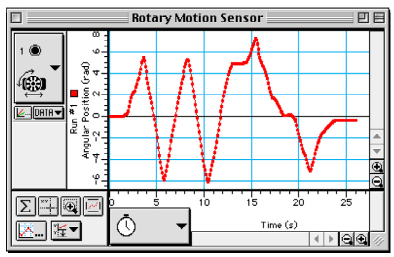
Start recording data

- In *DataStudio*, click the ‘Start’ button (
). In *ScienceWorkshop*, click the ‘REC’ button (
).



- Rotate the pulley back-and-forth several times (or roll the sensor back-and-forth along a flat surface several times.) Watch the results in the Graph.

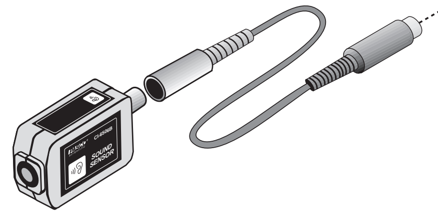




Stop recording data

- Click ‘Stop’ to end data recording.

Sound Sensor



The Sound Sensor measures relative sound intensity. The sensor includes a cable for connecting to the interface.

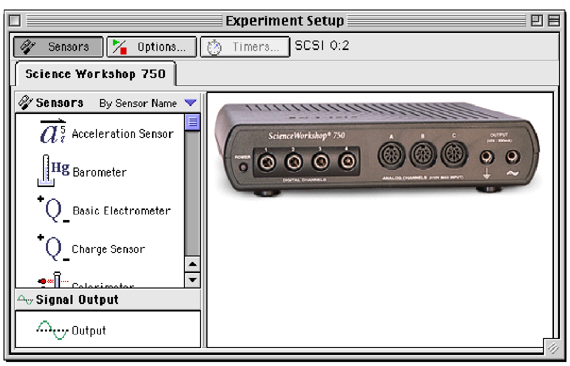
The sensor can detect sound levels ranging from 45 decibels (dB) to over 100 dB over a frequency range from 20 to 16,000 hertz (Hz). The sensor uses an electret condenser microphone. You can use the software to amplify the signal from the sensor. For example, if you select a 'Sensitivity' of Medium (10x) in the Sensor Properties window, the sensor detects sound levels that are barely audible to the human ear. (Note: Double-click the sensor's icon in the Experiment Setup window to open the Sensor Properties window.)

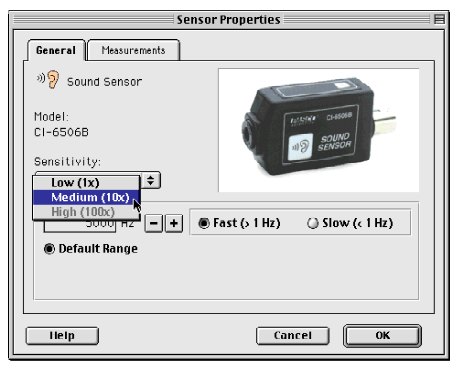
Set up the sensor

- Plug the DIN connector cable into the sensor's DIN plug and then connect the cable into **Analog Channel A** on the interface.
- Note: You can connect the sensor directly into the interface if needed.

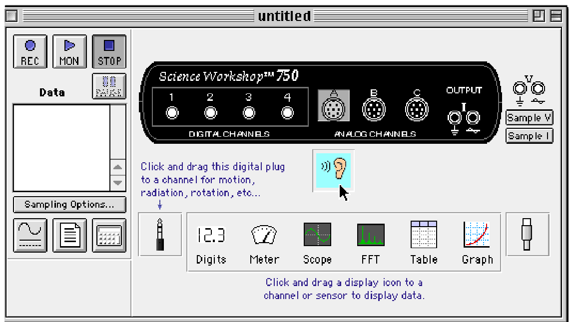
Set up the sensor in the software

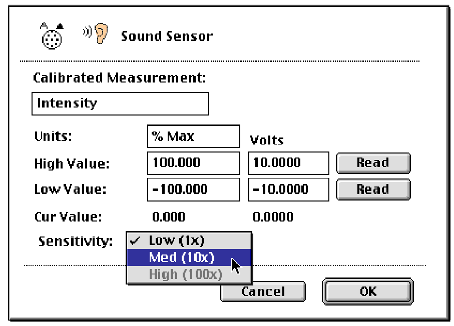
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameter (e.g., Voltage) appears in the Data list.
- Double-click the sensor's icon to open the Sensor Properties window. Select 'Medium (10x)' from the Sensitivity menu. Click 'OK' to return to the Experiment Setup window.





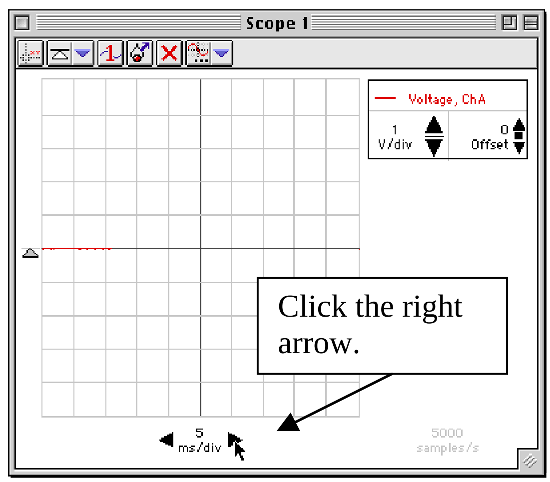
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon will appear below Channel A of the interface.
- Double-click the sensor's icon to open the Sensor Properties window. Select 'Med (10x)' from the Sensitivity menu. Click 'OK' to return to the Experiment Setup window.



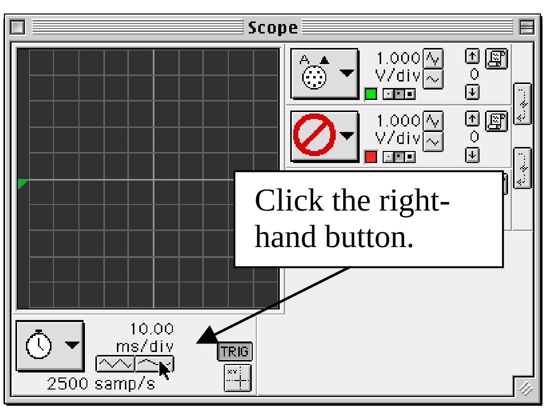


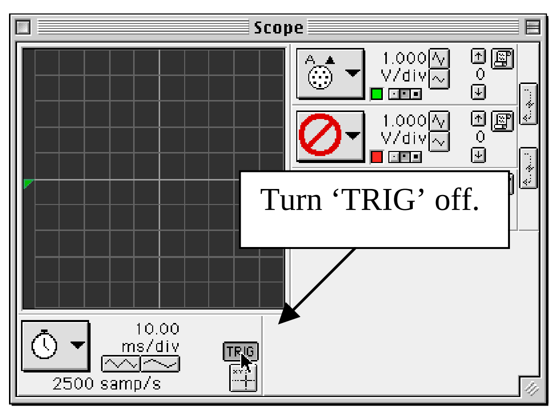
Set up a Scope display

- In *DataStudio*, double-click the 'Scope' icon in the Displays list. **Result**: The 'Scope' display automatically opens showing 'Voltage, ChA' versus time. Click the right arrow under 'ms/div' until the time per division is '1 ms/div' (or one millisecond per division).
- In *ScienceWorkshop*, click-and-drag the 'Scope' display icon to the sensor's icon in the Experiment Setup window. **Result**: The 'Scope' display automatically opens showing 'Voltage, ChA' as the top trace. Click the right-hand button under 'ms/div' until the time per division is '1 ms/div' (or one millisecond per division).

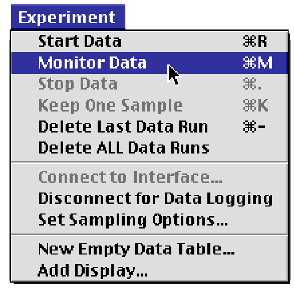


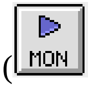
- Click the 'TRIG' button to de-select it (that is, turn off 'Triggering').



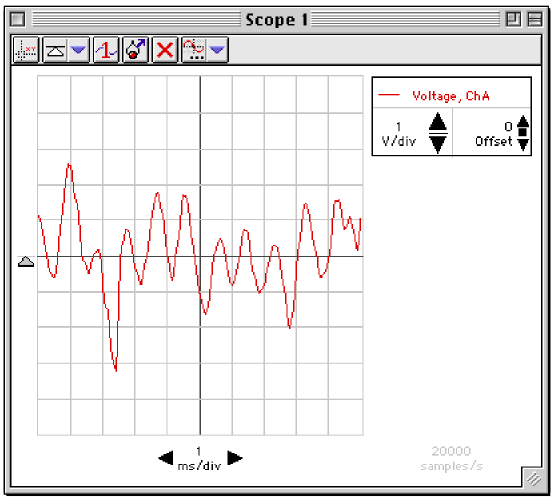


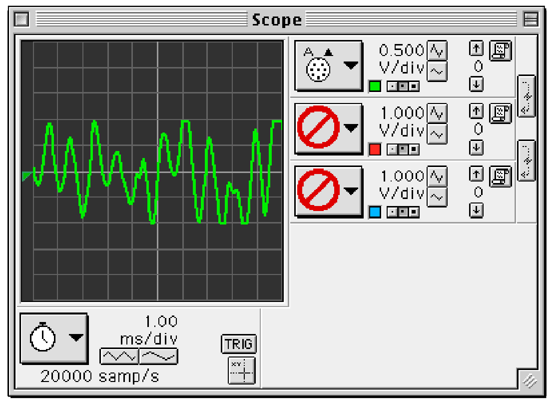
Start monitoring data



- In *DataStudio*, select 'Monitor Data' from the Experiment menu. In *ScienceWorkshop*, click the 'MON' button ().
- Hold the Sound Sensor near your lips and whistle into the end of the sensor. Watch the results on the Scope display.
- Try whistling louder and then softer. Try whistling different notes (high pitch and low pitch).

Stop monitoring data

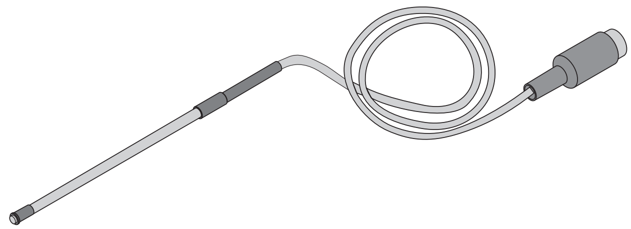




- Click 'Stop' to end data monitoring.

Temperature Sensor

The Temperature Sensor has a temperature sensitive integrated circuit in its tip that produces a voltage that is proportional to temperature. The sensor is covered with Teflon® tubing that is very chemical resistant. The sensor includes a removable Teflon sensor cover that is highly chemical resistant.



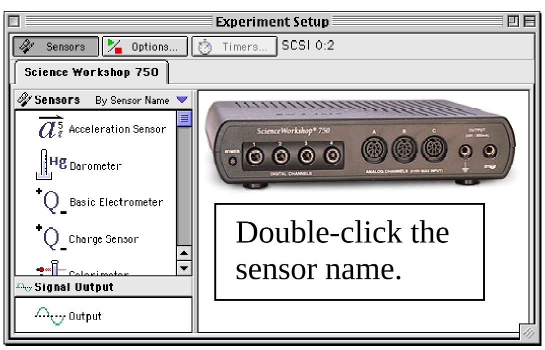
The sensor's operating range is from –5 ˚C to 105 ˚C. Do not use the sensor in a direct flame or on a hot plate.

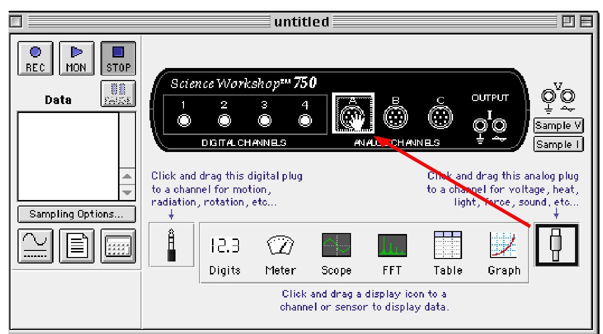
Set up the sensor

- Plug the sensor's DIN plug into **Analog Channel A** on the interface.

Set up the sensor in the software

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface. The sensor's parameter (e.g., Temperature) appears 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 the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.



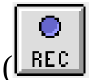


Set up a Graph display of Temperature versus Time

- In *DataStudio*, double-click the 'Graph' icon in the Displays list. **Result**: The Graph display automatically shows 'Temperature' versus 'Time'.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window. **Result**: The Graph display automatically shows 'Temperature' versus 'Time'.

Start recording data

- In *DataStudio*, click the 'Start' button (

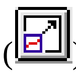
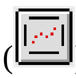
). In *ScienceWorkshop*, click the 'REC' button (

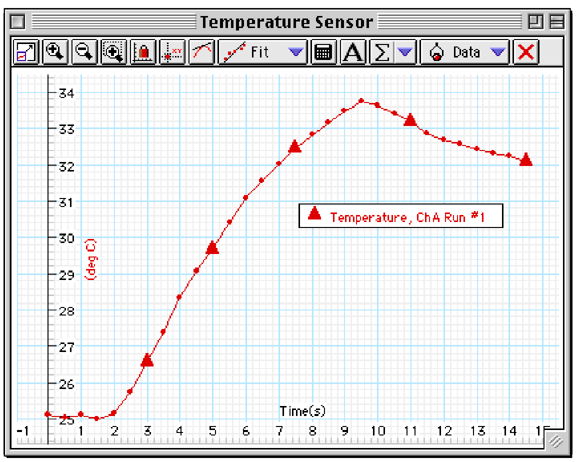
).
- Measure the temperature of your hand. Place the tip of the sensor in the palm of your hand and rub the sensor against your skin for several seconds. Note the temperature in the Graph display. Then move the tip of the sensor from the palm along one of your fingers to the end of the finger. Watch the change in temperature in the Graph display as you move the sensor.

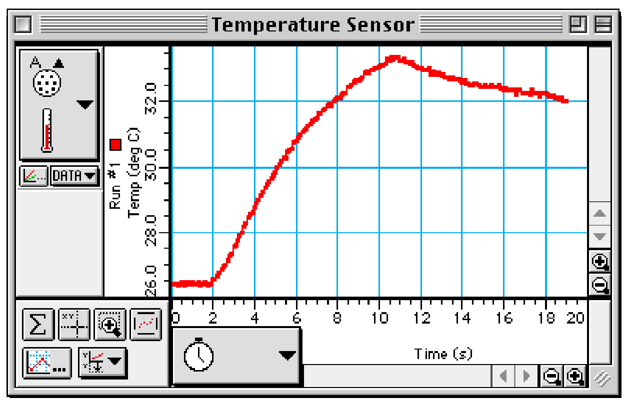
Stop recording data

- Click 'Stop' to end data recording.

Rescale the Graph display

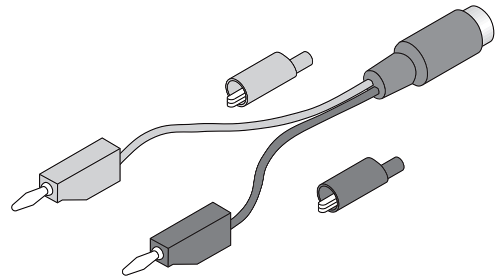
- In *DataStudio*, click the 'Scale-to-Fit' button () in the Graph display toolbar.
- In *ScienceWorkshop*, click the 'Autoscale' button () in the Graph tool palette.





Voltage Sensor

The Voltage Sensor measures voltages from –10 volts to +10 volts. The probe ends are stackable banana plugs. The sensor comes with two insulated alligator clips.



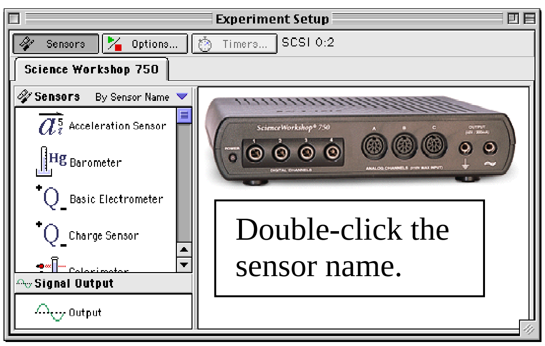
For this activity you need a 1.5 volt battery.

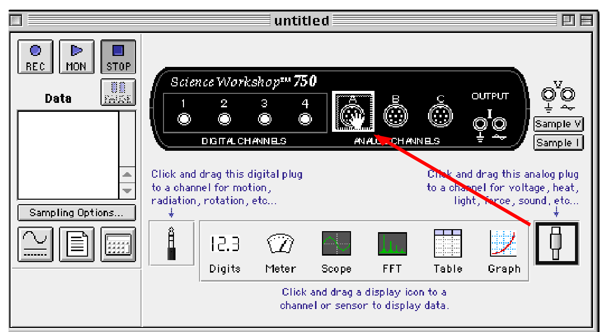
Set up the sensor with the interface

- Connect the Voltage Sensor’s DIN plug into **Analog Channel A** on the interface.

Set up the sensor in the software

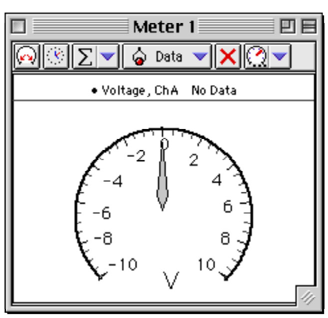
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor’s parameters appear in the Data list.
- In *ScienceWorkshop*, click-and-drag the ‘analog sensor plug’ icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click ‘OK’ to return to the Experiment Setup window. **Result**: The sensor’s icon appears below Channel A of the interface.

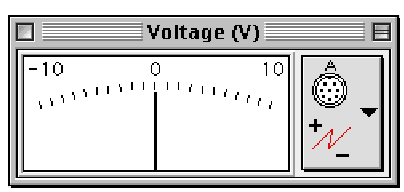




Set up a ‘Meter’ display

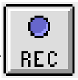
- In *DataStudio*, double-click the ‘Meter’ icon in the Display list. **Result**: The Meter display shows ‘Voltage, ChA’ and ‘Meter 1’ appears in the Display list.
- In *ScienceWorkshop*, click and drag the ‘Meter display’ icon to the Voltage Sensor icon in the Experiment Setup window. **Result**: The Meter display shows ‘Voltage (V)’.





Start recording data

- In *DataStudio*, click the ‘Start’ button (

). In *ScienceWorkshop*, click the ‘REC’ button (

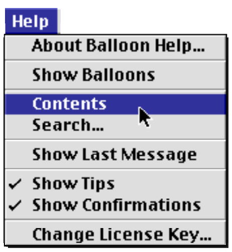
).
- Touch the red Voltage Sensor lead to one end of the battery and the black Voltage Sensor lead to the other end. If the Meter display shows negative volts, reverse the Voltage Sensor leads on the battery.

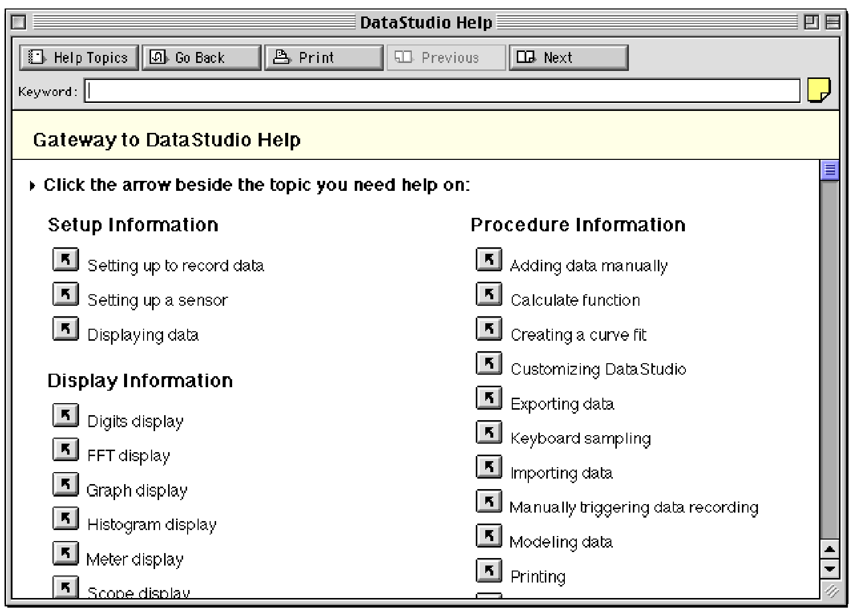
Stop recording data

- After about 90 seconds, stop recording data.
- Click ‘Stop’ to end data recording.

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.





Descriptions – Power Output and Power Amplifier

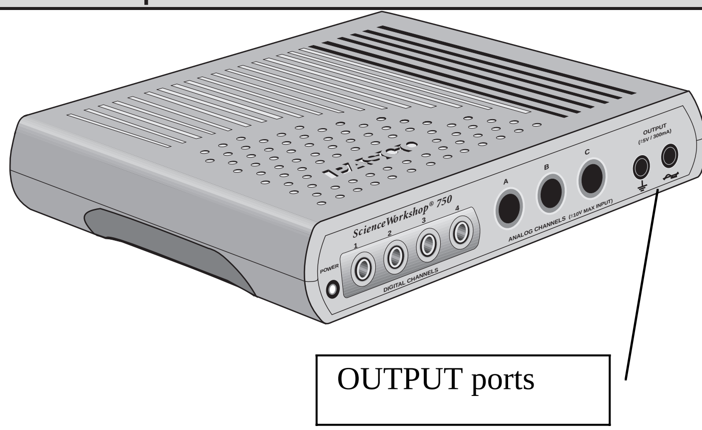
The *ScienceWorkshop* 750 interface has a built-in ‘Power Output’ feature. You can use the*ScienceWorkshop* or *DataStudio* program to control the interface as a 1.5 watt power supply or a function generator. The interface can also be used with the optional ‘Power Amplifier’ (CI-6552) to increase the voltage and current output (±10 volts at up to 1 amp).

You will need two banana plug patch cords and a small light bulb such as the bulb on the PASCO model CI-6512 RLC Circuit Board.

Power Output

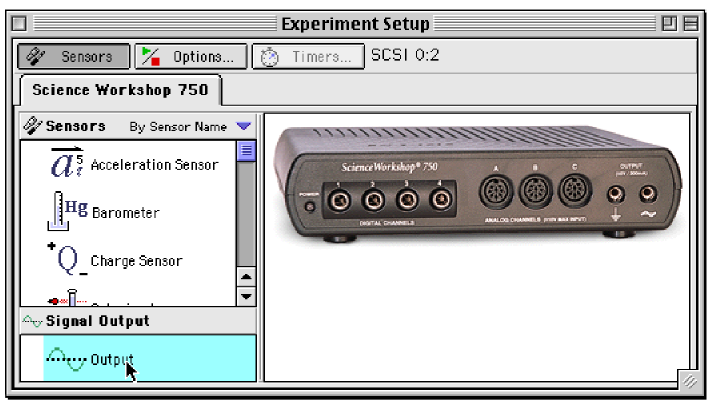
The *ScienceWorkshop* 750 interface can produce ±5 volts at up to 300 millamps (0.3 amps) through its ‘OUTPUT’ ports. As a power supply, the interface can provide up to 1.5 watts.

The *ScienceWorkshop* 750 interface can also act as a function generator to create a variety of AC waveforms. Use the ‘Signal Generator’ window to select the type of output and the frequency and amplitude.

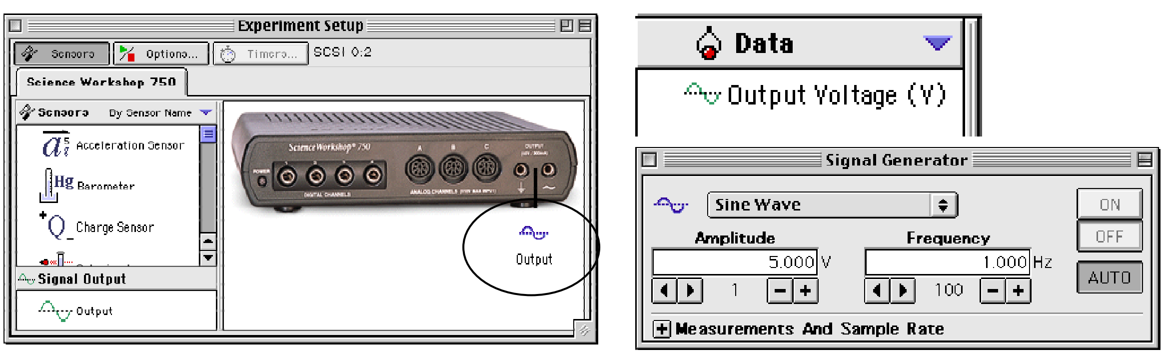


Set Up Power Output (DataStudio)

In *DataStudio*, double-click ‘Output’ under ‘Signal Output’ in the lower left corner of the Setup window.



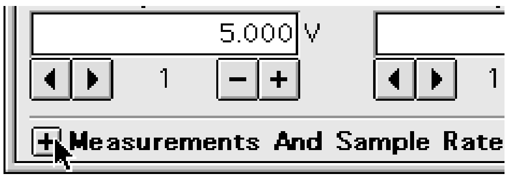
Result: The ‘Output’ icon appears below the OUTPUT ports in the picture of the interface and ‘Output Voltage (V)’ appears in the Data list. The Signal Generator window opens.

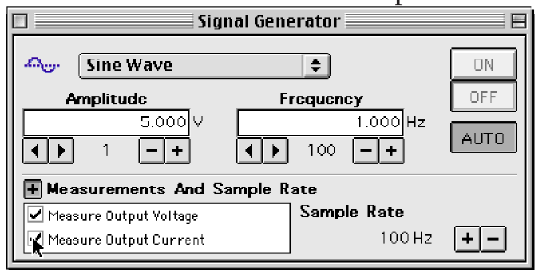


Select Measurements (DataStudio)

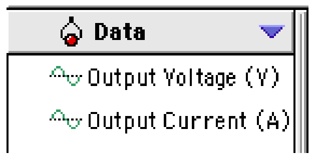
In addition to measuring the ‘Output Voltage’ you can also measure the ‘Output Current’.

In *DataStudio*, click the box in front of ‘Measurements And Sample Rate’ in the lower left corner of the Signal Generator window. Click the checkbox for ‘Measure Output Current.





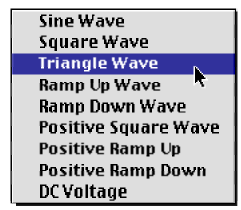
Result: ‘Output Current (A)’ appears in the Data list.



Select Type, Amplitude, and Frequency of Output (DataStudio)

The default output for the Signal Generator is a 5 volt ‘Sine Wave’. The maximum ‘Amplitude’ for ‘Output’ is 5 volts. The Maximum frequency is 50,000 Hz. The smallest increment of frequency change is 0.001 Hz.

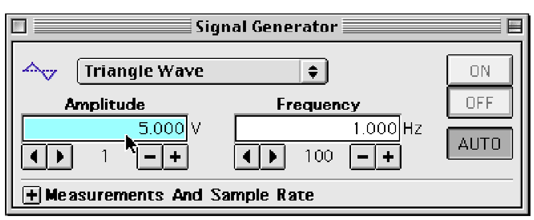
There are eight AC waveforms plus ‘DC Voltage’ on the waveform menu. To select a different waveform or to select ‘DC Voltage’, click the menu and highlight your choice.



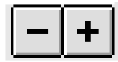
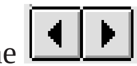
Result: The waveform icon and name appear in the Signal Generator window.

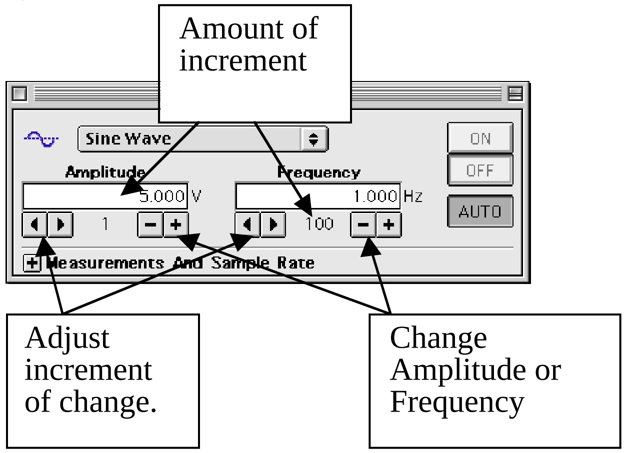
You can change Amplitude or Frequency for AC waveforms two ways:

1. Keyboard Method: Select the value under ‘Amplitude’ or under ‘Frequency’ and type in a new value. Press <enter> or <return> on the keyboard to record the change. (Note: The value you type in does not take effect until you press <enter> or <return> on the keyboard.)



Select Type, Amplitude, and Frequency of Output (continued)

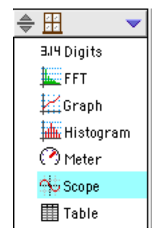
2. Button Method: Use the  buttons under the value of Amplitude or the value of Frequency to decrease or increase the output. Use the  buttons to change the increment of change.



- Use the same methods to change the Amplitude for ‘DC Voltage’.

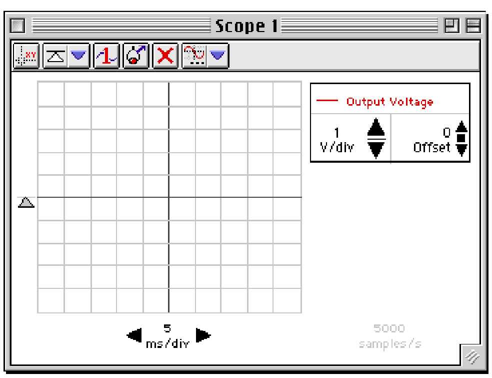
Set Up the Display (DataStudio)

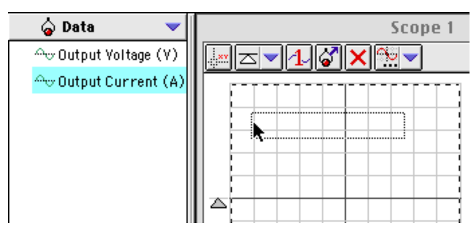
For this activity, set up a Scope display for ‘Output Voltage’ and ‘Output Current’.



- In the ‘Displays’ list, double-click the ‘Scope’ icon.

Result: A Scope display of ‘Output Voltage’ opens.





- Click and drag ‘Output Current’ from the Data list into the ‘Scope’ display.
- Change the sweep speed from 5 ms/div to 200 ms/div. Change the sensitivity for ‘Output Current’ from 1 A/div to 0.1 A/div.

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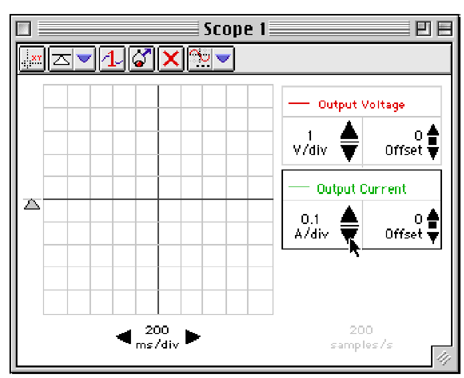
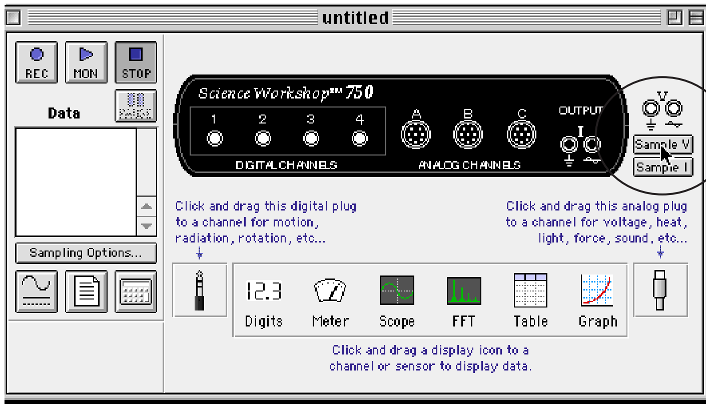


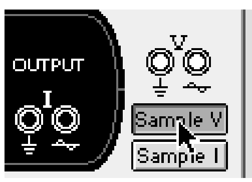
Set Up Power Output (ScienceWorkshop)

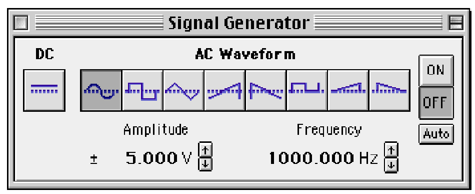
In addition to measuring the ‘Output Voltage’ you can also measure the ‘Output Current’.

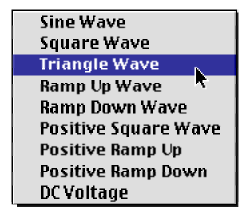
In *ScienceWorkshop*, click the ‘Sample V’ button on the right side of the Setup window.



Result: The ‘Sample V’ button is highlighted and the Signal Generator window opens.

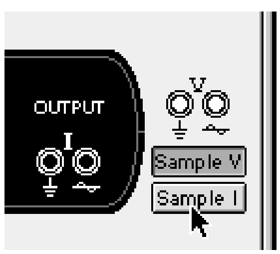


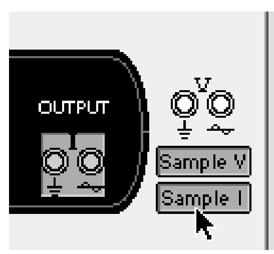




Select Measurements (ScienceWorkshop)

In *ScienceWorkshop*, click ‘Sample I’ in the Setup window (where ‘I’ represents current).





Result: The ‘Sample I’ button is highlighted and the ‘OUTPUT’ icon on the interface is highlighted.

Select Type, Amplitude, and Frequency of Output (ScienceWorkshop)

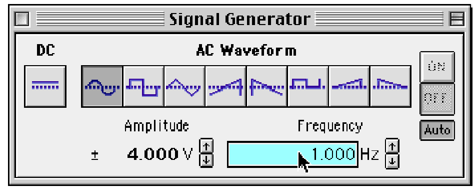
The default output for the Signal Generator is a 5 volt ‘Sine Wave’ at 1 Hz. The maximum ‘Amplitude’ for ‘Output’ is 5 volts. The Maximum frequency is 50,000 Hz. The smallest increment of frequency change is 0.001 Hz.

There is a button for ‘DC’ plus eight buttons for AC waveforms in the Signal Generator window. Click a button to ‘DC voltage’ or a different AC.

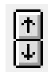
Result: The ‘DC’ or the ‘AC Waveform’ button is highlighted.

Select Type, Amplitude, and Frequency of Output (continued)

You can change Amplitude or Frequency for AC waveforms two ways:



1. Keyboard Method: Select the value under 'Amplitude' or under 'Frequency' and type in a new value. Press <enter> or <return> on the keyboard to record the change. (Note: The value you type in does not take effect until you press <enter> or <return> on the keyboard.)

2. Button Method: Use the  buttons next to the value of Amplitude or the value of Frequency to decrease or increase the output.

- You can press certain 'modifier' keys on the keyboard to change the increment of change as you click one of the 'up-down' arrows.

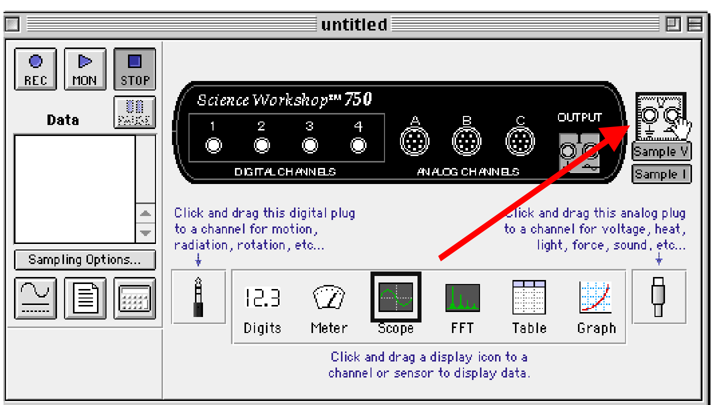
Key (with mouse click)	**Frequency change**	**Key (with mouse click)**
Macintosh®		**Windows™**
Shift key	100 Hz	Shift key
"No" key	10 Hz	"No" key
Control key	1 Hz	Ctrl (control) key
Option key	0.1 Hz	Alt key
Command key	0.01 Hz	Ctrl + Alt keys

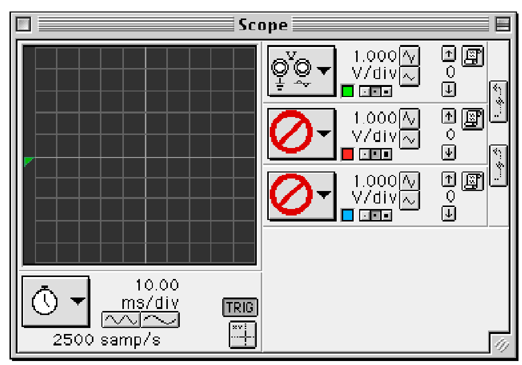
- Use the same methods to change the Amplitude for 'DC Voltage'.

Set Up the Display (ScienceWorkshop)

For this activity, set up a Scope display for 'Output Voltage' and 'Output Current'.

- In the Setup window, click and drag the 'Scope' display icon to the 'Output' icon above the 'Sample V' button.





Result: A Scope display of 'Output Voltage' opens.

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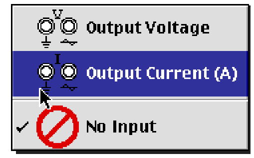
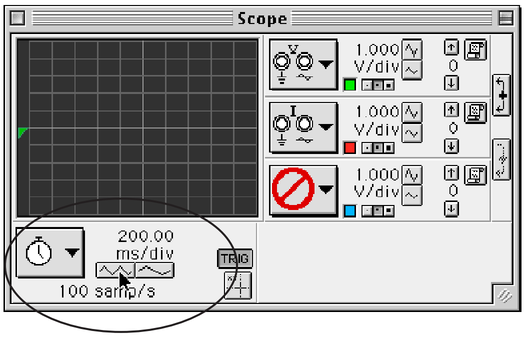
Set Up the Display (continued)

- Click the middle 'Input Menu' and select 'Output Current (A)' from the list.
- Change the sweep speed from 5 ms/div to 200 ms/div.



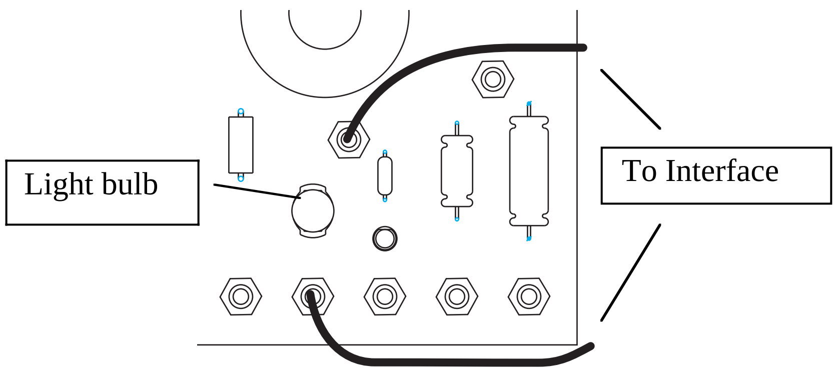


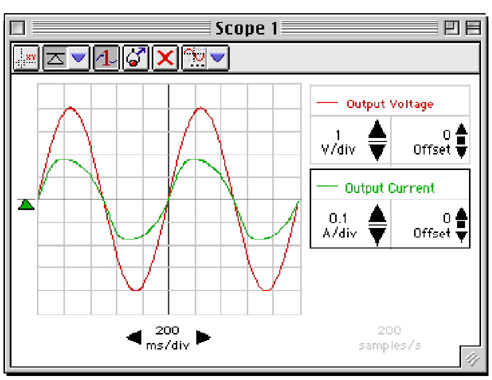
Measure Output Voltage and Output Current – Light Bulb

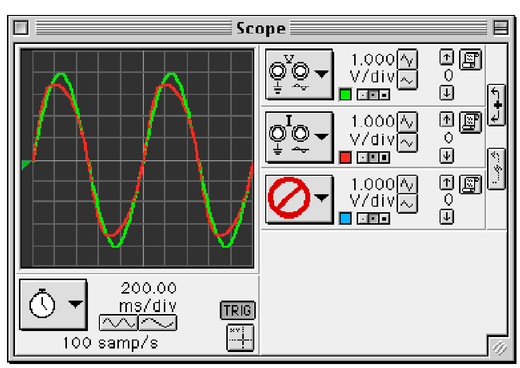
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect two banana plug patch cords into the 'OUTPUT' ports on the interface.
3. Connect the patch cords to the light bulb.
4. Start measuring data. (Click 'Start' in *DataStudio* or 'MON' in *ScienceWorkshop*.)

- Observe the traces of 'Output Voltage' and 'Output Current' in the Scope display.

5. After a few moments, stop measuring data.



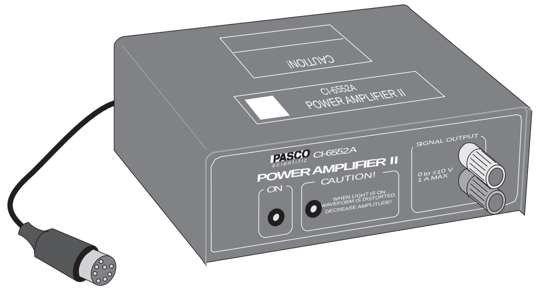




The *ScienceWorkshop* 750 interface can also be used with the optional ‘Power Amplifier’ (CI-6552) to increase the voltage and current output (±10 volts at up to 1 amp).

Power Amplifier

When connected to the *ScienceWorkshop* 750 interface, the Power Amplifier can produce ±10 volts at up to 1 amp through its ‘SIGNAL OUTPUT’ terminals. As a power supply, the Power Amplifier can provide up to 10 watts.



You can also use the Power Amplifier as a function generator. Use the ‘Signal Generator’ window in *DataStudio* or *ScienceWorkshop* to select the type of output and the frequency and amplitude and to control when the Power Amplifier is on or off. You can select one of eight AC waveforms up to a maximum frequency of 50,000 Hz. The minimum frequency increment is 0.001 Hz.

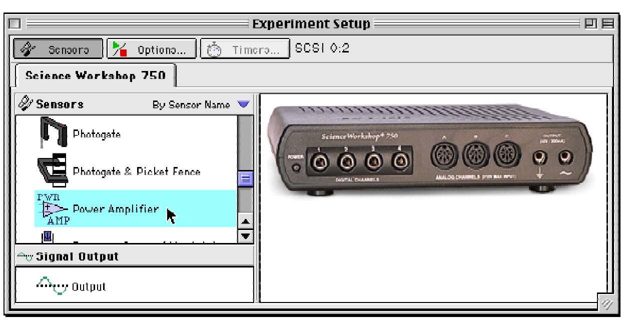
You can connect the Power Amplifier DIN plug into any of the three Analog Channels on the *ScienceWorkshop* interface.

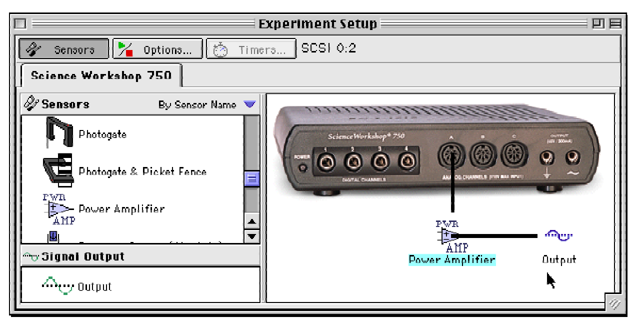
Connect the Power Amplifier

1. Connect the Power Amplifier DIN plug into Analog Channel A on the interface.
2. Connect the power cord into the socket on the back of the Power Amplifier. Plug the power cord into an appropriate electrical receptacle.
3. Connect patch cords into the ‘SIGNAL OUTPUT’ terminals of the Power Amplifier.

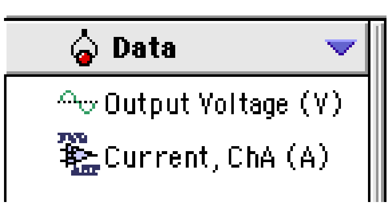
Set Up the Power Amplifier

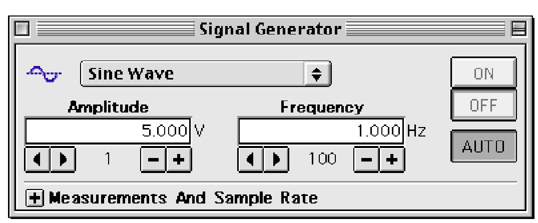
<u>In *DataStudio*</u>, double-click ‘Power Amplifier’ in the Setup window.





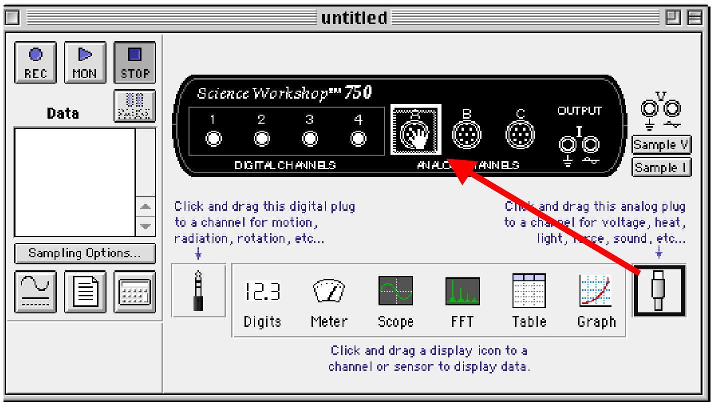
Result: The Setup window shows the icon for ‘Power Amplifier’ AND for ‘Output’. The ‘Signal Generator’ window opens. The Data list shows ‘Output Voltage (V)’ and ‘Current, ChA (A)’.

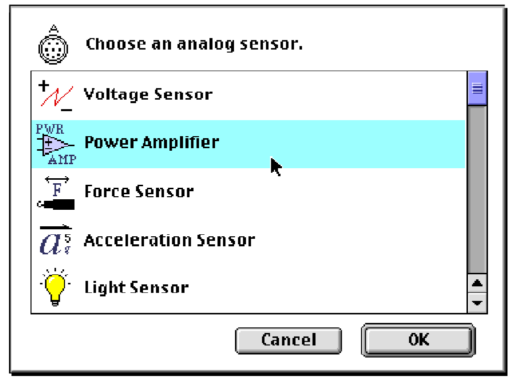




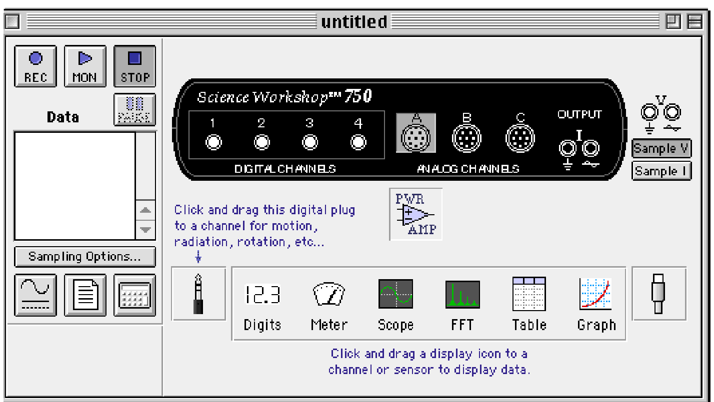
Set Up the Power Amplifier (continued)

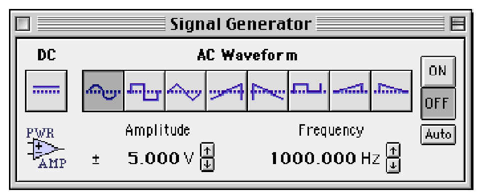
In *ScienceWorkshop*, click and drag the Analog Plug icon to Channel A on the interface in the Experiment Setup window.





Results: The ‘Choose an analog sensor’ window opens. Select ‘Power Amplifier’ and click ‘OK’. **Results**: The Power Amplifier icon appears below Channel A in the Setup window and the Signal Generator window opens.





Note that the Signal Generator window shows the Power Amplifier icon as well.

Using the Power Amplifier

The overall operation of the Power Amplifier is the same as the procedure for ‘Power Output’. For example, you can select the type, amplitude, and frequency of the output waveform in the same way you did for ‘Power Output’. The only difference is that the maximum amplitude is ±10 volts.

Also, selecting a display is the same for the Power Amplifier as it is for ‘Power Output’.

The ‘ON/OFF’ switch for the Power Amplifier is on the back panel. If the Signal Generator window is set to ‘Auto’, the Power Amplifier will automatically start and stop its output signal when you start and stop measuring data. You can also control the Power Amplifier output signal by clicking the ‘ON’ or ‘OFF’ buttons in the Signal Generator window.

Refer to the Power Amplifier instruction sheet for more information.

Name ____________________ Class _____________ Date _________

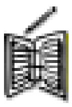
Activity P36: Instantaneous Speed versus Average Speed (Photogates)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P36 Average Speed.DS	P03 Average Speed	P03_AVSP.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Photogate (CI-6838 or ME-9204)	2	Meter stick	1
Dynamics Cart (w/ Track)	1	**Photogate Bracket (003-04662)**	2
Five Pattern Picket Fence (648-04704)	1	**1.2 m Track System (ME-9429A)**	1

What Do You Think?

If you are watching the Indianapolis 500 car race, which value will tell you who is winning: the average or instantaneous speed for each car? Which is more important for a car trying to set a speed record (to see how fast it can go)? Why?



Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

An average speed can be a useful value. It's the ratio of the overall distance an object travels and the amount of time that the object travels. If you know you will average 50 miles per hour on a 200 mile trip, it's easy to predict how long the trip will take. On the other hand, the highway patrol office following you doesn't care about your average speed over 200 miles. The patrol officer wants to know how fast you're driving at the instant the radar strikes your car, so he or she can determine whether or not to give you a ticket. The officer wants to know your *instantaneous* speed.

If you measure average speed of a moving object over smaller and smaller intervals of distance, the value of the average speed approaches the value of the object's instantaneous speed.

SAFETY REMINDERS

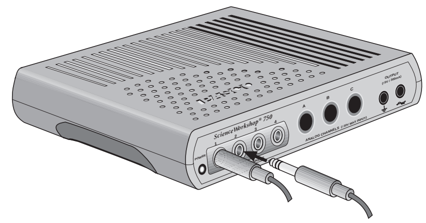
- Follow all directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

Procedure

Use two Photogates to measure the amount of time it takes for an object to move a measured distance. Enter the measured distance into the computer. Use *ScienceWorkshop* or *DataStudio* to calculate the average speed based on the distance you enter, and the time that is measured. Then change the distance over which the object's motion is measured and repeat the process.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect one Photogate's stereo phone plug to Digital Channel 1 on the interface. Connect the second Photogate's stereo phone plug to Digital Channel 2.
3. Open the file titled as shown:

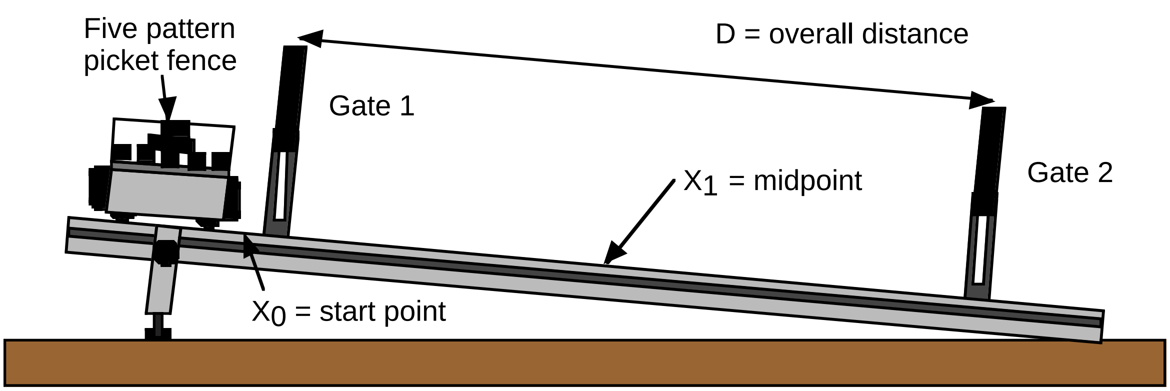
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P36 Average Speed.DS	P03 Average Speed	P03_AVSP.SWS

- The *DataStudio* file has a Graph display of Average Speed vs. Distance and a Workbook display. Read the instructions in the Workbook. Timing is set to 'Time Between Gates'.
- The *ScienceWorkshop* document has a Graph display and a Table display of Average Speed vs. Distance.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogate.

1. Place the Dynamics Track on a table. Raise one end of the track a few centimeters.
2. Mark a point at the center of the track with a pencil, and record the point as "X_1" in the Data Table.
3. Choose another point near the top end of the track as the starting point for the dynamics cart, and mark the point with a pencil as "X_0".
4. Place the Photogate connected to Digital Channel 1 ("Gate 1") at the top end of the track 40 cm away from the X_1 point. Place the Photogate connected to Digital Channel 2 ("Gate 2") at the bottom end of the track 40 cm away from the X_1 point.



5. Place the "five-pattern picket fence" into the accessory tray on the top of the dynamics cart. Place the picket fence so that one of the solid bands will block the Photogate beam as the cart moves down the track.
6. Put the cart on track. Adjust the height of both Photogates so that the photogate beams are blocked when the cart and picket fence move down the track.

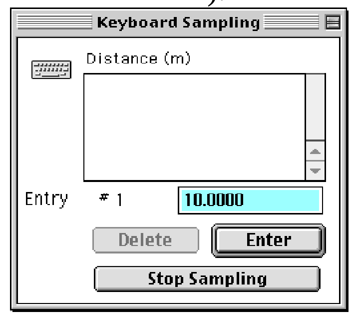
Name ____________________ Class _____________ Date _________

Preparing to Record Data

- Before recording any data for later analysis, you should experiment with the Photogate, cart, and picket fence. Put the cart at the starting point on the track.
- Start recording data. (Hint: In *DataStudio*, click ‘Start’. In *ScienceWorkshop*, click ‘REC’.

  In *DataStudio*, the ‘Start’ button changes to a ‘Keep’ button (

). In *ScienceWorkshop*, the ‘Keyboard Sampling’ window opens.)



- Release the cart so it moves down the track. Timing begins when the Photogate beam is first blocked.
- After the cart moves through the second Photogate, enter the distance between the Photogates as your first Distance value. (Hint: In *DataStudio*, click ‘Keep’. In the *ScienceWorkshop* ‘Keyboard Sampling’ window, type ‘0.80’ and click ‘Enter’.)
- Stop recording. The data will appear as ‘Run #1’.
- Erase your trial run of data. Select ‘Run #1’and press the ‘Delete’ key.

PART III: Data Recording

1. Make sure that the overall distance “D” between the centers of the two Photogates is the first value shown in the Distance Table.

Trial	Distance “D” (m)
1	0.80
2	0.70
3	0.60
4	0.50
5	0.40
6	0.30
7	0.20
8	0.10

2. Place the cart at the starting point on the track.
3. Start recording data. (In *DataStudio*, click ‘Start’. In *ScienceWorkshop*, click ‘REC’.)
4. Release the cart so it moves down the track. Timing begins when the Photogate beam is first blocked.
5. After the cart moves through the second Photogate, enter the distance between the Photogates as your first Distance value.

- In *DataStudio*, click ‘Keep’ to enter the first value for distance. (The file includes the default values for distance shown above.)
- In the *ScienceWorkshop* ‘Keyboard Sampling’ window, type ‘0.80’ and click ‘Enter’. The entered value will appear in the window.

‘Average Speed’ is automatically calculated based on the ‘Distance’ value and the ‘Time Between Gates’.

6. Move the two Photogates closer to the midpoint X1 by 5 cm for each Photogate. (For the second trial, the overall distance between the Photogates is 0.70 m.)

- Make sure that each Photogate is the same distance from the midpoint X_1!

7. Repeat the data recording process. Place the cart at the starting point at the top of the track. Release the cart. Enter the Distance value.

- In *DataStudio*, click 'Keep' to enter the next default value for distance. In *ScienceWorkshop*, enter '0.70' in the Keyboard Sampling window and click 'Enter'.

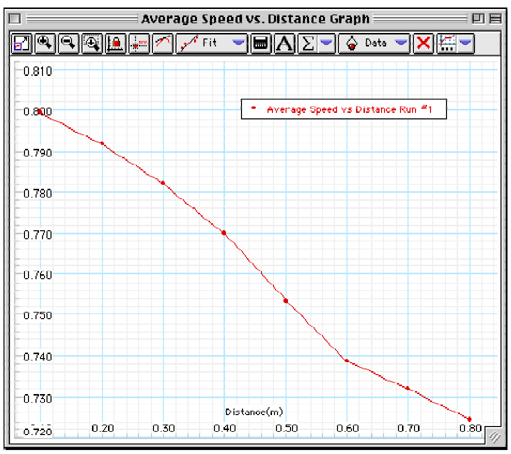
8. For each new trial, continue to decrease the distance between Photogates by 10 cm (or 5 cm for each Photogate.) Make sure the Photogates are equidistant from the midpoint X1. Record data as described above. (Stop when the Photogates are 10 centimeters apart.)

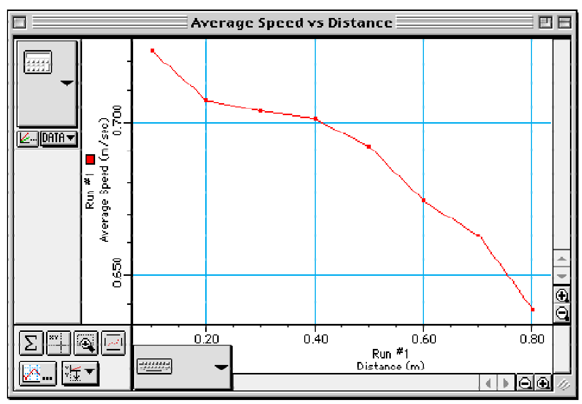
9. End data recording. (In *DataStudio*, click the 'Stop' button (
). In *ScienceWorkshop*, click 'Stop Sampling' in the Keyboard Sampling window.)

- The data will appear as 'Run #1'.

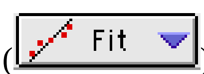
Analyzing the Data

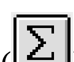
1. Rescale your Average Speed vs. Distance plot so the data fills the window.





2. Find the slope and 'Y Intercept' of the best-fit line through your data.

- In *DataStudio*, click 'Fit' (
) in the Graph toolbar and select 'Linear'. The 'Y Intercept' appears in the 'Linear Fit' window.

- In *ScienceWorkshop*, click 'Statistics' () to open the statistics area. In the statistics area, click the 'Statistics Menu' button () and select 'Curve Fit, Linear Fit'. The coefficient 'a1' in the statistics area is the 'Y Intercept'.

Use your results to answer the questions in the Lab Report section.

Name ____________________ Class _____________ Date _________

Lab Report - Activity P36: Instantaneous Speed and Average Speed

What Do You Think?

If you are watching the Indianapolis 500 car race, which value will tell you who is winning: the average or instantaneous speed for each car? Which is more important for a car trying to set a speed record (to see how fast it can go)? Why?

Data Table

Y Intercept	m/s

Questions

1. What is the relationship between the 'Y Intercept' on the Graph and the instantaneous speed of the cart as it moved through the midpoint X_1?

2. Which of the average speeds that you measured do you think gives the closest approximation to the instantaneous speed of the cart as it moved through the midpoint X_1?

3. What factors (accuracy of timing, object being timed, release of object, type of motion) influence the results? Discuss how each factor influences the result.

4. Are there ways to measure instantaneous speed directly, or is instantaneous speed always a value that must be derived from average speed measurements?

Name ____________________ Class _____________ Date _________

Activity P37: Time of Flight versus Initial Speed (Photogate)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Projectile motion	P37 Time of Flight.DS	P08 Time of Flight	P08_TOF.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Photogate (CI-6838 or ME-9204)	2	**Photogate Mounting Bracket (ME-6821)**	1
C-clamp	1	**Projectile Launcher (ME-6800)**	1
Extension Cable (PI-8117)	1	**Time-of-Flight Accessory (ME-6810)**	1

What Do You Think?

Can you predict how long a ball will stay in the air? Does a change in its initial speed change the "time of flight"? If so, how?

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

Background

The vertical motion of a freely falling ball launched horizontally off a table of height **d** is independent of any horizontal motion the ball may have. Thus the time for a ball to fall to the ground is independent of its horizontal speed. The distance **d** a ball falls from rest as a function of the time of fall **t** is given by:

$$d = \frac{1}{2}gt^2$$

where **g** is the acceleration due to gravity in free fall.

Thus the time for a ball to fall straight down a distance **d** from rest to the ground is given by:

$$t = \sqrt{2\frac{d}{g}}$$

<u>If</u> a ball launched horizontally with a non-zero initial speed takes the same amount of time to reach the ground as a ball that drops from rest from the same height, this equation also gives the time of flight for any ball launched horizontally regardless of the initial speed of the ball.

SAFETY REMINDERS

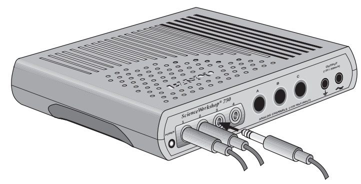
- Follow all directions for using the equipment.

Procedure

Use two Photogates measure the initial speed of a ball that is fired from a Projectile Launcher. Use the Time-of-Flight pad to measure the time of flight for the ball. Use *ScienceWorkshop* or *DataStudio* to record and display the time-of-flight and the initial speed.

Compare the time-of-flight for different values of initial speed when the launcher is aimed horizontally to the time-of-flight for different values of initial speed when the launcher is aimed at an angle above horizontal.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the stereo phone plug of one Photogate into Digital Channel 1 on the interface. Connect the stereo phone plug of the second Photogate into Digital Channel 2 on the interface. Connect the Extension Cable's stereo phone plug into Digital Channel 3 on the interface.
3. Open the file titled as shown:

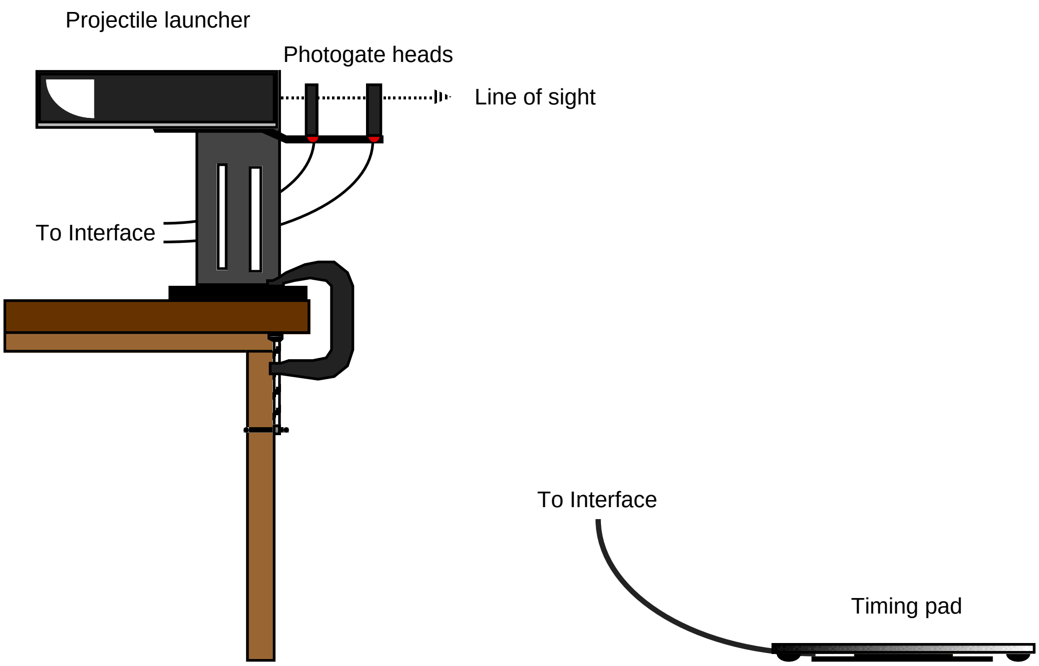
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P37 Time of Flight.DS	P08 Time of Flight	P08_TOF.SWS

- The *DataStudio* file has a Table display of 'Time of Flight' vs. 'Initial Speed' and a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Table display of "tFlight (s)", or Time of Flight, and "vInitial (m/s)", or Initial Velocity.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogates or the Time-of-Flight pad

1. Clamp the base of the projectile launcher to the edge of a sturdy table. Aim the launcher away from the table toward the center of an open area at least 3 meters away.
2. Adjust the angle of the launcher to zero degrees so the plastic ball will be launched horizontally.
3. Slide the photogate mounting bracket into the T-slot on the bottom side of the projectile launcher. Mount the Photogate that is connected to Digital Channel 1 on the bracket in the position closest to the end of the launcher. Mount the Photogate that is connected to Digital Channel 2 on the bracket in the position farthest from the end of the launcher.
4. Connect the Time-of-Flight pad's stereo phone plug into the end of the extension cable.



Name ____________________ Class ______________ Date _________

PART IIIA: Data Recording – Horizontal Launch Angle

1. Put the plastic ball into the projectile launcher. Cock the launcher to the short-range position.
2. Test fire the ball to determine where to place the timing pad on the floor. Put the timing pad on the floor where the ball hits.
3. Reload the ball into the projectile launcher, and cock the launcher to the short range position.
4. Start recording data. (In *DataStudio*, click 'Start'. In *ScienceWorkshop*, click 'REC'.)
5. Shoot the ball on the short-range position. After the ball hits the Time-of-Flight pad, do the following:

- <u>In *DataStudio*</u>, click 'Stop'. **Result**: Run #1 appears in the Summary list.
- <u>In *ScienceWorkshop*</u>, click 'PAUSE' to momentarily pause data recording. **Result**: The PAUSE button allows you to reload the launcher without accidentally recording data when the Photogates are blocked during reloading.

6. Reload the ball into the launcher, but cock the launcher to the middle range position. Test-fire the ball to determine the new location to put the Time-of-Flight pad. Move the pad.
7. Reload the ball into the launcher and put the launcher in the middle range position.
8. When you are ready, resume recording data.
9. Shoot the ball with the launcher in the middle range position. After the ball hits the Time-of-Flight pad, click 'Stop' (in *DataStudio*) or click 'PAUSE' (in *ScienceWorkshop*).
10. Reload the ball into the launcher, but cock the launcher to the long-range position. Test-fire the ball to determine the new location to put the Time-of-Flight pad. Move the pad.
11. Repeat the data recording process as you did for the short and middle ranges.
12. After completing the data recording for the long-range position, end data recording.

- In *DataStudio*, the Summary list shows three runs of data.
- In *ScienceWorkshop*, the Data list shows 'Run #1'.

PART IIIB: Data Recording – Non-horizontal Launch Angle

1. Adjust the angle of the projectile launcher to 30 degrees above horizontal.
2. Test-fire the ball on the short-range position. Move the timing pad.
3. When you are ready, begin data recording. Shoot the ball on the short-range position at 30 degrees above horizontal.
4. After the ball hits the timing pad, click 'Stop' in *DataStudio* or click 'PAUSE' in *ScienceWorkshop*.
5. Repeat the process for the middle range position.
6. Repeat the process for the long-range position.
7. End data recording.

- In *DataStudio*, the Summary list shows six runs of data.
- In *ScienceWorkshop*, the Data list shows 'Run #1' and 'Run #2'.

Analyzing the Data – *DataStudio*

1. Use the 'Data' menu in the Table display toolbar to select 'Run #1' for the 'Initial Speed' and for the 'Time-of-Flight'. Record the values for speed and time-of-flight for the first projectile launcher range in the Launch Angle Horizontal Data Table in the Lab Report section.
2. Repeat the process to select 'Run #2' and then 'Run #3'. Record the values.
3. Use the 'Data' menu in the Table display toolbar to select 'Run #4' for the 'Initial Speed' and for the 'Time-of-Flight'. Record the values for speed and time-of-flight for the first projectile launcher range in the Launch Angle 30° above Horizontal Data Table in the Lab Report section.
4. Repeat the process to select 'Run #5' and 'Run #6'. Record the values.

Analyzing the Data - *ScienceWorkshop*

1. Open the Table display for 'Run #1' and record the initial speeds and time-of-flight values for each of the projectile launcher ranges in the Launch Angle Horizontal Data Table in the Lab Report section.
2. Open the Table display for 'Run #2' and record the initial speeds and time-of-flight values for each of the projectile launcher ranges in the Launch Angle 30° above Horizontal Data Table in the Lab Report section.

Use your results to answer the questions in the Lab Report section.

Name ____________________ Class ______________ Date _________

Activity P37: Time of Flight versus Initial Speed

What Do You Think?

Can you predict how long a ball will stay in the air? Does a change in its initial speed change the "time of flight"? If so, how?

Data Table

Launch Angle Horizontal

Range	Initial Speed (m/sec)	Time of Flight (sec)
Short		
Middle		
Long		

Launch Angle 30° above Horizontal

Range	Initial Speed (m/sec)	Time of Flight (sec)
Short		
Middle		
Long		

Questions

1. How do the values for the time of flight for the short, middle, and long range distances compare when the ball was launched horizontally?

2. How do the values for the time of flight for the short, middle, and long range distances compare when the ball was launched at 30 degrees above the horizon?

3. Why would time of flight depend on the angle of the launch?

Name ____________________ Class _____________ Date _________

Activity P38: Conservation of Linear Momentum (Motion Sensors)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P38 Linear Momentum.DS	P16 Cons. of Momentum 1	P16_CON1.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Motion Sensor (CI-6742)	2	**Dynamics Cart (w/ Track)**	2
Balance (SE-8723)	1	**2.2 m Track System (ME-9452)**	1

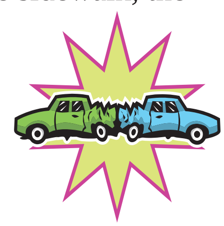
What Do You Think?

How does the total momentum of two carts before an elastic collision compare to the total momentum of two carts after the collision?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

When objects collide, whether locomotives, shopping carts, or your foot and the sidewalk, the results can be complicated. Yet even in the most chaotic of collisions, as long as there are no external forces acting on the colliding objects, one principle always holds and provides an excellent tool for understanding the dynamics of the collision. That principle is called the conservation of momentum. For a two-object collision, momentum conservation is easily stated mathematically by the equation:



$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2'$$

If external forces such as friction are ignored, the sum of the momenta of two carts prior to a collision is the same as the sum of the momenta of the carts after the collision.

SAFETY REMINDERS

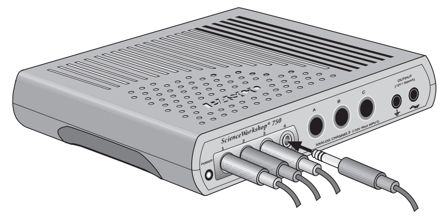
- Follow all directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use Motion Sensors to measure the motion of two carts before and after an elastic collision. Use *DataStudio* or *ScienceWorkshop* to determine the momentum for both carts before and after the collision. Compare the total momentum of the two carts before collision to the total momentum of both carts after collision.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect one Motion Sensor into Digital Channels 1 and 2 on the interface. Connect the yellow plug into Channel 1 and the other plug into Channel 2.
3. Connect the second Motion Sensor into Digital Channels 3 and 4 on the interface. Connect the yellow plug into Channel 3 and the other plug into Channel 4.
4. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P38 Linear Momentum.DS	P16 Cons. of Momentum 1	P16_CON1.SWS

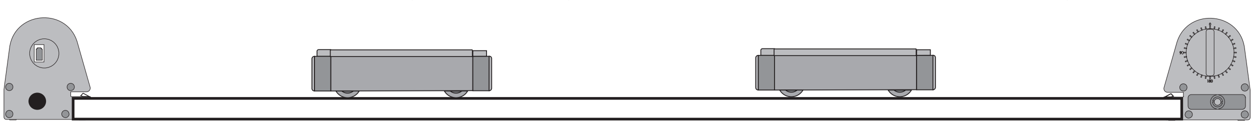
- The document will open with a Graph display of ‘Position’ for two objects.
- The *DataStudio* file also has a Workbook display. Read the instructions in the Workbook.
- The Motion Sensor ‘Trigger Rate’ is 20 Hz (20 times per second).

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the sensors for this activity.
- Make sure that magnets are installed in at least one end of each cart so the carts can repel each other during the collision.

1. Place the track on a horizontal surface.
2. Level the track by placing a cart on the track. If the cart rolls one way or the other, use the adjustable feet at one end of the track to raise or lower that end until the track is level and the cart will not roll one way or the other.
3. Use the balance to find the mass of each cart and record the values in the Data Table in the Lab Report section.
4. Mount the Motion Sensor that is connected to Digital Channels 1 and 2 on the left end of the track. Mount the other Motion Sensor on the right end of the track.
5. Adjust each sensor so it can measure the motion of a cart as it moves from the end of the track to the middle and back again. Put the ‘SWITCH SETTING’ on the sensor to ‘Narrow’. Put pencil marks on the track at spots that are 0.15 m (15 cm) from each Motion Sensor.

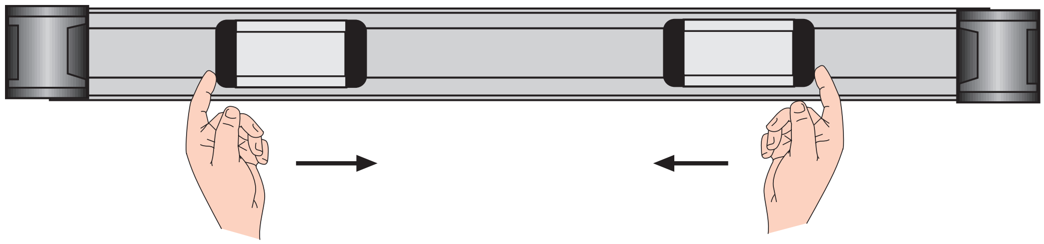
- Remember, the closest that a target can approach the sensor is 15 cm (for the Motion Sensor II, Model CI-6742), or 40 cm (for the Motion Sensor, Model CI-6529).



6. Place a cart at each end of the track. Let the cart on the left be ‘cart 1’ and the cart on the right be ‘cart 2’. Be sure that the magnetic ends of the carts will repel each other.

PART III: Data Recording

1. Prepare to measure the motion of each cart as it moves toward the other cart and then collides elastically. (Be sure the magnetic ends of the carts will repel.)
2. Start recording data. (In *DataStudio*, click 'Start'. In *ScienceWorkshop*, click 'REC'.)
3. Gently push the carts toward each other at the same time.



- Continue collecting data until the carts have collided and returned to the ends of the track.

4. Stop recording data.

- 'Run #1' will appear in the Data list.

> **Troubleshooting Note:** If your data are not smooth, check the alignment of the motion sensors. You may need to increase the reflecting area of each cart by attaching a rectangular cardboard "flag" (about 2 by 6") to the front of the cart. To erase a trial run of data, select "Run #1" in the data list and press the "Delete" key.

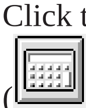
Analyzing the Data

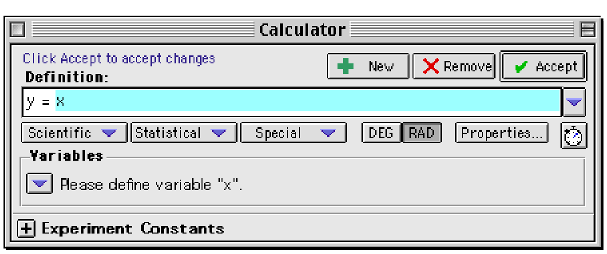
Find the slope of the position versus time plot for each cart just prior to collision and the slope of the plot for each cart just after collision. The slope is the average velocity of the cart. Use the velocity and mass of the cart to calculate the momentum of each cart before and after collision. Compare the total momentum of the two carts before the collision with the total momentum of the two carts after the collision.

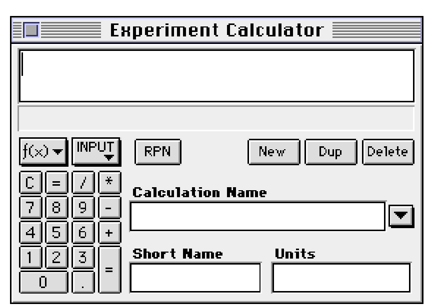
Momentum is a vector quantity. Since the carts move in opposite directions, one cart's momentum is in the opposite direction to the other cart's momentum. However, each Motion Sensor measures motion away from it as 'positive' and motion toward it as 'negative'. Use the software's built-in calculator to "reverse" the directions of the motion of one of the carts.

Create a Calculation for the Motion of 'Cart 2'

1. Click the 'Calculate' button (

) in *DataStudio* or the 'Calculator' button () in *ScienceWorkshop*. Result: The Calculator window opens.

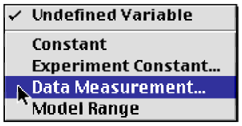


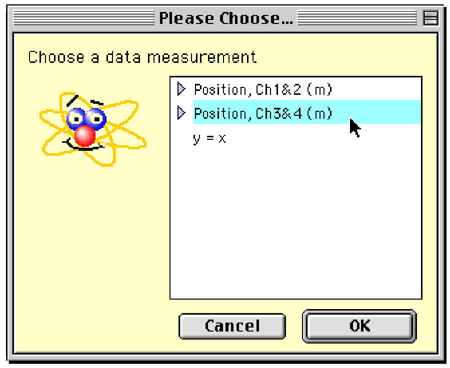


2. Create a calculation to 'reverse' the values of position for 'cart 2'.

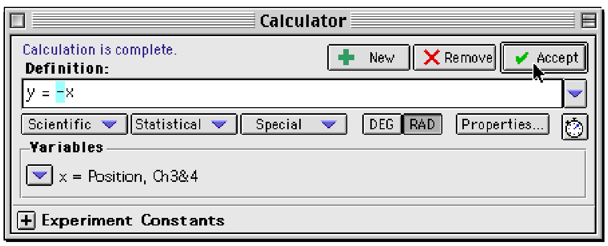
In *DataStudio*, do the following:

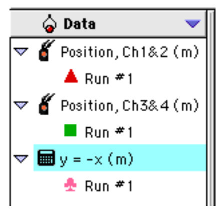
- Click the 'Variables' menu and select 'Data Measurement'. **Result**: The 'Choose a data measurement' window opens. Select 'Position, Ch 3&4' and click 'OK'.





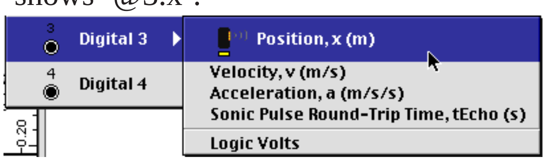
- In the 'Definitions' text area, put a negative sign "-" in front of 'x'. Click 'Accept'. **Result**: The calculation appears in the Data list.

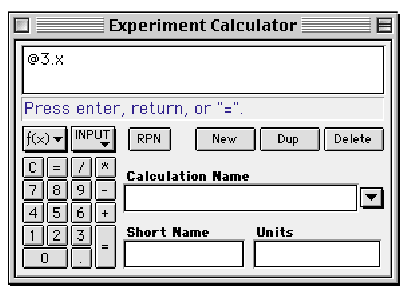




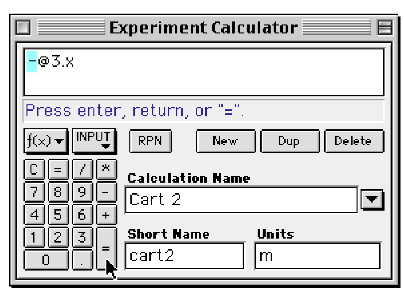
In *ScienceWorkshop*, do the following:

- Click the 'INPUT' menu and select 'Digital 3, Position'. **Result**: The formula text area shows '@3.x'.





- In the formula area, put a negative sign "-" in front of '@3.x'. Enter a 'Calculation Name' (such as 'Cart 2'), a 'Short Name' ('cart2'), and 'm' for 'Units'. Press 'enter', 'return', or the '=' key on the keypad. **Result**: The calculation is complete.



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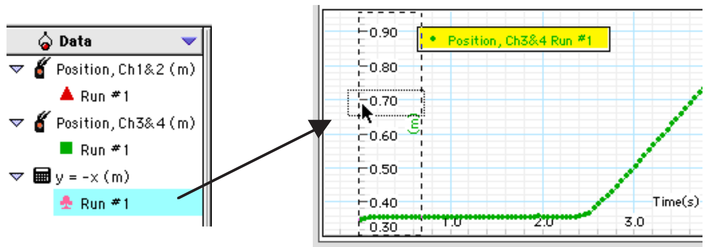
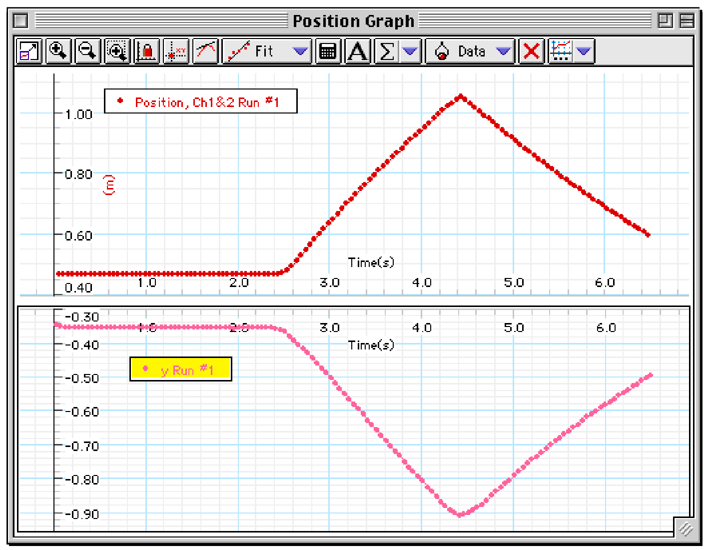
Display the Calculation of Motion for ‘Cart 2’ in the Graph

3. Display the calculation that shows the direction of motion for ‘cart 2’.

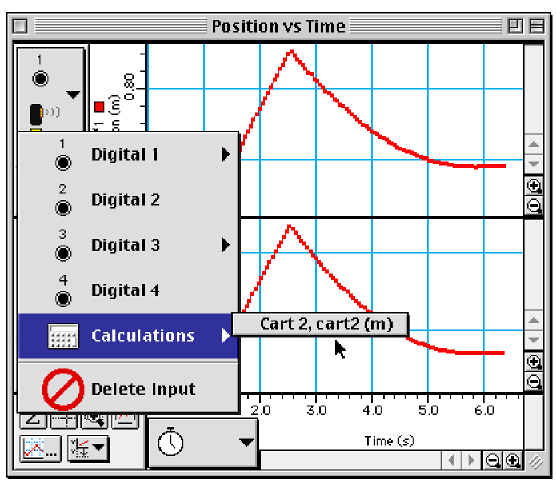
- In *DataStudio*, click and drag ‘Run #1’ from the calculation in the Data list to the Y axis of the plot of ‘Position’ for the second cart.



Result: The Graph display shows ‘Position’ for cart 1 and the calculation of position for cart 2.



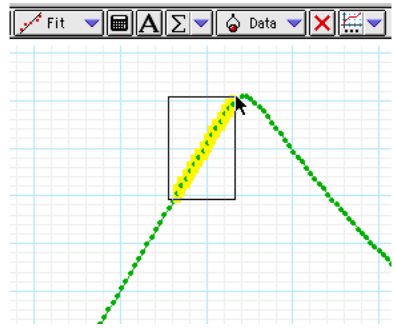
- In *ScienceWorkshop*, click the ‘Input’ menu for the plot of motion for ‘cart 2’. Select ‘Calculations, Cart 2’. **Result**: The Graph shows ‘Position’ for cart 1 and the calculation of position for cart 2.



Find the Slope

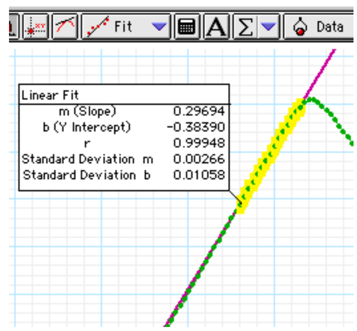
1. Use the Graph display's built-in analysis tools to find the slope of the position vs. time plot just before and just after the collision for each cart.

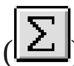
In *DataStudio*, do the following:

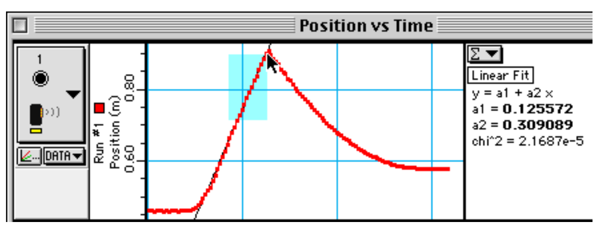


- In the plot for 'cart 1', select a small portion just before collision (e.g., about 10 or 15 data points before the peak).
- Click the 'Fit' menu and select 'Linear'. Record the slope as the 'Velocity Before Collision' for 'cart 1'.
- Repeat the process for a small portion of the plot just after collision and record the slope as the 'Velocity After Collision' for 'cart 1'.
- Do the same analysis for the plot of motion for 'cart 2'.

In *ScienceWorkshop*, do the following:



- Click the 'Statistics' button () to open the Statistics area on the right side of the Graph.
- Click the 'Statistics Menu' button () and select 'Curve Fit, Linear Fit' from the Statistics menu.
- In the plot area for 'cart 1', use the mouse to click-and-draw a rectangle around a small portion of the plot just before the collision.



- The slope is the coefficient 'a2' in the Statistics area. Record the slope as the 'Velocity Before Collision' for 'cart 1'.
- Repeat the process for a small portion of the plot just after collision and record the slope as the 'Velocity After Collision' for 'cart 1'.
- Do the same analysis for the plot of motion for 'cart 2'.

2. Calculate the momentum before and after the collision for each cart. Calculate the total momentum before and after the collision.

3. Calculate the percentage difference between the total momentum before and the total momentum after the collision.

$$\%\ difference = \frac{pTotal_{Before} - pTotal_{After}}{pTotal_{Before}}$$

Record your results in the Lab Report section.

Name ______________________ Class _______________ Date _________

Lab Report - Activity P38: Conservation of Linear Momentum

What Do You Think?

How does the total momentum of two carts before an elastic collision compare to the total momentum of two carts after the collision?

Data Table

Item	Cart 1	Cart 2
mass (kg)		
velocity before (m/s)		
momentum before (kg•m/s)		
velocity after (m/s)		
momentum after (kg•m/s)		

total momentum$_{before}$	total momentum$_{after}$	percent difference

Questions

1. How does the total momentum before the collision compare to the total momentum after the collision?

2. What factors do think may cause there to be a difference between the momentum before and the momentum after collision?

Optional

Repeat the experiment for different speeds. Find the speeds for which the difference in momentum before and after collision is least. Repeat the experiment with different masses added to the carts.

Extension

Use the Calculator Window to create a formula for the momentum of each cart. Add a plot to the Graph or change one of the existing plots so it displays Momentum vs. Time. Compare the momentum before the collision to the momentum after the collision.

Name ____________________ Class _____________ Date _________

Activity P39: Motor Efficiency
(Photogate, Power Amplifier, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P39 Motor Efficiency.DS	P24 Motor Efficiency	P24_MOTO.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Power Amplifier (CI-6552A)	1	Mass Set (SE-8705)	1
Photogate (ME-9204B)	1	Motor/Generator Kit (CI-6513)	1
Voltage Sensor (CI-6503)	1	String (SE-8050)	1.2 m
Balance (SE-8723)	1		

What Do You Think?

How does the efficiency of an electric motor compare with the efficiency of a generator?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

We rely on electric motors and generators in a variety of applications. Several factors such as durability and efficiency are important in the design of a motor.

In essence, an electric motor can operate in one of two modes:

Motor - delivering mechanical energy when powered electrically.

Generator - delivering electrical energy when powered mechanically.

Motor Efficiency

The percent efficiency of a motor is the ratio of the work done by the motor to the electrical energy input to the motor:

$$efficiency = e = \frac{W_{out}}{E_{input}} \times 100\%$$

The work done in lifting a weight of mass **m** a distance **h** is **W = mgh**. The electrical energy input to the motor is the time-integral of power, which is power multiplied by time (for constant power), or:

$$E_{input} = P \times \Delta t = I \times V \Delta t$$

The voltage **V** across the motor is held constant and the power input is the product of voltage and current. The energy input is found by integrating under the power input versus time curve.

Generator Efficiency

The percent efficiency of the generator is the ratio of the electrical energy produced to the work done:

$$e = \frac{E_{output}}{W_{in}} \times 100\%$$

The work done by the dropping weight is the same as the work done in lifting the weight (**W = mgh**). The electrical energy produced is the electrical power multiplied by the time of the fall:

$$E_{out} = P \times \Delta t = \frac{V^2}{R} \times \Delta t$$

The power generated is found by squaring the voltage generated and dividing by the resistance. The energy output is found by integrating the power generated versus time curve. **R** is the load resistor across which the voltage generated is applied and Δ**t** is the time it takes the weight to fall the distance **h**.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Motor Efficiency

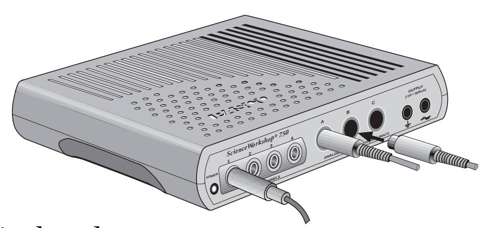
For the first part of this activity, use a motor/generator to lift a mass. Use the Photogate to measure the distance the mass is lifted. Use *DataStudio* or *ScienceWorkshop* to display the distance and calculate the gravitational potential energy gained by the mass.

At the same time, the program measures the output current drawn from the Power Amplifier by the motor while it lifts the mass. Use the program to control the output voltage from the Power Amplifier to the motor. Use the program to integrate under the curve of power input versus time and calculate the electrical energy used by the motor (Energy Input) to lift the mass.

Generator Efficiency

For the second part of this activity, turn the motor off. As the mass falls slowly back to the floor, it pulls the string that turns the motor. The motor becomes a generator, producing a voltage. Use the Voltage Sensor to measure the voltage drop across a 10-ohm resistor that is in parallel with the output of the generator. Use the program to display the voltage and integrate under the curve of power generated versus time and calculate the electrical energy produced by the generator (Energy Output) as the mass drops.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and then turn on the computer.
2. Connect the Power Amplifier's DIN plug into Analog Channel A on the interface. Plug the power cord into the back of the Power Amplifier. Connect the other end of the power cord to an electrical outlet.
3. Connect the Voltage Sensor's DIN plug into Analog Channel B on the interface.
4. Connect the Photogate's stereo phone plug into Digital Channel 1 on the interface.
5. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P39 Motor Efficiency.DS	P24 Motor Efficiency	P24_MOTO.SWS

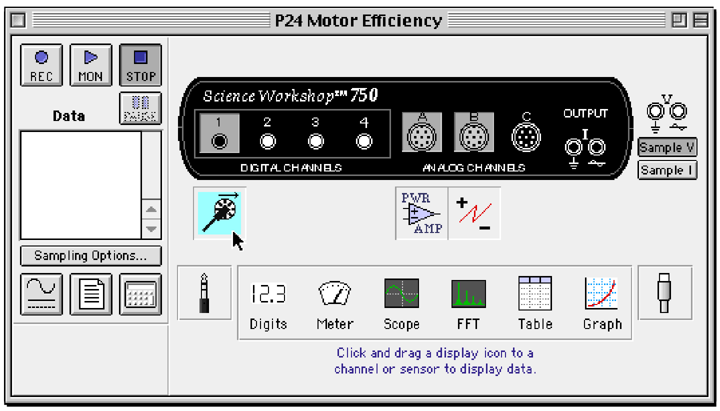
- The *DataStudio* file has a Graph display of Position, Current, and Voltage and a Graph display of GPE (gravitational potential energy), Power Input, and Power Generated. It also has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Position, Current, and Voltage versus Time.

- The Signal Generator window controls the voltage to the Power Amplifier. The Signal Generator is set to output DC voltage. The Signal Generator will automatically generate a signal when you start collecting data and automatically stop when you end.
- The ‘GPE’ (gravitational potential energy), ‘Power Input’ (to the motor), and the ‘Power Generated’ (by the generator) are built-in calculations. You will use these calculations during data analysis.

PART II: Sensor Calibration and Equipment Setup

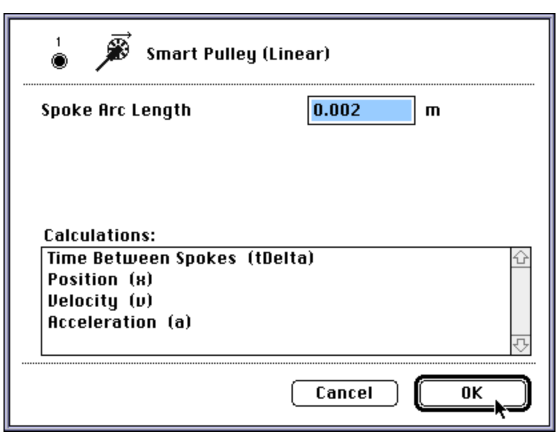
Sensor Calibration

- You do not need to calibrate the Power Amplifier or Voltage Sensor.
- The Motor/Generator has a pulley with ten spokes attached to one end of its axle. As the pulley turns, its spokes interrupt the Photogate’s beam. The pulley and Photogate act the same as a ‘Smart Pulley’. Therefore, a ‘Smart Pulley’ icon is shown beneath Channel 1.
- In *ScienceWorkshop* change the default setting for the ‘Smart Pulley’. Double-click the ‘Smart Pulley’ icon in the Experiment Setup window to open the Smart Pulley setup window.

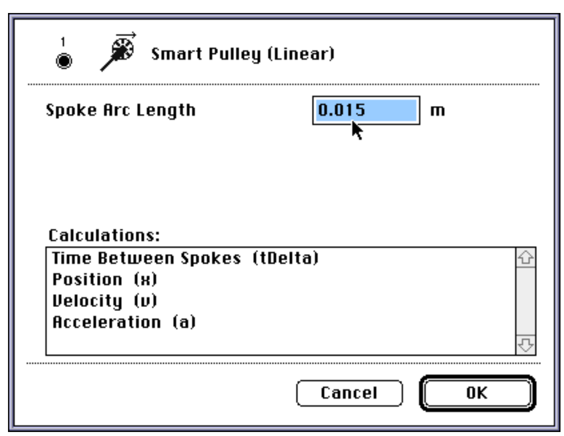


- The default for the ‘Spoke Arc Length’ is 0.015 m (1.5 cm). This assumes that the string is the in the groove of the Smart Pulley, where the circumference is 15 cm. In this case, the string is on an axle that has a circumference of 2 cm, so each spoke-to-spoke interruption represents 2 cm ÷ 10, or 0.2 cm (0.002 m).

Default value (15 cm circumference)



New value (2 cm circumference of axle)



- Enter ‘0.002’ for the new Spoke Arc Length. Click ‘OK’ to return to the setup window.

Equipment Setup

1. Clamp the motor/generator to a table about one meter above the floor. Attach a string through the small hole in the axle of the motor/generator. Make sure the string can reach to the floor.

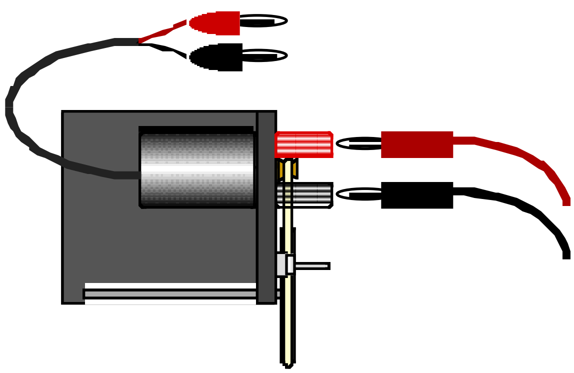
2. Measure the mass (e.g., 1.2 kg) that will be attached to the end of the string and record this value. Record the mass in the Lab Report section.

- Put the mass on the end of the string that is connected to the axle of the motor/generator.

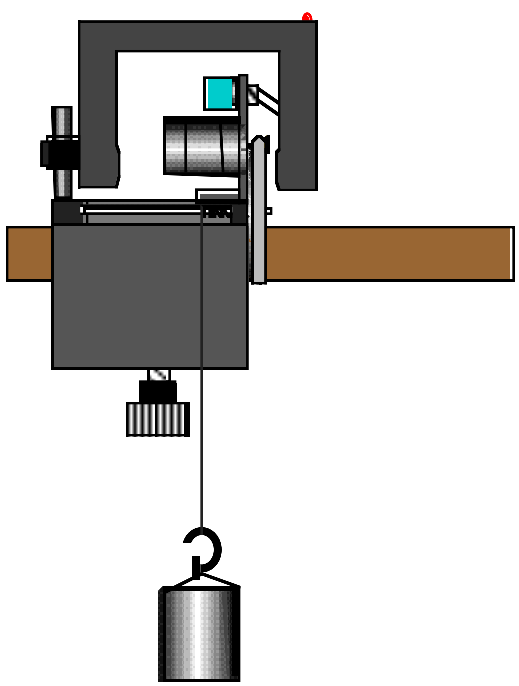
3. Connect the banana plugs of the motor/generator's cable to the output terminals on the Power Amplifier.

- Do not turn on the Power Amplifier yet. Put the switch on the motor/generator in the "OFF" (down) position.

4. Connect the banana plugs of the Voltage Sensor to the red and black terminals on the side of the motor/generator, matching colors.



5. Mount the Photogate on the vertical post on the side of the motor/generator. Position the Photogate so that the spokes of the pulley on the motor/generator will interrupt its beam.



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Preparing to Record Data

- Before recording any data for later analysis, you should experiment with the motor/generator setup.
- Be sure the mass is attached to the end of the string.
- Turn on the power switch on the back of the Power Amplifier.
- Start recording data (Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*). The output from the Signal Generator will begin automatically. Put the switch on the motor in the **"up"** position. The motor will begin to lift the mass.
- When the mass is almost up to the axle on the motor/generator, put the switch on the motor to the **"down"** position BUT SUPPORT THE MASS SO IT WON'T FALL DOWN, YET.
- Disconnect the stereo phone plug of the Photogate from Digital Channel 1 on the interface. This is necessary so it will not record the motion of the falling mass.
- Let the mass fall. (Remember to leave the switch on the motor in the **"down"** position for this part!)
- When the mass is down, stop data recording.
- Rescale the graph and examine the plots of Position, Current, and Voltage versus Time.
- Delete your trial run of data.

PART III: Data Recording – Lifting the Mass, THEN Letting the Mass Fall

1. Get ready to record data. Reconnect the Photogate's stereo phone plug into Digital Channel 1 of the interface. Be sure that the switch on the back of the Power Amplifier is on. The mass should be at its down position.
2. When everything is ready, start recording data. The output from the Signal Generator will begin automatically.
3. After a second or two, put the switch on the motor in the **"up"** position. The motor will begin to lift the mass.

- Allow the motor to lift the mass until the string is almost completely wound around the axle.

4. When the mass is almost to the axle, switch the motor off (put the switch in the **"down"** position) and SUPPORT THE MASS TO KEEP IT FROM FALLING BACK DOWN.
5. Quickly disconnect the Photogate's plug from Digital Channel 1 of the interface. This is necessary so it will not record the motion of the falling mass.
6. After disconnecting the Photogate, allow the mass to fall.
7. When the mass reaches its lowest point, stop recording data.

- You have completed data recording for BOTH Part A (motor lifting the mass) AND Part B (falling mass powering the motor-as-generator).

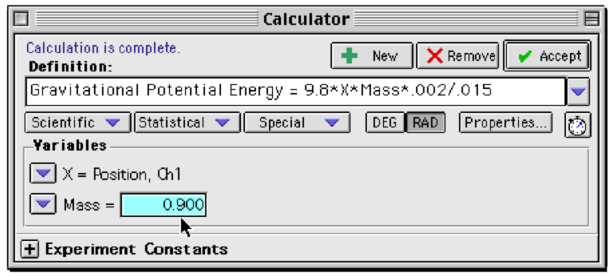
Analyzing the Data

- Use the included calculations from the Experiment Calculator to determine the gravitational potential energy, power input, and power generated.

1. In the calculation for **GPE**, the mass of the object must be entered using the Experiment Calculator.

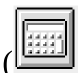
In *DataStudio*, do the following:

- Double-click the 'Gravitational Potential Energy' calculation in the Data list. **Result**: The Calculator window opens.

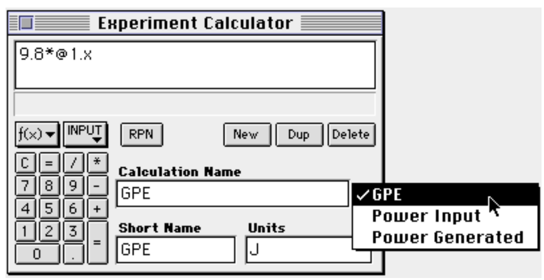


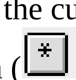
- Under 'Variables', enter the mass of the object. Click 'Accept' to save the change.

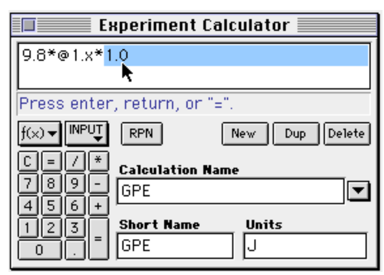
In *ScienceWorkshop*, do the following:

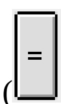
- Click the Calculator button () in the Experiment Setup window to open the Experiment Calculator window.

- Click the 'Calculation Menu' button (). Select **GPE** from the Calculation Menu.



- Move the cursor to the end of the formula in the formula area. Click the multiplication button (
) in the keypad. Type the mass of the object. (For example, type "1.0" if the mass was 1.0 kilograms).



- Click the 'equal' button (
) in the calculator keypad, or press <enter> or <return> on the keyboard to finish your calculation.

2. The other two built-in calculations are **Power Input** and **Power Generated**. They do not need to be modified.

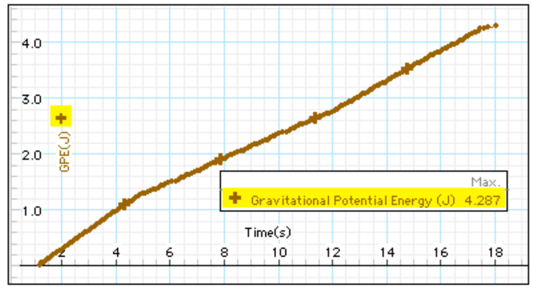
- The **Power Input** is calculated as follows:

  $\boldsymbol{P = VI}$ where $\boldsymbol{V}$ is the DC Voltage set in the Signal Generator and $\boldsymbol{I}$ is the current drawn from the Power Amplifier by the motor as it works.

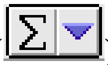
- The **Power Generated** is calculated as follows:

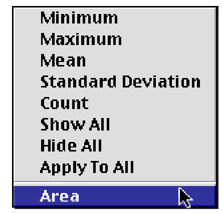
  $$\boldsymbol{P} = \frac{\boldsymbol{V}^2}{\boldsymbol{R}}$$ where $\boldsymbol{V}$ is the generator's output voltage measured by the Voltage Sensor in Channel B and $\boldsymbol{R}$ is the 10 ohm resistor that is in parallel with the output voltage.

3. Use the Graph display's built-in analysis tools to determine the maximum **GPE** (gravitational potential energy) gained by the mass, the energy input to the motor (the time-integral of **Power Input**), and the energy output by the 'motor-as-generator' (the time-integral of **Power Generated**).



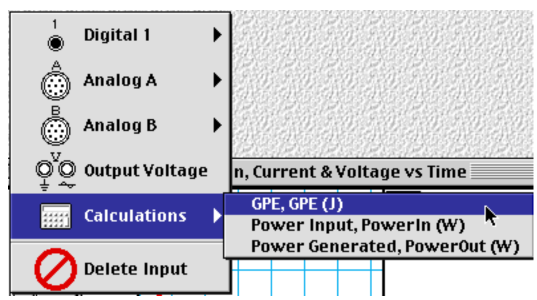
<u>In *DataStudio*,</u> do the following in the Graph of Gravitational Potential Energy, Power Input, and Power Generated:

- Select the plot of 'Gravitational Potential Energy'. Select 'Maximum' from the Statistics menu (). **Result**: The maximum value of 'GPE' appears in the Legend box. Record the value in the Lab Report section.

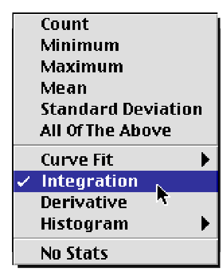


- Select the plot of 'Power Input'. Select 'Area' from the Statistics menu. **Result**: The time-integral of Power Input (area under the curve) appears in the Legend box. Record the value as 'Energy Input' in the Lab Report section.
- Select the plot of 'Power Generated'. Select 'Area' from the Statistics menu. **Result**: The time-integral of Power Generated (area under the curve) appears in the Legend box. Record the value as 'Energy Output' in the Lab Report section.

<u>In *ScienceWorkshop*</u>, do the following in the Graph display:



- In the plot of Position vs. Time, use the 'Input' menu to replace 'Position' with the '**GPE**' calculation. Open the statistics area and select 'Maximum' from the 'Statistics' menu to determine the maximum **GPE** (gravitational potential energy) gained by the mass. Record the 'y' value in the Lab Report section.
- In the plot of Current vs. Time, use the 'Input' menu to select the **Power Input** calculation. To find the electric energy input (Energy Input), select 'Integration' from the 'Statistics' menu. Record the value as 'Energy Input' in the Lab Report section.



- In the plot of Voltage vs. Time, use the 'Input' menu to select the **Power Generated** calculation. Select 'Integration' from the 'Statistics' menu. Record the value as 'Energy Output' in the Lab Report section.

4. Determine the percent efficiency of the motor and the percent efficiency of the 'motor-as-generator'.

Record your results in the Lab Report Section

Name ____________________ Class _____________ Date _________

Lab Report - Activity P39: Motor Efficiency

What Do You Think?

How does the efficiency of an electric motor compare with the efficiency of an electric generator?

Data Table

mass of object = _________ kg

Item	Value
GPE (joules)	
Energy Input (watt*s)	
Energy Output (watt*s)	

Mode	% Efficiency
Motor (lifting the mass)	
Generator (as the mass falls)	

Questions

1. What is the efficiency of the motor as it lifted the mass?

2. What is the efficiency of the motor-as-generator as the mass was allowed to drop?

Optional Activity

- Change the output voltage of the power amplifier and determine how a different voltage affects the efficiency of the motor.

Name ____________________ Class _____________ Date _________

Activity P40: Driven Harmonic Motion - Mass on a Spring (Force Sensor, Motion Sensor, Power Amplifier)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Harmonic motion	P40 DHM.DS	P20 Driven Harmonic Motion	P20_DRIV.SWS

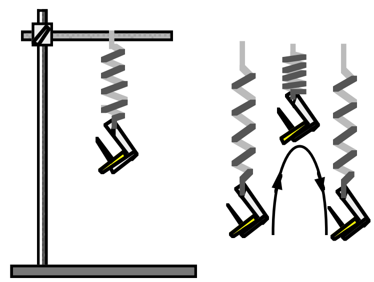
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Force Sensor (CI-6537)	1	**Mass Set (SE-8705)**	1
Motion Sensor (CI-6742)	1	Meter stick	1
Power Amplifier (CI-6552)	1	**Patch Cords (SE-9750)**	2
Balance (SE-8723)	1	**Rod (ME-8736)**	1
Base and Support Rod (ME-9355)	1	**Spring, k ~ 2 to 4 N/m (632-04978)**	1
Clamp, right angle (SE-9444)	1	**Wave Driver (WA-9753)**	1

What Do You Think?

The purpose of this activity is to investigate the motion of a mass oscillating on a spring that is being driven at a frequency close to the natural frequency of the mass-spring system. What will happen to the amplitude of oscillation when the mass-spring system is at its natural frequency?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background



Imagine a spring that is hanging vertically from a support. When no mass hangs at the end of the spring, it has a length **L** (called its rest length). When a mass is added to the spring, its length increases by Δ**L**. The equilibrium position of the mass is now a distance **L** + Δ**L** from the spring's support. What happens if the mass is pulled down a small distance from the equilibrium position? The spring exerts a restoring force, **F = -kx**, where **x** is the distance the spring is pulled down and **k** is the force constant of the spring. The negative sign indicates that the force points opposite to the direction of the displacement of the mass. The restoring force causes the mass to oscillate up and down. The period of oscillation for simple harmonic motion depends on the mass and the force constant of the spring.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

The frequency of the mass-spring system is **1/T**.

If the mass-spring system is driven at a frequency that is close to its natural frequency (resonance), the amplitude of oscillation will increase to a maximum.

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

For You To Do

In the Pre-Lab for this activity, use the Force Sensor to measure the force that stretches a spring as weight is added to one end of the spring. Measure the amount of distance that the spring stretches and use 'Manual Sampling' (in *DataStudio*) or 'Keyboard Sampling' (in

ScienceWorkshop) to record the distance. Use the software program to display the force and the distance. Determine the spring constant, ‘k’, (the slope of the best-fit line of a graph of force versus distance).

In the Procedure for this activity, suspend a mass-spring system from a wave driver. Use the software program to control the frequency of oscillation of the wave driver. Use the Motion Sensor to measure the motion of the mass on the end of the spring and display its position versus time.

Compare the plot of position when the wave driver frequency is *not* at its natural frequency of the mass-spring system to the plot of position when the wave driver is at its natural frequency.

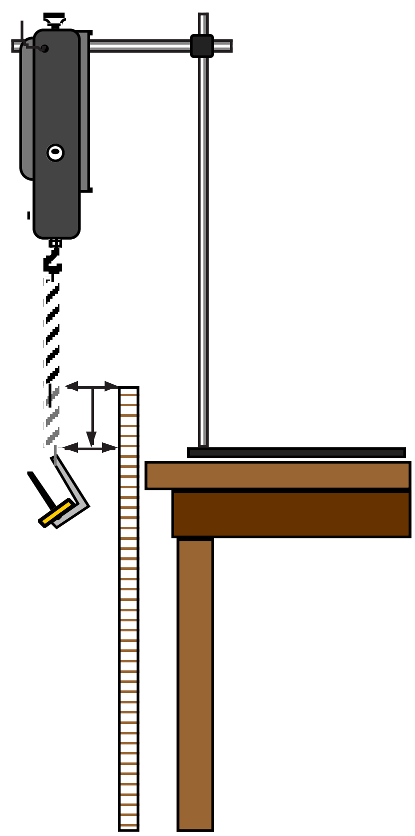
Pre-Lab: Determine the Spring Constant

Pre-Lab Part A: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Force Sensor’s DIN plug into Analog Channel A of the interface.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P40 Prelab DHM.DS	X20 Spring Constant	X20_SPNG.SWS

- The *DataStudio* document opens with a Table display and a Graph display of Force (N) versus Stretch (m), and a Digits display of Force. The document also has a Workbook display.
- The *ScienceWorkshop* document opens with a Table display and a Graph display of Force (N) versus Stretch (m), and a Digits display of Force. The Keyboard Sampling parameter is ‘Stretch’ and the unit is ‘m’ (meters).
- Data recording is set at 5 samples per second (5 Hz).



Pre-Lab Part B: Equipment Setup

1. Mount the Force Sensor vertically so its hook end is down.
2. Suspend the spring from the Force Sensor’s hook so that it hangs vertically.
3. Use the meter stick to measure the position of the bottom end of the spring (without any mass added to the spring). Record this measurement as the spring’s equilibrium position.

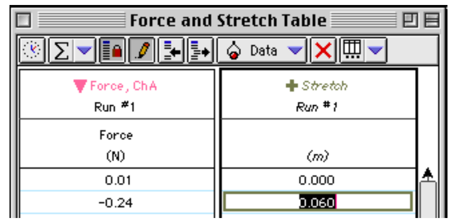
Pre-Lab Part C: Data Recording

1. Press the tare button on the side of the Force Sensor to zero the Force Sensor.
2. Record data to determine the spring constant.

In *DataStudio*, do the following:

- Click ‘Start’. The ‘Start’ button changes to a ‘Keep/Stop’ button (

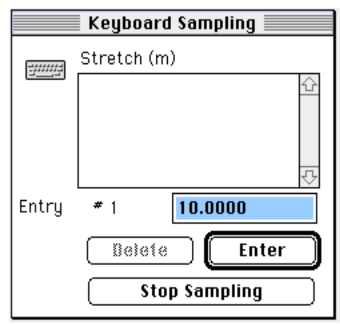
). Click ‘Keep’. In the Table of Force and Stretch, type ‘)’ as the first value under ‘Stretch’ (since the spring is not stretched yet).

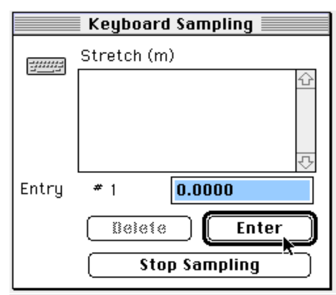


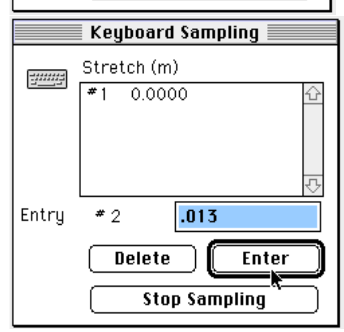
- Add 20 g of mass to the end of the spring (be sure to include the mass of the hanger). Measure the new position of the end of the spring. Determine how far the spring has stretched. Click ‘Keep’ and enter the amount of ‘Stretch’ in the second row of the Table.
- Add 10 grams to the spring and repeat the measurement of the new position of the end of the spring.
- Continue to add mass in 10 gram increments until you have added 70 grams. Measure the new stretched position of the end of the spring each time you add mass. Click ‘Keep’ and type in each new Δx in the Table under ‘Stretch’.
- Click the ‘Stop’ button (

) to end data recording.

In *ScienceWorkshop*, do the following:







- Click ‘REC’. The ‘Keyboard Sampling’ window will open.
- For Entry #1, type in “0” (since the spring is not stretched yet). Click ‘Enter’ to record your value. The value you type in will appear in the Data list in the Keyboard Sampling window.
- Add 20 grams of mass to the end of the spring (be sure to include the mass of the hanger). Measure the new position of the end of the spring. Determine how far the spring has stretched. For Entry #2, type in the value of Δx (in meters). Click ‘Enter’ to record your value. The value you type in for Entry #2 will appear in the Data list, and the default value for Entry #3 will reflect the pattern of your first two entries.
- Add 10 grams to the spring and repeat the measurement of the new position of the end of the spring.
- Continue to add mass in 10 gram increments until you have added 70 grams. Measure the new stretched position of the end of the spring each time you add mass. Type in each new Δx in the Keyboard Sampling window. Click ‘Enter’ each time to record your value.
- Click the ‘Stop Sampling’ button to end data recording.
- The Keyboard Sampling window will close, and “Run #1” will appear in the Data list in the Experiment Setup window.

Table 1: Determine the spring constant

Equilibrium Position = _______ m

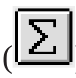
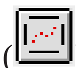
Mass (g)	20	30	40	50	60	70
Δx, "Stretch" (m)						

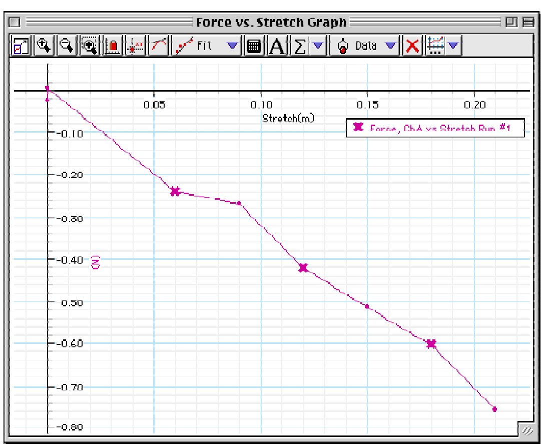
Pre-Lab Part D: Analyzing the Data

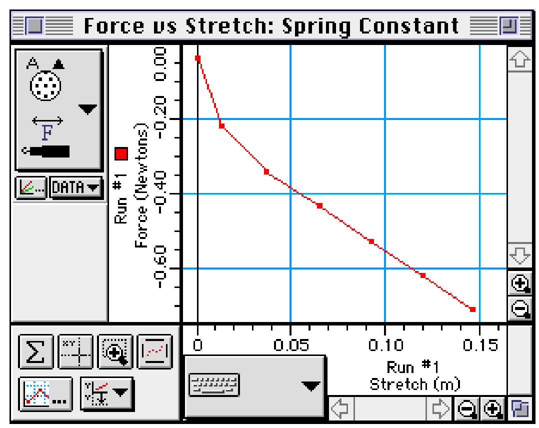
1. Use the Graph display's built-in analysis tools to find the spring constant (the slope of the best-fit line in the plot of Force versus Stretch).

- In *DataStudio*, select 'Linear' from the 'Fit' menu (

). If needed, select the region where the plot of force vs. stretch appears to be most linear. **Result**: The slope (m) appears in the Legend box.

- In *ScienceWorkshop*, click 'Statistics' () to open the Statistics area. Click 'Autoscale' () to rescale the Graph. Select the region where the plot of force vs. stretch appears to be most linear. Select 'Curve Fit, Linear Fit', from the 'Statistics Menu' () in the Statistics area. **Result**: The slope of the best-fit line is coefficient 'a2'.





2. Record the value of "k" in the Lab Report section.

Spring Constant "k" = _________ N/m

For You To Do

In this part of the activity, use a Motion Sensor to measure the motion of a mass that is suspended from the end of a spring. The spring is attached to a wave driver that is connected to the Power Amplifier. Use the *DataStudio* or *ScienceWorkshop* program to record the motion and display position and velocity of the oscillating mass. Use the program to control the Power Amplifier output to the wave driver. Observe the amplitude of oscillation as the frequency of the wave driver is adjusted to match the natural frequency of the mass-spring system.

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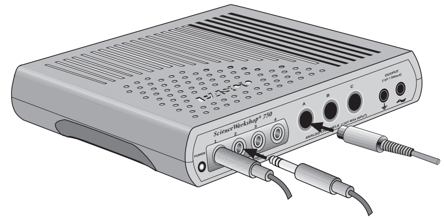
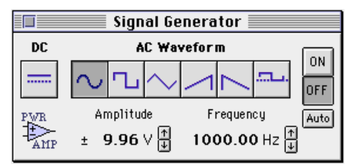
PART I: Computer Setup



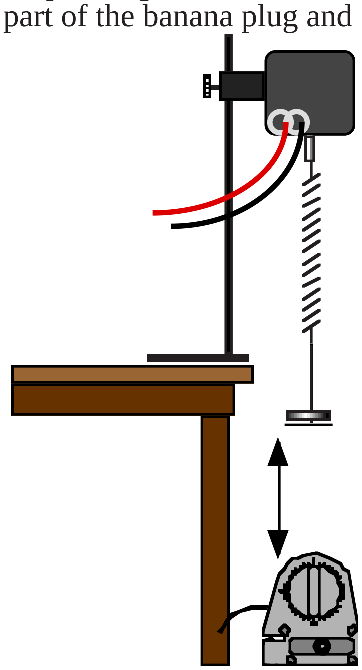
1. Unplug the Force Sensor’s DIN plug from the *ScienceWorkshop* interface.
2. Connect the Motion Sensor’s stereo phone plugs into Digital Channels 1 and 2 of the interface. Plug the yellow plug into Digital Channel 1 and the other plug into Digital Channel 2.
3. Connect the Power Amplifier’s DIN plug into Analog Channel A of the interface. Plug the power cord into the back of the Power Amplifier and connect the power cord to an appropriate electrical receptacle. Don’t turn the Power Amplifier on yet.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P40 DHM.DS	P20 Driven Harmonic Motion	P20_DRIV.SWS

- An alert window appears when you select ‘Open’ from the File menu. Click ‘Don’t Save’ or ‘No’, and then find the document.
- The *DataStudio* document opens with a Graph display of Position vs. Time and a Workbook display.
- The *ScienceWorkshop* document opens with a Graph display of Position vs. Time and the Signal Generator window for controlling the Power Amplifier.
- The Signal Generator window controls the Amplitude, Frequency, and AC Waveform of the Power Amplifier.



PART II: Equipment and Signal Generator Setup



1. Mount the wave driver on a support rod so that its drive shaft is pointing <u>down</u>. Attach the spring to the end of the drive shaft (hint: unscrew the plastic part of the banana plug and attach the spring through the hole in the metal part). Connect patch cords from the SIGNAL OUTPUT jacks on the Power Amplifier to the input jacks on the wave driver.
2. Put a mass hanger on the end of the spring. Add enough mass to the hanger so that the spring's stretched length is between 6 and 7 times its unloaded length (about 70 grams if you are using the harmonic spring from the PASCO Introductory Dynamics System.)
3. Remove the hanger and masses temporarily. Measure and record their total mass (in kilograms). Return the hanger and masses to the end of the spring.

Mass (m) = ________ kg

4. Place the Motion Sensor on the floor directly <u>below</u> the mass hanger.
5. Adjust the position of the wave driver and spring so that the <u>minimum distance from the mass hanger to the motion sensor is greater than 15 cm at the bottom of the mass hanger's movement</u>.

Signal Generator Setup

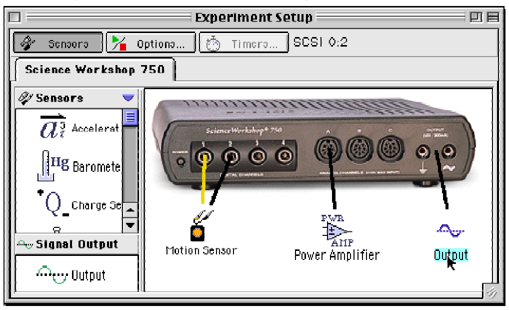
1. Use your measured value for the spring constant, **“k”**, and the total mass **“m”** to calculate the theoretical natural frequency of oscillation for the mass-spring system. Record the frequency.

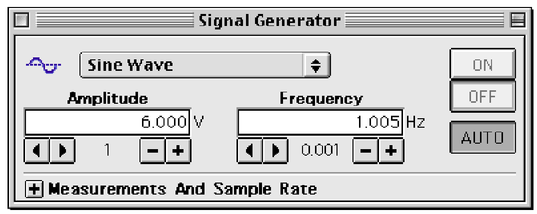
$$\nu = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Theoretical Natural Frequency = _______ Hz

2. Adjust the Amplitude and Frequency in the Signal Generator window.

- In *DataStudio*, double-click the ‘Output’ icon in the Setup window, or ‘Output Voltage’ in the Data list. **Result**: The Signal Generator window opens. Adjust the Amplitude and Frequency if needed. (The Signal Generator is set so it will automatically output the signal when you start recording data and will stop automatically when you stop.)

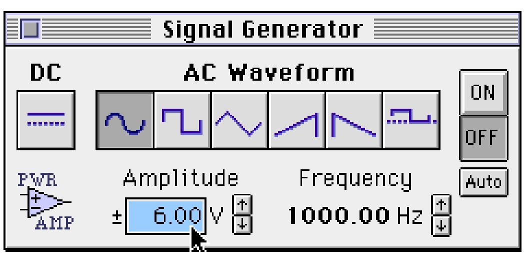


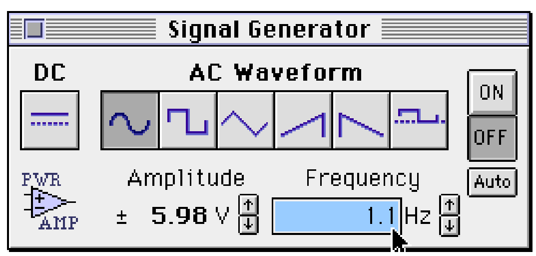


In *ScienceWorkshop*, do the following:

- Click the value of Amplitude (e.g., ‘9.96’) in the Signal Generator window. Enter ‘6.00’ as the new value in the Amplitude window. Press <enter> or <return> on the keyboard to record your change.

- Click n the value of Frequency (e.g, ‘1000’) in the Signal Generator window. Enter a new value in the Frequency window that is slightly <u>larger</u> than theoretical frequency. Press <enter> or <return> on the keyboard to record your change.





- Click the ‘Auto’ button () so the Signal Generator will automatically output the signal when you start recording data and will stop automatically when you stop

PART III: Data Recording

1. Prepare to record data. Position the displays so you can see the Signal Generator window and the Graph. Turn on the Power Amplifier. Make sure that the mass is not oscillating. (It should be stationary when you begin recording data.)
2. Start recording data. (Click ‘Start’ in *DataStudio* or click ‘REC’ in *ScienceWorkshop*.) **Result**: The output from the Power Amplifier will begin automatically.
3. Record data for 120 seconds and then stop data recording.
4. Examine the plot in the Graph display (rescale if necessary). Write a brief description of your first plot of position versus time in the Lab Report section.

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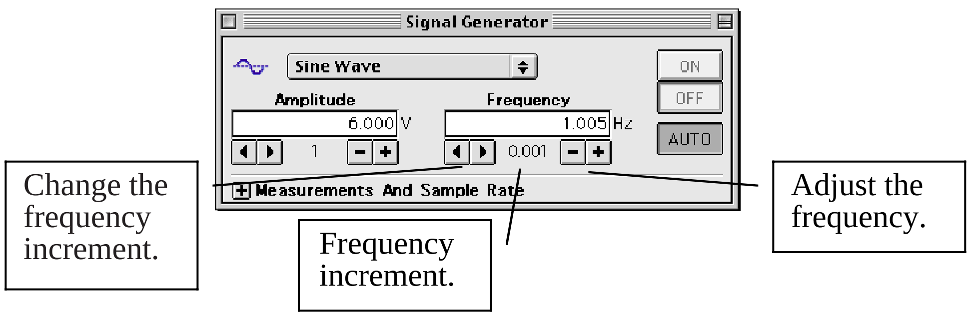
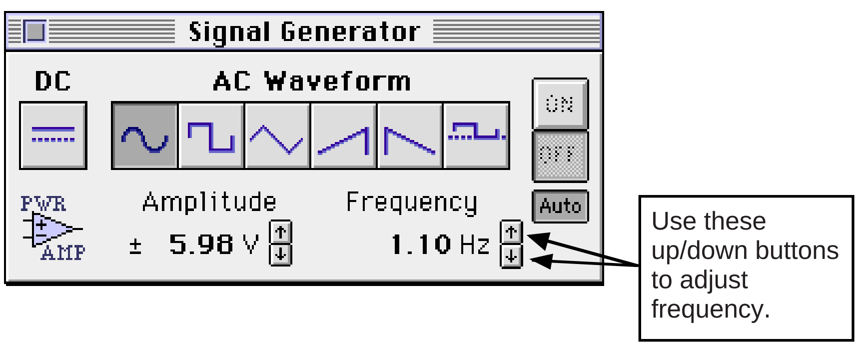
5. Stop the motion of the mass. When the mass is at rest, begin recording a new run of data.
6. Slightly adjust the frequency in the Signal Generator window so that the frequency is closer to the theoretical natural frequency.

- In *DataStudio*, use the ‘right-left’ arrows to change the frequency increment. Use the ‘minus-plus’ buttons to adjust the frequency.



- In *ScienceWorkshop*, use the ‘up/down’ arrows to adjust the frequency.



- In *ScienceWorkshop*, adjust the amount of frequency change for each ‘up/down’ click with the following keys:

Key (with mouse click) Macintosh®	**Frequency change**	**Key (with mouse click) Windows™**
Shift key	100 Hz	Shift key
“No” key	10 Hz	“No” key
Control key	1 Hz	Ctrl (control) key
Option key	0.1 Hz	Alt key
Command key	0.01 Hz	Ctrl + Alt keys

7. Observe what happens to the amplitude of the oscillations of the mass-spring system. Continue to adjust the frequency by small amounts until the amplitude of driven motion is a maximum.

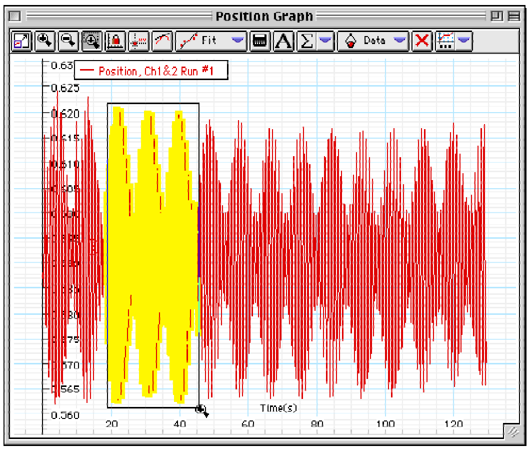
• NOTE: If the oscillations start to become too large, stop recording data immediately.

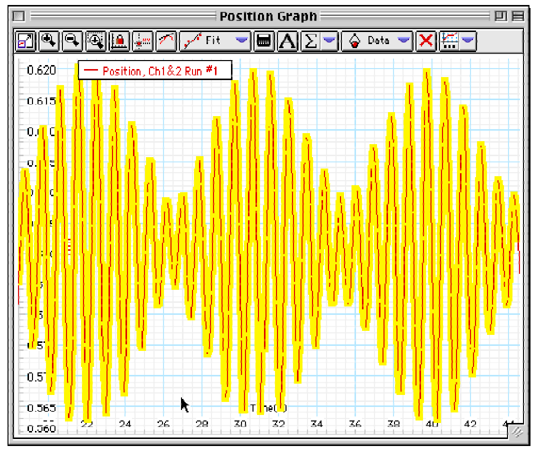
8. End data recording.

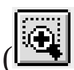
Analyzing the Data

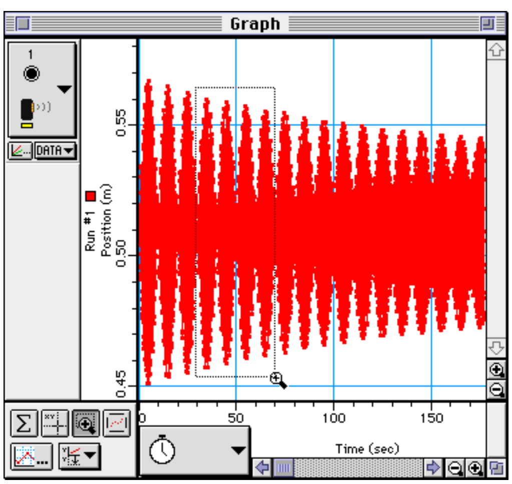
1. Use the Graph display to examine the two data runs. If necessary, select a region of the plot in order to expand the view.

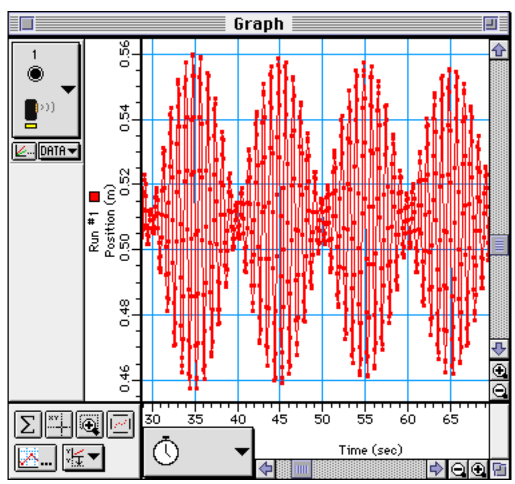
• In *DataStudio*, click 'Zoom Select' () and click-and-draw a rectangle around a region of the plot.





• In *ScienceWorkshop*, click 'Magnifier' () and click-and-draw a rectangle around a region.





Use your observations to answer the questions in the Lab Report section

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Lab Report - Activity P40: Driven Harmonic Motion – Mass on a Spring

What Do You Think?

The purpose of this activity is to investigate the motion of a mass oscillating on a spring that is being driven at a frequency close to the natural frequency of the mass-spring system. What will happen to the amplitude of oscillation when the mass-spring system is at its natural frequency?

Data

Table 1: Determine the spring constant

Equilibrium Position = m

Mass (g)	20	30	40	50	60	70
Δx, "Stretch" (m)						

- Record the value of "k"

Spring Constant "k" = N/m

- Measure and record the total mass on the end of the spring.

Mass (m) = kg

- Use your measured value for the spring constant, **"k"**, and the total mass **"m"** to calculate the theoretical natural frequency of oscillation for the mass-spring system. Record the frequency.

$$\nu = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Theoretical Natural Frequency = Hz

Questions

1. Describe the position versus time plot of driven harmonic motion when the driving frequency is slightly higher than the theoretical natural frequency.

2. Describe the position versus time plot of driven harmonic motion when the driving frequency is at the theoretical natural frequency.

3. What are possible reasons for the difference in the two plots?

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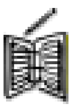
Activity P41: Waves on a String (Power Amplifier)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Waves	P41 Waves.DS	P31 Waves on a String	P31_WAVE.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Power Amplifier (CI-6552)	1	**Pulley Mounting Rod (w/ ME-6838)**	1
Balance (SE-8723)	1	**Rod (ME-8736)**	1
Clamp, Table (ME-9376)	2	**String (SE-8050)**	10 m
Mass Set (SE-8705)	1	**Super Pulley (w/ ME-6838)**	1
Meter stick	1	**Wave Driver (WA-9753)**	1
Patch Cords (SE-9750)	2		

What Do You Think?

The purpose of this activity is to investigate standing waves in a string. What is the relationship between the tension in the string and the number of segments in the standing wave? What is the relationship between the frequency of oscillation of the string and the number of segments in the standing wave? How can you use these relationships to find the linear mass density of the string?



Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

When a stretched string is plucked it will vibrate in its fundamental mode in a single segment with nodes on each end. If the string is driven at this fundamental frequency, a standing wave is formed. Standing waves also form if the string is driven at any integer multiple of the fundamental frequency. These higher frequencies are called the harmonics.

Each segment is equal to half a wavelength. In general for a given harmonic, the wavelength λ is

$$\lambda = \frac{2L}{n}$$

where **L** is the length of the stretch string and **n** is the number of segments in the string.

The linear mass density of the string can be directly measured by weighing a known length of the string. The density is the mass of the string per unit length.

$$\mu = \frac{mass}{length}$$

The linear mass density of the string can also be found by studying the relationship between the tension, frequency, length of the string, and the number of segments in the standing wave. To derive this relationship, the velocity of the wave is expressed in two ways.

The velocity of any wave is given by $v = \lambda f$ where **f** is the frequency of the wave. For a stretched string:

$$v = \frac{2Lf}{n}$$

The velocity of a wave traveling in a string is also dependent on the tension, **T**, in the string and the linear mass density, **μ**, of the string:

$$v = \sqrt{\frac{T}{\mu}}$$

Setting these two expressions for the velocity equal to each other and solving for tension gives:

$$T = \left(4L^2 f^2 \mu\right)\left(\frac{1}{n^2}\right)$$

If the tension is varied while the length and frequency are held constant, a plot of tension, **T**, vs. $(1/n^2)$ will give a straight line which will have a slope equal to $4L^2 f^2 \mu$. The slope of this line can be used to calculate the linear mass density of the string.

The equation for the tension can also be solved for the frequency:

$$f = \sqrt{\frac{T}{4L^2\mu}}\,n$$

If the frequency is varied while the tension and length are held constant, a plot of frequency, **f**, vs. number of segments, **n**, will give a straight line. The slope of this line can also be used to calculate the linear mass density of the string.

Overview

- First, determine the linear mass density of the string directly (**Pre-Lab**).
- Next, determine the linear mass density of the string using the relationship of tension, length, number of segments, and frequency for standing waves on the string.

In Part A use different hanging masses to change the tension of a string but keep the length and frequency constant. Plot a graph of tension vs. $1/n^2$ to determine the linear mass density of the string.

In Part B use the wave driver to vary the frequency but keep the length and tension constant. Use *DataStudio* or *ScienceWorkshop* to control the frequency of the wave driver. Plot a graph of frequency vs. n to determine the linear mass density of the string.

Compare the values of linear mass density for all three methods.

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

Pre-Lab

Direct Calculation of the Linear Mass Density

1. Measure the mass of a known length (about 10 m) of the string.

   length = L = _______________ meters

   mass = M = ________________ kilograms

2. Calculate the linear mass density by dividing the mass by the length (μ = mass/length): Record this value in the Lab Report section.

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For You To Do

In Part A of this activity, use different hanging masses to change the tension in the string but keep the length and frequency constant. Use *DataStudio* or *ScienceWorkshop* to keep the wave driver frequency constant.

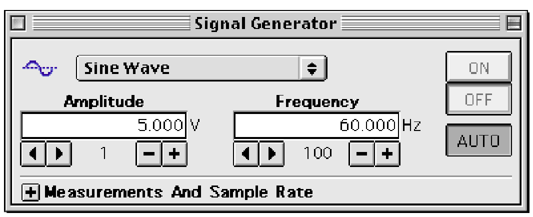
Part A: Change Tension – Keep Length and Frequency Constant

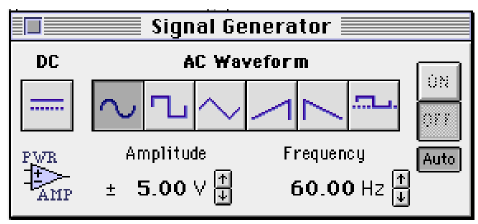
PART IA: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Power Amplifier DIN plug into Analog Channel A of the interface.
3. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P41 Waves.DS	P31 Waves on a String	P31_WAVE.SWS

- The *DataStudio* document has Table and Graph displays of Tension and $1/n^2$ and Frequency and Segments. It also has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document opens with a Signal Generator window.
- The Signal Generator is set to **Auto**. The Signal Generator output will begin when you start data recording and will stop when you end data recording.

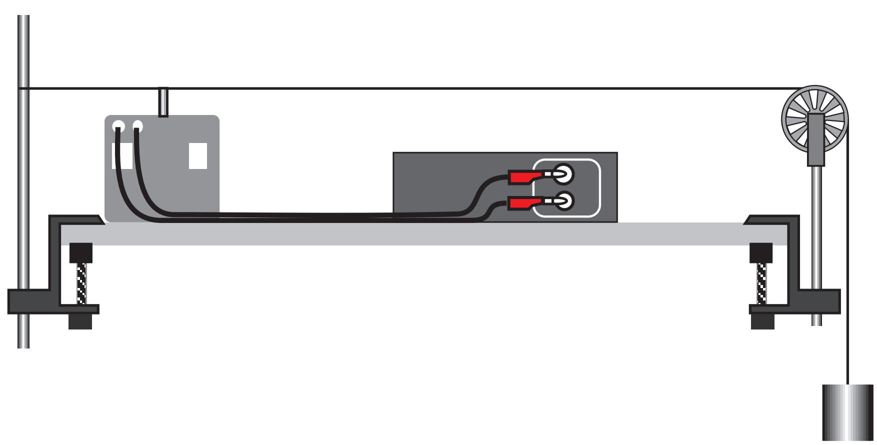




PART IIA: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Power Amplifier.

1. To avoid overloading the equipment, do not turn on the power switch of the Power Amplifier until the equipment setup is complete.
2. Set up the equipment. Tie one end of a 2-m long piece of string to a vertical support rod that is clamped to one end of a table. Pass the other end of the string over a pulley that is mounted on a rod that is clamped to the other end of the table. Attach about 500 g to the end of the string.



3. Place the wave driver under the string near the vertical support rod. Insert the string in the slot on the top of the driver plug of the wave driver so the wave driver can cause the string to vibrate up and down. Use patch cords to connect the wave driver into the output jacks of the Power Amplifier.

4. Use the meter stick to measure the length of the section of the string, L, that will be vibrating (the part between the driver plug of the wave driver and the top of the pulley). Record this length in the Lab Report section, Table 1.

PART IIIA: Data Recording – Change Tension

1. Turn on the power switch on the back panel of the Power Amplifier.

2. Put enough mass on the mass hanger to make the string vibrate in its fundamental mode (one antinode in the center) at a frequency of 60 Hz. Adjust the amount of mass until the nodes at each end are “clean” (not vibrating). Record the initial mass in the Lab Report section, Table 1. (Be sure to include the mass of the hanger.)

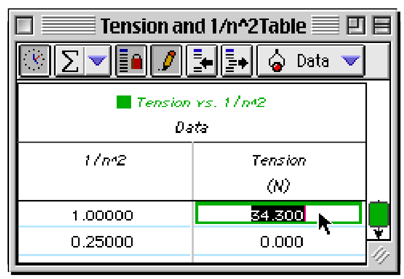
3. Now change the amount of mass on the mass hanger until the string vibrates in each of the higher harmonics (for 2 segments through 8 segments) and record these masses in Table 1 section. **Hint**: Decrease the mass to increase the number of segments.

Analyzing the Data: Change Tension

1. Calculate the tension for each different mass used (tension = mass in kilograms x ‘g’ where g = 9.8 newtons per kilogram).

2. Plot a graph of Tension vs. $1/n^2$.

- In *DataStudio*, enter the values of Tension in the Table of Tension vs. $1/n^2$. (Hint: The default values of $1/n^2$ are already in one column of the Table. Enter a value for Tension and press <tab> or <return> to move to the next cell.)

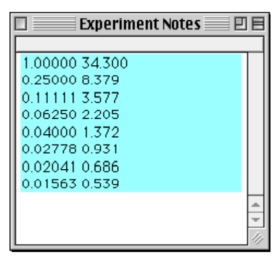


- Note: The data are automatically plotted in the Graph display of Tension vs. $1/n^2$ as the values are entered in the Table.

In *ScienceWorkshop*, do the following:

- Clear the ‘Notes’ window.
- In the ‘Notes’ window, enter the values of 1/n2 and Tension as ordered ‘X’-‘Y’ pairs. Use the following format to type in the values:

$1/n^2$ value <tab> Tension value <return>



- When the ordered pairs are entered in the ‘Notes’ window, use ‘Select All’ from the ‘Edit’ menu to highlight the data. Select ‘Copy’ from the ‘Edit’ menu to copy the data.

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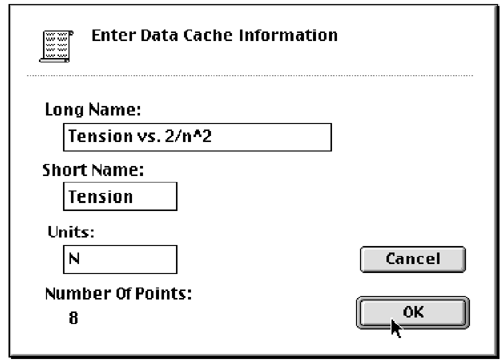
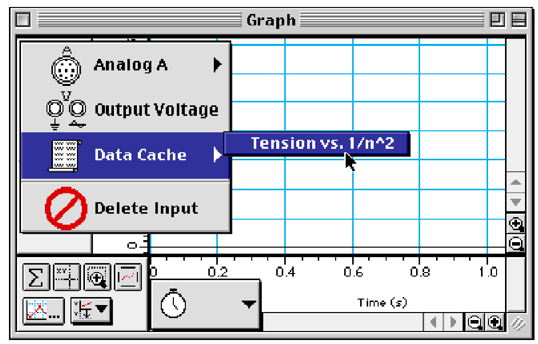
- Click the Experiment Setup window to make it active. Select ‘Paste’ from the ‘Edit’ menu to paste the data pairs into the Data list. **Result**: The ‘Enter Data Cache Information’ window opens.



- Enter a ‘Long Name’ (e.g. Tension vs. 1/n^2), a ‘Short Name’ (e.g. Tension), and ‘Units’ (e.g. N). Click ‘OK’ to return to the Experiment Setup window. **Result**: The ‘Short Name’ appears in the Data list.
- Select ‘New Graph’ from the ‘Display’ menu. **Result**: A Graph display of Current vs. Time automatically opens.
- Use the ‘Input’ menu in the Graph display to select ‘Data Cache, Tension vs. 1/n^2’. **Result**: The Graph display will show ‘Tension vs. 1/n^2’ on the vertical axis. Note: The horizontal axis shows the correct values for $1/n^2$ but the label remains ‘Time (s)’.



3. Determine the slope of the best-fit line on the Tension vs. $1/n^2$ graph.

- In *DataStudio* click the ‘Fit’ menu (Fit) and select ‘Linear’. **Result**: The slope appears in the Legend box. Note: To see the mathematical formula and its parameters, double-click the Legend box in the Graph.
- In *ScienceWorkshop*, click the ‘Statistics’ button (Σ) to open the statistics area and use the ‘Statistics Menu’ (Σ) to select ‘Curve Fit, Linear Fit’. **Result**: The coefficient ‘a2’ is the slope.

4. Using the slope, length, and frequency, calculate the linear mass density of the string. (Hint: The slope is equal to $4L^2 f^2 \mu$. Solve for the linear density.) Record the value in the Lab Report section, Table 1.
5. Calculate the percent difference between this value and the directly measured value and record it in the Lab Report, Table 3.

Part B: Change Frequency – Keep Tension and Length Constant

PART IB: Computer Setup

- Use the same setup as in the first part of this procedure.

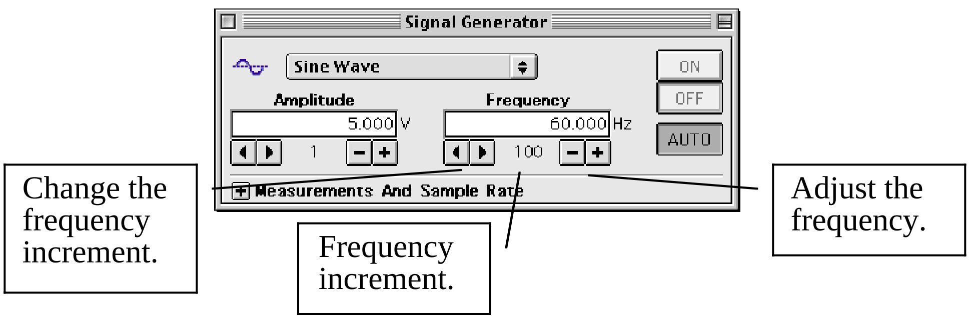
PART IIB: Sensor Calibration and Equipment Setup

- Put 500 g on the mass hanger. Calculate and record this Tension in Table 2.

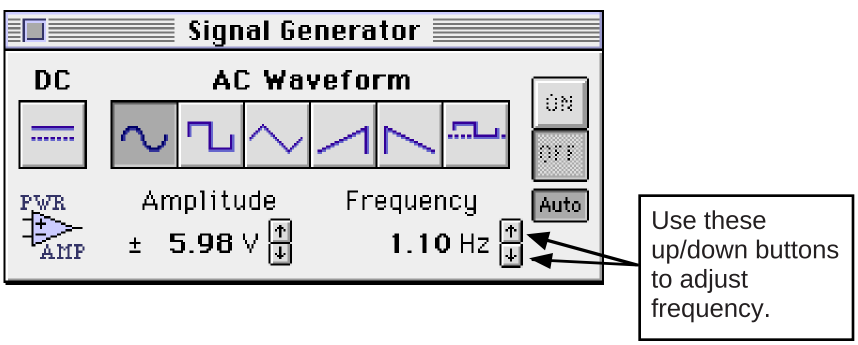
PART IIIB: Data Recording – Change Frequency

1. Vary the output frequency of the Signal Generator until the string vibrates in one segment (the fundamental frequency).

- In *DataStudio*, use the 'right-left' arrows to change the frequency increment. Use the 'minus-plus' buttons to adjust the frequency.



- In *ScienceWorkshop*, use the 'up/down' arrows to adjust the frequency.



- In *ScienceWorkshop*, adjust the amount of frequency change for each 'up/down' click with the following keys:

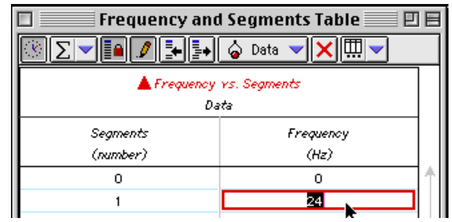
Key (with mouse click) Macintosh®	Frequency change	Key (with mouse click) Windows™
Shift key	100 Hz	Shift key
"No" key	10 Hz	"No" key
Control key	1 Hz	Ctrl (control) key
Option key	0.1 Hz	Alt key
Command key	0.01 Hz	Ctrl + Alt keys

2. Find the frequencies required for the higher harmonics (n = 2 through 7) and record these in the Lab Report section, Table 2.

Name ____________________ Class _____________ Date _________

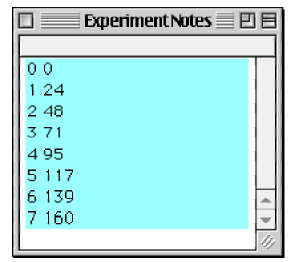
Analyzing the Data: Change Frequency – Constant Tension and Length

3. Plot a graph of Frequency vs. Segments.



- In *DataStudio*, enter the values of Frequency in the Table of Frequency vs. Segments. (Hint: The default values of ‘n’ are already in one column of the Table. Enter a value for Frequency and press <tab> or <return> to move to the next cell.)
- Note: The data are automatically plotted in the Graph display of Frequency vs. Segments as the values are entered in the Table.

In *ScienceWorkshop*, do the following:



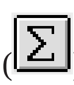
- Clear the ‘Notes’ window.
- In the ‘Notes’ window, enter the values of ‘n’ and Frequency as ordered ‘X’-‘Y’ pairs. Use the following format to type in the values:

  n value <tab> Frequency value <return>

- When the ordered pairs are entered in the ‘Notes’ window, use ‘Select All’ from the ‘Edit’ menu to highlight the data. Select ‘Copy’ from the ‘Edit’ menu to copy the data.
- Click the Experiment Setup window to make it active. Select ‘Paste’ from the ‘Edit’ menu to paste the data pairs into the Data list. **Result**: The ‘Enter Data Cache Information’ window opens.
- Enter a ‘Long Name’ (e.g. Frequency vs. n), a ‘Short Name’ (e.g. Frequency), and ‘Units’ (e.g. Hz). Click ‘OK’ to return to the Experiment Setup window. **Result**: The new ‘Short Name’ appears in the Data list.
- Use the ‘Input’ menu in the Graph display to select ‘Data Cache, Frequency vs. n’. **Result**: The Graph display will show ‘Frequency vs. n’ on the vertical axis. Note: The horizontal axis shows the correct values for n but the label remains ‘Time (s)’.

4. Determine the slope of the best-fit line on the Frequency vs. n graph.

- In *DataStudio* click the ‘Fit’ menu () and select ‘Linear’. **Result**: The slope appears in the Legend box.

- In *ScienceWorkshop*, click the ‘Statistics’ button () to open the statistics area and use the ‘Statistics Menu’ () to select ‘Curve Fit, Linear Fit’. **Result**: The coefficient ‘a2’ is the slope.

5. Using the slope, length, and frequency, calculate the linear mass density of the string. (Hint: The slope is equal to $\sqrt{\frac{T}{4L^2\mu}}$. Solve for the linear density.) Record the value in the Lab Report section, Table 1.

6. Calculate the percent difference between this value and the directly measured value and record it in the Lab Report, Table 3.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report – Activity P41: Waves on a String

What Do You Think?

The purpose of this activity is to investigate standing waves in a string. What is the relationship between the tension in the string and the number of segments in the standing wave? What is the relationship between the frequency of oscillation of the string and the number of segments in the standing wave? How can you use these relationships to find the linear mass density of the string?

Data

Table 1: Change Tension – Constant Frequency and Length

Frequency = _____ Hz

Length = _____ m

Segments, n	Mass (kg)	Tension, T (N)	$1/n^2$
1			
2			
3			
4			
5			
6			
7			
8			

Linear mass density = __________ kg/m

Table 2: Vary Frequency

Tension = ______ N

Length = ______ m

Segments, n	Frequency (Hz)
0	
1	
2	
3	
4	
5	
6	
7	

Linear mass density = ___________ kg/m

Table 3: Results

Method	Linear mass density	% difference
Direct		
Tension vs. $1/n^2$		
Frequency vs. n		

Questions

1. As the tension is increased, does the number of segments increase or decrease when the frequency is kept constant?

2. As the frequency is increased, does the number of segments increase or decrease when the tension is kept constant?

3. As the tension is increased, does the speed of the wave increase, decrease, or stay the same when the frequency is kept constant?

4. As the frequency is increased, does the speed of the wave increase, decrease, or stay the same when the tension is kept constant?

5. Suppose that String #1 is twice as dense as String #2, but both have the same tension and the same length. If each of the strings is vibrating in the fundamental mode, which string will have the higher frequency?

Name ____________________ Class _____________ Date _________

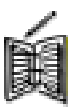
Activity P42: Sound Waves (Power Output, Sound Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Waves	P42 Sound.DS	P32 Sound Waves	P32_SOUN.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Sound Sensor (CI-6506B)	1	**Speaker (WA-9303)**	1
Musical instrument	1	***Tuning Forks (SF-9326)***	1 set

What Do You Think?

If you could see a sound, what would it look like? Would a pure musical tone look different from a scream? What about a sneeze?



Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

Most of the sounds we hear are noises. The impact of a falling object, the clapping of hands, the sound of traffic, and most of human speech are noises. Noise corresponds to an irregular vibration of the eardrum produced by some irregular vibration source.

The sound of music has a different characteristic, having more or less periodic tones produced by some regular vibration source. (Of course, musical instruments can make noise as well!) A graph representing musical sounds has a shape that repeats itself over and over again. Such graphs can be displayed on the screen of an oscilloscope when the electrical signal from a Sound Sensor is measured.

Pythagoras found that notes played together on musical instruments were pleasing to the ear when the ratios of the string lengths were the ratios of whole numbers. Galileo introduced the concept of frequency. A sequence of notes of increasing frequency makes up a musical scale. Many different scales exist. The simplest musical scale in many Western cultures is the "just major scale" (for example, "do-re-mi-fa-so-la-ti-do"). In this scale, the ratio between frequencies of two successive notes is 9:8, 10:9, or 16:15. For example, the ratio of "re" (297 Hz) to "do" (264 Hz) is 9:8 (or 1.125). Most music written in the Western world uses the "even-tempered scale", which has thirteen notes and twelve intervals. The ratio between all successive notes is exactly the same (1.05946).

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

This activity has two parts. In the first part, use the *DataStudio* or *ScienceWorkshop* program to generate output signals to a speaker. Use the Sound Sensor to measure sounds from the speaker. In the second part, use the Sound Sensor to measure sounds from an instrument such as a harmonica or recorder and from a human voice.

Use the program to monitor and display input signals measured by the Sound Sensor.

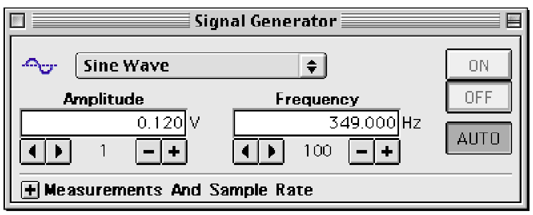
Part A: Generate Musical Tones

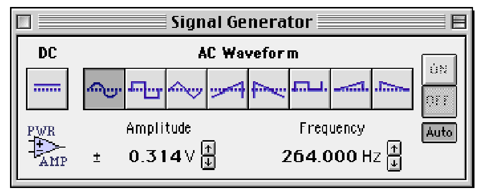
PART IA: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Sound Sensor's DIN plug to Analog Channel A.
3. Connect the speaker into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P42 Sound.DS	P32 Sound Waves	P32_SOUN.SWS

- The document opens with a Scope display and a Fast Fourier Transform (FFT) display. The Signal Generator output is set to automatically start and stop with data recording.



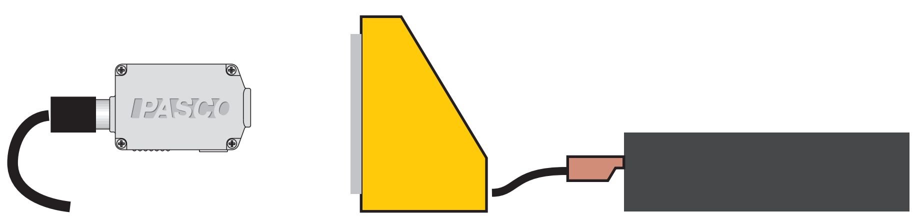


- The *DataStudio* file also has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* file also has a Signal Generator window.

PART IIA: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Sound Sensor.

1. Arrange the Sound Sensor in front of the speaker so the Sound Sensor can detect the signal.



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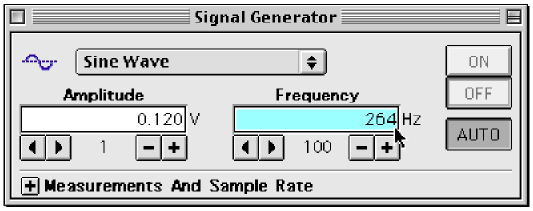
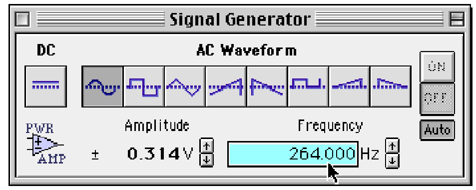
PART IIIA: Data Recording – Generate Musical Tones

1. Start recording data. (In *DataStudio*, click ‘Start’. In *ScienceWorkshop*, click ‘MON’.)

2 Hold the Sound Sensor near the speaker. Set the first Signal Generator frequency at 264 Hz (‘do’ on the ‘just major scale’).

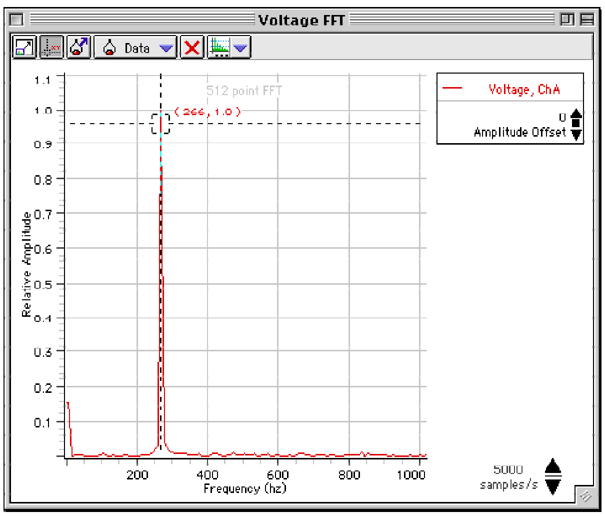
- Click the ‘Frequency’ to highlight the value and type in the new value. Press <enter> or <return> to activate the new frequency.

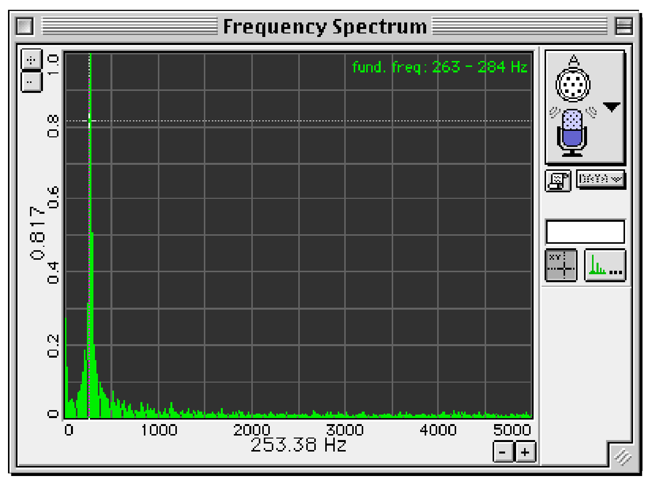




3. Examine the FFT display. Compare the value of the fundamental frequency in the FFT to the output frequency in the Signal Generator.

- Use the ‘Smart Tool’ (in *DataStudio*) or the ‘Smart Cursor’ (in *ScienceWorkshop*) to measure the fundamental frequency in the FFT.





4. Repeat the process for the rest of the frequencies in the first musical scale (the diatonic scale).

Note	Letter name	Frequency (Hz)
do	C	264
re	D	297
me	E	330
fa	F	352
so	G	396
la	A	440
ti	B	495
do	C(octave higher)	528

Diatonic C Major scale (just major scale)

5. Repeat the process for the frequencies in the second musical scale (even-tempered chromatic scale).

Note	Letter name	Frequency (Hz)
do	C	262
	C Sharp	277
re	D	294
	D Sharp	311
me	E	330
fa	F	349
	F Sharp	370
so	G	392
	G Sharp	415
la	A	440
	A Sharp	466
ti	B	494
do	C(octave higher	524

Equal-tempered Chromatic scale

6. Click ‘Stop’ to end.

Part B: Musical Instrument

PART IB: Computer Setup

1. Use the same computer setup as in Part A. However, you will not need to use the 'Output' feature. Click the 'AUTO' button in the Signal Generator window to turn off the automatic signal output.
2. Disconnect the speaker from the interface.

PART IIB: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Sound Sensor.

1. Arrange the musical instrument so you can play musical tones into the Sound Sensor.

- This part is easier to do with a partner who can run the computer and hold the Sound Sensor while you play the musical instrument.

PART IIIB: Data Recording – Musical Instrument

1. Start recording data. (Remember: Click 'MON' in *ScienceWorkshop*.) The data should appear in the Scope and FFT displays.
2. Play a single note (for example, middle C) into the Sound Sensor.
3. Examine the waveform of the musical sound in the Scope display.
4. Measure the fundamental frequency in the FFT display. If the waveform has harmonic frequencies, use the 'Smart Tool' or 'Smart Cursor' to measure and record them as well.

   How can you distinguish the harmonics from the fundamental frequency in the FFT display?
5. Repeat the process for a different note.
6. Click 'Stop' to end.

Part C: Voice

PART IC: Computer Setup

- Use the same computer setup as in Part B.

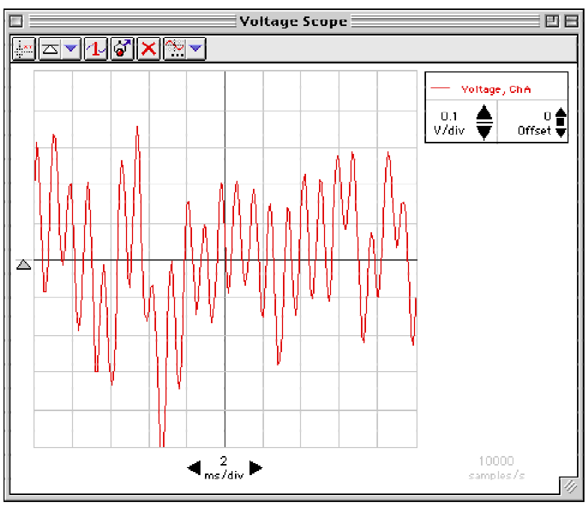
PART IIC: Sensor Calibration and Equipment Setup

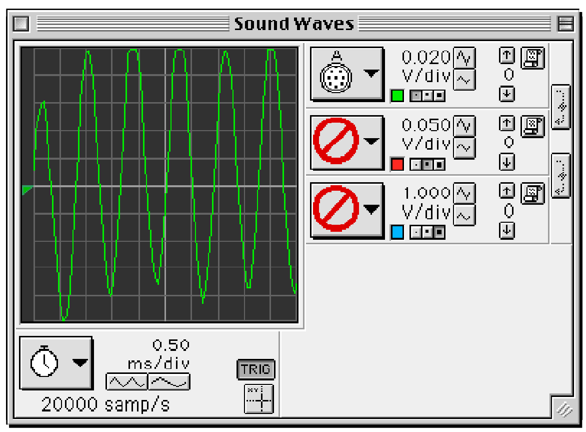
- You do not need to calibrate the Sound Sensor

1. Arrange the Sound Sensor so it will be able to record your voice.

PART IIIC: Data Recording – Voice

1. Start recording data. (Remember: Click 'MON' in *ScienceWorkshop*.) The data should appear in the Scope and FFT displays.
2. "Sing" a single tone into the Sound Sensor.
3. Examine the waveform of your singing in the Scope display. Experiment by trying different vowel sounds at approximately the same pitch. For example, switch from "OO" to "EE" to "AH" to "UU" to "AY". Try other mouth shapes.
4. Measure the fundamental and harmonic frequencies in the FFT display.
5. "Whistle" a single note into the sensor. Examine the waveform in the Scope and measure the fundamental and harmonic frequencies in the FFT display.





6. Change the pitch of your whistle. Examine the waveform and measure the frequencies.
7. Stop monitoring data.

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Lab Report – Activity P42: Sound Waves

What Do You Think?

If you could see a sound, what would it look like? Would a pure musical tone look different from a scream? What about a sneeze?

Questions

Analyzing the Data: Generate Musical Tones

1. How do the notes in the diatonic scale sound compared to the notes in the chromatic scale?

2. Do any of the notes in either scale have harmonic frequencies?

Analyzing the Data: Musical Instrument

1. Describe the waveform of a single note on the musical instrument. Does it have harmonic frequencies?

2. If the note has harmonic frequencies, how does the value of each harmonic compare to the value of the fundamental frequency?

Analyzing the Data: Voice

1. Describe the waveform of one of your singing tones. Does it have harmonic frequencies?

2. How does the waveform of one of your singing tones compare to the waveform of a single note from the musical instrument?

3. If the tone has harmonic frequencies, how does the value of each harmonic compare to the value of the fundamental frequency?

4. Which vowel sounds have the least complex waveform? The most complex?

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Activity P43 Resonance Modes – Sonometer
Resonance Modes of a Stretched String
(Power Amplifier, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Waves	P43 Sonometer.DS	P34 Resonance Modes 1	P34_SONO.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Power Amplifier (CI-6552)	1	Mass Set (SE-8705)	1
Voltage Sensor (CI-6503)	1	Sonometer with Coils (WA-9757)	1

What Do You Think?

A string on a musical instrument such as a guitar will vibrate at a specific frequency when plucked. The string vibrates at a different frequency if the length or tension is changed.

If the tension of the string is constant, what the relationship is between the length of a stretched string and the frequencies at which resonance occurs?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

Standing Waves

A simple sine wave traveling along a stretched string can be described by the equation:

$$y_1 = y_m \sin 2\pi\left(\frac{x}{\lambda} - \frac{t}{n}\right)$$

where **y** is amplitude, $\mathbf{y_m}$ is maximum amplitude, **x** is horizontal distance, λ is wavelength, **t** is time, and **n** is the number of antinodes.

If the string is fixed at one end, the wave will be reflected back when it strikes that end. The reflected wave will then interfere with the original wave. The reflected wave can be described by the equation:

$$y_2 = y_m \sin 2\pi\left(\frac{x}{\lambda} + \frac{t}{n}\right)$$

Assuming the amplitudes of these waves are small enough so that the elastic limit of the string is not exceeded, the resultant waveform will be just the sum of the two waves:

$$y = 2y_m \sin 2\pi\left(\frac{x}{\lambda}\right)\cos 2\pi\left(\frac{t}{\lambda}\right)$$

This equation has some interesting characteristics. At a fixed time, $\mathbf{t_0}$, the shape of the string is a sine wave with a maximum amplitude of:

$$y = 2y_m \cos 2\pi\left(\frac{t_0}{\lambda}\right)$$

At a fixed position on the string, $\mathbf{x_0}$, the string is undergoing simple harmonic motion, with an amplitude of

$$y = 2y_m \sin 2\pi\left(\frac{x_0}{\lambda}\right)$$

Therefore, at points of the string where $\mathbf{x_0 = \lambda/4,\ 3\lambda/4,\ 5\lambda/4,\ 7\lambda/4}$, etc., the amplitude of the oscillations will be a maximum (oscillations from both waves reinforce each other). At points of the string where $\mathbf{x_0 = \lambda/2,\ \lambda,\ 3\lambda/2,\ 2\lambda}$, etc., the amplitude of the oscillations will be zero (oscillations from both waves cancel each other).

This waveform is called a **standing wave** because there is no propagation of the waveform along the string. Each point of the string oscillates up and down with its amplitude determined by whether the interfering waves are reinforcing or canceling each other. The points of maximum amplitude are called antinodes. The points of zero amplitude are called nodes.

Resonance

The analysis above assumes that the standing wave is formed by the superposition of an original wave and one reflected wave. In fact, if the string is fixed at both ends, each wave will be reflected every time it reaches either end of the string. In general, the multiple reflected waves will not all be in phase, and the amplitude of the wave pattern will be small. However, at certain frequencies of oscillation, all the reflected waves are in phase, resulting in a very high amplitude standing wave. These frequencies are called **resonant frequencies**.

In this activity, the relationship between the length of the string and the frequencies at which resonance occurs is investigated. It is shown that the conditions for resonance are more easily understood in terms of the wavelength of the wave pattern, rather than in terms of the frequency.

In general, resonance occurs when the wavelength (λ) satisfies the condition:

$$\lambda = 2L/n; \qquad n = 1,\ 2,\ 3,\ 4,\ldots$$

Another way of stating this same relationship is to say that the length of the string is equal to an integral number of half wavelengths. This means that the standing wave is such that a node of the wave pattern exists naturally at each fixed end of the string.

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

For You To Do

In this activity, use a Driver Coil connected to the Power Amplifier to vibrate a thin wire that is stretched over two “bridges” on a Sonometer. Use the Signal Generator in *ScienceWorkshop* or *DataStudio* controls the frequency at which the wire is vibrated. Use a Voltage Sensor connected to the Detector Coil on the Sonometer to measure the amplitude of the vibrating wire.

Use the *ScienceWorkshop* or *DataStudio* program to display the output signal that controls the Driver Coil, and the input signal from the Detector Coil. Determine the resonant frequencies of the stretched wire by watching the amplitude of the input signal from the Detector Coil.

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PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor DIN plug to Analog Channel A of the interface.
3. Connect the Power Amplifier to Analog Channel B of the interface.
4. Open the document titled as shown:

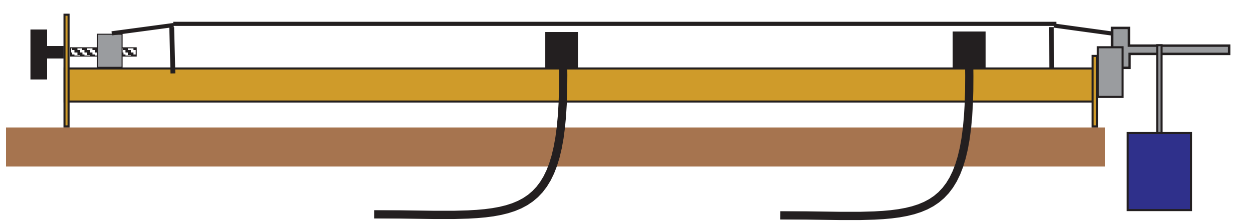
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P43 Sonometer.DS	P34 Resonance Modes 1	P34_SONO.SWS

- The *ScienceWorkshop* document opens with the Signal Generator window, a Scope display, and a Frequency Spectrum (FFT) display.
- The *DataStudio* document also has a Workbook display. Read the instructions in the Workbook.
- The Scope display is set to show the voltage from the Power Amplifier (Output Voltage) and the voltage from the detector coil (Voltage, ChA).

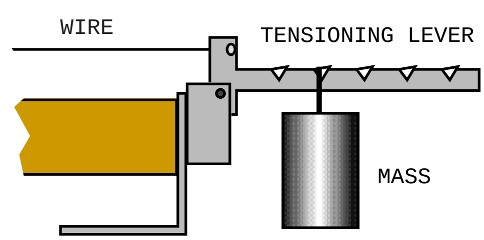
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor or Power Amplifier.

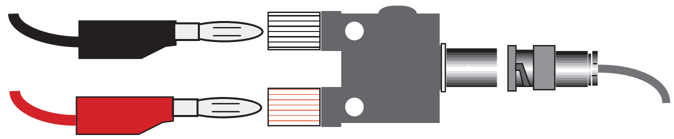
1. Set the Sonometer at the edge of a table so the tensioning lever extends beyond the table.



2. Start with the bridges 60 cm apart. Select one of the wires that is included with the Sonometer. Attach the wire to the peg on the cylinder with the string adjustment knob, and to the rounded slot in the vertical section of the tensioning lever.
3. Hang a mass of approximately 1 kg from the SECOND notch in the tensioning lever. Use the string adjustment knob to tighten or loosen the wire until the tensioning lever is horizontal.



4. Position the Driver Coil approximately 5 cm from one of the bridges. Connect the Driver Coil banana plugs into the Power Amplifier output jacks.



5. Position the Detector Coil near the center of the wire between the two bridges. Attach the BNC connector on the Detector Coil cable to the BNC-to-banana-jack Adapter Plug. Connect the Voltage Sensor banana plugs into the jacks on the Adapter Plug.

6. Calculate the tension in the wire by multiplying the number of the notch on the tensioning lever by the weight of the hanging mass (mass (kg) x 9.8 N/kg).

7. Record the length, tension, and linear density of the wire in the Lab Report section.

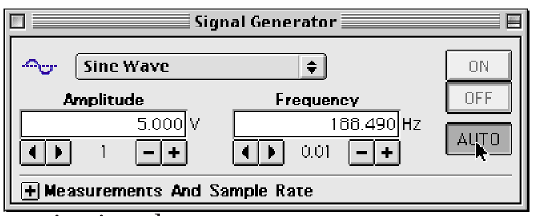
PART IIIA: Data Recording – Fundamental Frequency

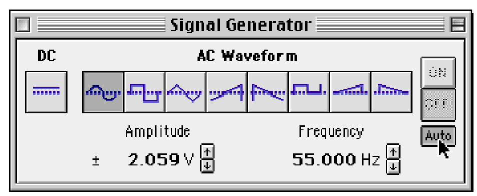
Fundamental Frequency

- The fundamental frequency is the natural frequency at which the wire vibrates when it is plucked.

1. Use the Frequency Spectrum (FFT) display to measure the approximate value of the fundamental frequency of the wire on the Sonometer.

- Turn *off* the 'automatic signal output'. Click 'AUTO' in the Signal Generator window to turn off the automatic signal output feature temporarily.
- Start measuring. Click 'MON' in *ScienceWorkshop* or 'Start' in *DataStudio* to begin





monitoring data.

- Pluck the wire near the center of its length. As the wire vibrates, the Frequency Spectrum (FFT) display will show the fundamental frequency recorded by the detector coil. Use the 'Smart Cursor' (*ScienceWorkshop*) or 'Smart Tool' (*DataStudio*) to find the fundamental frequency of the wire.
- Click 'STOP' to end the measuring.

2. Set up the Signal Generator. Click the Signal Generator window to make it active and set the frequency in the Signal Generator window at a value that is approximately <u>one-half of the fundamental frequency of the wire</u>. (For example, if the approximate fundamental frequency is 110 Hz, set the frequency in the Signal Generator window to 55 Hz.)

- Turn *on* the 'automatic signal output'. Click 'AUTO' in the Signal Generator to turn the automatic signal output feature back on.

- NOTE: The reason that the driving frequency in the Signal Generator should be approximately one-half of the fundamental frequency is because the driver coil (an electromagnet) pulls on the metal wire TWICE per cycle. Therefore, if you set the driving frequency at 60 Hz, the wire will vibrate at 120 Hz.

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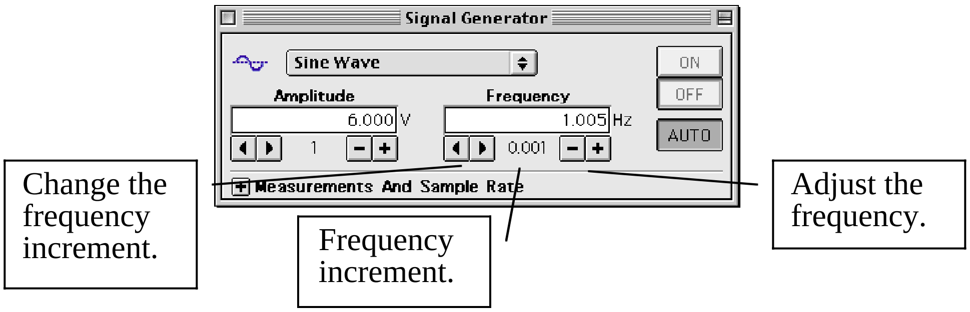
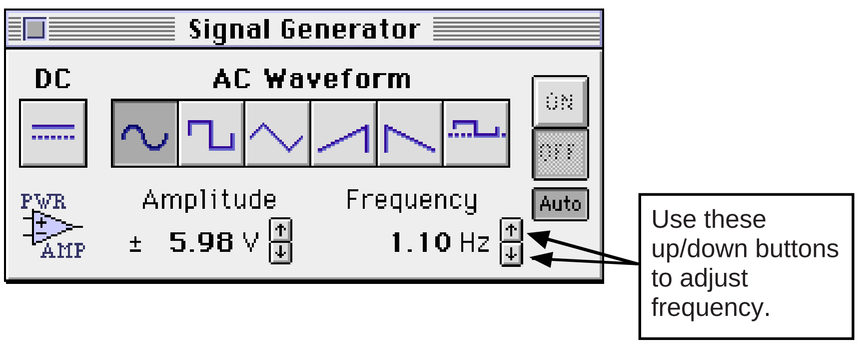
Frequency Adjustment

- In the Signal Generator window, you can enter a value for frequency from the keyboard. Click on the value of frequency to highlight it. Type in the new value and press <return> or <enter> to accept the value.
- You can also adjust the frequency in the Signal Generator by using the cursor.
- In *DataStudio*, click the ‘right-left’ arrows to change the frequency increment. Click the ‘minus-plus’ buttons to adjust the frequency.



- In *ScienceWorkshop*, click the ‘up/down’ arrows to adjust the frequency.



- In *ScienceWorkshop*, adjust the amount of frequency change for each ‘up/down’ click with the following keys:

Key (with mouse click) Macintosh®	**Frequency change**	**Key (with mouse click) Windows™**
Shift key	100 Hz	Shift key
“No” key	10 Hz	“No” key
Control key	1 Hz	Ctrl (control) key
Option key	0.1 Hz	Alt key
Command key	0.01 Hz	Ctrl + Alt keys

Record the Fundamental Resonant Mode

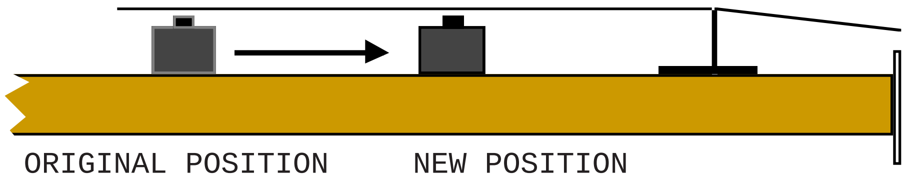
1. Click ‘MON’ or ‘Start’ to begin measuring again. Observe the middle area of the wire, and the traces on the Scope display.

- Frequencies that result in maximum amplitude (string vibration) are resonant frequencies. When resonance occurs, the voltage from the Detector Coil will be at its maximum amplitude.

2. Slightly adjust the signal frequency up and down. Watch the wire and the traces on the Scope. The lowest frequency at which resonance (and maximum amplitude) occurs is the first, or fundamental, resonant mode. When you are satisfied that the wire is in its fundamental resonant mode, record the Signal Generator frequency.

Second Resonant Mode

3. Find the second resonant mode. Slide the detector coil away from the driver coil so the detector coil is at a position about three-fourths of the distance between the bridges.



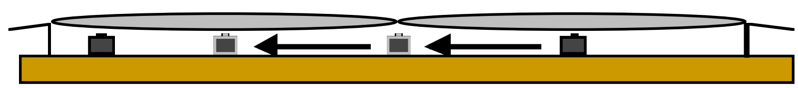
4. Set the Signal Generator frequency to <u>twice</u> its original frequency. Observe the vibrating wire. Adjust the frequency up and down until you are satisfied that the wire is in its second resonant mode. Record the Signal Generator frequency. Calculate and record the frequency at which the wire is vibrating.

Remember that the Signal Generator frequency is one-half the *wire's* vibration frequency.

Measure Antinode Positions

5. Slightly adjust the position of the detector coil back and forth. Observe the change in amplitude of the trace on the Scope display. When you are satisfied that the detector coil is beneath an <u>antinode</u> on the wire, record the position of the detector coil. Slide the detector coil toward the center position so it is beneath a node on the wire (where the voltage from the detector is at its minimum amplitude).

Continue to slide the detector coil until it is beneath another antinode (at approximately one-fourth the distance between bridges). Watch the amplitude of voltage on the Scope display.



- When you are satisfied that the detector coil is beneath an antinode, record the position of the detector coil.

NOTE: The distance between antinodes is one-HALF wavelength.

Higher Resonant Modes

6. Record the Signal Generator frequencies and the distances between adjacent antinodes for the next three resonant modes by adjusting the frequency in the Signal Generator window and by sliding the detector coil from one antinode to the next antinode.

7. From your results, calculate and record the wire's vibration frequency and the wavelength of each resonance pattern you discovered. (Remember that adjacent nodes are one-half wavelength apart.)

Record your data in the Lab Report section

Name ____________________ Class ______________ Date _________

Lab Report – Activity P43: Resonance Modes-Sonometer

What Do You Think?

A string on a musical instrument such as a guitar will vibrate at a specific frequency when plucked. The string vibrates at a different frequency if the length or tension is changed.

If the tension of the string is constant, what the relationship is between the length of a stretched string and the frequencies at which resonance occurs?

Data

Distance between bridges = m

Linear density = g/m

Tension (notch x mass x 'g') = N

Mode	Sig. Gen. Freq. (Hz)	Wire Freq. (Hz)	Antinode distance (m)	Wavelength (m)
first				
second				
third				
fourth				
fifth				

Questions

1. What do you think the relationship is between the length of a stretched string and the frequencies at which resonance occurs?

2. What is the shape of each resonant waveform?

3. What is the relationship between the number of antinode segments and the number of the resonant mode?

4. What is the relationship between the wavelength and the frequency for each resonant mode?

.

5. What is the mathematical relationship between the lowest resonant frequency and the higher frequencies at which resonance occurred?

Name ____________________ Class _____________ Date _________

Activity P44: Resonant Modes - Tube

Resonant Modes of a Column of Air

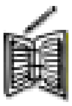
(Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Waves	P44 Resonance.DS	P35 Resonance Modes 2	P35_TUBE.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Voltage Sensor (CI-6503)	1	**Resonance Tube (WA-9612)**	1
Patch Cords (SE-9750)	2		

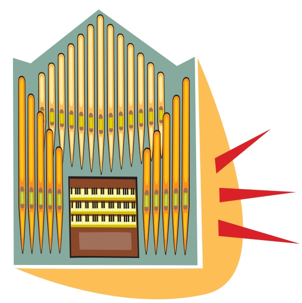
What Do You Think?

Disturbing the air in a tube or column can create a variety of frequencies. What are some common applications of this phenomenon?



Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background



When a tuning fork or a speaker vibrates near a tube, there are certain frequencies of sound at which the tube will resonate (vibrate at the same frequency or multiples of the frequency of the tuning fork or speaker). A standing wave occurs in the tube when a wave is reflected from the end of the tube and the return wave interferes with an on-coming wave. When a single pulse is generated at one end of the tube, the pulse will reflect several times back and forth between the ends of a tube. If we continue to drive the sound with a source, all the multiple reflections interfere with each other.

At **resonant** frequencies the reflected waves are in phase resulting in a high amplitude (loud) standing wave. At frequencies other than a tube's resonant frequency, the multiple reflected waves will not be in phase and the sound will not be as loud. These resonant frequencies occur at various lengths for either an open end or closed end tube.

Like a standing wave on a string or wire, a standing sound wave has nodes and antinodes. A displacement node in a standing sound wave is a point where the air does not vibrate very much. A displacement antinode is a point where the movement of the air is a maximum. Pressure nodes and antinodes also exist in a standing sound wave. A pressure antinode occurs at a displacement node. Think of a pressure antinode as being the point located halfway between two displacement antinodes. When the air molecules of the two displacement antinodes are moving toward each other, the pressure of the pressure antinode in the middle is a maximum. Likewise, a pressure node occurs where the air molecules are most dispersed, namely, a displacement antinode.

Reflection of a sound wave can occur at both open and closed tube ends. If the end of the tube is closed, the air has nowhere to go, so a displacement node must exist. If the end of the tube is open, the pressure stays very nearly at room pressure, so a pressure node exists.

This activity investigates the relationship between the length of the tube and the frequencies at which resonance occur. The conditions for **resonance** are more easily understood in terms of the wavelength of the wave pattern, rather than in terms of the frequency. The resonant states also depend on whether the ends of the tube are open or closed.

For an **Open Tube** (open at both ends), resonance occurs when the wavelength (λ) satisfies the condition:

$$\lambda = \frac{2L}{n}; \quad \mathbf{n = 1, 2, 3, 4, \ldots}$$

where **L** equals the tube's length. Another way of stating this same relationship is to say that the length of the tube is equal to an integral number of half wavelengths.

$$L = \frac{n}{2}\lambda$$

For a **Closed Tube** (open at only one end), resonance occurs when the wavelength (λ) satisfies the condition:

$$\lambda = \frac{4L}{n}; \quad \mathbf{n = 1, 3, 5, 7, \ldots}$$

where **L** equals tube length. Another way of stating this same relationship is to say that the length of the tube is equal to an odd number of quarter wavelengths.

$$L = \frac{4}{n}\lambda; \quad \mathbf{n = 1, 3, 5, 7, \ldots}$$

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Investigate open and closed tube resonant modes.

Use the 'Output' feature of the interface to drive a speaker to vibrate the air inside the Resonance Tube. Use *DataStudio* or *ScienceWorkshop* to control the speaker's output frequency with the Signal Generator window. Use the microphone mounted in the Resonance Tube to measure the amplitude of sound. Use the Voltage Sensor to measure the signal from the microphone.

Use *DataStudio* or *ScienceWorkshop* to display the output signal of the speaker and the input signal from the microphone. Determine the relationship between the resonant frequencies for the column of air inside the tube when it is open and when it is closed.

PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor DIN plug to Channel A of the interface.
3. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P44 Resonance.DS	P35 Resonance Modes 2	P35_TUBE.SWS

- The document opens with the Signal Generator window, a Scope display, and a Frequency Spectrum (FFT) display.

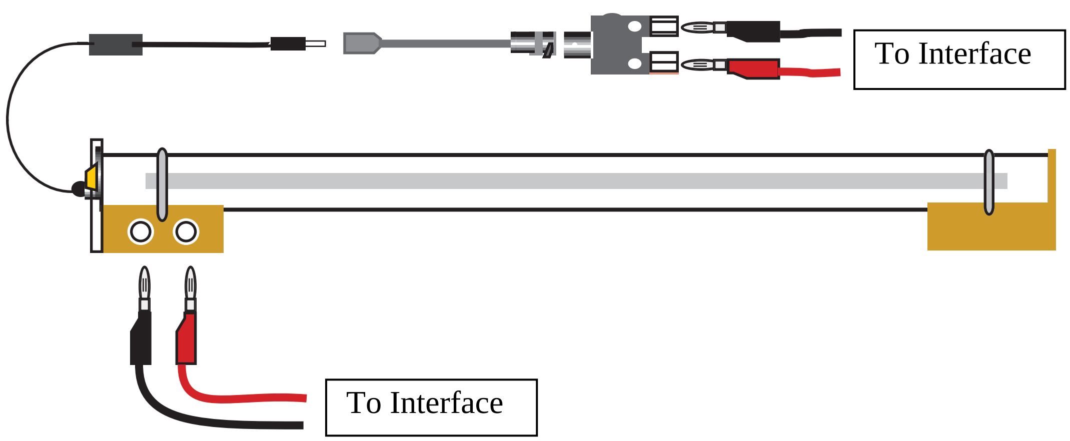
Name ____________________ Class ______________ Date __________

- The *DataStudio* document also has a Workbook display. Read the instructions in the Workbook.
- The Scope display will show the voltage from the 'Output' of the interface to the speaker on the Resonance Tube and the input voltage from the microphone connected to the Resonance Tube. The Frequency Spectrum (FFT) display will show the input voltage from the microphone.
- The Signal Generator is set to produce a sine wave. It is set to 'Auto' so it will automatically start or stop the signal when you start or stop measuring data.

PART II: Sensor Calibration and Equipment Setup for Open Tube Resonance

- You do not need to calibrate the Voltage Sensor.

1. Set up the Resonance Tube on a level surface. You will not need the piston for the first part of this activity, but you will use it during the second part. Remove the support from the tube at the end that does not have the speaker.
2. Connect patch cords from the 'OUTPUT' ports of the interface to the speaker jacks on the Resonance Tube.
3. Make sure that a fresh battery is installed in the microphone (part number 23-115 from Radio Shack, or its equivalent). Place the microphone in the small hole below the speaker. Use the thumbscrew on the side of the speaker assembly to hold the microphone in place.
4. Connect the microphone plug into the Mini-phone-jack-to-BNC adapter cable (included with the Resonance Tube). Connect the BNC adapter cable into the BNC ADAPTER PLUG (also included with the Resonance Tube).
5. Connect the Voltage Sensor banana plugs into the BNC ADAPTER PLUG.



PART IIIA: Data Recording – Open Tube

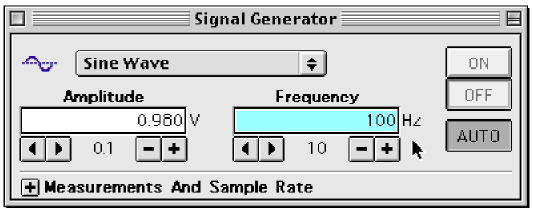
- The operation of the Scope, FFT, and Signal Generator displays are similar to both *DataStudio* and *ScienceWorkshop*.

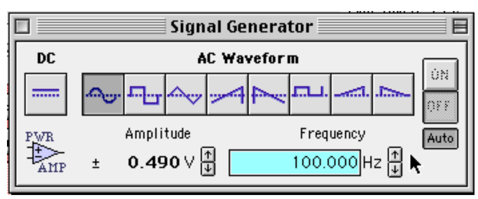
- **WARNING:** You can damage the speaker by overdriving it (increasing the amplitude too much). The sound from the speaker should be *barely* audible. Please keep the amplitude in the Signal Generator window at 0.98 volts or less.

1. Begin measuring data. (Click 'Start' in *DataStudio* or click 'MON' in *ScienceWorkshop*.)

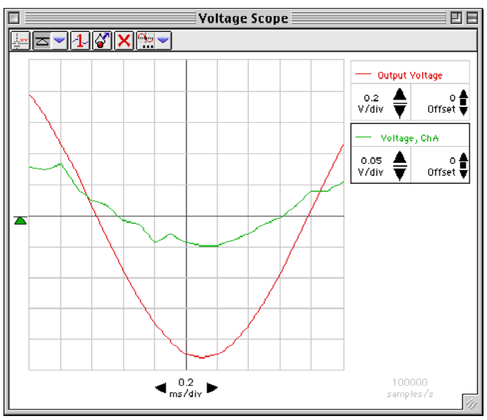
- The Signal Generator will begin automatically.

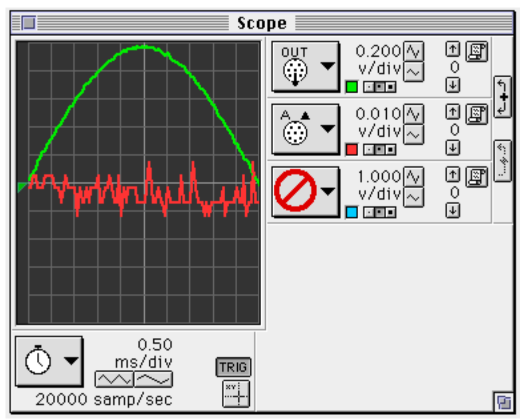
2. Set the frequency in the Signal Generator to 100 Hz. Enter the value for frequency from the keyboard. Click on the value of frequency to highlight it. Type in the new value and press <return> or <enter> to accept the value.





- The Scope displays the 'Output' signal from the interface and the input signal from the microphone.

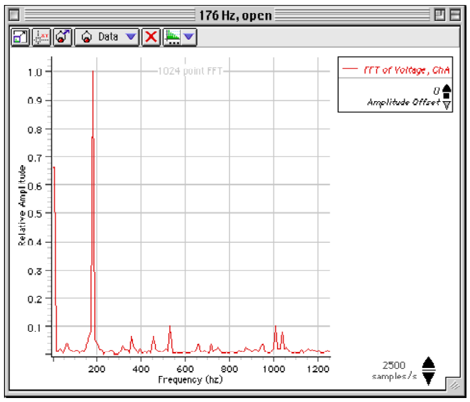


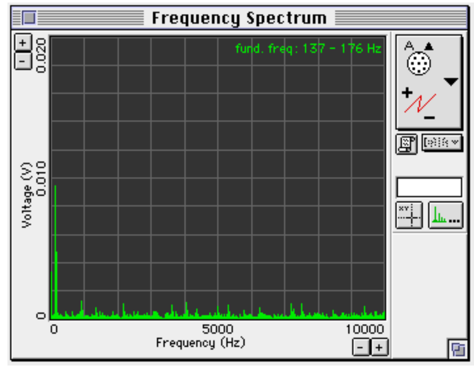


3. Find the resonant frequencies. Use the Signal Generator window to gradually change the frequency. Carefully listen to the speaker and watch the Scope and FFT displays.

- First, listen. In general, the sound will become louder as you increase the frequency because the speaker is more efficient at higher frequencies. However, listen for a *relative* maximum in the sound level – a frequency where there is a slight decrease in the sound level as you increase the frequency slightly. This relative maximum indicates a *resonance mode* in the tube. Adjust the frequency carefully to find the lowest frequency at which a relative maximum occurs.

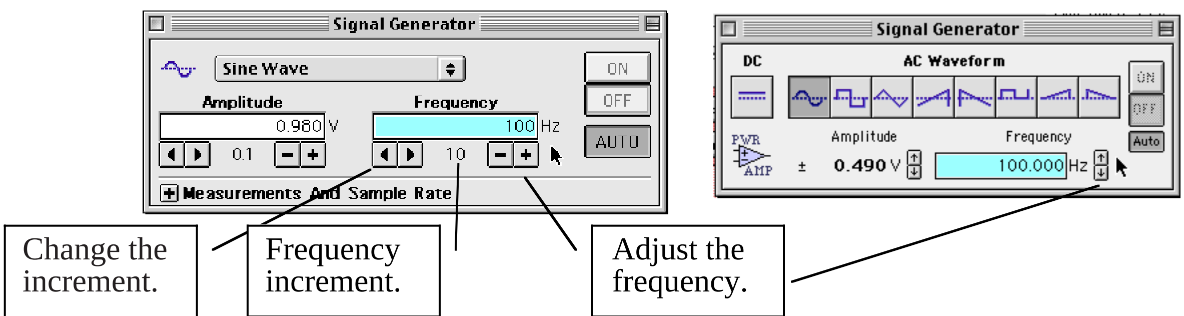
- Second, use the FFT display. The FFT display shows the signal from the microphone. The fundamental frequency will grow in height if the frequency is a *resonant frequency*. As the peak begins to grow, adjust the frequency in smaller steps. If you think you have reached a resonant frequency, adjust the frequency to a value slightly above and then slightly below the resonant frequency. The peak will decrease at frequencies that are slightly higher or lower than the resonant frequency.





Frequency Adjustment

- In the Signal Generator window, you can enter a value for frequency from the keyboard. Click on the value of frequency to highlight it. Type in the new value and press <return> or

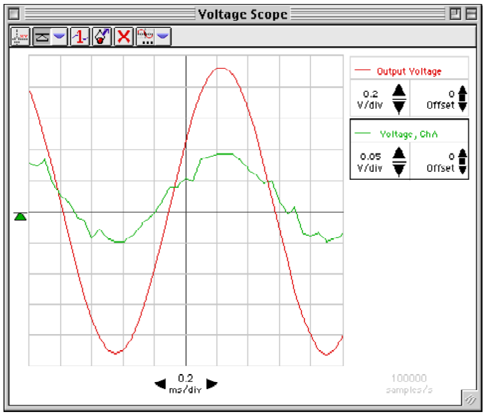


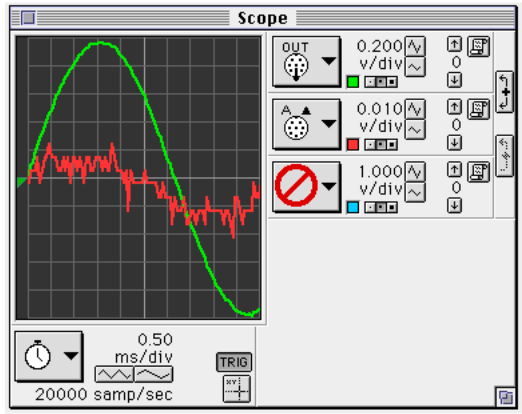
<enter> to accept the value.

- You can also adjust the frequency in the Signal Generator by using the cursor.
- In *DataStudio*, click the 'right-left' arrows to change the frequency increment. Click the 'minus-plus' buttons to adjust the frequency.
- In *ScienceWorkshop*, click the 'up/down' arrows to adjust the frequency.
- In *ScienceWorkshop*, adjust the amount of frequency change for each 'up/down' click with the following keys:

Key (with mouse click)	Frequency change	Key (with mouse click)
Macintosh®		**Windows™**
Shift key	100 Hz	Shift key
"No" key	10 Hz	"No" key
Control key	1 Hz	Ctrl (control) key
Option key	0.1 Hz	Alt key
Command key	0.01 Hz	Ctrl + Alt keys

- Finally, use the Scope display. You can also find the relative maximum by watching the trace on the Scope display. When the input signal is a maximum height, you have reached a resonant frequency.





4. Record the value of this lowest resonant frequency as ν_o in the Data section.
5. Raise the frequency slowly until you find a new resonant frequency. Again measure and record the frequency.
6. Continue finding still higher resonant frequencies. Find at least five.
7. Stop measuring data when you are done with this part of the activity.

PART IIIB: Data Recording – Closed Tube

1. Put the piston through the hole on the support bracket that goes on the end of the tube without the speaker. Put the piston into the open end of the tube, and put the support bracket onto the Resonance Tube. Position the piston at the 70 centimeter mark inside the tube.
2. Click on the Signal Generator window to make it active. Type in 60 Hz as the beginning frequency.
3. Begin measuring data.
4. Repeat the steps for finding each resonant frequency. Record the frequencies in the Data section.

Analyzing the Data

1. For each tube configuration (open and closed) divide each of your resonant frequencies (ν) by the lowest resonant frequency (ν_o) that you were able to find. Record this series for each tube configuration.

- If you do not get a series of whole numbers, you may not have found the lowest resonant frequency for the tube. If this is the case, try to use your results to determine what the lowest resonant frequency would have been, had you been able to detect it.

Record your data in the Lab Report section

Name ____________________ Class _____________ Date _________

Lab Report – Activity P35: Resonant Modes – Tube

What do you think?

Disturbing the air near a tube or column can create a variety of frequencies. What are some common applications of this phenomenon?

Data

	Lowest resonant frequency (ν_o), Hz
Open tube	
Closed tube	

Resonance Frequencies – Open Tube		Resonance Frequencies – Closed Tube	
ν (Hz)	ratio (ν/ν_0)	ν (Hz)	ratio (ν/ν_0)

Questions

1. Is the number series you determined the same for both closed and open tubes?

2. Which tube configuration gives a series of consecutive whole numbers?

3. How do you explain your results in terms of the types of standing wave patterns that are excited in each tube configuration?

4. Is there a node or an antinode at a closed end of the tube?

5. Is there a node or an antinode at an open end of the tube?

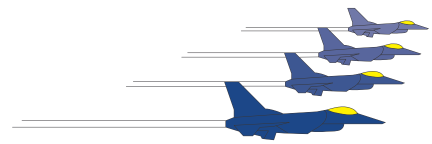
Name ____________________ Class ______________ Date _________

Activity P45: Resonant Modes and the Speed of Sound (Voltage Sensor, Power Output)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Waves	P45 Speed of Sound 2.DS	P36 Speed of Sound	P36_MACH.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Voltage Sensor (CI-6503)	1	Resonance Tube (WA-9612)	1
Patch Cords (SE-9750)	2		

What Do You Think?



The speed of sound can be determined by various methods. How can you calculate the speed of sound in a column of air inside a tube?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

For a given frequency of sound in a resonance tube, there are a variety of tube lengths at which a standing wave will be formed. Likewise, for any given tube length, there are a variety of resonant frequencies—frequencies at which standing waves will be formed in the tube. In general, if the sound frequency is many times higher than the lowest resonant frequency (the fundamental frequency) for the tube, there will be several nodes and antinodes in the standing wave. For an open tube, the distance between successive antinodes in a standing wave is one-half wavelength.

The speed of sound is the product of the wavelength and the frequency, or $v = \lambda \times f$ where **v** is the speed of sound, λ is the wavelength, and ***f*** is the frequency.

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

For You To Do

Use the 'Output' feature of the interface to drive a speaker to vibrate the air inside a Resonance Tube at a fixed frequency (1000 Hz). Use *DataStudio* or *ScienceWorkshop* to control the speaker's output frequency with the Signal Generator. Use a microphone mounted in the Resonance Tube to measure the amplitude of sound. Use the Voltage Sensor to measure the signal from the microphone. Use a piston inside the tube is used to adjust the length of the column of air inside the tube.

Use the software to display the output signal of the speaker, and the input signal from the microphone. Change the position of the piston to determine the distances between successive antinodes in the standing sound waves that occur inside the tube. Use the distance to determine the wavelength of the sound and then calculate the speed of sound.

PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor DIN plug to Channel A of the interface.
3. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

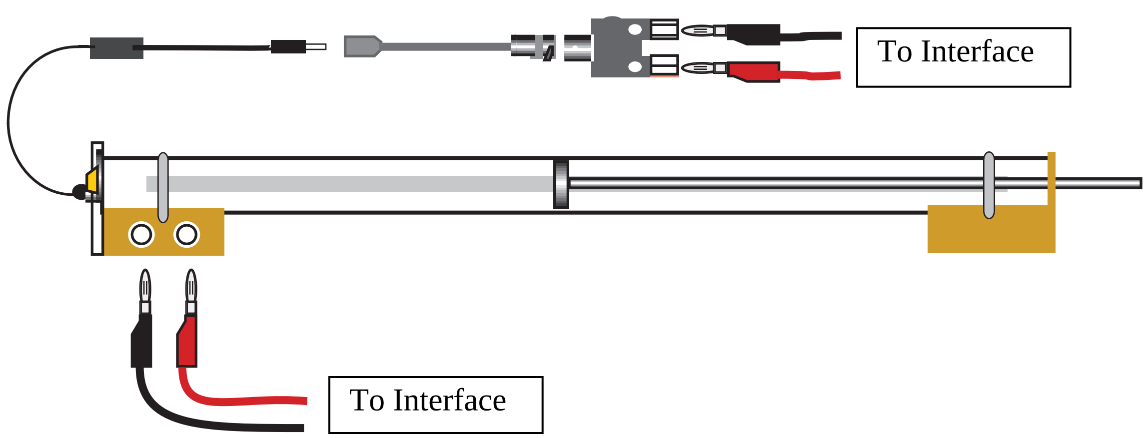
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P45 Speed of Sound 2.DS	P36 Speed of Sound	P36_MACH.SWS

- The document opens with the Signal Generator window, a Scope display, and a Frequency Spectrum (FFT) display.
- The *DataStudio* document also has a Workbook display. Read the instructions in the Workbook.
- The Scope display will show the voltage from the 'Output' of the interface to the speaker on the Resonance Tube and the input voltage from the microphone connected to the Resonance Tube. The Frequency Spectrum (FFT) display will show the input voltage from the microphone.
- The Signal Generator is set to produce a sine wave at 1000 Hz. It is set to 'Auto' so it will automatically start or stop the signal when you start or stop measuring data.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.

1. Set up the Resonance Tube on a level surface. Place the piston inside the tube. Put the piston rod through the hole in the support and mount the tube into the support using the elastic cord. Position the piston at the *80 centimeter* mark inside the Resonance Tube.
2. Connect patch cords from the 'OUTPUT' ports of the interface to the speaker jacks on the Resonance Tube.
3. Make sure that a fresh battery is installed in the microphone (part number 23-115 from Radio Shack, or its equivalent). Place the microphone in the small hole below the speaker. Use the thumbscrew on the side of the speaker assembly to hold the microphone in place.



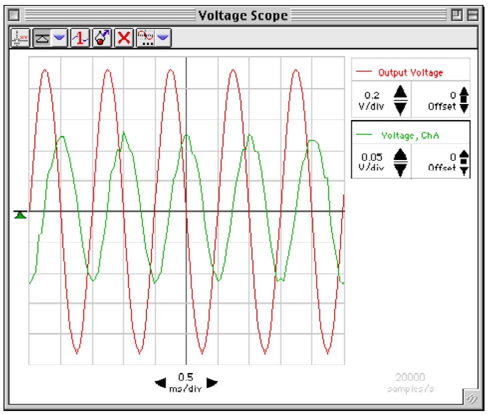
4. Connect the microphone plug into the Mini-phone-jack-to-BNC adapter cable (included with the Resonance Tube). Connect the BNC adapter cable into the BNC ADAPTER PLUG (also included with the Resonance Tube).
5. Connect the Voltage Sensor banana plugs into the BNC ADAPTER PLUG.

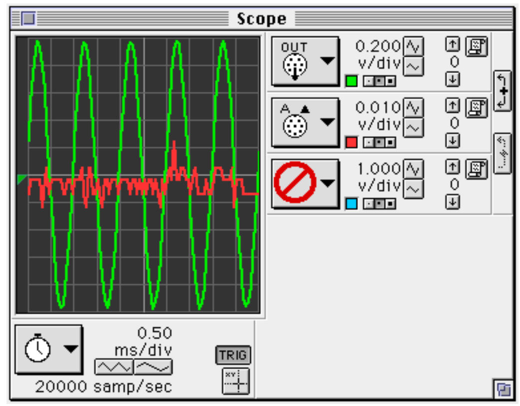
PART IIIA: Data Recording

- **WARNING:** You can damage the speaker by overdriving it (increasing the amplitude too much). The sound from the speaker should be barely audible. Please keep the amplitude at 0.98 volts.

1. Begin measuring data. (Click 'Start' *DataStudio* or 'MON' in *ScienceWorkshop*.)

- The Signal Generator will begin automatically. The Scope will display the output signal from the Power Amplifier and the input signal from the microphone.





2. Determine the position of the first antinode in the standing wave inside the tube. Slowly push the piston further into the tube.

- First, listen for an increase in the sound from the speaker indicating that you have produced a standing wave in the tube.
- Also watch the signal on the Scope display. The input signal from the microphone reaches a maximum when the length of the column of air is adjusted so there is an antinode at the microphone.
- Finally, check the height of the fundamental frequency in the Frequency Spectrum (FFT) display.

3. Adjust the piston position carefully until you are satisfied that the piston is at the point which produces the loudest sound as well as the largest signal on the Scope and FFT displays. Record the piston's position in the Data section.
4. Continue moving the piston into the tube until you reach a new position where a standing wave is produced. Record this new position in the Lab Report section. Continue moving the piston until you have found all of the piston positions inside the tube that produce standing waves.
5. Click the 'STOP' button to stop measuring data.

Optional:

Repeat the procedure for different frequencies.

Analyzing the Data

1. Find the average distance between each piston position. Use this distance to determine the wavelength. (Remember, $\lambda = 2L$.)
2. Use the wavelength and the frequency to calculate the speed of sound in air inside the tube.

Record your data and results in the Lab Report section

Name ____________________ Class ______________ Date _________

Lab Report – Activity P45: Resonant Modes and Speed of Sound

What Do You Think?

The speed of sound can be determined by various methods. How can you calculate the speed of sound in a column of air inside a tube?

Data

Position	Distance (m)	Δx (m)
1		
2		
3		
4		
5		
	Average	

Frequency = 1000 Hz

1. Find the average distance between each piston position. Use this distance to determine the wavelength.

   Wavelength = m

2. Use the wavelength and the frequency to calculate the speed of sound in air inside the tube.

   Speed of sound = m/s

Questions

1. Use the data that you recorded to sketch the wave activity along the length of your tube with the piston in the position furthest from the speaker.

2. The theoretical value of the speed of sound in air is:

   331.5 m/s + 0.607 x Temperature (˚C) m/s.

   For example, at Temp = 18 C, the speed of sound is 342.42 m/s. Determine the theoretical value of the speed of sound in air based on the temperature of air in your room. How does your measured speed of sound compare to the theoretical value of the speed of sound?

Name ____________________ Class _____________ Date _________

Activity P46: Heat Transfer (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P46 Heat Transfer.DS	P38 Heat Transfer	P38_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?

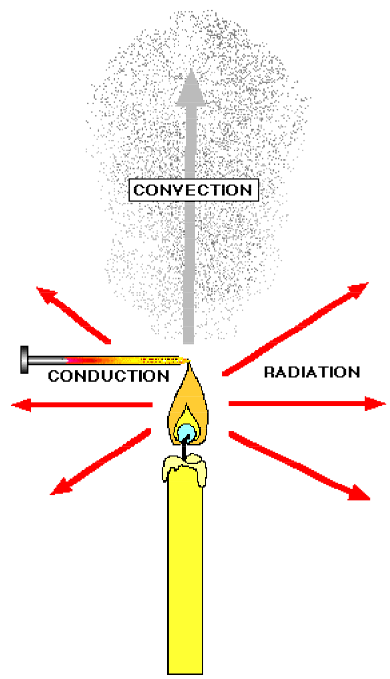
Parts of robot spacecraft are painted black while other parts are left unpainted. Part of the reason is that unpainted sections of the spacecraft hull absorb energy more slowly than sections that are painted black. Do you think the reverse is possible, will an unpainted aluminum can emit energy faster or slower than a black colored aluminum can?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

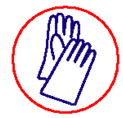
Heat is energy in transit. Heat transfer happens when two objects are at different temperatures.

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)
P46 Heat Transfer.DS	P38 Heat Transfer	P38_HEAT.SWS

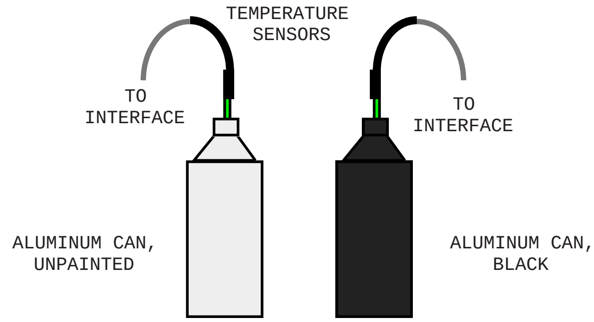
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document will open with a Graph display showing plots of Temperature vs. Time for each Temperature Sensor.
- Data recording is set so there is one measurement each 10 seconds. Data recording stops automatically at 900 seconds (15 minutes).

Name ____________________ Class _____________ Date _________

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.

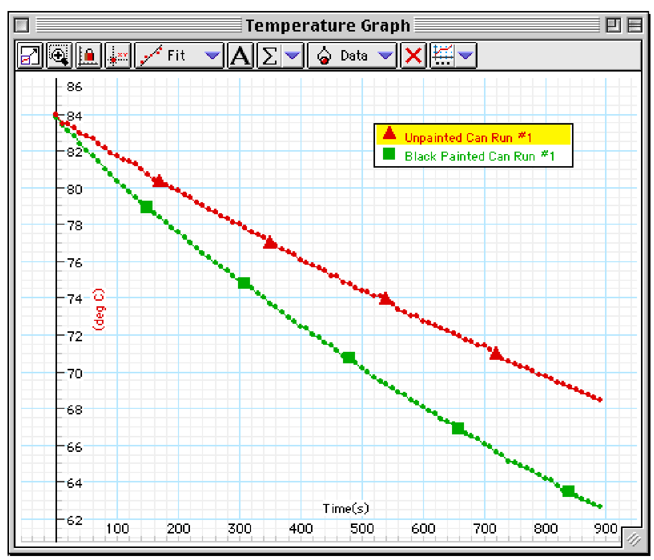
2. Swirl the water in the cans continuously for 15 minutes. Data collecting will stop automatically at 15 minutes.

Analyzing the Data

1. Set up your Graph to show statistics.

In *DataStudio*, click the 'Statistics' menu

button (). Check that 'Minimum' and 'Maximum' are selected.



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 'Minimum' and 'Maximum'.

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.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P46: 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		
Black		

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?

Name ____________________ Class ______________ Date _________

Activity P47: Electrical Equivalent of Heat (Voltage Sensor and Power Amplifier)

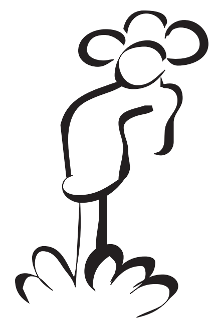
Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P47 EEH.DS	P39 EEH	P39_EEH.SWS

Equipment Needed	Qty	Other	Qty
Temperature Sensor (CI-6505A)	1	Styrofoam cup with lid	1
Power Amplifier (CI-6552A)	1	Water	200 mL
Balance (SE-8723)	1	Protective gear	PS
Heating resistor,10 Ω, 1 W (CI-6514A)	1		

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 the 'What Do You Think?' question(s) 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

$$P = IV$$

where I is the current through the resistor and V is the voltage across 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 Amplifier 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.

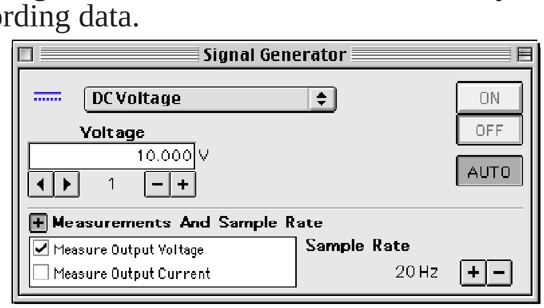
Use *DataStudio* or *ScienceWorkshop* to record the voltage and current output by the Power Amplifier and the change in temperature of the water. Use the program to calculate the electrical energy by integrating the electrical power (voltage multiplied by current) over time. Calculate the thermal energy 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.

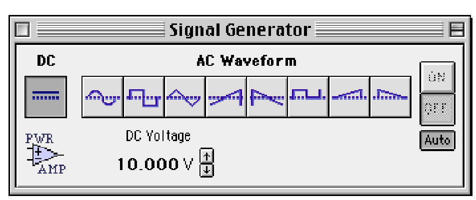
PART I: Computer Setup

1. Connect the *ScienceWorkshop* 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 Power Amplifier DIN plug to Analog Channel B.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P47 EEH.DS	P39 EEH	P39_EEH.SWS

- The *DataStudio* document has a Graph display, a Digits display, and a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Digits display of Temperature and a Graph display.
- ‘Power Output’ is a calculation based on the voltage across the resistor and the current through the resistor, which are assumed to be the same as the ‘Output Voltage’ and ‘Current’ from the Power Amplifier. Data recording is set at 1 second per measurement.
- The Signal Generator is set to automatically output DC voltage at 10 volts when you begin recording data.





Name ______________________ Class _______________ Date __________

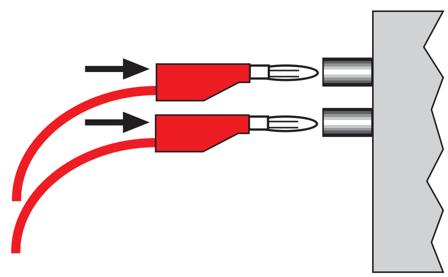
PART II: Sensor Calibration and Equipment Setup

- 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. Measure the mass of the Styrofoam cup and lid. Record the mass in the Data Table.

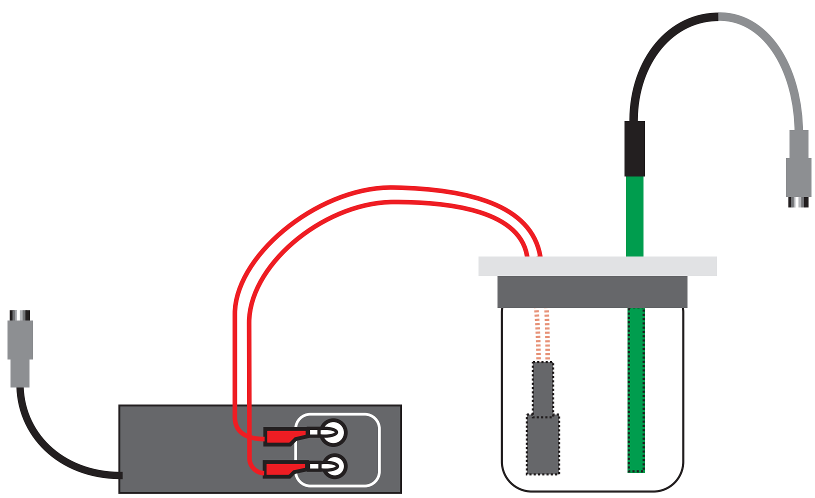
- NOTE: Use water that is about three degrees Celsius below room temperature when data collection begins. Take data until the temperature of the water is about three degrees above room temperature. This minimizes the effect of the surroundings because the water gains energy from its surroundings for 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.
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

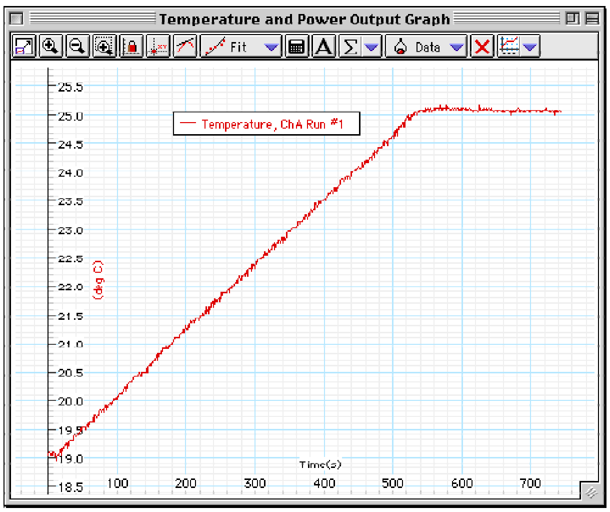
1. Turn on the Power Amplifier (the power switch is on the back panel).
2. Start recording data. (The Signal Generator turns on automatically when you start recording.) Note the beginning temperature.

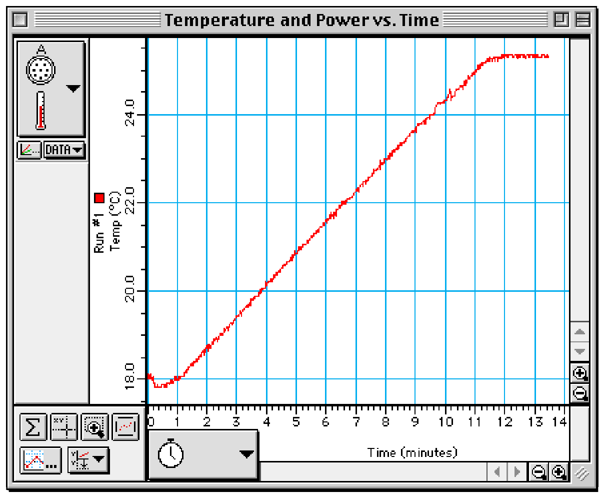
- IMPORTANT: While the data is being taken, gently swirl the water in the cup so the water will be heated evenly. Watch the Digits display to keep track of the temperature.

3. When the temperature reaches three degrees above room temperature, turn off the Power Amplifier, 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 stops rising and levels off, stop recording data.

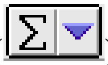


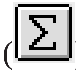


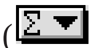
Name ____________________ Class _____________ Date _________

Analyzing the Data

1. Set up your Graph display so it shows statistics.

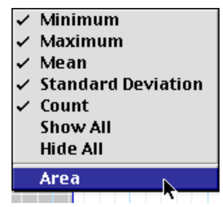
- <u>In *DataStudio*</u>, click the plot of Temperature to make it active. Click the 'Statistics' menu button () in the Graph toolbar. **Result**: The Graph legend shows 'Min' and 'Max'.

- <u>In *ScienceWorkshop*</u>, 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 'Minimum' and 'Maximum' from the Statistics menu. **Result**: The Statistics area shows the minimum and maximum values of x and y.

2. Record the minimum and maximum temperatures (values of y). 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 vs. Time.



- <u>In *DataStudio*</u>, click plot of Power Output to make it active. Click the Statistics button in the Graph toolbar and select 'Area'.

- <u>In *ScienceWorkshop*</u>, click the 'Statistics Menu' button in the Statistics area for the plot of Power Output. Select 'Integration' from the Statistics menu.

4. Record the 'Area' value as the electrical energy ('watt * s' or joules) used by the heating resistor.

- Hint: In *DataStudio*, the 'Area' value is in the Graph legend.

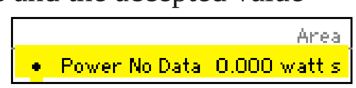
5. Calculate (in calories) the thermal energy ($\boldsymbol{Q}$) absorbed by the water using $\boldsymbol{Q} = \boldsymbol{mc}\Delta\boldsymbol{T}$, where $\boldsymbol{m}$ is the mass of the water, $\boldsymbol{c}$ is the specific heat of water (1cal/g°C), and $\Delta\boldsymbol{T}$ is the change in 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:

$$E.E.H.\ \left(\frac{J}{cal}\right) = \frac{Electrical\ Energy}{Thermal\ Energy}$$

  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.

Name ____________________ Class _____________ Date _________

Lab Report - Activity P47: 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		Temperature (max)	
Mass of Foam Cup with Water		Temperature (min)	
Mass of Water		Change in Temp. (ΔT)	

Item	Amount
Electrical Energy, $E = Pt$	
Thermal Energy, $\Delta Q = mc\Delta T$	
Electrical Equivalent of Heat	

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? 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?

Name ____________________ Class ______________ Date _________

Activity P48: Ohm's Law (Power Output)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electricity	P48 Ohm's Law.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Light bulb, 3 volt (from EM-8656)	1	**Resistor, 10 ohm (from EM-8656)**	1
Patch Cords (SE-9750)	2	**Wire leads, 10 inch (from EM-8656)**	2

What Do You Think?

What is the relationship between current and voltage in a simple resistor? What is the relationship between current and voltage in the filament of an incandescent light bulb?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

Ohm discovered that when the voltage (potential difference) across a resistor changes, the current through the resistor changes. He expressed this as

$$\boldsymbol{I} = \frac{\boldsymbol{V}}{\boldsymbol{R}}$$

where $\boldsymbol{I}$ is current, $\boldsymbol{V}$ is voltage (potential difference), and $\boldsymbol{R}$ is resistance. Current is directly proportional to voltage and inversely proportional to resistance. In other words, as the voltage increases, so does the current. The proportionality constant is the value of the resistance. Since the current is inversely proportional to the resistance, as the resistance increases, the current decreases.

A resistor is 'Ohmic' if as voltage across the resistor is increased, a graph of voltage versus current shows a straight line (indicating a constant resistance). The slope of the line is the value of the resistance. A resistor is 'non-Ohmic' if the graph of voltage versus current is not a straight line. For example, if resistance changes as voltage changes, the graph of voltage versus current might show a curve with a changing slope.

For certain resistor, the value of its resistance does not change appreciably. However, for a light bulb, the resistance of the filament will change as it heats up and cools down. At high AC frequencies, the filament doesn't have time to cool down, so it remains at a nearly constant temperature and the resistance stays relatively constant. At low AC frequencies (e.g., less than one Hertz), the filament has time to change temperature. As a consequence, the resistance of the filament changes dramatically and the resulting change in current through the filament is interesting to watch.

In the first part of this activity, investigate the relationship between current and voltage in a simple ten-ohm (Ω) resistor. In the second part, investigate the relationship between current and voltage in the filament of a small light bulb.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Part A – Resistor

Use the 'Output' feature of the interface to supply voltage to a ten-ohm resistor. Use *DataStudio* or *ScienceWorkshop* to measure the output voltage across the resistor and the current through the resistor (the current drawn from the interface).

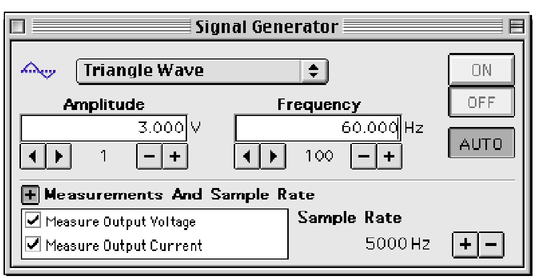
Use the program to display the voltage and current. Use a plot of voltage versus current to confirm the resistance value of the resistor.

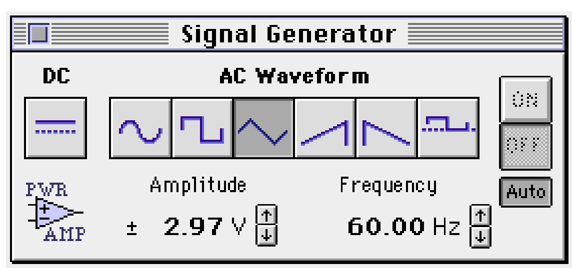
PART IA: Computer Setup for Resistor

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P48 Ohm's Law.DS	(See end of activity)	(See end of activity)

- The *DataStudio* document opens with a Signal Generator window and a Scope display. The document also has a Workbook display. Read the instructions in the Workbook.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Scope display will show the voltage from the 'Output' of the interface to the ten-ohm resistor and the output current from the interface through the resistor.
- The Signal Generator is set to produce a triangle wave at 60 Hz. It is set to 'Auto' so it will automatically start or stop the signal when you start or stop measuring data.





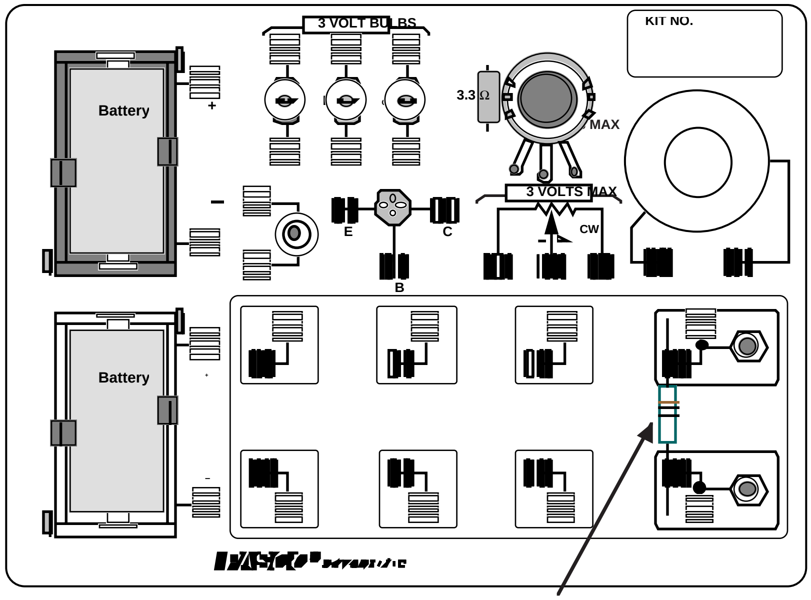
- In *DataStudio*, make sure that 'Measure Output Voltage' and 'Measure Output Current' are checked in the Signal Generator window.
- Arrange the Scope display and the Signal Generator window so you can see both of them.

Name ______________________ Class _______________ Date _________

PART IIA: Equipment Setup - Resistor

- You do not need to calibrate a sensor because, in this activity, the interface is the sensor.

1. Place a ten-ohm (Ω) resistor in the pair of component springs nearest to the banana jacks at the lower right corner of the AC/DC Electronics Lab Board.
2. Connect banana plug patch cords from the 'OUTPUT' ports of the interface to the banana jacks on the AC/DC Electronics Lab circuit board.

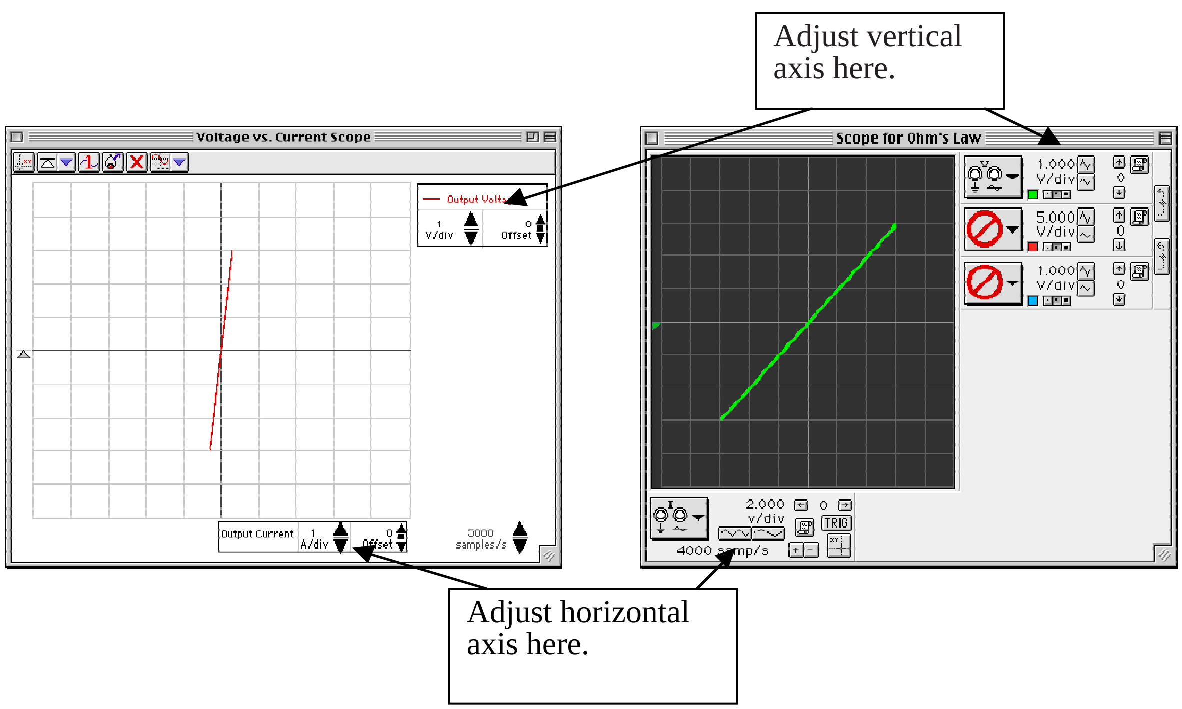


10 Ω RESISTOR (BROWN, BLACK, BLACK)

Part IIIA: Data Recording – Resistor

1. Begin measuring data. (Click 'Start' in *DataStudio* or 'MON' in *ScienceWorkshop*.)

- Observe the Scope display of Voltage and Current. Adjust the vertical axis or the horizontal axis if necessary.

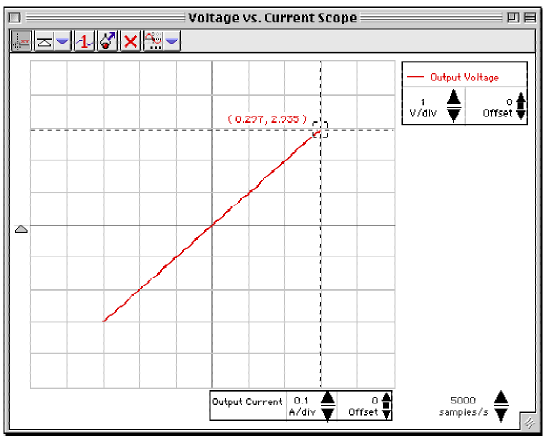


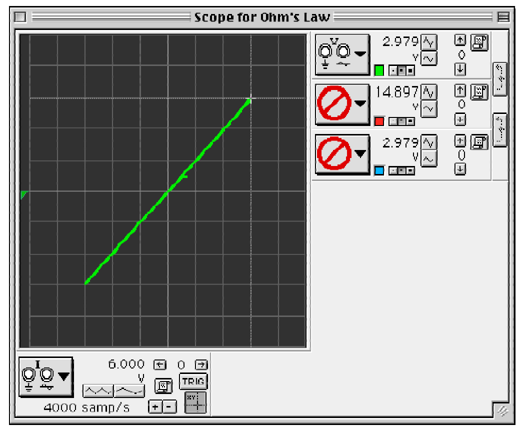
2. Observe the trace of voltage vs. current for a few seconds and then stop measuring data.

Analyzing the Data – Resistor

1. Use the 'Scope's built-in analysis tools to determine the voltage and current for the ten-ohm resistor.

- In *DataStudio*, click the 'Smart Tool'. Move the 'Smart Tool' so it shows the coordinates of a point on the trace of voltage versus current. **Result**: The 'X-Y' coordinates are voltage and current.
- In *ScienceWorkshop*, click the 'Smart Cursor'. Move the cursor into the display area of the Scope. **Result**: The value for voltage appears below the 'V/div' control for the vertical axis and the value for current appears above the 'sweep speed' control for the horizontal axis.





2. Use the coordinates of the point on the trace to determine the ratio of voltage versus current. Record the ratio as the resistance of the resistor.

- In *DataStudio*, the 'X' coordinate is the current and the 'Y' coordinate is the voltage. Divide one by the other to calculate the resistance.
- In *ScienceWorkshop*, the output current displayed in the Scope must be converted. Multiply the 'X' coordinate by 0.05 to determine the actual current. The 'Y' coordinate is the actual voltage. Divide the voltage by the current.

resistance (ten-ohm resistor) = ________ volt/amp

Optional

1. Replace the ten-ohm resistor with a 100-ohm resistor.
2. Adjust the horizontal scaling (x-axis) in the Scope display as needed.
3. Repeat the experiment. Record the new ratio as the resistance of the resistor.

resistance (100 Ω) = ________ volt/amp

Name ____________________ Class ______________ Date __________

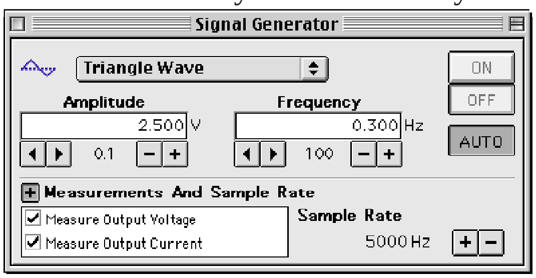
Part B – Light Bulb

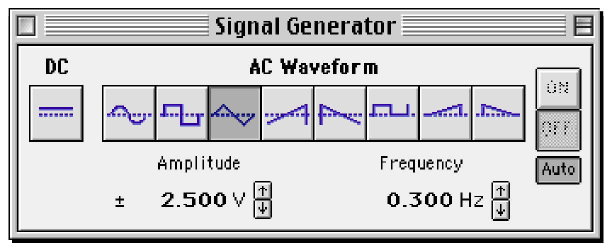
Use the ‘Output’ feature of the interface to supply voltage to small light bulb. Use *DataStudio* or *ScienceWorkshop* to measure the output voltage across the light bulb filament and the current through the filament (the current drawn from the interface).

Use the program to display the voltage and current. Use a plot of voltage versus current to confirm the resistance value of the resistor.

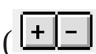
PART IB: Computer Setup for Light Bulb Filament

1. Change the Amplitude and Frequency of the output AC waveform. Click the Signal Generator window to make it active.
2. Click the Amplitude value to highlight it. Type in ‘2.5’ as the new value. Press <enter> or <return> on the keyboard to record your change.
3. Click the Frequency value to highlight it. Type in ‘0.30’ as the new value. Press <enter> or <return> on the keyboard to record your change.



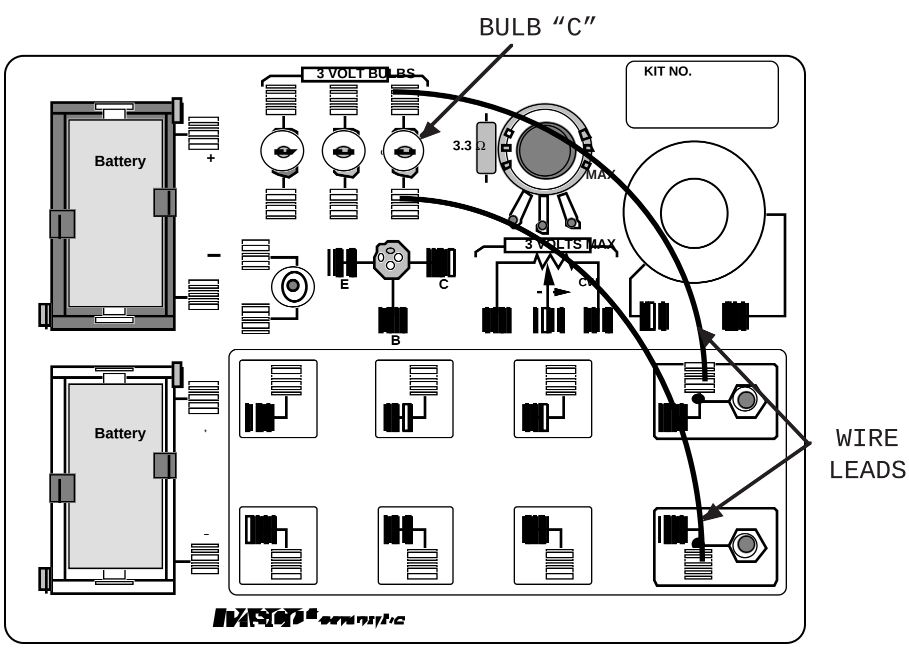


4. Adjust the sweep speed in the Scope display to 50 samples/second.

- In *DataStudio*, click the ‘down’ arrow next to ‘samples/s’.
- In *ScienceWorkshop*, click the ‘-‘ button () next to ‘samp/s’.

PART II: Equipment Setup for Light Bulb Filament

1. Remove the resistor from the component springs on the AC/DC Electronics Lab circuit board.
2. Use two of the 10” wire leads to connect between the component springs near the banana jacks and the component springs above and below **3 VOLT BULB “C”**.



PART III: Data Recording – Light Bulb Filament

1. Start measuring data. Observe the Scope display of voltage versus current for the light bulb filament. Adjust the vertical and horizontal scales if necessary.
2. Wait a few seconds and then stop measuring data.

Analyzing the Data – Light Bulb Filament

Use the built-in analysis tools in the Scope display to find the coordinates at several points on the trace of voltage versus current. Calculate the ratio of voltage to current at each point.

Answer the questions in the Lab Report section.

Name ____________________ Class _____________ Date _________

Lab Report - Activity P40: Ohm's Law

What Do You Think?

What is the relationship between current and voltage in a simple resistor? What is the relationship between current and voltage in the filament of an incandescent light bulb?

Data

resistance (ten-ohm resistor) = ________ volt/amp

resistance (100 Ω) = ________ volt/amp

Questions

1. Compare the ratio of voltage and current from the Scope display to the resistance of the resistor(s) used.

2. Does each resistor you used have a constant resistance?

3. Does the light bulb filament have a constant resistance (constant ratio of voltage to current? Why or why not?

4. The slope of the graph for the light bulb is not symmetric. Why is the trace on the Scope different when the filament is heating up compared to the trace when the filament is cooling down?

Appendix: Modify a *ScienceWorkshop* File

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

Open the file titled as shown:

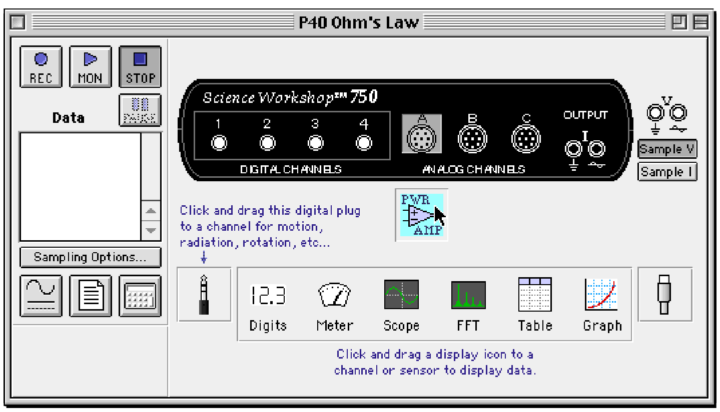
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P40 Ohm's Law	P40_OHM.SWS

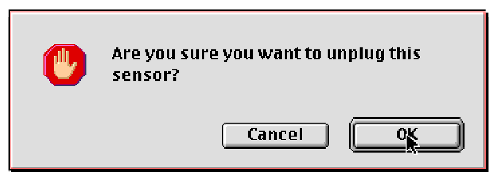
This activity uses the 'Output' feature of the *ScienceWorkshop* 750 interface to provide both output voltage and output current.

- Remove the Power Amplifier in the Experiment Setup window.
- Select 'Sample I' (sample the output current).
- Change the 'Scope' display to show output voltage versus output current.

Remove the Power Amplifier Icon

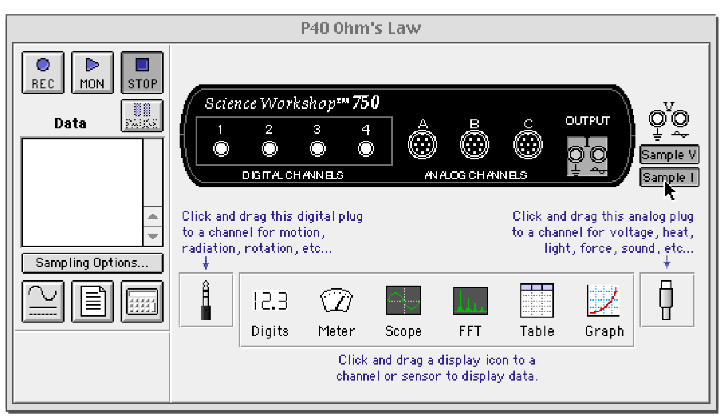
In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard. **Result**: A 'warning' window opens. Click 'OK' to return to the setup window.





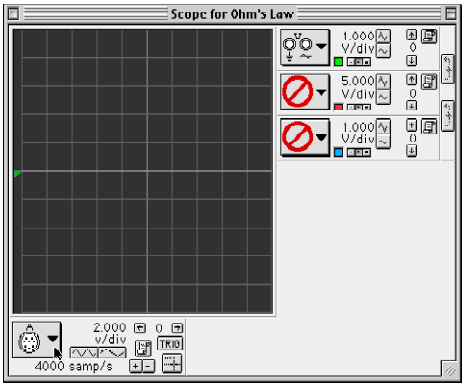
Select 'Sample I'

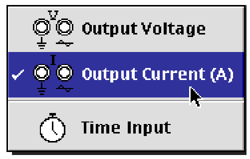
Click the 'Sample I' button in the Experiment Setup window. **Result**: If it was not already open, the 'Signal Generator' window opens.

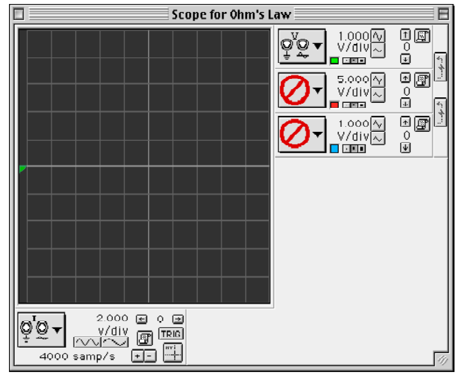


Change the Scope Display

The 'Scope' shows the 'Channel A' icon on its X-axis. Click the 'X-Axis Input' menu and select 'Output Current (A)'.







Set the 'sweep speed' to 2.000 v/div. Hint: Click the 'Decrease/Increase Sweep Speed' buttons ().

Results

The *ScienceWorkshop* document has a 'Scope' (oscilloscope) display of Output Voltage (V) versus Output Current (I) and the Signal Generator window which controls the output.

Name ____________________ Class _____________ Date ________

Activity P49: Transformer (Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electricity	P49 Transformer.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Voltage Sensor (CI-6503)	1	Primary/Second Coils (SE-8653)	1
Patch Cords (SE-9750)	2		

What Do You Think?

How is a transformer used to increase or decrease an AC voltage?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

A transformer can be used to increase or decrease AC voltages. An AC voltage is applied to the **primary** coil of a transformer, which is surrounded by the **secondary** coil but is not electrically connected to it. The primary coil produces a changing magnetic flux through the secondary coil, which will induce an AC voltage in the secondary coil. If the number of turns of wire in the secondary coil is <u>more</u> than the number of turns in the primary coil, the voltage induced in the secondary coil will be more than the voltage in the primary coil. This is called a step-up transformer. If the number of turns in the secondary coil is <u>less</u> than the number of turns in the primary coil, the voltage will be reduced. This is called a step-down transformer.

According to Faraday's Law of Induction, the induced emf (voltage) is proportional to the rate of change of magnetic flux through the coil ($d\phi/dt$) and the number of turns (N) in the coil:

$$\varepsilon = -N\frac{d\phi}{dt}$$

Since the rate of change in flux through both coils is the same, the ratio of the emfs (voltages) in the coils should be equal to the ratio of the numbers of turns in the coils:

$$-\frac{d\phi}{dt} = \frac{\varepsilon}{N} \rightarrow \frac{\varepsilon_s}{\varepsilon_p} = \frac{N_s}{N_p}$$

A core made of a ferrous material such as iron can change the amount of magnetic flux that influences the secondary coil.

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

For You To Do

In the first part of this activity, put together a step-up transformer (number of turns in the secondary coil is greater than the number of turns in the primary coil). In the second part of this activity, use the same coils to put together a step-down transformer (number of turns in the secondary coil is less than the number of turns in the primary coil.)

Use the 'Output' feature of the *ScienceWorkshop* interface to supply a voltage to the primary coil in both transformer setups. Use the Voltage Sensor to measure the induced emf (voltage) in the secondary coil. Record the voltage in the secondary coil for two configurations: one with an iron core inside the inner coil, and one without the iron core inside the inner coil.

Use *DataStudio* or *ScienceWorkshop* to control the voltage output of the interface. Use the software to collect and display the voltages across both the primary coil and the secondary coil. Finally, compare the voltage in the primary coil to the voltage in the secondary coil.

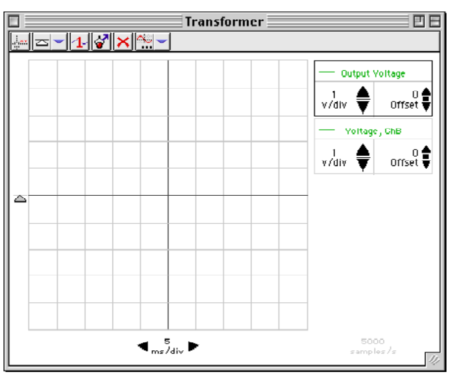
PART IA: Computer Setup for Step-Up Transformer

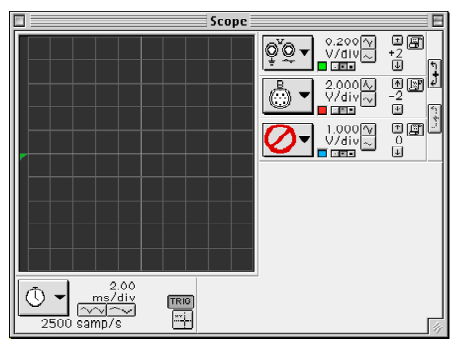
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Voltage Sensor DIN plug into Analog Channel B.
3. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

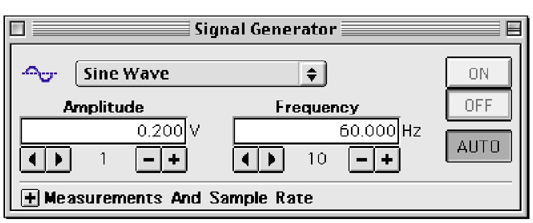
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P49 Transformer.DS	(See end of activity)	(See end of activity)

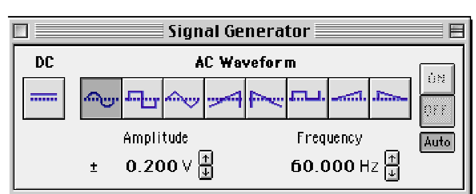
- The *DataStudio* document opens with a Signal Generator window and a Scope display. The document also has a Workbook display. Read the instructions in the Workbook.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Scope display shows the voltage from the 'Output' of the interface to the primary coil and the input voltage from the Voltage Sensor.





- The Signal Generator is set to produce a sine wave at 60 Hz. It is set to 'Auto' so it will automatically start or stop the signal when you start or stop measuring data.



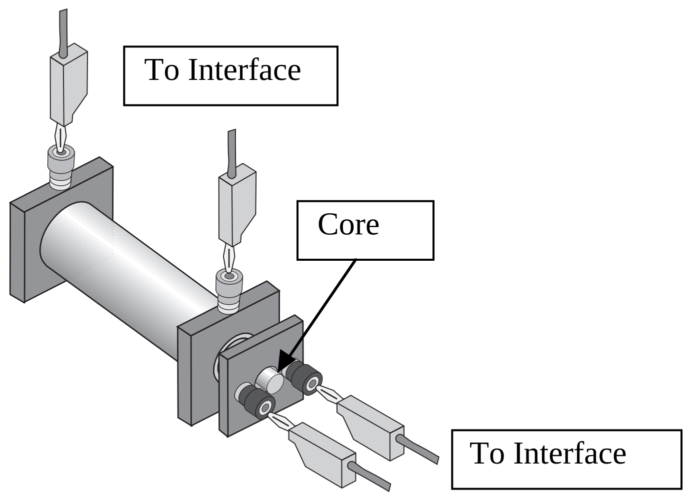


5. Arrange the Scope display and the Signal Generator window so you can see both of them.

PART IIA: Sensor Calibration and Equipment Setup Step-Up Transformer

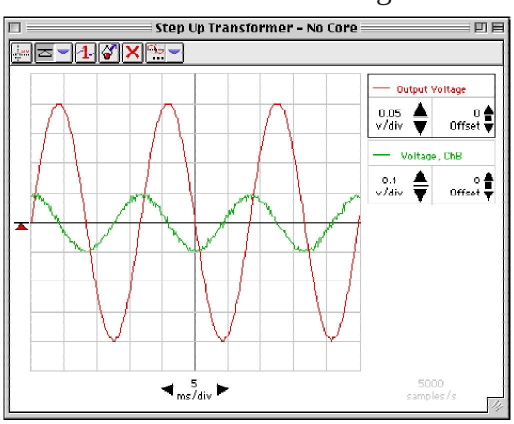
- You do not need to calibrate the Voltage Sensor.
- The Primary and Secondary Coils consist of an inner coil with about 200 turns of heavy gauge wire, an outer coil with about 2000 turns of thinner gauge wire, and an iron core that fits inside the inner coil. The inner coil fits inside the larger outer coil.

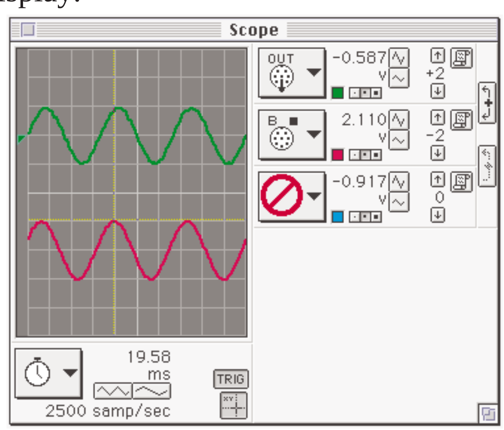
1. To build a step-up transformer, use banana plug patch cords to connect the <u>inner</u> coil to the 'OUTPUT' ports of the interface.
2. Connect the Voltage Sensor's banana plugs to the <u>outer</u> coil.
3. Put the inner coil completely inside the outer coil. Put the iron core as far into the inner coil as it will go.



PART IIIA: Data Recording for Step-Up Transformer

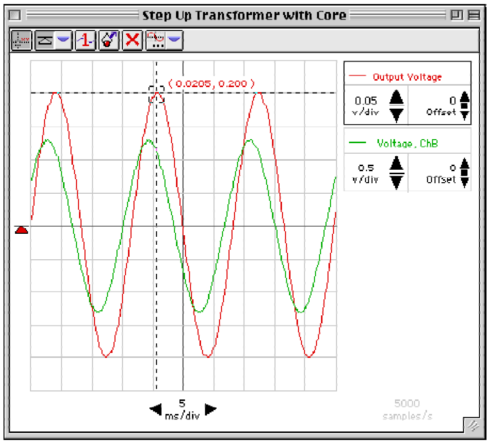
1. Start measuring data. (Click 'Start' in *DataStudio* or 'MON' in *ScienceWorkshop*.)
2. Observe the traces of voltage in the Scope display.

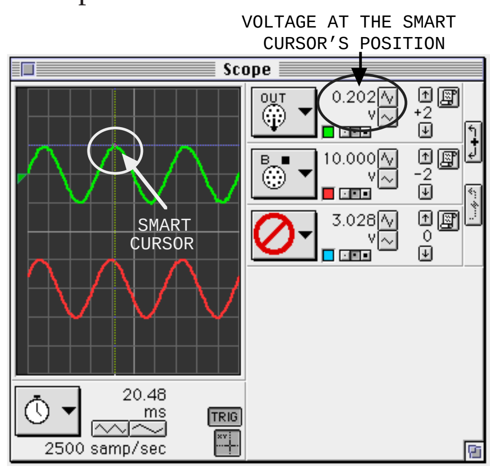




3. Use the Scope display's built-in analysis tools to determine the output voltage across the primary coil and the induced voltage across the secondary coil.

- Click the *ScienceWorkshop* 'Smart Cursor' or the *DataStudio* 'Smart Tool' button in the Scope display. The cursor changes to a cross-hair shape.
- Move the cursor/cross-hair to a peak of the top trace of 'Output' voltage (the primary coil voltage). In *DataStudio*, the value of the voltage at that point is the y-coordinate that is displayed adjacent to the cross hairs of the 'Smart Tool.' In *ScienceWorkshop* the value of voltage at that point is displayed next to the channel Input Menu button.

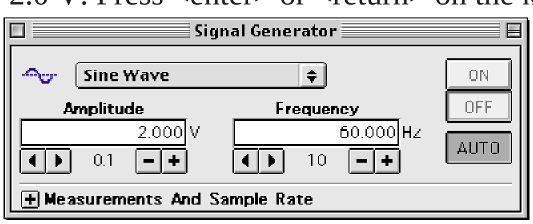


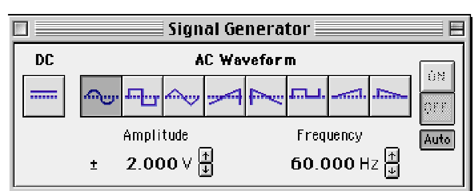


4. Record the 'Output' voltage across the primary (inner) coil in the Lab Report section.
5. Move the 'Smart Tool/Smart Cursor' to the corresponding peak of the 'Voltage, Channel B' trace (the secondary coil voltage). Record the voltage across the secondary (outer) coil.
6. Remove the iron core from the inner coil.
7. Use the 'Smart Tool/Smart Cursor' to once again find the 'Output' (primary) voltage and the 'Voltage, Channel B' (secondary voltage).
8. Record the new voltages across the primary (inner) and secondary (outer) coils when the core is removed.
9. Stop monitoring data. Turn off the switch on the back of the Power Amplifier.

PART IB: Computer Setup for Step-Down Transformer

1. Click the Signal Generator window to make it active. Change the Amplitude from 0.2 V to 2.0 V. Press <enter> or <return> on the keyboard to record your change.





2. Click the Scope display to make it active. Change the Sensitivity (volts per division) for both the 'Output' trace and the 'Voltage, Channel B' trace. Change the 'Output' trace from 0.200 v/div to 2.000 v/div. Change the 'Channel B' trace from 2.000 v/div to 0.200 v/div.

Name ____________________ Class _____________ Date ________

PART IIB: Sensor Calibration and Equipment Setup for Step-Down Transformer

1. Put the iron core back inside the inner coil.

- Change the transformer from step-up to step-down.

2. Disconnect the banana plug patch cords from the inner coil. Disconnect the Voltage Sensor from the outer coil.

3. Connect the banana plug patch cords from the 'OUTPUT' ports of the interface to the outer coil. Connect the Voltage Sensor's banana plugs to the inner coil.

PART IIIB: Data Recording for Step-Down Transformer

1. Repeat the data recording procedure outlined in Part IIIA.

- Hint: If the voltage appears to be too small to measure, change the volts per division in the 'Scope' display to 0.050 V/div.

2. Record the voltage across the primary (outer) coil and the voltage across the secondary (inner) coil for both 'with core' and 'without core' in the Lab Report section.

Analyzing the Data

1. Calculate the ratio of primary voltage to secondary voltage for each of the four measurements and record the ratios in the Data section.

2. Express your calculated ratios for the step-up transformer and for the step-down transformer in a way that shows by how much the voltage is increased or decreased (for example, '3 to 1').

3. The number of turns in the inner coil is 235 (#18 gauge wire) and the number of turns in the outer coil is 2920 (#29 gauge wire). Calculate the ratio of the number of turns.

Put your results in the Lab Report section

Name ______________________ Class _______________ Date __________

Lab Report – Activity P49: Transformer

What do you think?

How is a transformer used to increase or decrease an AC voltage?

Data

Part A: Step Up Transformer

Step-Up Transformer	Primary (inner) Voltage (V)	Secondary (outer) Voltage (V)
With core		
Without core		

Step-Up Transformer	Ratio: V_p – to -V_s
With core	
Without core	

Part B: Step Down Transformer

Step-Down Transformer	Primary (outer) Voltage (V)	Secondary (inner) Voltage (V)
With core		
Without core		

Step-Down Transformer	Ratio: V_p – to -V_s
With core	
Without core	

Ratio of turns = _________

Questions

1. When the inner coil (with core) was used as the primary coil, was the ratio of the voltages equal to the ratio of the number of turns? How do you account for any difference?

2. Why did the secondary voltage change when the iron core was pulled out of the inner coil?

3. When the outer coil (with core) was used as the primary coil, why is the voltage stepped down a different amount than it was stepped up when the inner core was the primary coil?

4. Which had the greater effect: Pulling the core out of the step-up transformer (inner-primary) or pulling the core out of the step-down transformer (outer-primary)? Why?

5. Why did you have to use AC voltage in this laboratory activity instead of DC?

Name ____________________ Class _____________ Date _________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

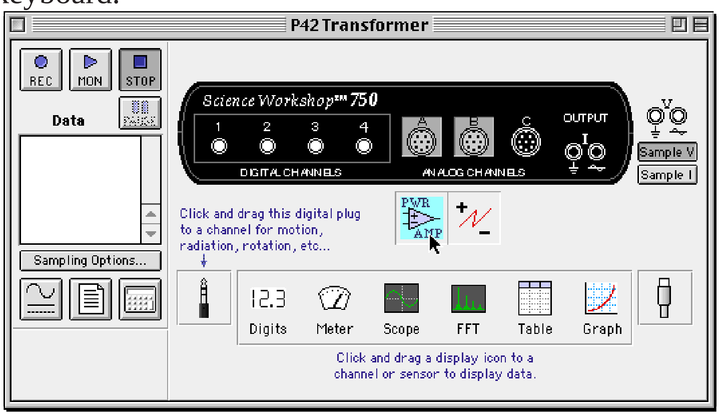
Open the file titled as shown:

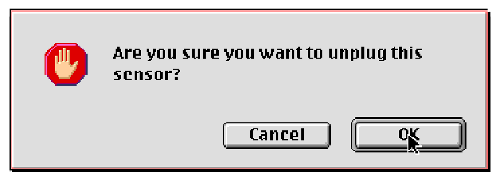
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P48 Transformer	P48_XTRN.SWS

This activity uses the ‘Output’ feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

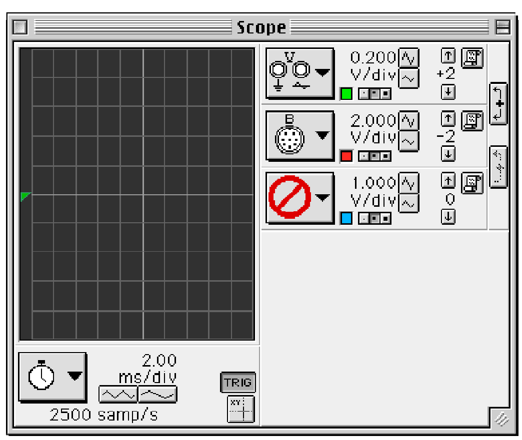




Result: A ‘warning’ window opens. Click ‘OK’ to return to the setup window.

Results

The *ScienceWorkshop* document has a ‘Scope’ (oscilloscope) display of ‘Output’ voltage (V) and ‘Channel B’ voltage (B) and the Signal Generator window which controls the output.



Name ____________________ Class _____________ Date _________

Activity P50: RC Circuit
(Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Circuits	P50 RC Circuit.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**From AC/DC Electronics Lab***	**Qty**
Voltage Sensor (CI-6503)	1	**Capacitor, 330 microfarad**	1
LCR Meter (SB-9754)	1	**Resistor, 100 ohm**	1
Patch Cords (SE-9750)	2		

(*The AC/DC Electronics Lab is PASCO Model EM-8656)

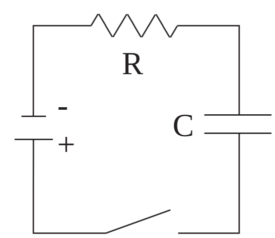
What Do You Think?

The voltage across a capacitor varies as it charges. How can you investigate this relationship? Capacitors also have what is known as the capacitive time constant. How can this constant be calculated?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

When a DC voltage source is connected across an uncharged capacitor, the rate at which the capacitor charges up decreases as time passes. At first, the capacitor is easy to charge because there is very little charge on the plates. But as charge accumulates on the plates, the voltage source must "do more work" to move additional charges onto the plates because the plates already have charge of the same sign on them. As a result, the capacitor charges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully charged. The charge on the plates at any time is given by:



$$\mathbf{q} = \mathbf{q_o}\left(\mathbf{1} - e^{-t/\tau}\right)$$

where $\mathbf{q_o}$ is the maximum charge on the plates and τ is the capacitive time constant (τ = RC, where R is resistance and C is capacitance). NOTE: The stated value of a capacitor may vary by as much as ±20% from the actual value. Taking the extreme limits, notice that when t = 0, q = 0 which means there is not any charge on the plates initially. Also notice that when t goes to infinity, q goes to q_o which means it takes an infinite amount of time to <u>completely</u> charge the capacitor.

The time it takes to charge the capacitor to half full is called the half-life and is related to the capacitive time constant in the following way:

$$\mathbf{t_{1/2}} = \tau\,\mathbf{ln2}$$

In this activity the charge on the capacitor will be measured indirectly by measuring the voltage across the capacitor since these two values are proportional to each other: q = CV.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the 'Output' feature of the *ScienceWorkshop* interface to supply a voltage to the resistor-capacitor circuit. Use the Voltage Sensor to measure the voltage across the capacitor as it charges and discharges. Record the voltage in the secondary coil for two configurations: one with an iron core inside the inner coil, and one without the iron core inside the inner coil.

Use *DataStudio* or *ScienceWorkshop* to control the voltage output of the interface and to record and display the voltage across the capacitor. Finally, measure the time for the capacitor to charge to the 'half-maximum' voltage. Use the half-time constant and the known value of the resistance to calculate the capacitance of the capacitor.

Compare the calculated value of the capacitor to the stated value of the capacitor.

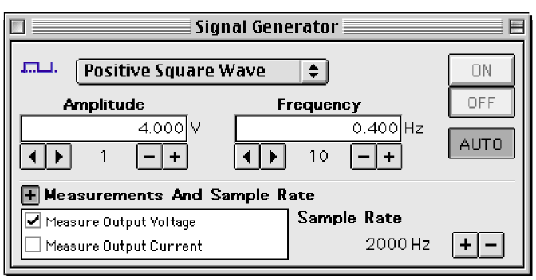
In this activity, the interface outputs a low frequency 'positive-only' square wave (0 to 4 V). This waveform imitates the action of charging and then discharging a capacitor by connecting and then disconnecting a DC voltage source.

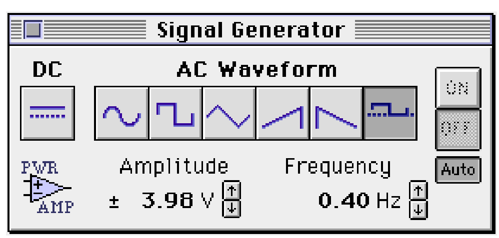
PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor DIN plug into Analog Channel B.
3. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P50 RC Circuit.DS	(See end of activity)	(See end of activity)

- The *DataStudio* document has a Graph display of voltage versus time and the Signal Generator window for controlling the 'Output' of the interface. The document also has a Workbook display. Read the instructions in the Workbook.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- Data recording is set to stop automatically at 4 seconds.
- The Signal Generator is set to output a 4 volt, "positive only" square wave at 0.40 Hz. The Signal Generator is set to 'Auto' so it will start and stop automatically when you start and stop measuring data.



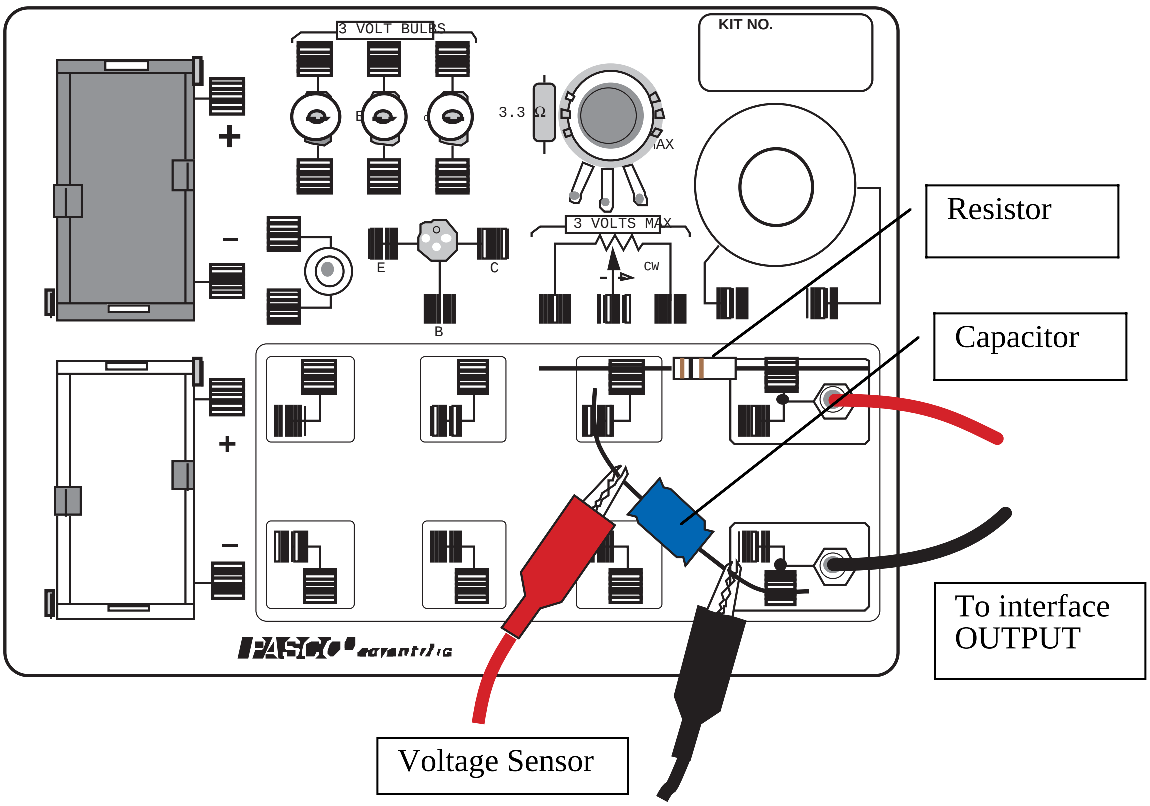


Name ____________________ Class ______________ Date _________

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.

1. Place a 100-ohm (Ω) resistor (brown, black, brown) in the pair of component springs nearest to the top banana jack at the lower right corner of the AC/DC Electronics Lab Board.
2. Connect a 330 microfarad (µF) capacitor between the component spring on the left end of the 100-Ω resistor and the component spring closest to the bottom banana jack.



3. Put alligator clips on the Voltage Sensor banana plugs. Connect the alligator clips to the wires at both ends of the 330 µF capacitor.
4. Connect banana plug patch cords from the 'OUTPUT' ports of the interface to the banana jacks on the AC/DC Electronics Lab Board.

Part III: Data Recording

1. Start measuring data. (Hint: Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*.) The Signal Generator output will automatically start when data recording begins.

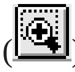
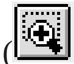
- Watch the plot of voltage versus time in the Graph display.

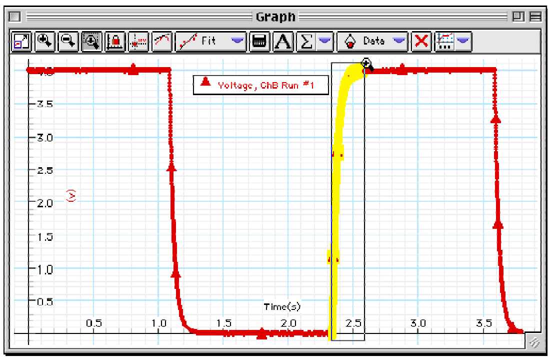
2. Data recording will continue for <u>four seconds</u> and then stop automatically.

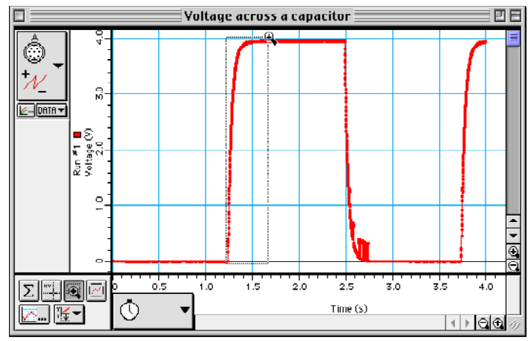
- 'Run #1' will appear in the Data list.

Analyzing the Data

1. Rescale the Graph display if needed.

2. Expand a region of the Graph display. Use the 'Zoom Select' tool in *DataStudio* () or the 'Magnifier' tool in *ScienceWorkshop* () to click-and-draw a rectangle over a region of the plot of Voltage versus Time that shows the voltage rising from zero volts to the maximum volts.

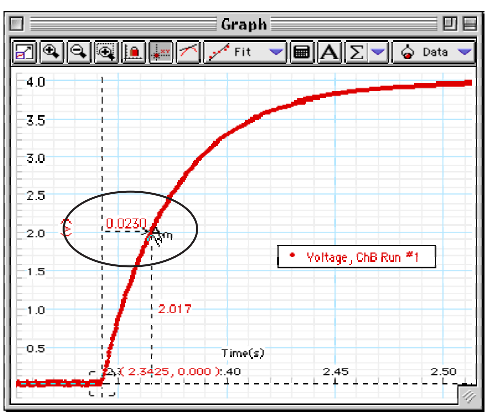


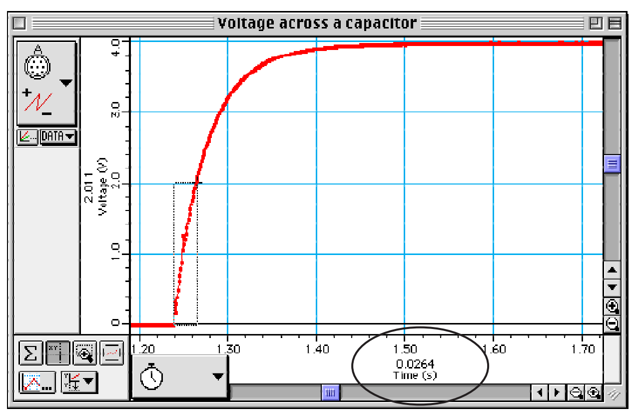


- **Result**: Your selected region expands to fill the Graph display.

3. Use the built-in analysis tools in the Graph display to find the time to 'half-max'.

- In *DataStudio*, click the 'Smart Tool'. Move the cursor to the point on the plot where the voltage begins to rise. Drag the corner of the 'Smart Tool' to the point where the voltage is about 2 volts. The time to 'half-max' is the 'x-coordinate'.
- In *ScienceWorkshop*, click the 'Smart Cursor'. The cursor changes to a cross hair when you move the cursor into the display area of the Graph. Move the cursor to the point on the plot where the voltage begins to rise. Click-and-drag the cursor to the point where the voltage is about 2 volts. The time to 'half-max' is displayed under the horizontal axis.





4. Use $t_{1/2} = \tau \ln 2$ = 0.693 RC to calculate the capacitance (C) of the capacitor.

Put your results in the Lab Report section

Name ______________________ Class _______________ Date _________

Lab Report- Activity P50: RC Circuit

What Do You Think?

The voltage across a capacitor varies as it charges. How can you investigate this relationship? Capacitors also have what is known as the capacitive time constant. How can this constant be calculated?

Data

Time to half-max ($t_{1/2}$) = _________ s

Capacitance = __________ F = _________ μF

(Remember, $C = \dfrac{t_{\frac{1}{2}}}{\ln 2} \div R$)

Percent Difference between stated capacitance value of 330 microfarad = _________

1. The time to half-maximum voltage is how long it takes the capacitor to charge halfway. Based on your experimental results, how long does it take for the capacitor to charge to 75% of its maximum?

2. After four “half-lifes” (i.e., time to half-max), to what percentage of the maximum charge is the capacitor charged?

3. What is the maximum charge for the capacitor in this experiment?

4. What are some factors that could account for the percent difference between the stated and experimental values?

Name ____________________ Class _____________ Date ________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

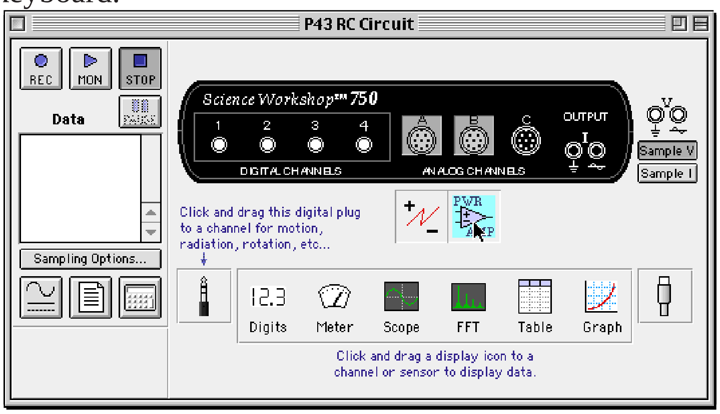
Open the file titled as shown:

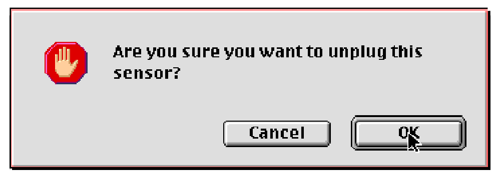
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P43 RC Circuit	P43_RCCI.SWS

This activity uses the ‘Output’ feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

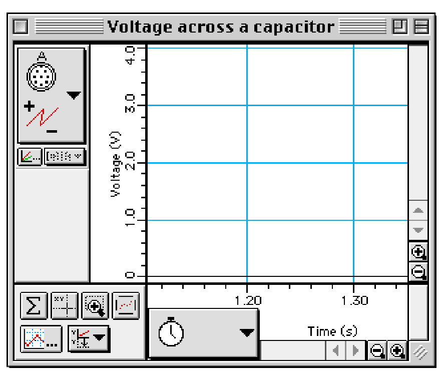




Result: A warning window opens. Click ‘OK’ to return to the setup window.

Results

The *ScienceWorkshop* document has a Graph display of ‘Channel A’ voltage.



Plug in the Voltage Sensor

Connect the Voltage Sensor DIN’s plug into Channel A on the interface (rather than Channel B).

Name ____________________ Class ______________ Date _________

Activity P51: LR Circuit (Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Circuits	P51 LR Circuit.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	From AC/DC Electronics Lab*	Qty
Voltage Sensor (CI-6503)	1	**Inductor Coil and Iron Core**	1
LCR Meter (SB-9754)	1	**Resistor, 10 ohm**	1
Multimeter (SE-9786)	1	**Wire Lead, 5 inch (13 cm)**	2
Patch Cords (SE-9750)	2		

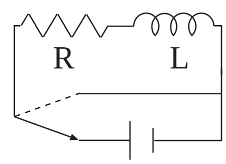
(*The AC/DC Electronics Lab is PASCO Model EM-8656)

What Do You Think?

What is the relationship between the voltage across the inductor and the voltage across the resistor in an inductor-resistor circuit? What is the relationship between the current through the inductor and the behavior of an inductor in a DC circuit?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background



When a DC voltage is applied to an inductor and a resistor in series a steady current will be established:

$$I_{\max} = \frac{V_o}{R}$$

where V_O is the applied voltage and R is the <u>total</u> resistance in the circuit.
But it takes time to establish this steady-state current because the inductor creates a back-emf in response to the rise in current. The current will rise exponentially:

$$I = I_{\max}(1 - e^{-(R/L)t}) = I_{\max}(1 - e^{-t/\tau})$$

where L is the inductance and the quantity $L/R = \tau$ is the inductive time constant. The inductive time constant is a measure of how long it takes the current to be established. One inductive time constant is the time it takes for the current to rise to 63% of its maximum value (or fall to 37% of its maximum). The time for the current to rise or fall to half its maximum is related to the inductive time constant by

$$t_{1/2} = \tau(\ln 2)$$

$$\tau = \frac{t_{1/2}}{\ln 2}$$

Since the voltage across a resistor is given by $V_R = IR$, the voltage across the resistor is established exponentially:

$$V_R = V_o(1 - e^{-t/\tau})$$

Since the voltage across an inductor is given by $V_L = L\left(\frac{dI}{dt}\right)$, the voltage across the inductor starts at its maximum and then decreases exponentially:

$$V_L = V_o e^{-(t/\tau)}$$

After a time $t >> \tau$, a steady-state current I_{max} is established and the voltage across the resistor is equal to the applied voltage, V_o. The voltage across the inductor is zero. If, after the maximum current is established, the voltage source is turned off, the current will then decrease exponentially to zero while the voltage across the resistor does the same and the inductor again produces a back emf which decreases exponentially to zero. In summary:

DC Voltage applied:

$$I = I_{\max}\left(1 - e^{-(t/\tau)}\right)$$

$$V_R = V_o\left(1 - e^{-(t/\tau)}\right)$$

$$V_L = V_o e^{-(t/\tau)}$$

DC Voltage turned off:

$$I = I_{\max} e^{-(t/\tau)}$$

$$V_R = V_o e^{-(t/\tau)}$$

$$V_L = V_{emf}\left(1 - e^{-(t/\tau)}\right)$$

At any time, Kirchhoff's Loop Rule applies: The algebraic sum of all the voltages around the series circuit is zero. In other words, the voltage across the resistor plus the voltage across the inductor will add up to the source voltage.

For You To Do

Use the 'Output' feature of the *ScienceWorkshop* interface to provide voltage for a circuit consisting of an inductor and a resistor. (The interface produces a low frequency square wave that imitates a DC voltage being turned on and then turned off.) Use Voltage Sensors to measure the voltages across the inductor and resistor.

Use *ScienceWorkshop* or *DataStudio* to record and display the voltages across the inductor and resistor as the current is established exponentially in the circuit. Use the graph display of the voltages to investigate the behavior of the inductor-resistor circuit.

PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect one Voltage Sensor to Analog Channel A. This sensor will be "Voltage Sensor A". Connect the second Voltage Sensor to Analog Channel B. This sensor will be "Voltage Sensor B".
3. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P51 LR Circuit.DS	(See end of activity)	(See end of activity)

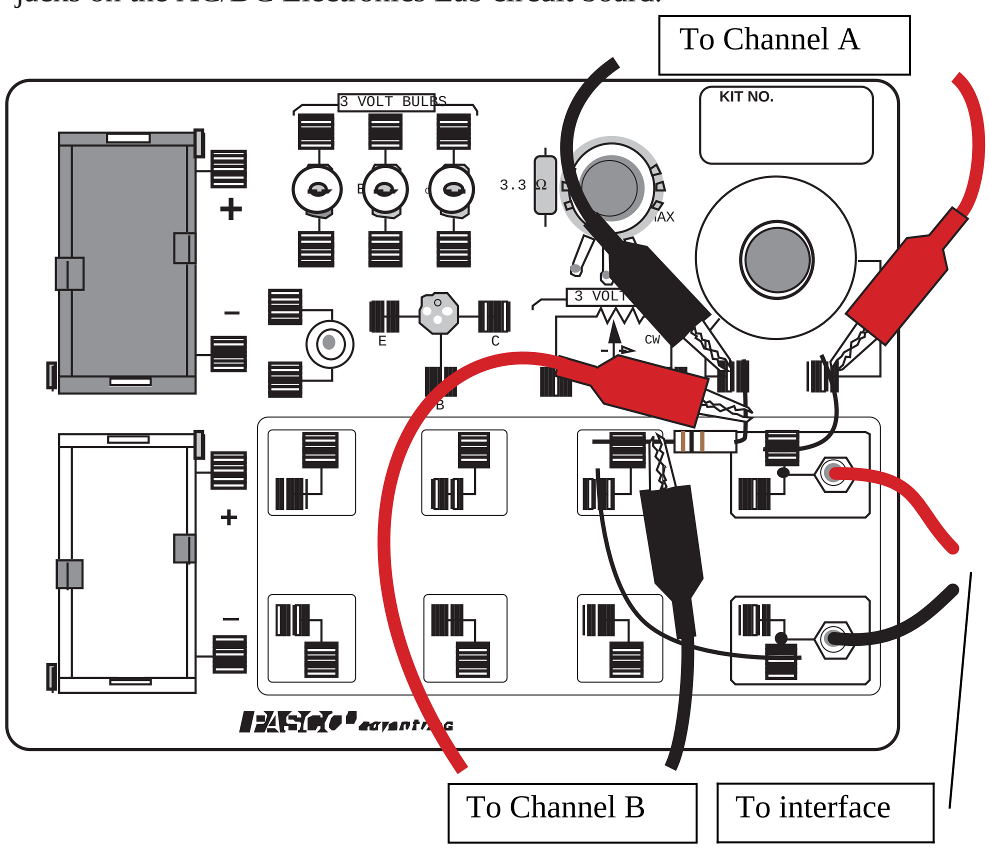
- The *DataStudio* document opens with a Graph display of voltage versus time for the 'Output', the resistor, and the inductor. The document also has a Workbook display. Read the instructions in the Workbook.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Signal Generator is set to output a 'positive-only' square wave at 3.00 volts and 50.00 Hz. The Signal Generator is set to 'Auto' so it will start and stop automatically when you start and stop measuring data.
- Data recording is set to automatically stop at 0.12 seconds.

Name ____________________ Class ______________ Date _________

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.

1. Put the iron core into the inductor coil on the AC/DC Electronics Lab circuit board.
2. 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 on the circuit board.
3. Connect the 10-ohm 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.
4. Connect another 5-inch wire lead between the component spring nearest to the one in which one end of the 10-ohm resistor is connected, and a component spring nearest to the bottom banana jack at the lower right corner of the circuit board.
5. Put alligator clips on the banana plugs of both Voltage Sensors. Connect the alligator clips of Voltage Sensor "A" to the component springs at both sides of the inductor coil.
6. Connect the alligator clips of Voltage Sensor "B" to the wires at both ends of the 10-Ω resistor.
7. Connect banana plug patch cords from the 'OUTPUT' ports of the interface to the banana jacks on the AC/DC Electronics Lab circuit board.



SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

PART III: Data Recording

1. Use a multimeter to measure the resistance of the inductor coil on the AC/DC Electronics Lab circuit board. Record the coil resistance in the Data section.
2. Use a multimeter to measure the resistance of the 10-ohm resistor. Record the measured resistor value in the Data section.

- (Optional: If you have a meter that measures inductance, use it to measure the inductance of the inductor coil with the iron core inside.)

3. Begin measuring data. The Signal Generator will start automatically.

- Data recording will end automatically. 'Run #1' will appear in the Data list

Analyzing the Data

- The voltage across the resistor is in phase with the current. The voltage is also proportional to the current (that is, V = IR). Therefore, the behavior of the current is studied indirectly by studying the behavior of the voltage across the resistor (measured on Channel B).

1. Use the built-in analysis tools in the Graph display to determine the time to 'half-max' voltage.

- In *DataStudio*, use the 'Smart Tool'. In *ScienceWorkshop*, use the 'Smart Cursor'.
- Move the cursor to the top of the exponential part of the curve where the plot of voltage across the resistor (Channel B) is at its maximum. Record the peak voltage (Y-coordinate) and the time (X-coordinate) for that point in the Data table. Determine the voltage that is half of the peak (the "half-max" voltage).
- Move the cursor down the exponential part of the plot of resistor voltage until you reach the "half-maximum" (peak) voltage. Record the X-coordinate (time) for this point.
- Subtract the time for the peak voltage from the time for the half-max voltage to get the time for the voltage to reach half-max. Record this time in the Data table.

2. Calculate the inductive time constant based on the total resistance in the circuit and the value for the inductance of the inductor coil with the iron core: L = 18.9 millihenry or 0.0189 H.

- NOTE: If you have a meter that measures inductance, use your measured value for the inductance of the coil plus core.

Inductive time constant, $\tau = \frac{L}{R}$.

3. Record the calculated value for the inductive time constant in the Data section.

Put your results in the Lab Report section

Name ______________________ Class _______________ Date __________

Lab Report- Activity P51: LR Circuit

What Do You Think?

What is the relationship between the voltage across the inductor and the voltage across the resistor in an inductor-resistor circuit? What is the relationship between the current through the inductor and the behavior of an inductor in a DC circuit?

Data

L = 18.9 millihenry or 0.0189 H for the coil plus core, unless measured otherwise.

Item	Value
Inductor resistance	
Resistor resistance	
Total resistance	
Peak voltage (for resistor)	
Time at peak voltage	
Time at half-maximum voltage	
Time to reach half-maximum	
$\tau = \frac{t_{1/2}}{\ln 2}$	
τ = L/R	

Questions

1. How does the inductive time constant found in this experiment compare to the theoretical value given by τ = L/R? (Remember that R is the total resistance of the circuit and therefore must include the resistance of the coil as well as the resistance of the resistor.)

2. Does Kirchhoff's Loop Rule hold at all times? Use the graphs to check it for at least three different times: Does the sum of the voltages across the resistor and the inductor equal the source voltage at any given time?

Name ____________________ Class _____________ Date _________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

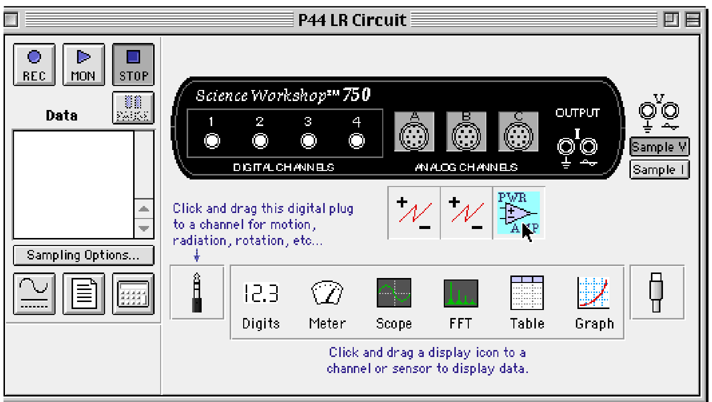
Open the file titled as shown:

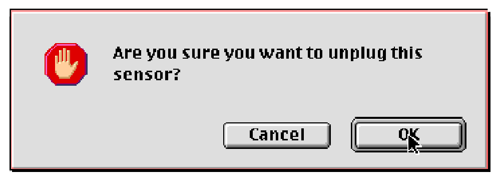
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P44 LR Circuit	P44_LRCI.SWS

This activity uses the 'Output' feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

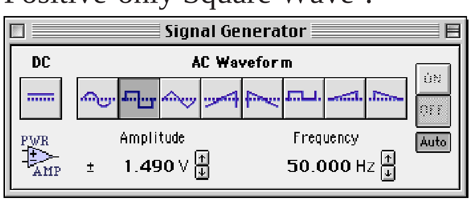


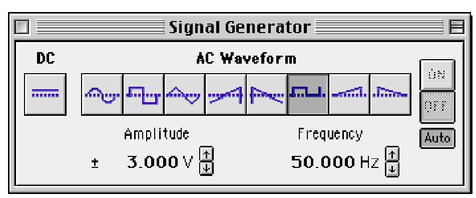


Result: A warning window opens. Click 'OK' to return to the setup window.

Modify the Signal Generator Window

Change the Signal Generator window so the Amplitude is 3.00 volts and the AC waveform is 'Positive-only Square Wave'.





Change the Sampling Options

Open the Sampling Options window. Remove the 'Start' condition. Change the 'Stop' condition to '0.12 s'.

Name ____________________ Class _____________ Date _________

Activity P52: LRC Circuit (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
AC circuits	P52 LRC Circuit.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**From AC/DC Electronics Lab (EM-8656)**	**Qty**
Voltage Sensor (CI-6503)	1	**Capacitor, 100 microfarad (100 μF)**	1
Patch Cord (SE-9750)	2	**Inductor Coil and Iron Core**	1
Graph paper (optional)	1	**Resistor, 10 ohm (10 Ω)**	1
LCR Meter (SB-9754) (optional)	1	**Wire Lead, 5 inch**	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 answer the 'What Do You Think?' question(s) 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 = $2\pi f$ (f = 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 REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the 'Output' feature of the *ScienceWorkshop* interface to produce an alternating current through the LRC circuit. Use the 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 *ScienceWorkshop* or *DataStudio* program 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 *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor to Analog Channel B.
3. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

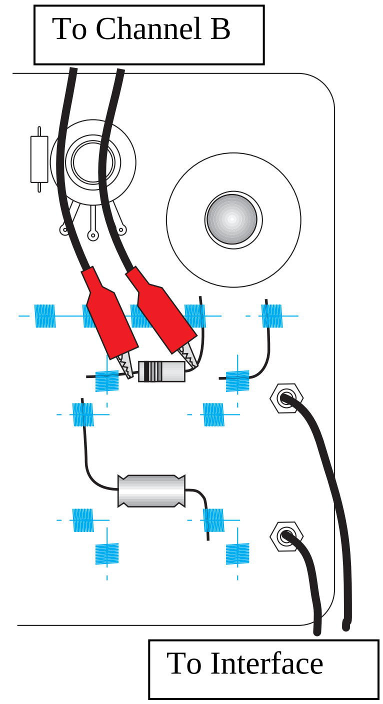
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P52 LRC Circuit.DS	(See end of activity)	(See end of activity)

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook. The document also has a Scope display of 'Output Voltage' and 'Voltage, Ch B'.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Signal Generator is set to output a sine wave at 2.97 volts with the initial frequency at 10 Hz. The Signal Generator is set to 'Auto' so it will start and stop automatically when you start and stop measuring data.

Name ____________________ Class ______________ Date _________

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).

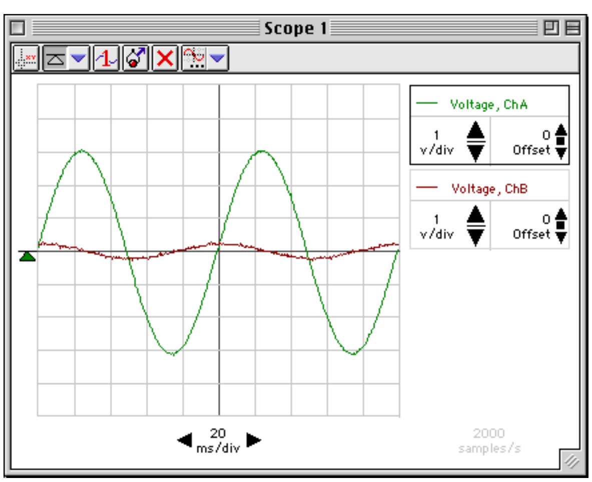


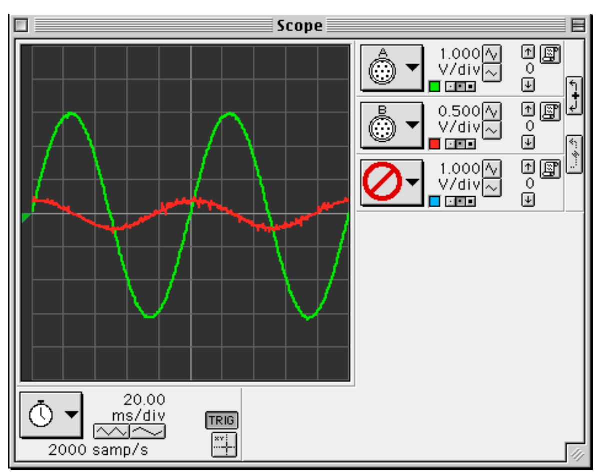
1. Connect a 5-inch wire lead between a component spring next to the top banana jack, and the component spring at the right hand edge of the inductor coil. Put the iron core inside the inductor coil.
2. Connect the 10-Ω resistor (brown, black, black) between the component spring at the left-hand edge 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 $I = \frac{V_R}{R}$.
5. Connect banana plug patch cords from the banana jacks on the edge of the AC/DC Electronics Lab Board to the 'OUTPUT' ports on the *ScienceWorkshop* interface.

Part III: Data Recording

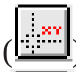
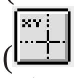
1. Check the Signal Generator window. Set the waveform to "sine". Set the output voltage to 3 volts. Set the output frequency to 10 Hz.
2. Start measuring data. (Click 'Start' in *DataStudio* or 'MON' in *ScienceWorkshop*.)

- The Scope display shows the 'Output' voltage, V, from the interface, and the voltage, V_R, across the resistor (Channel B).



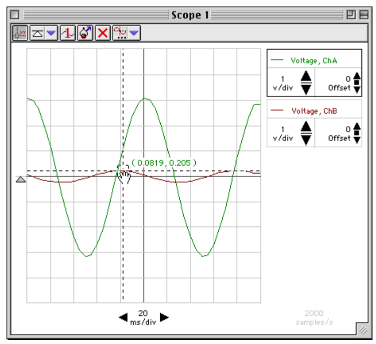


3. In the Scope display, determine the voltage, V_R, across the resistor (i.e., voltage from Channel B).

• 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.

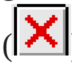
• Hint: Switch the Scope display to X-Y mode to check whether the trace of voltage from Channel B (resistor voltage) is *in phase* with the trace of voltage from Channel A (the function generator). See the descriptions below.

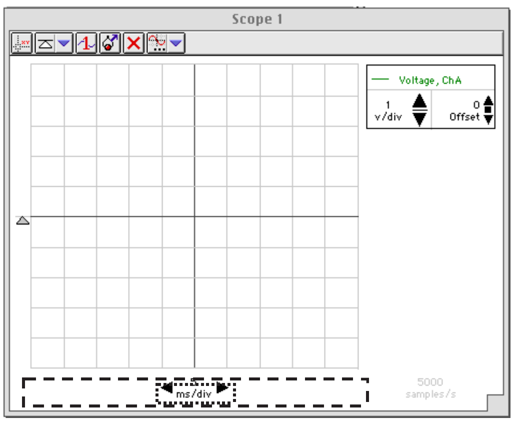
9. Record the new resonant frequency in the Data Table.

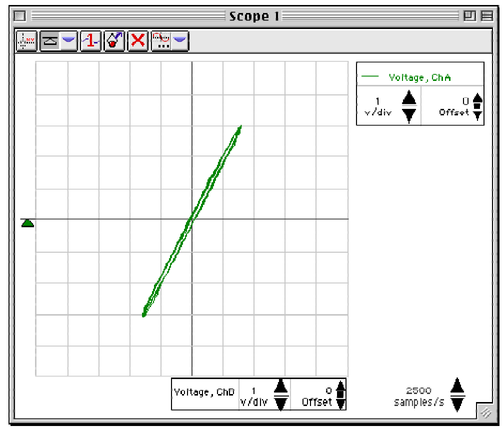
10. Stop measuring data.

Name ____________________ Class _____________ Date _________

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 () 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.

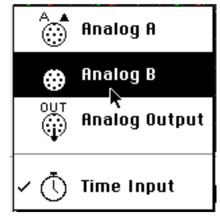


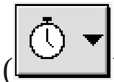
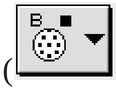


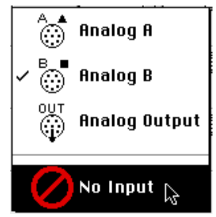
- Note: The Sweep Speed control panel will be surrounded by a dashed rectangle when the new input (‘Voltage ChB (v)’) is on top of the control panel. (See the illustration.)

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.

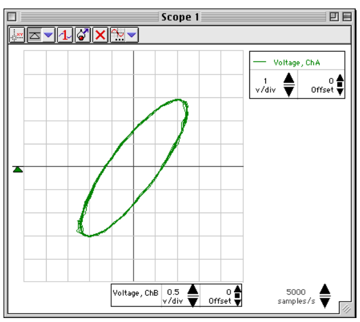
Frequency Adjustment in XY Mode: *ScienceWorkshop*

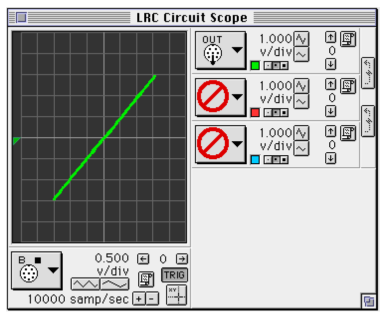


- Click STOP.
- In the Scope display, click the 'Horizontal Axis Input' menu button (). Select 'Analog B' from the Horizontal Axis Input menu.
- In the Scope, click the 'Channel B Input' menu button (). Select 'No Input' from the Channel B Input menu.



- 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 <u>is</u> the linear frequency.)
3. Using the resonant frequency found from the Scope display, calculate the resonant <u>angular</u> frequency and record the value in the Data Table:

$$\omega_{res} = 2\pi\nu_{res}$$

4. Calculate the <u>theoretical</u> 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.

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Lab Report - Activity P52: 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	
Resistance	
Capacitance	

Resonant frequency (linear)	
Resonant angular frequency	
Theoretical resonant angular frequency	

Questions

1. How does your measured value for resonant angular frequency compare to the theoretical value for resonant angular frequency?

Remember, $\textbf{Percent difference} = \left| \dfrac{|\textbf{\textit{theoretical}} - \textbf{\textit{actual}}|}{\textbf{\textit{theoretical}}} \right| \times 100\%$

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 $R = \frac{V}{I}$ (where V is the amplitude of the applied voltage). Is this resistance equal to 10 ohms? Why not?

Optional

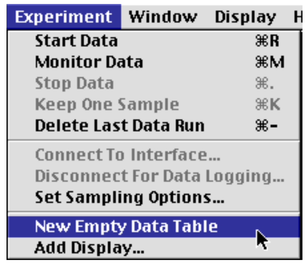
1. Use the Voltage Sensor in Analog Channel B to measure the peak voltage across each of the components of the circuit individually. The sum of these peak voltages do not equal the applied peak voltage. Why not? Draw a phasor diagram to explain this.
2. Determine whether the resonant frequency depends 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?)

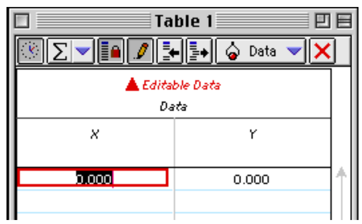
Graphing Current vs. Linear Frequency using *DataStudio*

You can enter data into a Table display and then show the data in a Graph window.

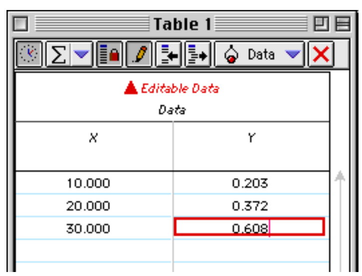
1. Select 'New Empty Data Table' from the Experiment menu.



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.



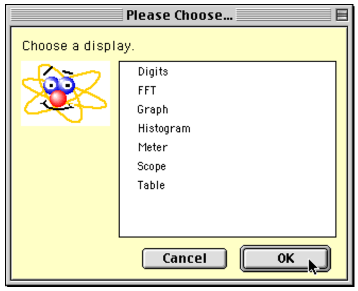
3. Enter the first value of frequency (Freq (Hz)), click <TAB>, and enter the first value of current (Current = V_R/R). Click <TAB> to move to the second row.



4. Continue to enter values of frequency and current. (Note: *DataStudio* anticipates the next value of frequency for you.)

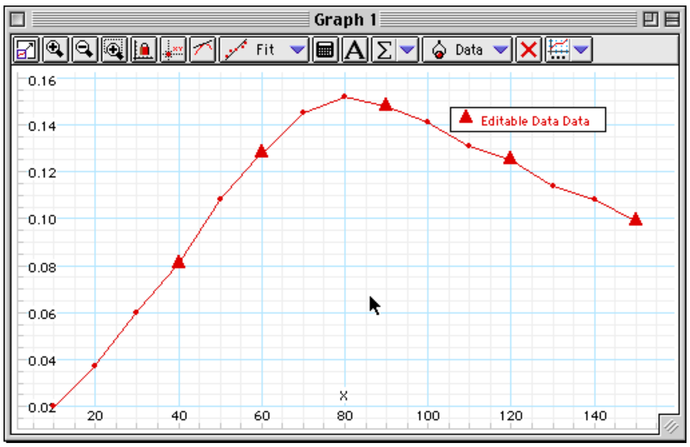
5. Select 'Add Display…' from the Experiment menu.

6. Click ‘Graph’ and then click ‘OK’ in the ‘Please Choose…’ window.

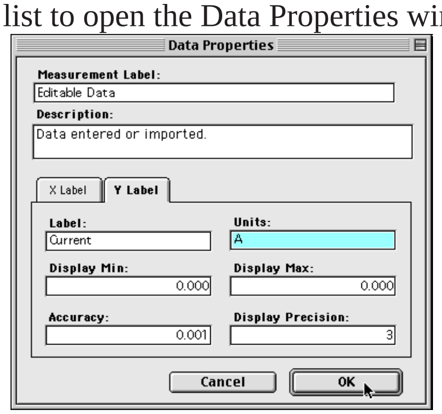


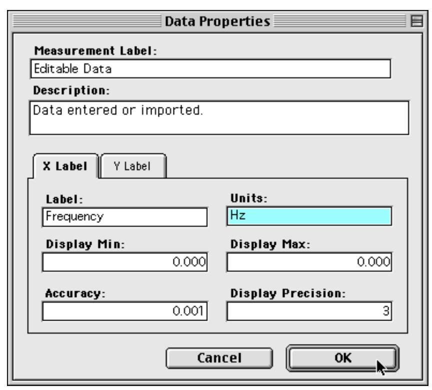
7. From the Summary list, click and drag ‘Data’ (under ‘Editable Data’) to the new Graph.

- 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.

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Graphing Current vs. Linear Frequency using *ScienceWorkshop*

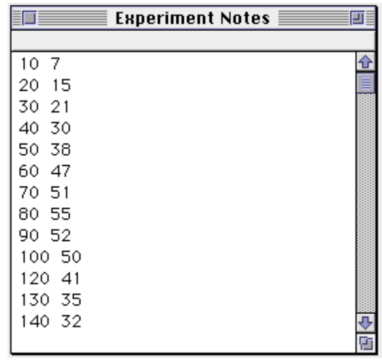
You can type data into the Notes window and then display the data in a Graph window.

1. Clear the text and graphics (if any) from the Notes window.
2. Type data into the Notes window using the following procedure:

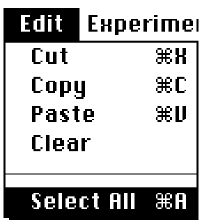
   <independent variable value #1><TAB><dependent variable value #1><return>

   <independent variable value #2><TAB><dependent variable value #2><return>, etc.

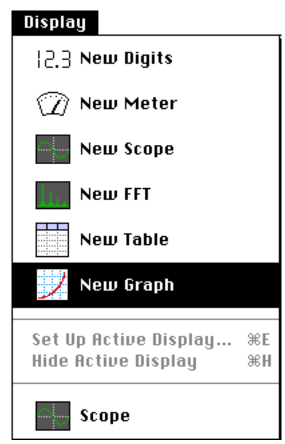
- In this case, the independent variable is frequency, and the dependent variable value is the current.
- For example, the figure shows two columns of numbers typed into a Notes window. The first column represents the linear **frequencies**. The second column represents hypothetical values of **current**.

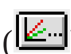
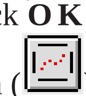


3. Use the cursor to select (highlight) the two columns of numbers, or click the 'Edit' menu and pick 'Select All'.

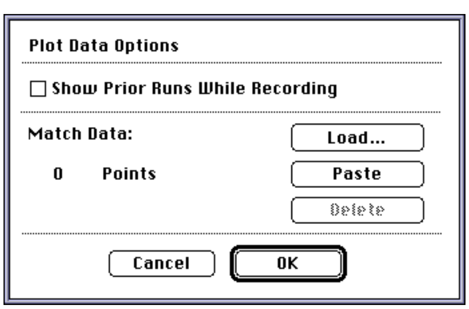


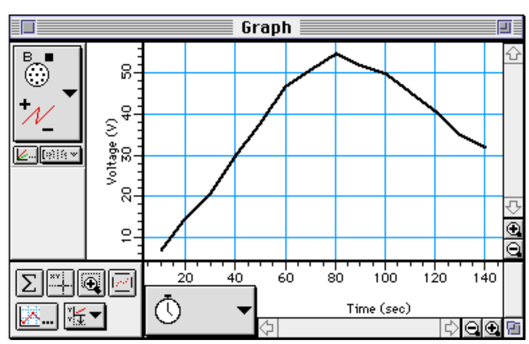
4. Copy the selection (use 'Copy' from the Edit menu).
5. Click the Display Menu and select 'New Graph'.



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 **OK** 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.





Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

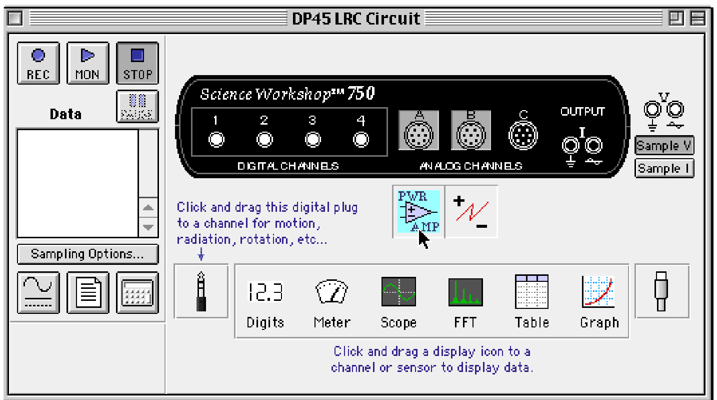
Open the file titled as shown:

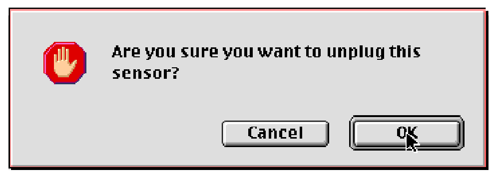
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P45 LRC Circuit	P45_LRCC.SWS

This activity uses the ‘Output’ feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.





Result: A warning window opens. Click ‘OK’ to return to the setup window.

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Activity P53: Diodes Lab 1 – Properties & LED's
(Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Semiconductors	P53 LED.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty
Voltage Sensors (CI-6503)	2
Patch Cord (SE-9750)	2

From AC/DC Electronics Lab (EM-8656)	Qty
Diode, 1N-4007	1
Light-emitting diode (LED), red	1
Light-emitting diode (LED), yellow	1
Light-emitting diode (LED), green	1
Light-emitting diode (LED), bi-color	1
Resistor, 1 kilo-ohm (kΩ)	1
Wire Lead, 5 inch	1

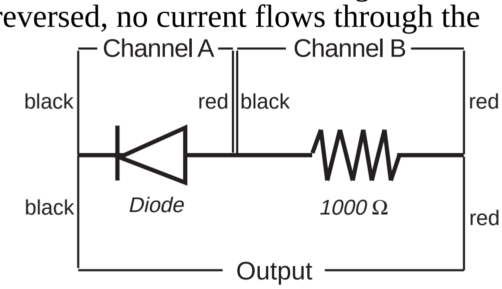
What Do You Think?

What are the properties of various types of diodes?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

A diode (or *p-n* junction rectifier) is an electronic device that only allows current to flow in one direction through it once a certain forward voltage is established across it. If the voltage is too low, no current flows through the diode. If the voltage is reversed, no current flows through the diode (except for a very small reverse current).



A light-emitting diode emits light as current passes through the diode in the forward direction. A red-green diode is actually two diodes connected together anti-parallel so that the red diode allows current to flow in one direction and the green diode allows current to flow in the opposite direction. Thus, if DC (direct current) is applied to the red-green diode, it will be only red or only green depending on the polarity of the applied DC voltage. But if AC (alternating current) is applied to the red-green diode (bi-color LED), the diode will repeatedly blink red then green as the current repeatedly changes direction.

A bi-color LED is an example of a Zener diode. A Zener diode allows current to flow in one direction when the forward voltage is large enough, and it allows current to flow in the opposite direction when reverse voltage (called the "breakdown" voltage) is large enough (usually a few volts).

Overview

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

There are four units in the Diode Labs. You will complete the first two units in Lab 1 (this experiment). You will complete Unit Three and Unit Four in Lab 2 (the next experiment).

In the first unit you will investigate the general properties of a diode. In the second unit you will investigate different types of diodes, including light-emitting diodes (LED's) and a Zener diode. In the third unit you will rectify a sine wave generated by the 'Output' of the interface. In the last unit you will setup the basic circuitry for a power supply. Use *DataStudio* or *ScienceWorkshop* to record and analyze the data.

Unit One – Diode Properties

For You To Do

Use the 'Output' feature of the *ScienceWorkshop* interface to produce a voltage through a circuit with a diode and a resistor. Use one Voltage Sensor to measure the voltage drop (potential difference) across the diode. Use the other Voltage Sensor to measure the voltage drop across the resistor.

Use the built-in calculation in the software to determine the current through the resistor. Use the Graph display of current versus voltage to determine the characteristics of the diode.

PART I: Computer Setup

1. Connect the *ScienceWorkshop* 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. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P53 LED 1.DS	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook. The document also has a Graph display of current in milliamperes (mA) versus voltage (V), and the Signal Generator window that controls the 'Output'.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The current is a built-in calculation based on the voltage drop across a 1000 ohm (1 kΩ) resistor (as measured by the Voltage Sensor connected to Channel B).
- The Signal Generator is set to output 5.00 volt, up-ramp AC Waveform, at 2.00 Hz.
- Data recording is set for 500 measurements per second. Data recording stops automatically at 0.5 seconds.

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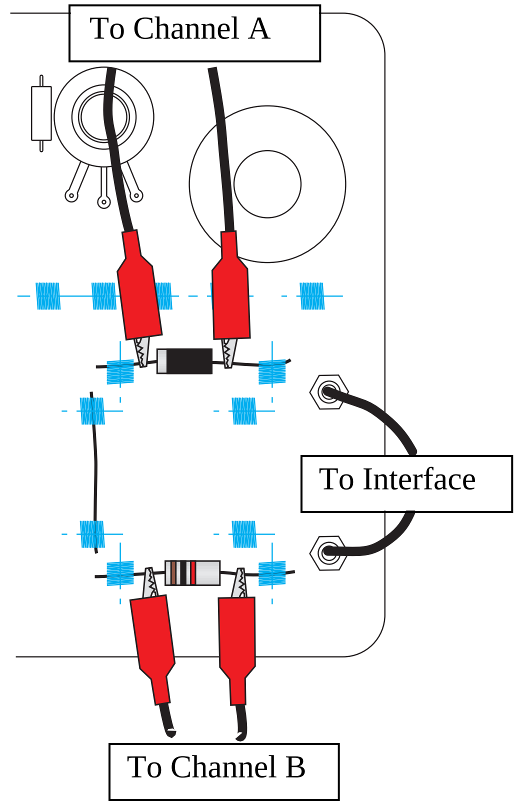
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensors.



1. Connect the 1N-4007 diode (black with gray stripe at one end) between the component spring next to the top banana jack and the component spring to the left of the banana jack. Arrange the diode so the gray stripe is at the left end.
2. Connect the 1 kΩ resistor (brown, black, red) between the component spring next to the bottom banana jack and the component spring to the left of the bottom banana jack.
3. Connect a 5-inch wire lead between the component spring at the left end of the diode and the component spring at the left end of the 1 kΩ resistor.
4. Put alligator clips on the banana plugs of both voltage sensors. Connect the alligator clips of the Channel A voltage sensor to the wires at both ends of the diode.
5. Connect the alligator clips of the Channel B voltage sensor to the wires at both ends of the 1 kΩ resistor.
6. Connect banana plug patch cords from the ‘OUTPUT’ ports of the *ScienceWorkshop* interface to the banana jacks on the AC/DC Electronics Lab circuit board.

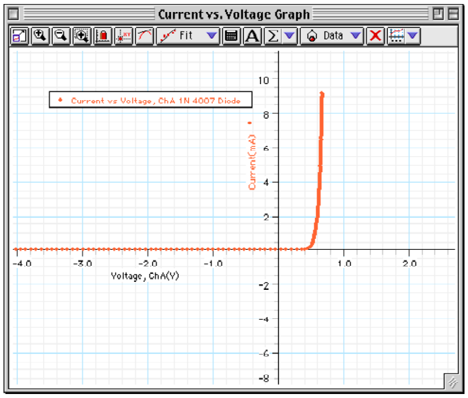
PART III: Data Recording - Diode and 1 kΩ Resistor

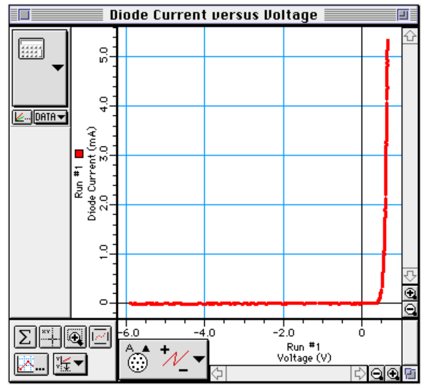
1. When everything is ready, start measuring data. (Click ‘Start’ in *DataStudio* or ‘REC’ in *ScienceWorkshop*.) The Signal Generator will start automatically.

- Data recording will end automatically after 0.5 seconds.
- Note: If the plot rapidly increases at the beginning then levels off to zero, the diode is reversed. Turn it around and record a new set of data.

Analyzing the Data: Diode and 1 kΩ Resistor

1. Resize the Graph to fit the data.

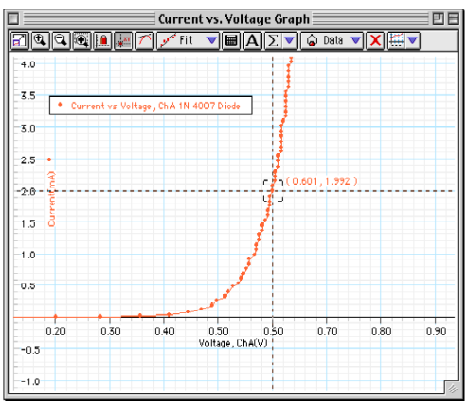


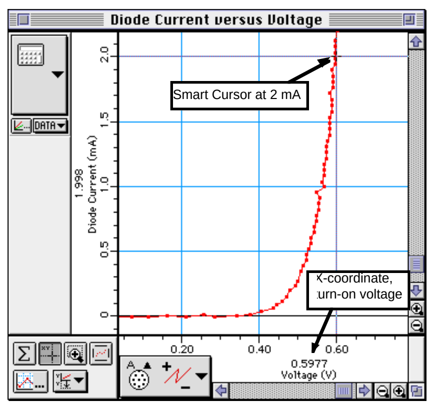


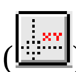
- The vertical axis shows the current in milliamperes based on a calculation using the voltage drop across the 1 kΩ resistor. The horizontal axis shows Voltage across the diode.

2. Zoom in on the region of the plot of current and voltage where the current begins to increase. Make sure the upper boundary is beyond 2 milliamperes (mA).

3. Use the built-in analysis tools to measure the value of the turn-on voltage at the point on the plot where the current reaches 2 milliamperes.





- Hint: In *DataStudio*, use the 'Smart Tool' (). The 'Smart Tool' displays the coordinates of its position as you move it to any position in the Graph display. When the 'Smart Tool' is on a data point, the 'y' coordinate is the current and the 'x' coordinate is the voltage value at that point. In *ScienceWorkshop*, use the 'Smart Cursor'.

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Unit Two – Light-Emitting Diodes

For You To Do

Use the 'Output' feature of the *ScienceWorkshop* interface to produce a voltage through a circuit with a light-emitting diode (LED) and a resistor. Use one Voltage Sensor to measure the voltage drop (potential difference) across the LED. Use the other Voltage Sensor to measure the voltage drop across the resistor.

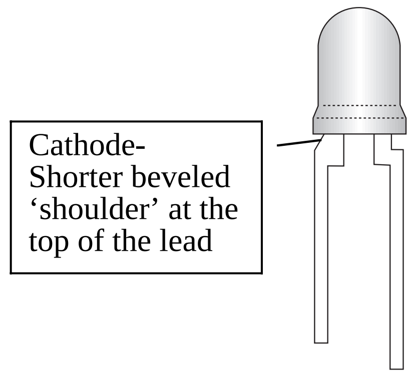
PART I: Computer Setup

- You do not need to change the computer setup.

PART II: Sensor Calibration and Equipment Setup

1. Prepare the red, yellow, and green LED's by very carefully bending the wire leads so they can fit in the component springs in place of the diode you used in Unit One.
2. Replace the diode from Unit One with the first LED (red). Arrange the first LED so the short lead (cathode) is to the left.

- The wire lead that is connected to the cathode of the LED is slightly shorter, and has a beveled shoulder near where the wire enters the LED.



PART IIIA: Data Recording – Light-Emitting Diodes

1. When everything is ready, start recording data.

- The Signal Generator will start automatically. Data recording will end automatically after 0.5 seconds.

2. Replace the first LED (red) with the next LED (yellow).
3. Repeat the data recording procedure with the yellow and green LED.

- You should now have four data sets.

Analyzing the Data: Light-Emitting Diodes

1. Setup the Graph display to show only the data for the red LED. Resize the Graph to fit the data.
2. Zoom in on the region of the plot of current and voltage where the current begins to increase. Make sure the upper boundary is beyond 2 milliamperes (mA).
3. Use the built-in analysis tools to measure the value of the turn-on voltage at the point on the plot where the current reaches 2 milliamperes.
4. Repeat the analysis process for the plot of Current versus Voltage for the yellow LED.
5. Repeat the analysis process for the plot of Current versus Voltage for the green LED.

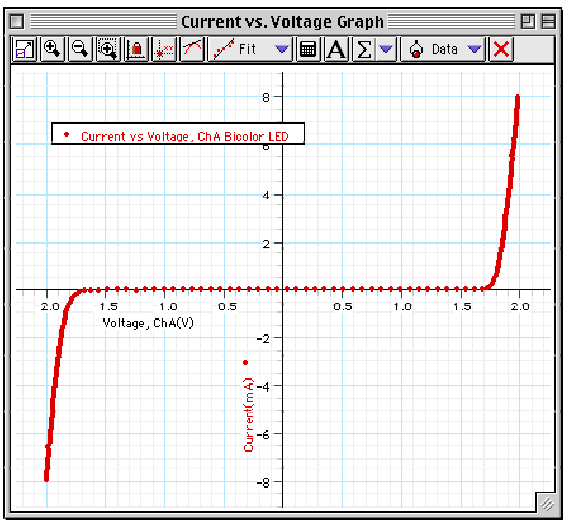
PART IIIB: Data Recording - Bi-Color Diode

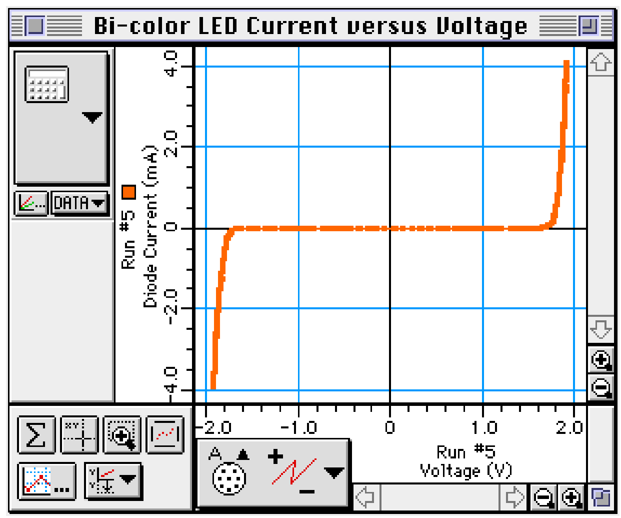
1. Carefully bend the wire leads of the CLEAR (bi-color) light-emitting diode so they can fit in the component springs in place of the last diode you used in PART IIIA of this unit.
2. Replace the green LED with the bi-color LED.
3. When everything is ready, start recording data. The Signal Generator will start automatically.
4. Data recording will end automatically after 0.5 seconds.

• How does the behavior of the bi-color LED differ from the other LED's?

Analyzing the Data: Bi-Color Led

1. Setup the Graph display to show only the data for the bi-color LED. Resize the Graph to fit the data.





2. Zoom in on the RIGHT hand region of the plot of current and voltage where the current begins to increase. Make sure the upper boundary is beyond 2 milliamperes (mA).
3. Use the built-in analysis tools to measure the value of the turn-on <u>voltage</u> at the point on the plot where the current reaches 2 milliamperes.
4. Resize the Graph to fit the data. Zoom in on the LEFT-hand region of the plot of current and voltage where the current begins to increase. Make sure the lower boundary is below -2 milliamperes (mA).
5. Use the built-in analysis tools to measure the value of the turn-on <u>voltage</u> at the point on the plot where the current reaches <u>-2 milliamperes</u>.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report – Activity P53: Diodes Lab 1 – Properties & LED's

What Do You Think?

What are the properties of various types of diodes?

Data Table 1: Light-Emitting Diodes

Description	Voltage (V) at 2 mA
Diode & 1 kΩ resistor	
Red LED	
Yellow LED	
Green LED	

Data Table 2: Bi-Color LED

	Voltage (V) at 2 mA	Voltage (V) at -2 mA
Bi-Color LED		

Questions

1. In Unit One, what does the plot of Diode Current vs. Voltage mean?

2. In Unit Two, which LED (light-emitting diode) has the lowest turn-on voltage? Which LED has the highest turn-on voltage?

3. In Unit Two, how does the forward turn-on voltage for the Bi-Color LED compare to any of the colored LED's? How does the reverse turn-on voltage for the Bi-Color LED compare to any of the colored LED's?

4. How does the behavior of the Bi-Color LED differ from the other LED's?

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Modify an existing *ScienceWorkshop* file

Open the *ScienceWorkshop* File

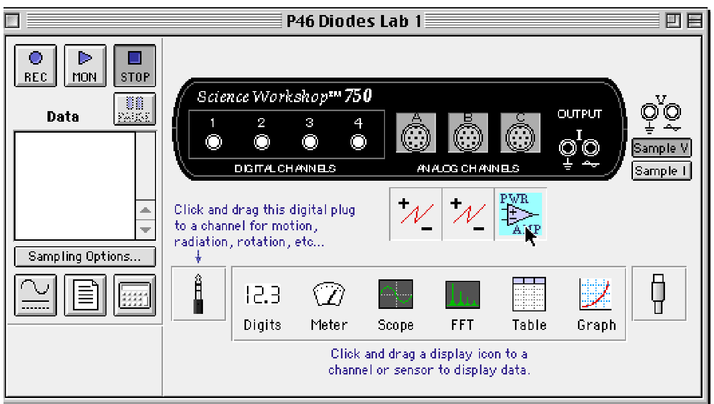
Open the file titled as shown:

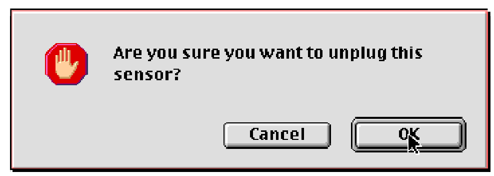
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P46 Diodes Lab 1	P46_DIO1.SWS

This activity uses the 'Output' feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

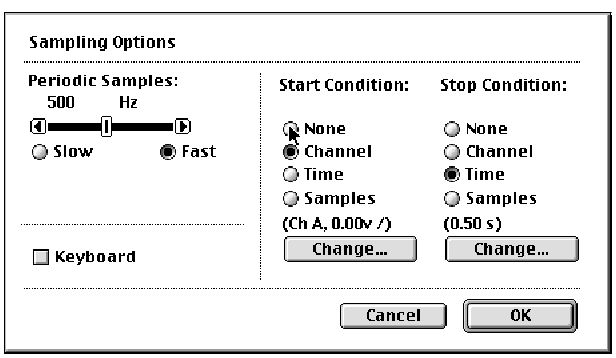


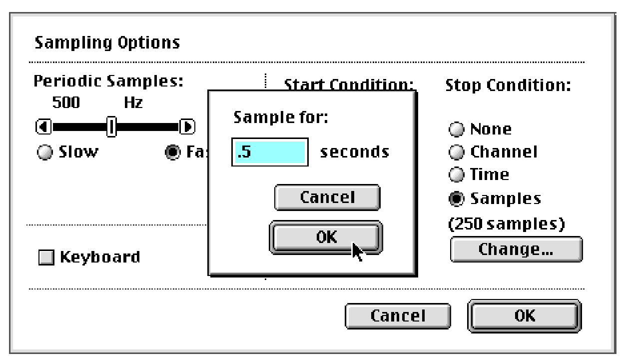


Result: A warning window opens. Click 'OK' to return to the setup window.

Change the Sampling Options

Open the 'Sampling Options' window. Change the 'Start' condition to 'None'. Change the 'Stop' condition from 'Samples' to 'Time'. Enter '0.5' as the amount of time. Click 'OK' to return to the Sampling Options window. Click 'OK' again to return to the Experiment Setup window.





Name ____________________ Class ______________ Date _________

Activity P54: Diodes Lab 2 – Rectifier & Power Supply (Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Semiconductors	P54 Rectifier.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**From AC/DC Electronics Lab (EM-8656)**	**Qty**
Voltage Sensors (CI-6503)	2	**Capacitor, 100 microfarad**	1
Patch Cord (SE-9750)	2	**Diode, 1N-4007**	4
		Light-emitting diode (LED), red	1
		Resistor, 1 kilo-ohm (kΩ)	1
		Resistor, 330 ohm	1
		Resistor, 10 ohm	1
		Wire Lead, 5 inch	1
		Wire Lead, 10 inch	1

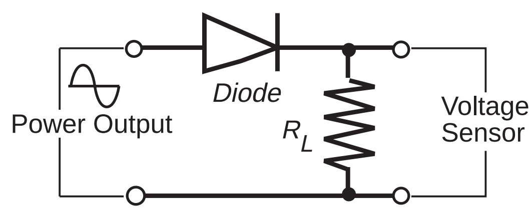
What Do You Think?

In this activity you will explore some of the basic applications of the diode. When the activity is concluded, you will understand further the importance of filtering and rectifying alternating current. What is one example of a device that uses the diode?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

A diode (or *p*-*n* junction rectifier) is an electronic device that only allows current to flow in one direction through it once a certain forward voltage is established across it. If the voltage is too low, no current flows through the diode. If the voltage is reversed, no current flows through the diode (except for a very small reverse current).



A diode can be used to provide DC current from an AC source. In other words, the diode rectifies the AC current.

When capacitors smooth the rectified current, the diodes make up part of a power supply.

Overview

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

There are four units in the Diode Lab. You completed the first two units in Lab 1 (the previous activity). You will complete Unit Three and Unit Four in this activity. In the third unit you will rectify a sine wave generated by the 'Output' feature of the interface. In the fourth unit you will setup the basic circuitry for a power supply. Use *DataStudio* or *ScienceWorkshop* to record and analyze the data.

Procedure: Unit Three – Rectify a Sine Wave

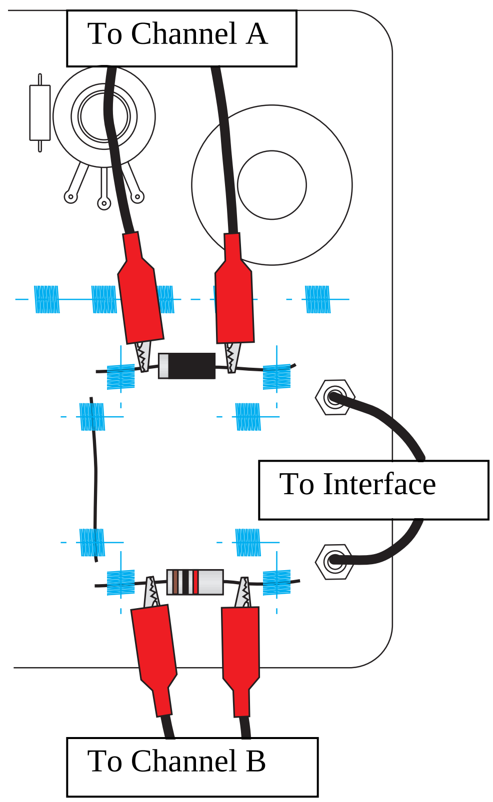
PART IA: Computer Setup

1. Connect the *ScienceWorkshop* 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. Connect two banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document title as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P54 Rectifier.DS	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook. The document also has a Scope display of 'Voltage, Ch A' and 'Voltage, Ch B' and the Signal Generator window that controls the 'Output'.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Signal Generator for Unit Three is set to output a 3 volt 'Sine Wave' at 2 Hz. The output is set to start and stop automatically when you start and stop measuring data.

PART IIA: Sensor Calibration and Equipment Setup



- You do not need to calibrate the Voltage Sensors.

1. Connect the 1N-4007 diode (black with gray stripe at one end) between the component spring next to the top banana jack and the component spring to the left of the banana jack. Arrange the diode so the gray stripe is at the left end.
2. Connect the 1 k Ω resistor (brown, black, red) between the component spring next to the bottom banana jack and the component spring to the left of the bottom banana jack.
3. Connect a 5-inch wire lead between the component spring at the left end of the diode and the component spring at the left end of the 1 kΩ resistor.
4. Put alligator clips on the banana plugs of both voltage sensors. Connect the alligator clips of the Channel A voltage sensor to the wires at both ends of the diode.
5. Connect the alligator clips of the Channel B voltage sensor to the wires at both ends of the 1 kΩ resistor.
6. Connect banana plug patch cords from the 'OUTPUT' ports of the *ScienceWorkshop* interface to the banana jacks on the AC/DC Electronics Lab circuit board.

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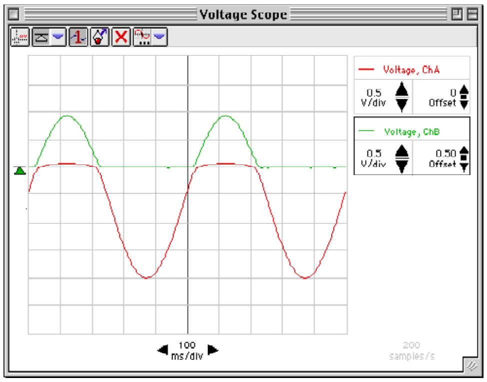
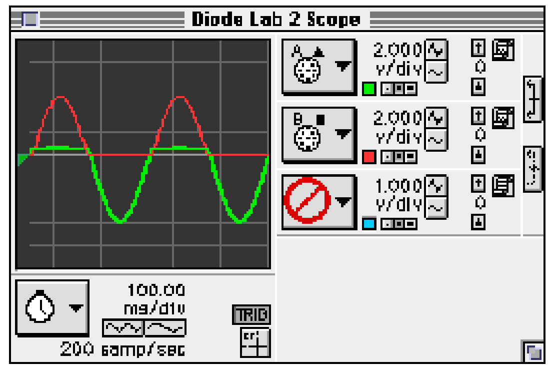
PART IIIA: Data Recording - Rectify a Sine Wave with a Diode

1. Begin measuring data. (Click ‘Start’ in *DataStudio* or ‘MON’ in *ScienceWorkshop*.)

- The channel “A” trace on the Scope display is the voltage across the diode. The channel “B” trace is the voltage across the resistor.



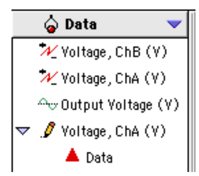


2. When both traces are completely across the Scope, stop measuring data.

The following information describes how to transfer data from the Scope display.

3. Transfer data from the Scope display so it can be analyzed.

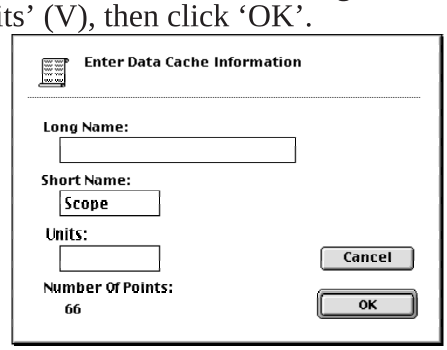
<u>In *DataStudio*</u>, click the ‘Voltage, Ch A’ input icon and then click the ‘Transfer Data’ button (). The data from Channel A’s Scope Display transfers to the ‘Data’ list. Rename ‘Data’ as ‘Diode Voltage’.

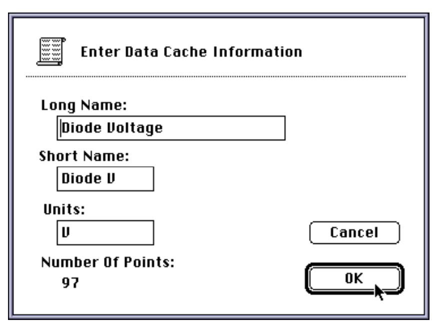


- Repeat the process for ‘Voltage, Ch B.’ Make sure you click on the ‘Voltage, Ch B’ input icon to make it active prior to clicking the ‘Transfer Data’ button. Rename ‘Data’ as ‘Resistor Voltage’.

<u>In *ScienceWorkshop*</u>, click the top ‘Data Snapshot’ button () in the right hand corner of the Scope display. This will open the ‘Data Cache Information’ window.

- Enter information for the ‘Long Name’ (e.g. Diode Voltage), ‘Short Name’ (Diode V), and ‘Units’ (V), then click ‘OK’.





- Save the data for the other trace on the Scope display. Click the middle ‘Data Snapshot’ button. Enter the needed information in the ‘Data Cache Information’ window and then click ‘OK’.
- The short names of the data caches will appear in the Data list in the Experiment Setup window.

Analyzing the Data: Rectify a Sine Wave with a Diode

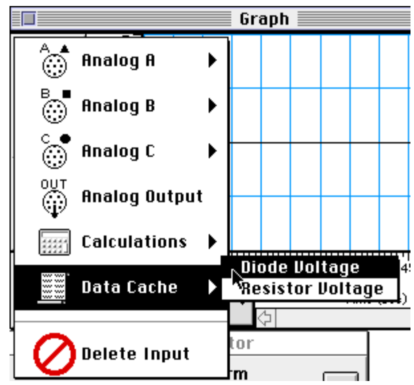
1. View data in a Graph display.

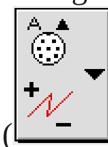
In *DataStudio*, drag the 'Voltage, Ch A Data' from the Data list to the Graph icon located in the Displays list.

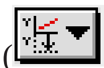
- Drag the 'Voltage, Ch B Data' from the Data list to the same graph as 'Voltage Ch A.'

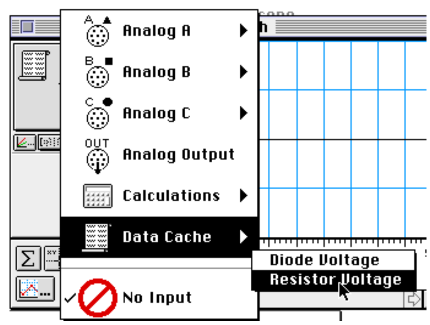
In *ScienceWorkshop*, select 'New Graph' from the 'Display' menu.

- Change the input for the vertical axis of the new graph.

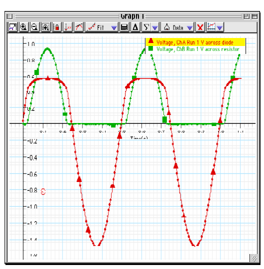


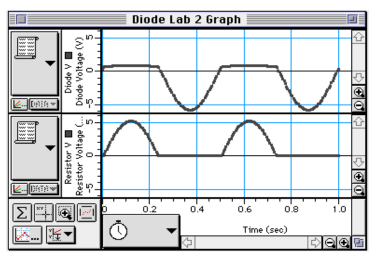
Click the vertical axis 'Input Menu' button (). Select 'Data Cache, Diode Voltage' from the Input Menu.

- Click the 'Add Plot Menu' button () at the lower left corner of the graph. Select 'Data Cache, Resistor Voltage' from the Add Plot Menu.



- Scale the axes so that both plots have approximately the same scale for the vertical axis.
- Optional: If a printer is available, select **Print Active Display…** from the File menu.





PART IIIB: Data Recording - Rectify a Sine Wave with a LED

1. Remove the diode from the component springs. Carefully place the red LED (light-emitting diode) in the component springs.
2. Repeat the data recording procedure as in Part IIIA.

Analyzing the Data: Rectify a Sine Wave with a LED

1. Repeat the data analysis procedure that followed Part IIIA.

• Optional: If a printer is available, select **Print Active Display…** from the File menu.

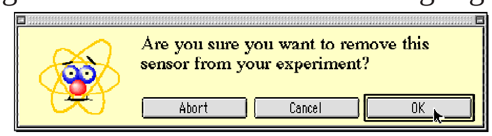
Procedure: Unit Four – Power Supply

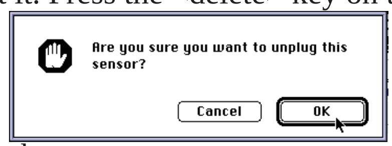
PART IC: Computer Setup – Power Supply: Single Diode

1. Remove the Voltage Sensor from Channel A of the interface.
2. Delete the Voltage Sensor icon in the Setup window.

• In *DataStudio*, click the icon of the Voltage Sensor under Channel A to highlight it. Press the <delete> key on the keyboard. Click 'OK' in the alert dialog window that opens.

• In *ScienceWorkshop*, expand the Experiment Setup window to full size. Click the icon of the Voltage Sensor under Channel A to highlight it. Press the <delete> key on the keyboard. Click 'OK' in the alert dialog window that opens.

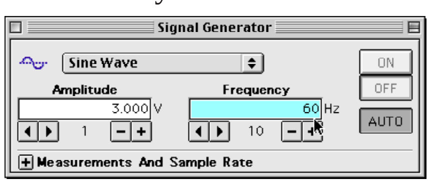


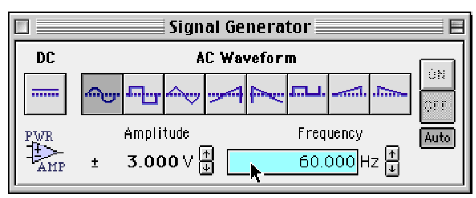


3. Modify the Signal Generator.

• In *DataStudio* , double-click 'Output Voltage' in the Data list. In *ScienceWorkshop* select 'Signal Generator' from the Experiment menu.)

• Click 'Frequency' to highlight it. Type in '60' as the new frequency, and press <enter> or <return> on the keyboard.

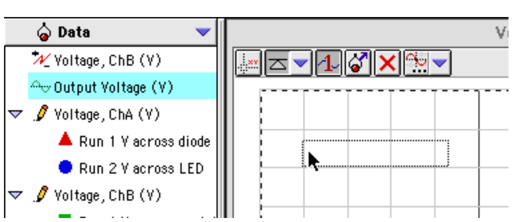


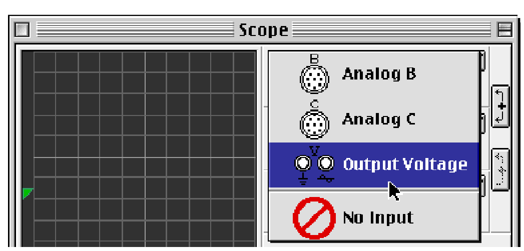


4. Modify the Scope display.

• In *DataStudio*, drag 'Output Voltage' from the Data list to the Scope display.

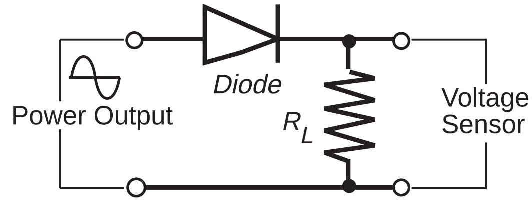
• In *ScienceWorkshop*, click the Input Menu for 'A'. Select 'Output Voltage' from the menu.





PART IIC: Equipment Setup – Power Supply: Single Diode

1. Replace the red LED with the 1N-4007 diode in the top component springs.



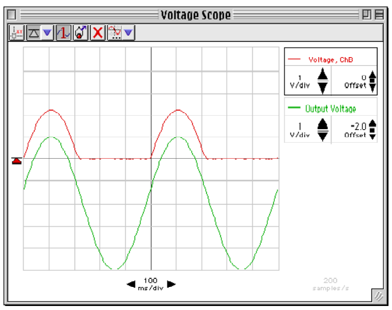
2. Replace the 1 kΩ resistor with a 330 Ω resistor in the component springs near the bottom banana jack. The 330 Ω resistor will be the “load” resistor.

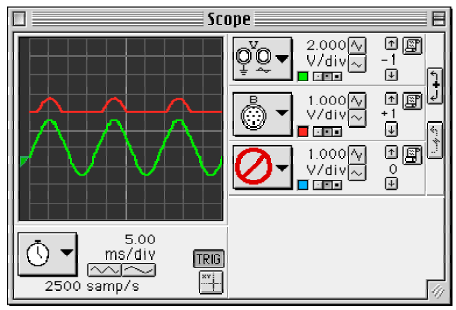
2. Get the following items for use later in this experiment: 100 microfarad (μF) capacitor, 10 ohm resistor, three additional 1N-4007 diodes.

PART IIIC: Data Recording – Power Supply: Single Diode

1. Start measuring data. (Hint: Click ‘Start’ in *DataStudio* or click ‘MON**’** in *ScienceWorkshop*.)

- The ‘sinusoidal’ trace on the Scope display is the ‘Output Voltage’ from the interface. The other trace is the voltage across the resistor.





(Note: The traces of ‘Output Voltage’ and ‘Voltage, Ch B’ have been offset so both traces can be seen.)

2. Stop measuring data.

3. Transfer the data from the Scope display as outlined in Part IIIA for later analysis.

- In *DataStudio*, click the input icon and then click the ‘Transfer Data’ button. Rename the ‘Data’ as ‘Rectified Voltage’.

- In *ScienceWorkshop*, click the Data Snapshot button for the channel. Enter Data Cache Information for ‘Long Name’ (e.g. Rectified Voltage), Short Name’ (Rectify V), and ‘Units’ (V) as needed to save the data for analysis.

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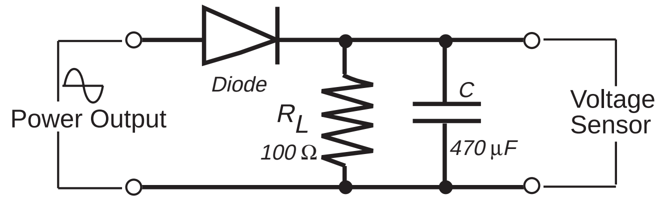
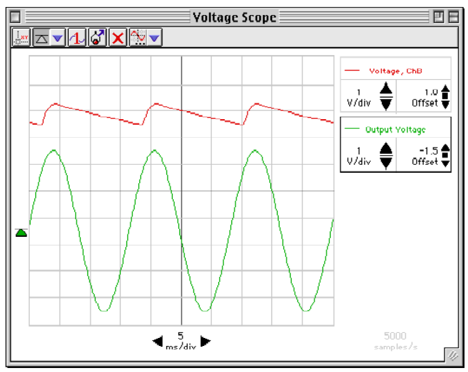
PART IIID: Data Recording – Power Supply: Diode and Capacitor (Filtered Voltage)

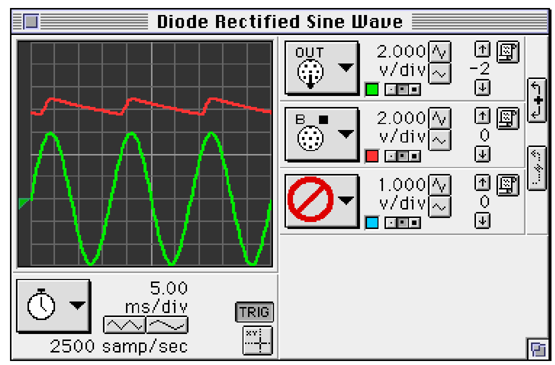
1. Add the 100 µF capacitor in parallel to the 330 Ω resistor. Carefully bend the leads of the capacitor so they can fit in the same component springs as the resistor. The capacitor acts as a “filter”.



2. Start measuring data for the capacitor in parallel with the 330 ohm resistor.

- The ‘sinusoidal’ trace on the Scope display is the ‘Output Voltage’ from the interface. The other trace is the voltage across the resistor.





3. Stop collecting data.

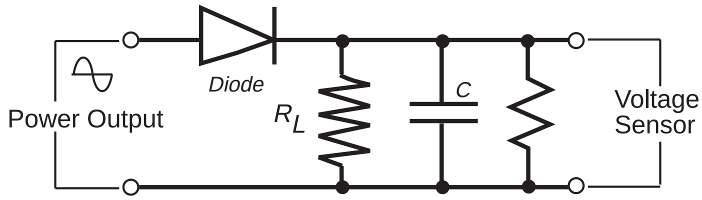
4. Transfer the data from the Scope display as outlined in Part IIIA for later analysis.

- In *DataStudio*, click the input icon and then click the ‘Transfer Data’ button. Rename the ‘Data’ as ‘Filtered Voltage’.

- In *ScienceWorkshop*, click the Data Snapshot button () for the channel. Enter Data Cache Information for ‘Long Name’ (Filtered Voltage), ‘Short Name’ (Filter V), and ‘Units’ (V) as needed to save the data for analysis.

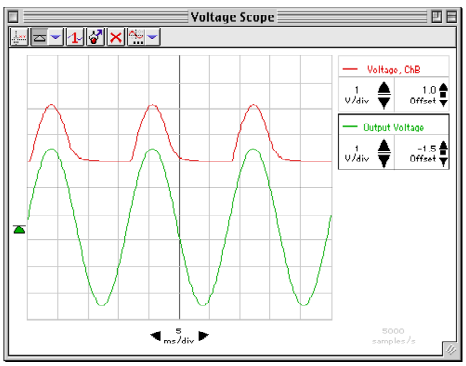
PART IIIE: Data Recording – Power Supply: Diode, Capacitor and Load

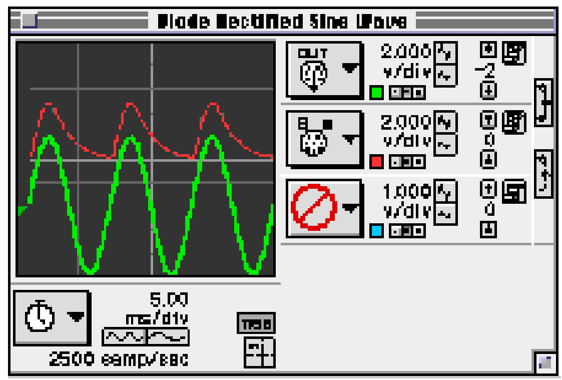
1. Add the 10 Ω resistor in parallel with the 330 Ω resistor and the 100 µF capacitor. The 10 Ω resistor simulates a motor or small light bulb.



2. Start measuring data.

• The ‘sinusoidal’ trace on the Scope display is the ‘Output Voltage’ from the interface. The other trace is the voltage across the resistor.





3. After a moment or two, stop measuring data.

4. Capture the data from the Scope Display as outlined in Part IIIA for later analysis.

• In *DataStudio*, click the input icon and then click the ‘Transfer Data’ button. Rename ‘Data’ as ‘Load Resistor’.

• In *ScienceWorkshop*, click the Data Snapshot button for the channel. Enter Data Cache Information for ‘Long Name’ (Load Resistor Voltage), ‘Short Name’ (Load V), and ‘Units’ (V) as needed to save the data for analysis.

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Analyzing the Data: Power Supply: Single Diode, Parts C, D, and E

- Optional: Select **Save As…** from the File menu to save your data.

1. View the data in Graph display.

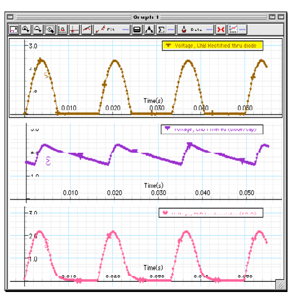
In *DataStudio*, drag the 'Voltage, Ch B Data' for the 'Rectified Voltage' from the Data list to the Graph icon located in the Displays list.

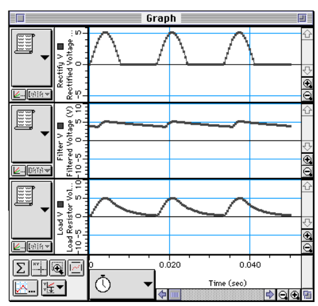
- Change the 'Layout' of the Graph to allow the captured data to appear on separate y-axes on the same display. Double click the graph, select the tab 'Layout', and then select 'Do Not Group'.
- Drag the 'Voltage, Ch B Data' for 'Filtered Voltage' and then for 'Load Resistor Voltage' from the Data list to the Graph.

Note: When you drag each of the 'Voltage, Ch B Data' from Data list into the Graph, make sure the rectangular indicator encompasses the entire graph and not just the y-axis.

In *ScienceWorkshop*, select 'New Graph' from the Display menu.

- Change the vertical axis input. Click the 'Input Menu' button. Select **Data Cache, Rectified Voltage** from the Input Menu.
- Click the 'Add Plot Menu' button at the lower left corner of the Graph. Select **Data Cache, Filtered Voltage** from the Add Plot Menu.
- Click the 'Add Plot Menu' button again. Select **Data Cache, Load Resistor Voltage** from the Add Plot Menu.
- Optional: If a printer is available, select **Print Active Display…** from the File menu.





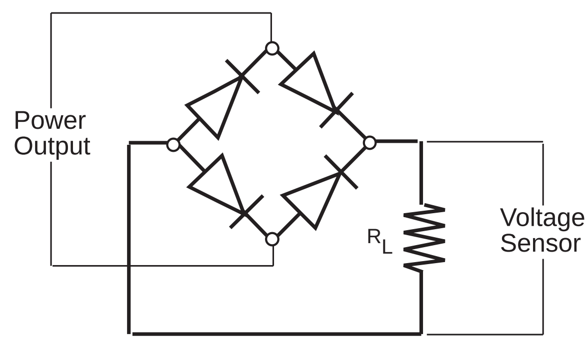
PART IF: Computer Setup – Power Supply, Four Diodes

- You do not need to change the computer setup.

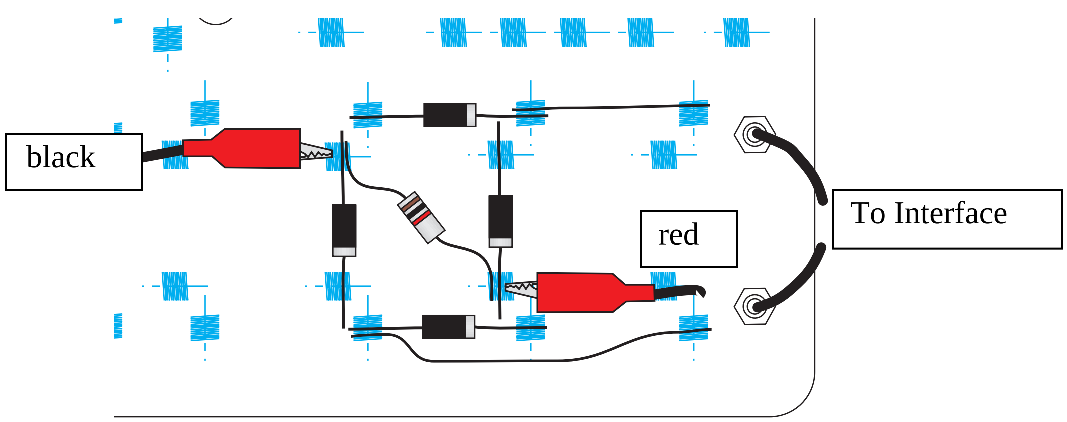
PART IIF: Equipment Setup – Power Supply, Four Diodes

1. Remove the components (resistors, diode, capacitor) from the AC/DC Electronics Lab circuit board. Leave the banana plug patch cords connected to the jacks on the board.
2. Put the diode between the second and third component springs to the left of the top banana jack. Place the diode so the gray stripe (cathode) end is to the right (toward the banana jack).
3. Place a second diode parallel to the first between the second and third component springs to the left of the bottom banana jack. Place the diode so the gray stripe (cathode) end is to the right (toward the banana jack).
4. Place a third diode between the component spring at the right end of the top diode, and the component spring at the right end of the bottom diode. Place the diode so the gray stripe (cathode) is toward the bottom.
5. Place a fourth diode between the component spring at the left end of the top diode, and the component spring at the left end of the bottom diode. Place the diode so the gray stripe (cathode) is toward the bottom.

- The diode arrangement forms a square.



6. Put the 330-Ω resistor diagonally between the upper left corner and the lower right corner of the square of diodes.
7. Use a five-inch wire lead to connect a component spring next to the top banana jack and the component spring at the RIGHT end of the first diode.
8. Use another wire lead to connect a component spring next to the bottom banana jack and the component spring at the LEFT end of the second (bottom) diode.
9. Connect the alligator clip of the black voltage sensor lead to the component spring at the upper left corner of the diode square (called a “bridge”). Connect the alligator clip of the red voltage sensor lead to the component spring at the lower right corner of the diode bridge.

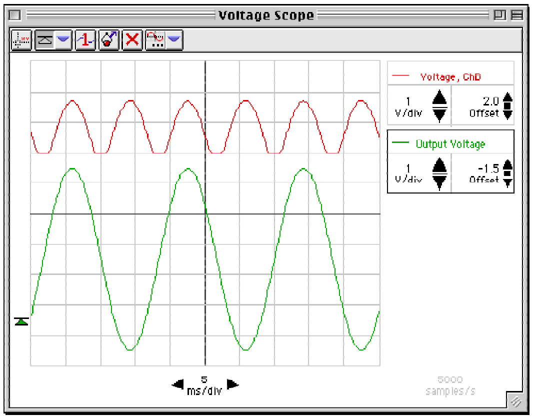


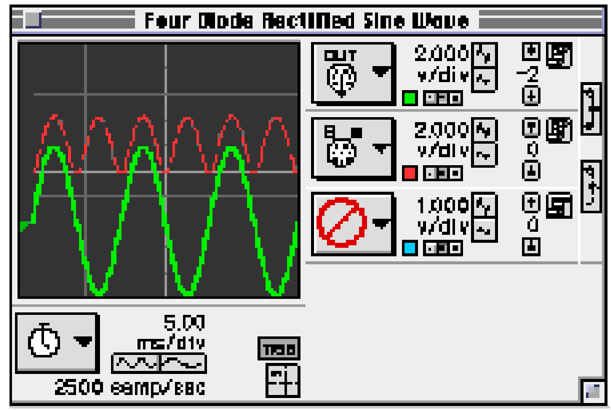
Name ____________________ Class _____________ Date ________

PART IIIF: Data Recording – Power Supply, Four Diodes

1. Start measuring data

- The 'sinusoidal' trace on the Scope display is the 'Output Voltage' from the interface. The other trace is the voltage across the resistor.
- Note: The traces have been offset so both traces can be seen.





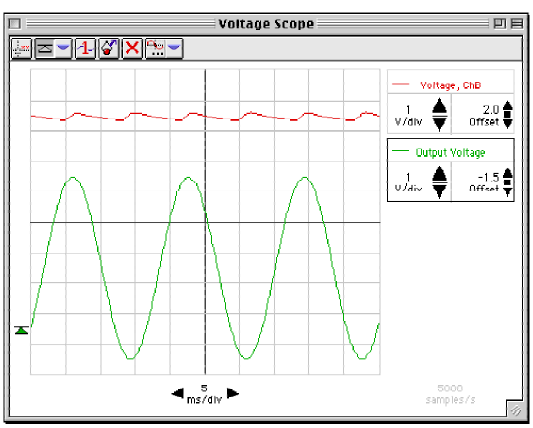
2. Stop measuring data.
3. Transfer the data from the Scope display as outlined in Part IIIA for later analysis.

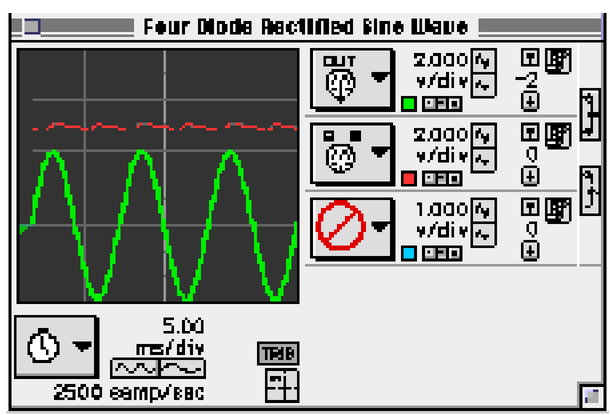
- In *DataStudio*, click the input icon and then click the 'Transfer Data' button. Rename 'Data' as 'Full Rectified'.
- In *ScienceWorkshop*, click the Data Snapshot button for the channel. Enter Data Cache Information for 'Long Name' (Full Rectified Voltage), 'Short Name' (Full V), and 'Units' (V) as needed to save the data for analysis.

PART IIIG: Data Recording – Power Supply, Four Diodes plus Capacitor

1. Put the 100 µF capacitor in parallel with the 330 Ω resistor.
2. Start measuring data.

- The 'sinusoidal' trace on the Scope display is the 'Output Voltage' from the interface. The other trace is the voltage across the resistor.
- Note: The traces have been offset so both traces can be seen.





3. After a moment or two, stop measuring data.

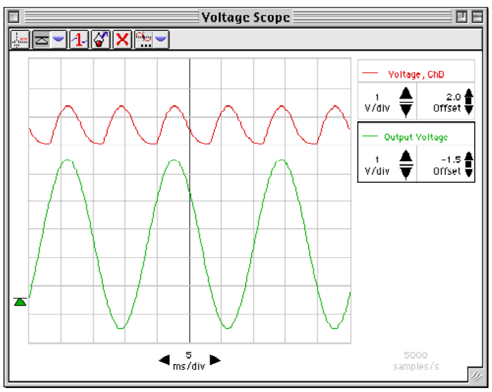
4. Transfer the data from the Scope display as outlined in Part IIIA for later analysis.

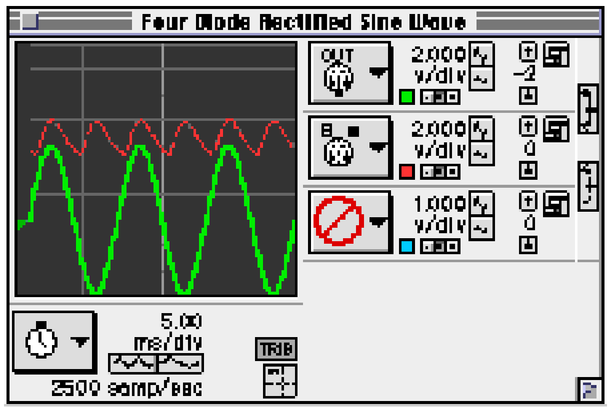
- In *DataStudio*, click the input icon and then click the 'Transfer Data' button. Rename 'Data' as 'Filtered Full Rectified'.
- In *ScienceWorkshop*, click the Data Snapshot button for the channel. Enter Data Cache Information for 'Long Name' (Filtered Full Rectified Voltage), 'Short Name' (Filtered V), and 'Units' (V) as needed to save the data for analysis.

PART IIIH: Data Recording – Power Supply, Four Diodes, Capacitor and Load

1. Put the 10 Ω resistor in parallel with the 100 μF capacitor and the 330 Ω resistor.
2. Start measuring data.

- The 'sinusoidal' trace on the Scope display is the 'Output Voltage' from the interface. The other trace is the voltage across the resistor.





3. After a moment or two, stop measuring data.
4. Transfer the data from the Scope Display as outlined in Part IIIA for later analysis.

- In *DataStudio*, click the input icon and then click the 'Transfer Data' button. Rename 'Data' as 'Load Resistor V.
- In *ScienceWorkshop*, click the Data Snapshot button for the channel. Enter Data Cache Information for 'Long Name' (Load Resistor Voltage), 'Short Name' (Load V), and 'Units' (V) as needed to save the data for analysis.

Name ____________________ Class ______________ Date _________

Analyzing the Data: Power Supply, Four Diodes

- Optional: Select **Save As…** from the File menu to save your data.

1. View the data in Graph display.

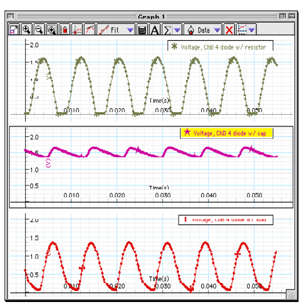
In *DataStudio*, drag the 'Voltage, Ch B Data' for the 'Full Rectified Voltage' from the Data list to the Graph icon located in the Displays list.

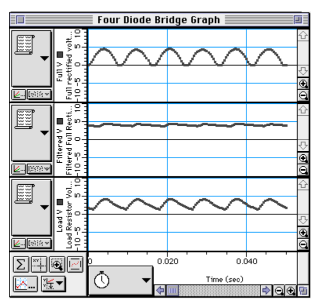
- Change the 'Layout' of the Graph to allow the captured data to appear on separate y-axes on the same display. Double click the graph, select the tab 'Layout', and then select 'Do Not Group'.
- Drag the 'Voltage, Ch B Data' for 'Filtered Full Rectified Voltage' and then for 'Load Resistor Voltage' from the Data list to the Graph.

Note: When you drag each of the 'Voltage, Ch B Data' from Data list into the Graph, make sure the rectangular indicator encompasses the entire graph and not just the y-axis.

In *ScienceWorkshop*, select 'New Graph' from the Display menu.

- Change the vertical axis input. Click the 'Input Menu' button. Select **Data Cache, <u>Full Rectified Voltage</u>** from the Input Menu.
- Click the **Add Plot Menu** button at the lower left corner of the Graph. Select **Data Cache, <u>Filtered Full Rectified Voltage</u>** from the Add Plot Menu.
- Click the **Add Plot Menu** button again. Select **Data Cache, <u>Load Resistor Voltage</u>** from the Add Plot Menu.
- Optional: If a printer is available, select **Print Active Display…** from the File menu.





Name ____________________ Class ______________ Date _________

Lab Report - Activity P54: Diodes Lab 2 – Rectifier & Power Supply

What Do You Think?

In this activity you will explore some of the basic applications of the diode. When the activity is concluded, you will understand further the importance of filtering and rectifying alternating current. What is one example of a device that uses the diode?

Questions

1. In Unit Three, how do the plots of voltage across the diode and voltage across the resistor compare to a complete sine wave?

2. Based on your previous investigate of diodes, why do the plots of voltage across the diode and voltage across the resistor from the first part of Unit Three have the shape and size they do?

3. In Unit Three, how did the plots of voltage across the diode and voltage across the resistor change when the diode was replaced with the LED? Explain.

4. In the first part of Unit Four, what happens to the trace of voltage across the diode when the capacitor is put in parallel with the resistor? Why is the capacitor considered to be a “filter”?

5. In the first part of Unit Four, what happens to the trace of voltage across the diode when the 10 Ω resistor is added in parallel to the capacitor and resistor?

6. In the second part of Unit Four, how does the trace of voltage across the resistor in the four diode bridge compare to the trace of voltage across the single diode in the first part of Unit Four?

7. What happens to the trace of voltage across the four diode bridge when the capacitor is put in parallel with the resistor? How does the shape of this trace compare to the similar “filtered” trace in the first part of Unit Four?

8. What happens to the trace of voltage across the four diode bridge when the 10 Ω resistor is added in parallel? How does the shape of this trace compared to the similar “load resistor voltage” trace in the first part of Unit Four?

9. Compare the performance of the single diode circuit to the four diode bridge as far as providing a steady, constant direct current when a low resistance load is connected.

Name ____________________ Class ______________ Date _________

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

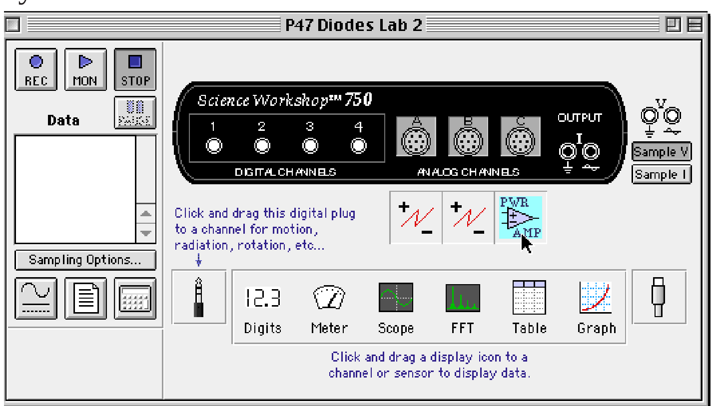
Open the file titled as shown:

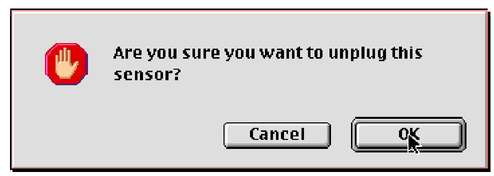
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P47 Diodes Lab 2	P47_DIO2.SWS

This activity uses the ‘Output’ feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

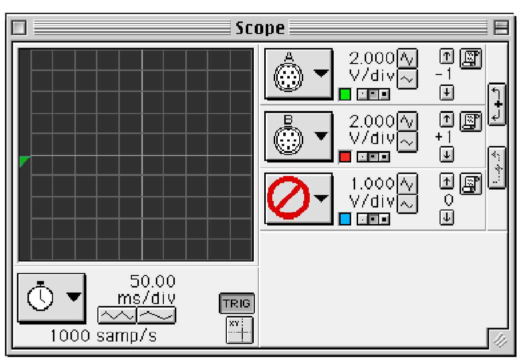


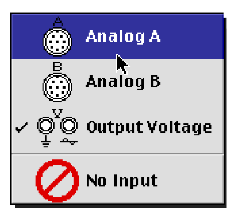


Result: A warning window opens. Click ‘OK’ to return to the setup window.

Check the Scope Display

The Scope display should show voltage from ‘Analog A’ and ‘Analog B’. If not, use the Input Menu to select ‘Analog A’ for the top trace.





Name ____________________ Class _____________ Date _________

Activity P55: Transistor Lab 1 – The NPN Transistor as a Digital Switch (Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Semiconductors	P55 Digital Switch.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	From AC/DC Electronics Lab*	Qty
Voltage Sensor (CI-6503)	1	Light-emitting diode (LED), red	1
Alligator Clip Adapters (SE-9756)	2	Resistor, 330 ohm (Ω)	1
Patch Cord (SE-9750)	4	Resistor, 22 kilo-ohm (Ω)	1
Power Supply, 5 V DC (SE-9720)	1	Transistor, 2N3904	1
		Wire Lead, 5 inch	2

(* The AC/DC Electronics Lab is EM-8656)

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?

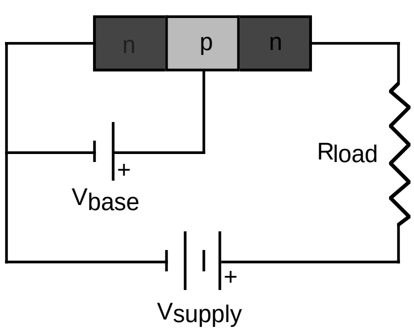
Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

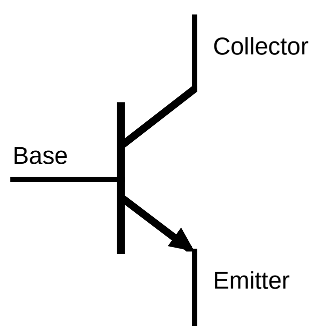
The purpose of this activity is to investigate how the ***npn*** **transistor** operates as a digital switch.

Background

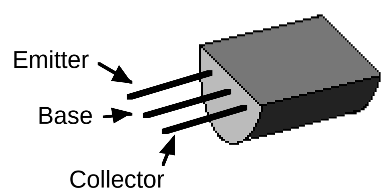
The transistor is the essential ingredient of every electronic circuit, from the simplest amplifier or oscillator to the most elaborate digital computer. Integrated circuits (IC's) which have largely replaced circuits constructed from individual transistors, are actually arrays of transistors and other 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.





npn transistor symbol



Transistor package

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 <u>power amplifier</u> (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 REMINDER	THINK SAFETY ACT SAFELY BE SAFE!
• Follow all safety instructions.	

For You To Do

Use the 'Output' feature of the *ScienceWorkshop* interface 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 *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' (voltage across the base) that causes the value of 'Vcollector' to increase from zero. In other words, determine the voltage at which the transistor 'switches on'.

Name ____________________ Class _____________ Date _________

PART I: Computer Setup

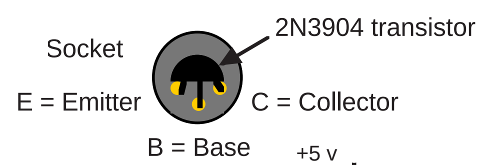
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor to Analog Channel A.
3. Connect two banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P55 Digital Switch.DS	(See end of activity)	(See end of activity)

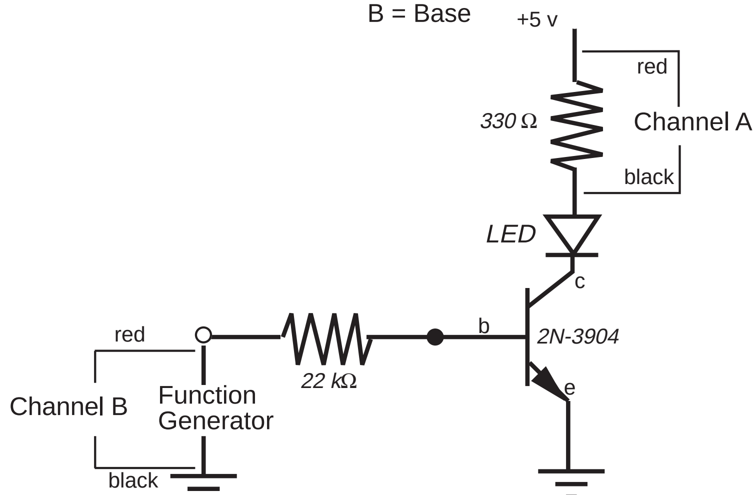
- The *DataStudio* document has a Graph display and a Workbook display. Read the instructions in the Workbook.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Signal Generator is set to output a 1.6 volt 'Sine Wave' at 1 Hz. The output is set to start and stop automatically when you start and stop measuring data.
- Data recording is set at 200 Hz with a Start Condition of 'Output Voltage' going above 0.01 V and a Stop Condition of Time equal 1 second (about 200 samples).

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.



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.

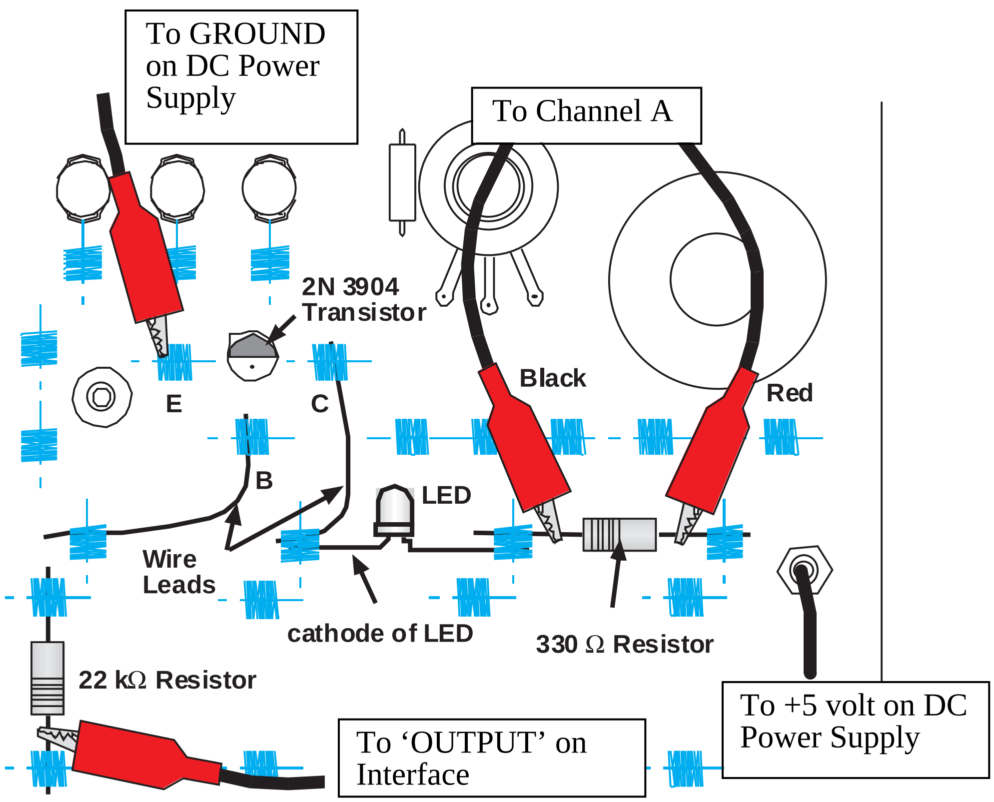
6. Connect another wire lead from the component spring at the collector terminal of the transistor to the component spring at the left end of the LED.

7. Connect a patch cord from the positive (+) terminal of the DC power supply to the top input jack on the edge of the circuit board.

8. Use an alligator clip adapter to connect another patch cord from the negative (-) terminal of the DC power supply to the component spring of the emitter terminal of the transistor

9. Use an alligator clip adapter to connect the patch cord from the positive (∿) output port of the *ScienceWorkshop* interface to the component spring below the 22 kΩ resistor on the circuit board.

10. Connect a black banana plug patch cord from the *ground* (⏚) output port of the interface to the *negative* (-) terminal of the DC power supply.



11. Put alligator clips on the banana plugs of the 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.

Name ____________________ Class ______________ Date _________

PART III: Data Recording

1. Turn on the DC power supply and adjust its voltage output to exactly +5 Volts.
2. Start recording data. (Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*.)

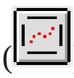
- Observe the behavior of the LED. Write a description of what you observe.
- Recording will stop automatically at 1 second.

3. Turn off the DC power supply.

Analyzing the Data

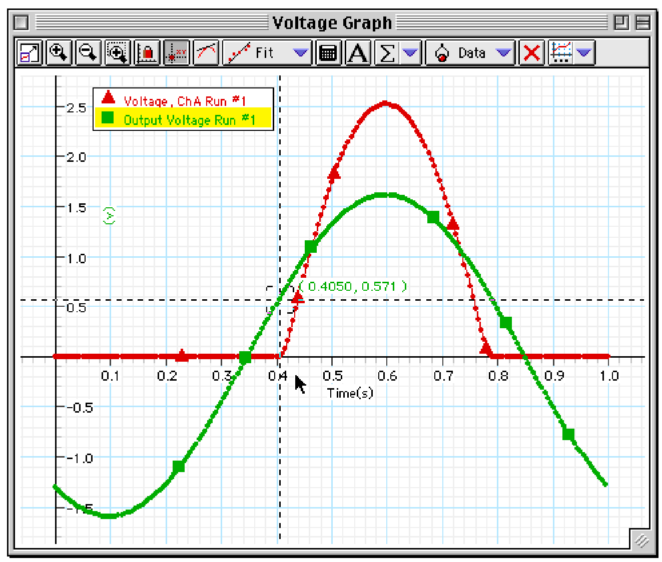
- Optional: Save your data. If a printer is available, print the Graph display.
- Remember, the Channel A voltage is Vcollector and the 'Output Voltage' (from the interface) is Vbase.

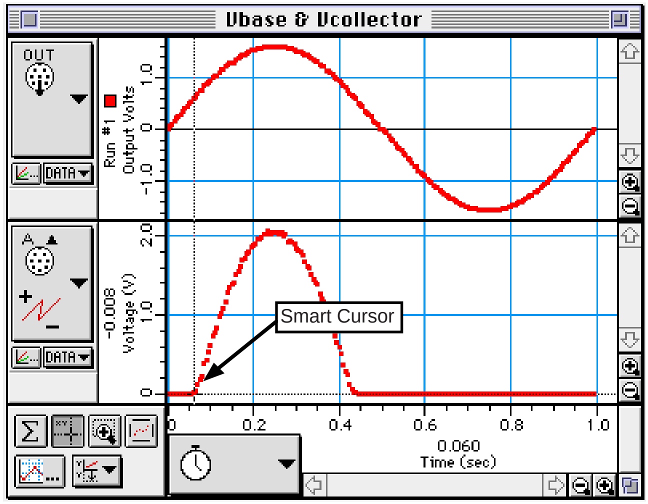
1. Set up your Graph display so it fits the data.

- Hint: In *DataStudio*, click the 'Scale to Fit' button in the Graph toolbar. In *ScienceWorkshop*, click the 'Autoscales button () 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 ('Output Voltage') 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 (Output Voltage) that corresponds to the same point on the plot of Vcollector.

3. Record the Y-coordinate of that point on the plot of Vbase.

Voltage = _________ (V)

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P55: 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?

Name ____________________ Class _____________ Date _________

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

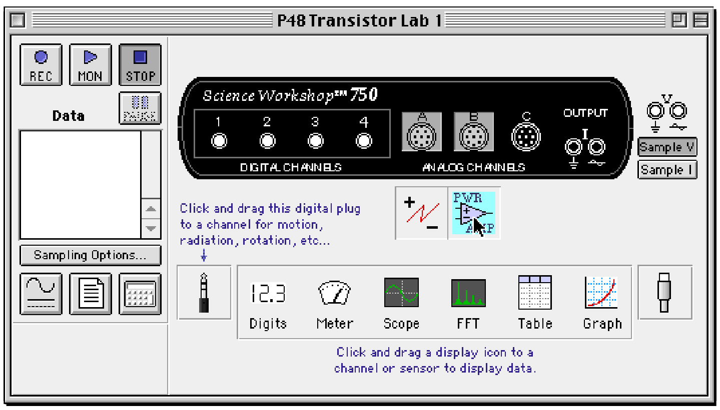
Open the file titled as shown:

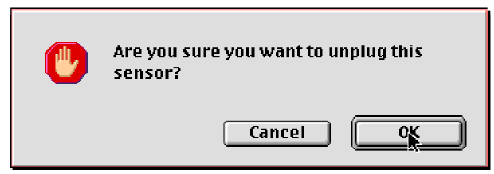
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P48 Transistor Lab 1	P48_TRN1.SWS

This activity uses the 'Output' feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

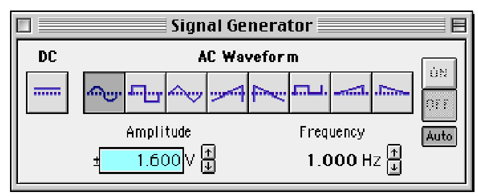




Result: A warning window opens. Click 'OK' to return to the setup window.

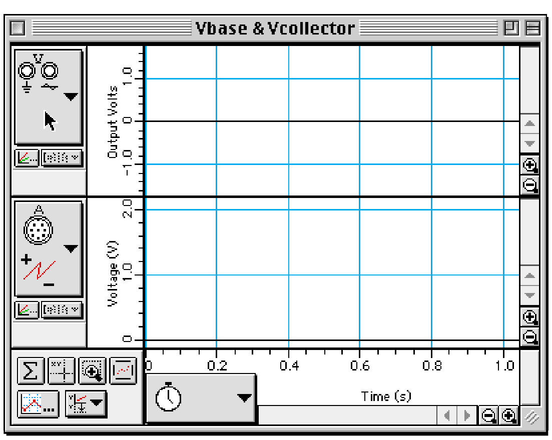
Modify the Signal Generator

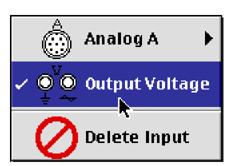
Set the Signal Generator to output a 1.6 volt 'Sine Wave' at 1 Hz.



Check the Graph Display

The Graph display should show 'Output Voltage' and 'A'. If not, use the Input Menu to select 'Output Voltage' for the top plot and 'A' for the bottom plot.





Name ____________________ Class _____________ Date ________

Activity P56: Transistor Lab 2 – Current Gain: The NPN Emitter-Follower Amplifier (Power Output, Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Semiconductors	P56 Emitter Follower.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**From AC/DC Electronics Lab**	**Qty**
Voltage Sensors (CI-6503)	2	**Resistor, 1 kilo-ohm (Ω)**	1
Alligator Clip Adapters (SE-9756)	2	**Resistor, 22 kilo-ohm (Ω)**	1
Patch Cord (SE-9750)	3	**Transistor, 2N3904**	1
Power Supply, 5 V DC (SE-9720)	1	**Wire Lead**	3

(* The AC/DC Electronics Lab is EM-8656)

What Do You Think?

What are the direct current (dc) transfer characteristics of the ***npn*** **transistor**?

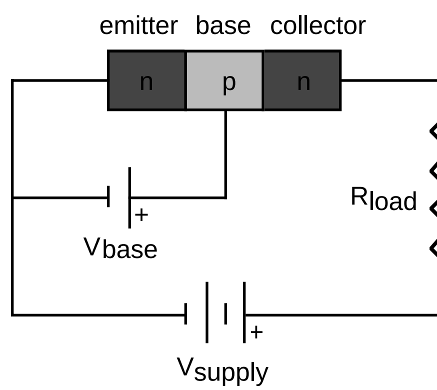
Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

Transistors are the basic elements in modern electronic amplifiers of all types. In a transistor circuit, the current to the base controls the current through the collector "loop".

The voltage applied to the base is called the *base bias voltage*. If it is positive, electrons in the emitter are attracted onto the base. Since the base is very thin (approximately 1 micron), most of the electrons in the emitter flow across into the collector, which is maintained at a positive voltage. A relatively large current, I_C, flows between collector and emitter and a much smaller current, I_B, flows through the base.

n-p-n transistor



A small change in the base voltage due to an input signal causes a large change in the collector current and therefore a large voltage drop across the output resistor, R_{load}. 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.

A transistor circuit can also amplify current. What is important for amplification (or *gain*) is the change in collector current for a given change in base current. *Gain* can be defined as the ratio of output current to input current.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY ACT SAFELY BE SAFE!

For You To Do

In this activity, use the 'Output' feature of the ScienceWorkshop interface to supply an alternating voltage to the base of the npn transistor. Use the DC power supply to supply 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 base of the transistor. Use a second Voltage Sensor to measure the voltage drop across a resistor in series with the emitter of the transistor.

Use *DataStudio* or *ScienceWorkshop* to control the 'Output' from the interface, record and display the output voltage across the resistor in series with the base, and record and display the input voltage across the resistor in series with the emitter. Use the program to calculate the Output Current and the Input Current and then plot Output Current vs. Input Current. Compare the output and input currents to determine the "gain".

PART I: Computer Setup

1. Connect the *ScienceWorkshop* 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. Connect two banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P56 Emitter Follower.DS	(See end of activity)	(See end of activity)

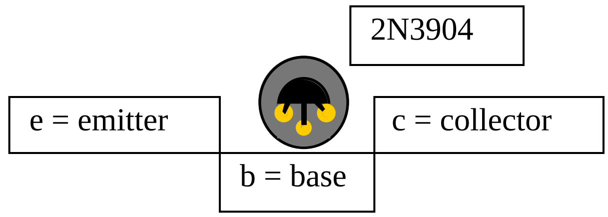
- The *DataStudio* file has a Graph display and a Workbook display. Read the instructions in the Workbook. The Graph display shows Emitter Current (Channel A) versus Base Current (Channel B).
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Signal Generator is set to output a 5.00 volt 'Sine Wave' at 1.00 Hz. The output is set to start and stop automatically when you start and stop measuring data.
- Data recording is set for 500 measurements per second. Data recording stops automatically at Time = 1 second.
- The Emitter Current (vertical axis) is calculated by dividing the voltage drop across the 1 kilo-ohm (1 kΩ) resistor (Voltage, Channel A) by the resistance. The Base Current (horizontal axis) is calculated by dividing the voltage drop across the 22 kilo-ohm (22 kΩ) resistor (Voltage, Channel B) by the resistance.

Name ______________________ Class _______________ Date ________

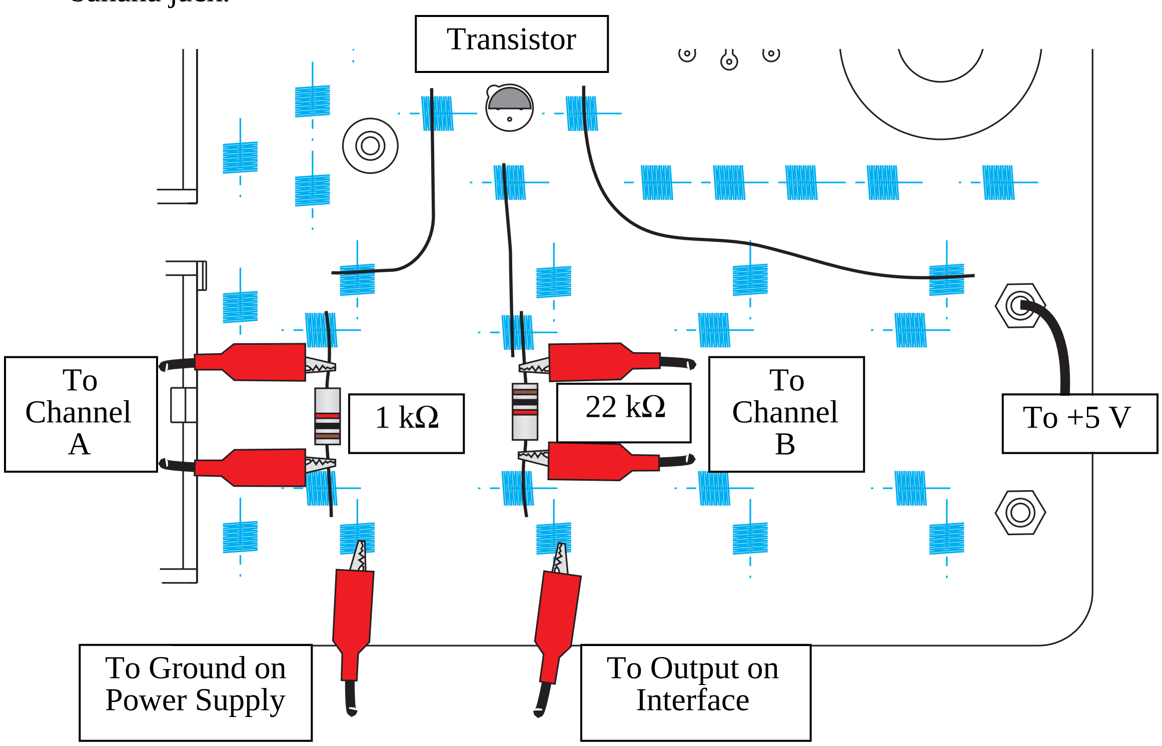
PART II: Sensor Calibration and Equipment Setup

- 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 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 the 1 kΩ resistor (brown, black, red) vertically between the component spring at the left edge of the component area on the AC/DC Electronics Lab circuit board.
3. Connect the 22 kΩ resistor (red, red, orange) vertically between the component springs to the right of the 1 kΩ resistor.
4. Connect a wire lead between the component spring next to the emitter terminal of the transistor, and the component spring at the top end of the 1 kΩ resistor.
5. Connect another wire lead between the component spring next to the base terminal of the transistor, and the component spring at the top end of the 22 kΩ resistor.
6. Connect another wire lead between the component spring next to the collector terminal of the transistor, and the component spring next to the top banana jack.
7. Connect a patch cord from the positive (+) terminal of the DC power supply to the top banana jack.



8. Use an alligator clip adapter to connect a patch cord from the signal output (∿) port of the interface to the component spring at the bottom end of the 22 kΩ resistor.

9. Use an alligator clip adapter to connect a patch cord from the negative (or *ground*) terminal of the DC power supply to the component spring at the bottom end of the 1 kΩ resistor.

10. Connect the patch cord from the *ground* output port (⏚) of the interface to the negative (or *ground*) terminal of the DC power supply.

11. Put alligator clips on the banana plugs of both Voltage Sensors. Connect the red alligator clip of the Voltage Sensor in Analog Channel A to the component spring at the top end of the 1 kΩ resistor, and the black clip to the component spring at the bottom end.

12. Connect the black alligator clip of the Voltage Sensor in Analog Channel B to the component spring at the top end of the 22 kΩ resistor, and the red clip to the component spring at the bottom end.

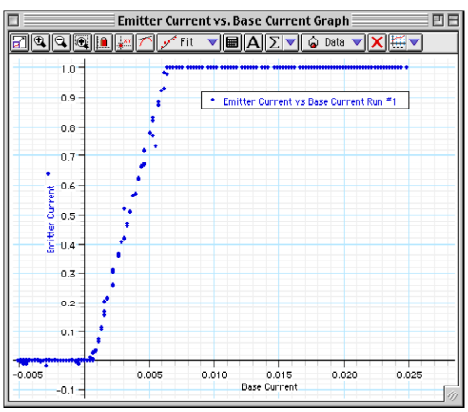
PART III: Data Recording

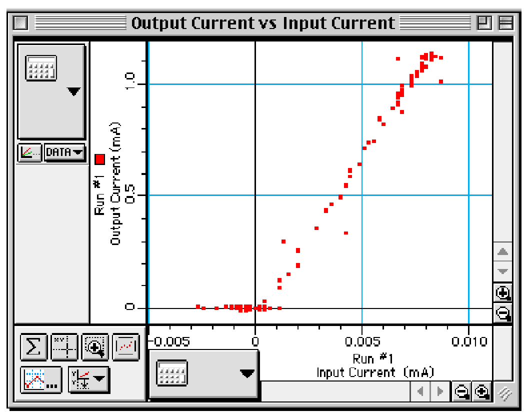
1. Turn on the DC power supply and adjust its voltage output to exactly +5 Volts.
2. When everything is ready, start recording data. Recording stops automatically after 1 s.
3. Turn off the DC power supply when data recording is finished.

Analyzing The Data

- Because the Graph displays the output or "collector" current (Ic) versus the input or "base" current (Ib), the slope of the linear region of the plot gives the current gain of the transistor.

1. Resize the Graph to fit the data. Zoom in on the linear region of the plot.
2. Use the built-in analysis tools to find the slope of a best-fit line applied to the linear region of the plot.





- The slope can be interpreted as follows:

$$slope = \frac{\Delta I_c}{\Delta I_b} = \beta$$

where ß is called current gain of the transistor.

3. Determine the current gain of the 2N3904 transistor.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date ________

Lab Report – Activity P49: Transistor Lab 2 – Current Gain: The NPN Emitter-Follower Amplifier

What Do You Think?

What are the direct current (dc) transfer characteristics of the ***npn*** **transistor**?

Data

current gain of the 2N3904 transistor = ________________

Questions

1. How does the general shape of the plot for the transistor compare to the plot of current versus voltage for a diode?

2. What is the current gain of the 2N3904 transistor?

Name ____________________ Class _____________ Date ________

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

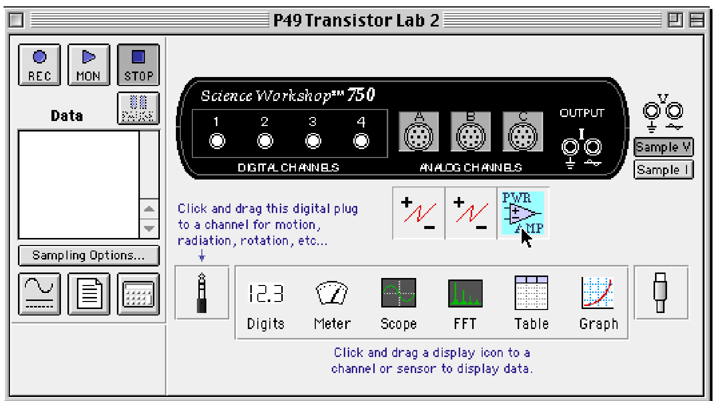
Open the file titled as shown:

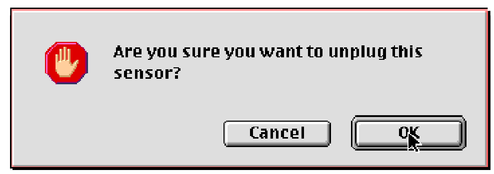
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P49 Transistor Lab 2	P49_TRN2.SWS

This activity uses the 'Output' feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

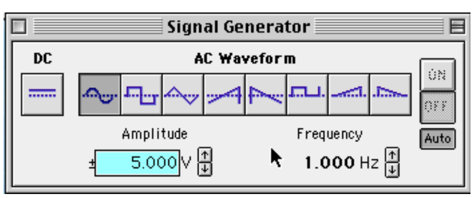




Result: A warning window opens. Click 'OK' to return to the setup window.

Modify the Signal Generator

Set the Signal Generator to output a 5 volt 'Sine Wave' at 1 Hz.



Name _____________________ Class ______________ Date _________

Activity P57: Transistor Lab 3 – Common-Emitter Amplifier (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Semiconductors	P57 Common Emitter.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**From AC/DC Electronics Lab (EM8656)**	**Qty**
Voltage Sensor (CI-6503)	1	**Capacitor, 1 microfarad (µF)**	1
Alligator Clip Adapters (SE-9756)	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, 2N3904	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 answer the 'What Do You Think?' question(s) in the Lab Report section.

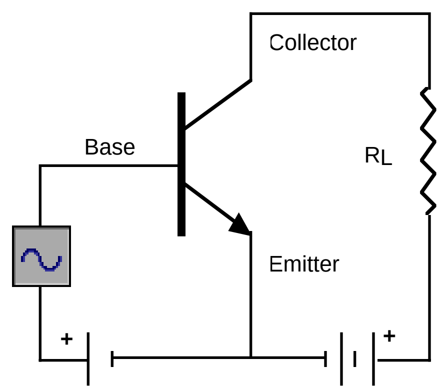
The purpose of this activity is to investigate the voltage and current amplification characteristics of the *npn* transistor in a *common-emitter* amplifier circuit.

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.

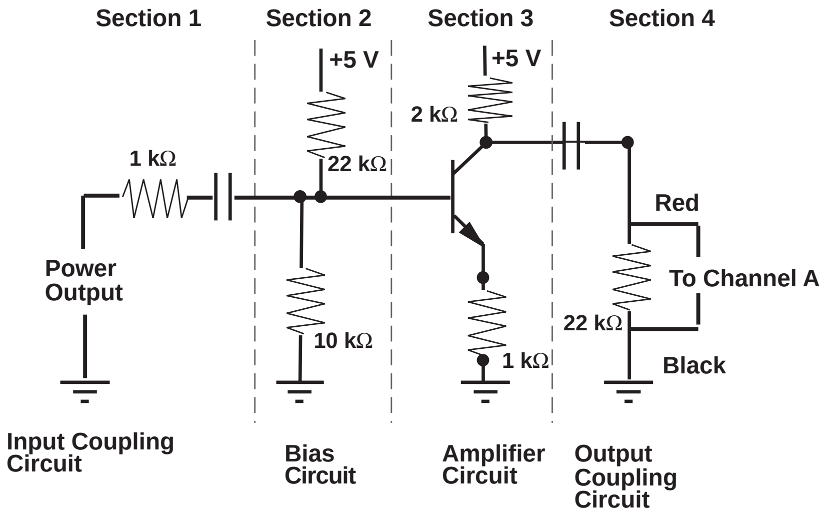
Additionally, since the output voltage across the load resistor R_L is the product of the output current (collector current) and the value of R_L, the output voltage can also be made large. As a result, the output voltage can be much larger than the input voltage.



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 REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the 'Output' feature of the *ScienceWorkshop* interface 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 a Voltage Sensor 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 *DataStudio* or *ScienceWorkshop* to record and display the voltage across the resistor in the Output Coupling Circuit as well as the 'Output' from the interface. 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.

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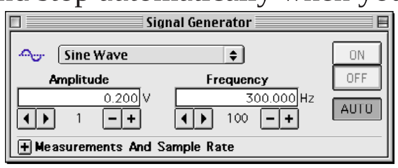
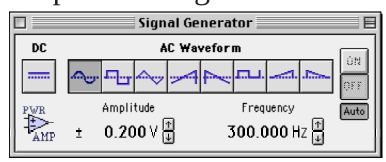
PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect one Voltage Sensor to Analog Channel A.
3. Connect two banana plug patch cords into the 'OUTPUT' ports on the interface.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P57 Common Emitter.DS	(See end of activity)	(See end of activity)

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook. The document has a Scope display of the 'Output Voltage' from the interface and 'Voltage, Ch A' from the Voltage Sensor.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Signal Generator is set to output a 0.2 volt 'Sine Wave' at 300 Hz. The output is set to start and stop automatically when you start and stop measuring data.



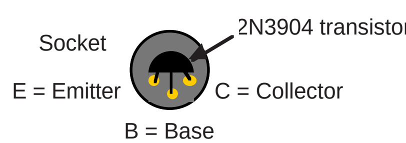


PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor. You will need the following components:

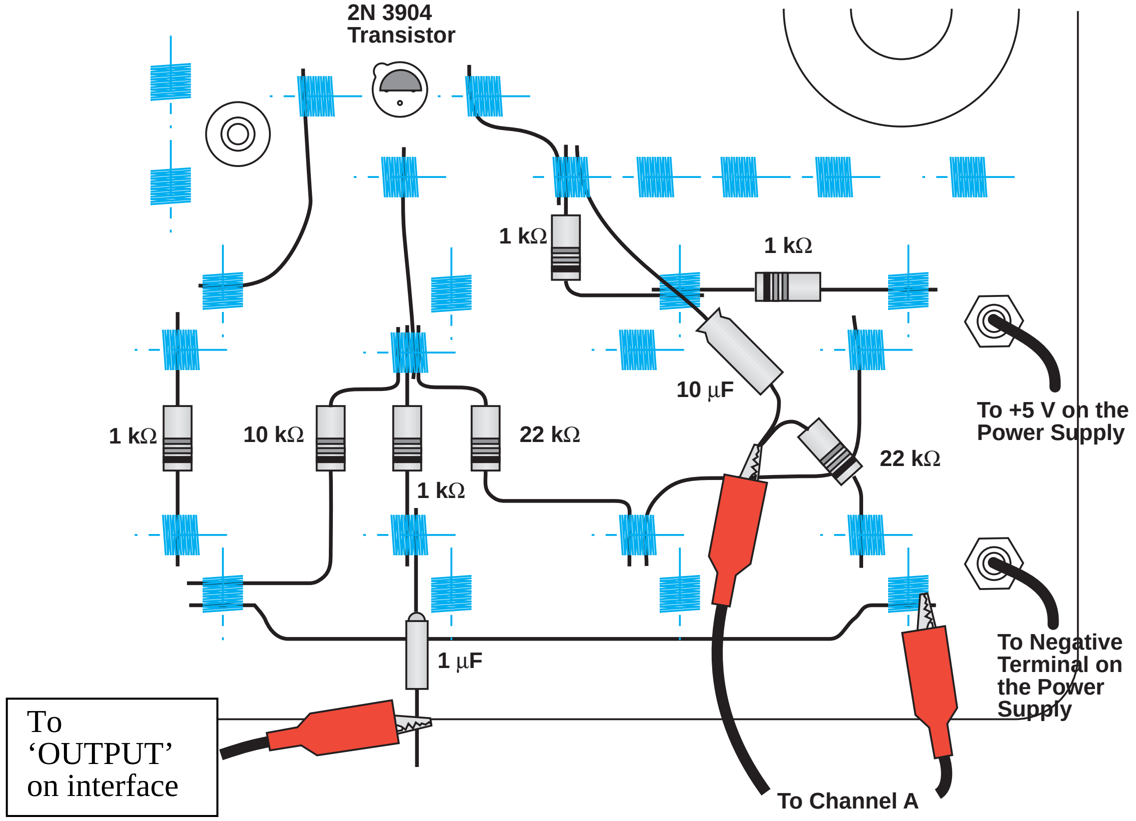
Item	Quantity	Item	Quantity
1 kΩ resistor (brown-black-red)	4	10 μF capacitor	1
10 kΩ resistor (brown-black-orange)	1	wire lead, five inch	4
22 kΩ resistor (red-red-orange)	2	wire lead, ten inch	1
1 μF capacitor	1	2N3904 transistor	1

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 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 patch cord from the negative (-) terminal of the DC power supply to the bottom banana jack on the AC/DC lab board.

Name ____________________ Class ______________ Date _________

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.

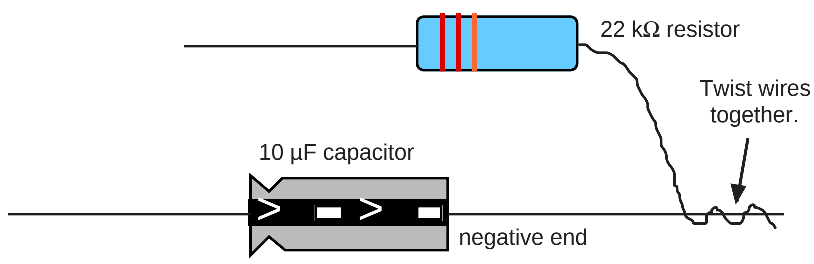
16. Put an alligator clip on one end of patch cord. Connect the alligator clip to the wire at the end of the 1 µF capacitor. Connect the other end of the patch cord to the 'OUTPUT' ( ) port of the *ScienceWorkshop* interface.

17. Connect a patch cord from the *ground* ( ) port of the *ScienceWorkshop* interface 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.

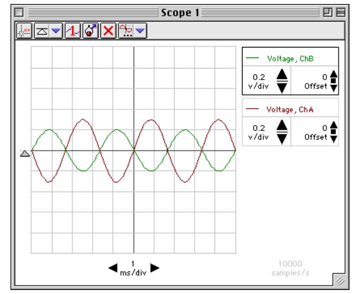


20. Connect the wire from the positive end of the 10-µF capacitor to the component spring at one end of the wire lead connected to the collector terminal of the transistor. Connect the wire from the 22-kΩ resistor to a component spring next to the bottom banana jack at the lower right corner of the AC/DC 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

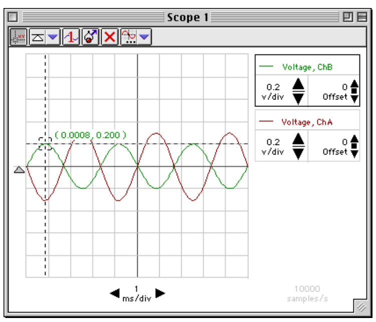
1. Start measuring data. (Click ‘Start’ in *DataStudio* or ‘MON’ in *ScienceWorkshop*.)
2. Turn on the DC power supply and adjust its voltage output to exactly +5 volts.

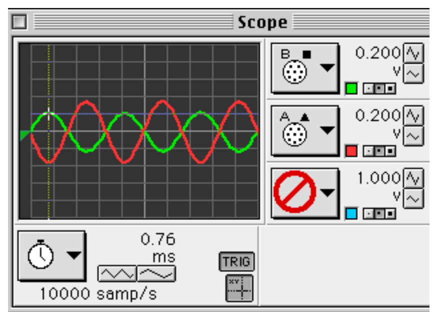


- Observe the trace of voltage going to the base terminal of the transistor from the ‘OUTPUT’ of the interface (the trace for ‘Output Voltage’). Compare this trace to the trace of voltage measured by the Voltage Sensor connected to Channel A (Voltage, Ch A).

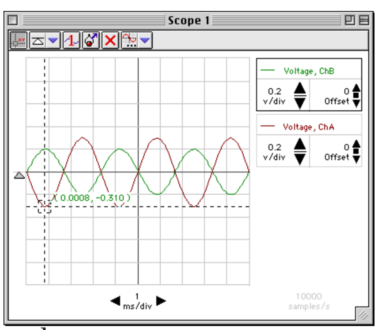
3. Measure the voltages. Use the built-in analysis tools in the Scope display. (Hint: In *DataStudio*, click the ‘Smart Tool’ button. In *ScienceWorkshop*, click the ‘Smart Cursor’ button. This will stop data monitoring temporarily.)

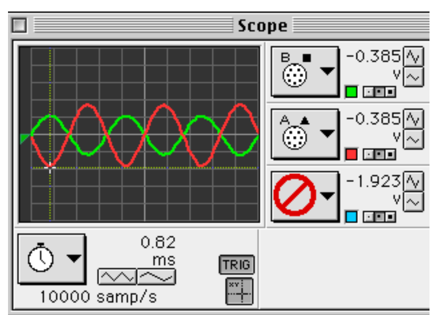
- Move the analysis tool (‘Smart Tool’ or ‘Smart Cursor’) to the first peak of the trace for the voltage from the ‘OUTPUT’ of the interface (‘Output Voltage’). Record the voltage value for the peak. (Hint: In *DataStudio*, the voltage is the second number in the ordered pair. In *ScienceWorkshop*, the 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 ‘Output Voltage’ trace). Record the voltage value for the





peak.

4. Stop measuring data.
5. Turn off the DC power supply.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P57: 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

Voltage (peak) of B	=	**V**
Voltage (peak) of A	=	**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).

$$\frac{V_{in}}{V_{out}} = \frac{Voltage\ "B"}{Voltage\ "A"} = \_\_\_\_\_\_\_\_\_\_\_\_$$

2. Calculate the theoretical output voltage as follows:

$$V_{out} = -V_{in}\frac{R_C}{R_E} = \_\_\_\_\_\_\_\_\_\_\_\_$$

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?

Name ____________________ Class ______________ Date _________

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

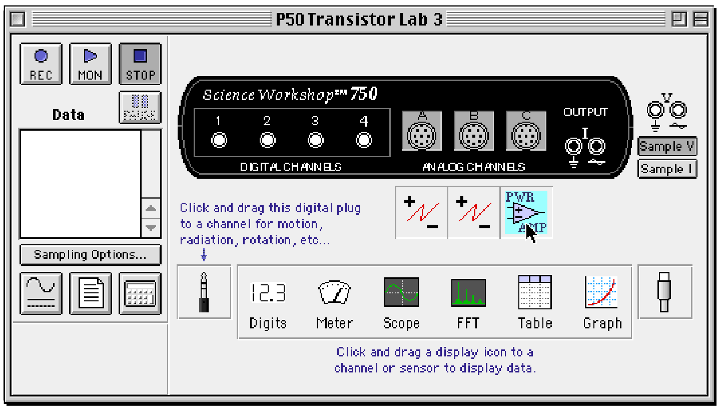
Open the file titled as shown:

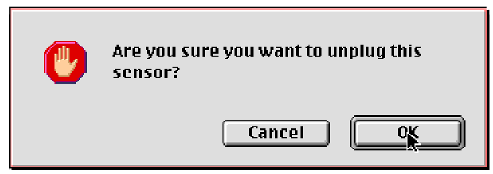
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P50 Transistor Lab 3	P50_TRN3.SWS

This activity uses the ‘Output’ feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the keyboard.

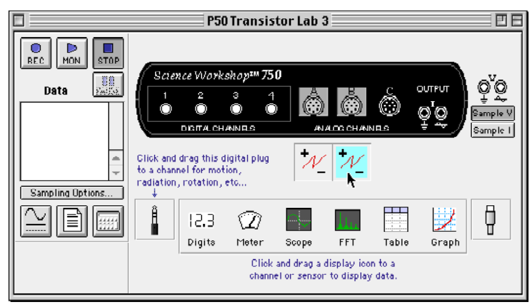




Result: A warning window opens. Click ‘OK’ to return to the setup window.

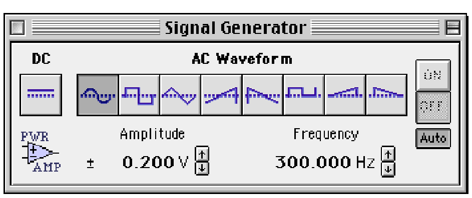
Remove the Channel B Voltage Sensor

In the Experiment Setup window, click the Voltage Sensor icon under Channel B and press <delete> on the keyboard. Click ‘OK’ in the warning window to return to the setup window.



Check the Signal Generator

Set the Signal Generator to output a 0.2 volt ‘Sine Wave’ at 300 Hz.



Name ____________________ Class _____________ Date _________

Activity P58: Magnetic Field of a Solenoid (Magnetic Field Sensor, Power Amplifier)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Magnetism	P58 Solenoid.DS	P52 Mag Field Solenoid	P52_SOLE.SWS

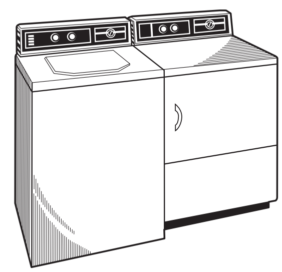
Equipment Needed	Qty	Equipment Needed	Qty
Magnetic Field Sensor (CI-6520)	1	**Patch Cord (SE-9750)**	2
Power Amplifier (CI-6552)	1	**Solenoid (SE-8563)**	1
Meter stick	1		

What Do You Think?

Solenoids are an important aspect of automated controls. Solenoids are used in common household appliances. Can you name a few? (Hint: Start with the washing machine.)

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background



The magnetic field inside a very long solenoid is given by:

$$B = \mu_o n I$$

where $\mu_o = 4\pi \times 10^{-7}$ (tesla•meters)/amp, I is the current (amps), and n is the number of turns of wire per unit length (#/meter) of the solenoid. Notice that this expression is independent of the radius of the coil and the position inside the coil.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

The goal of this laboratory activity is to measure the magnetic field inside a solenoid and compare the magnetic field to a theoretical value based on the current through the solenoid.

Use the Magnetic Field Sensor to measure the magnetic field strength inside a cylindrical solenoid. Use the Power Amplifier to provide a direct current through the solenoid.

Use *DataStudio* or *ScienceWorkshop* to record and display the magnetic field and the current through the solenoid. Compare the measured magnetic fields inside the solenoid to the theoretical magnetic field calculated on the basis of current and the number of turns of wire per unit length.

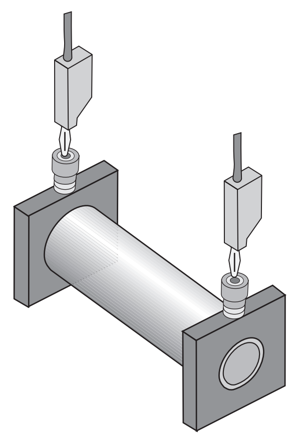
PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Magnetic Field Sensor DIN plug to Analog Channel A on the interface.
3. Connect the Power Amplifier to Analog Channel B.
   Plug the power cord into the back of the Power Amplifier and connect the power cord to an appropriate electrical receptacle.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P58 Solenoid.DS	P52 Mag Field Solenoid	P52_SOLE.SWS

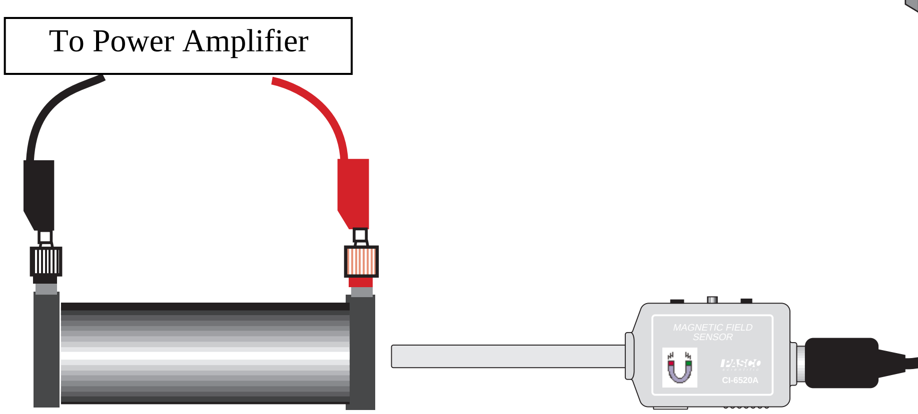
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook. It also h as a Digits display of magnetic field strength and current.
- The *ScienceWorkshop* document opens with a Digits display of magnetic field strength and a Digits display of current. It also has the Signal Generator window that controls the Power Amplifier.
- The Signal Generator is set to output DC at 10.0 V. It is set 'Auto' so it will start and stop automatically when you start and stop measuring data.

PART II: Sensor Calibration & Equipment Setup



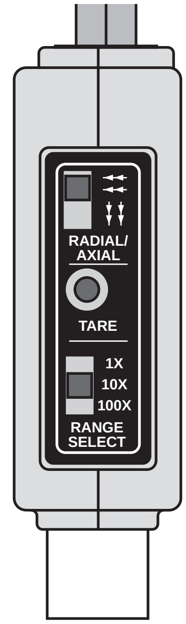
- You do not need to calibrate the Magnetic Field Sensor or the Power Amplifier. The Magnetic Field Sensor produces a voltage that is directly proportional to the magnetic field strength as follows: 10 millivolts = 10 gauss (where 1000 gauss = 0.1 tesla). The sensor's range is ±2000 gauss.

1. Use only the outer coil of the Primary/Secondary Coil set. Use patch cords to connect the output of the Power Amplifier to the input jacks on the solenoid.
2. Position the solenoid and Magnetic Field Sensor so the end of the sensor can be placed inside the solenoid.



Name ____________________ Class ______________ Date _________

PART III: Data Recording



1. Hold the Magnetic Field Sensor far away from any source of magnetic fields and zero the sensor by pushing the TARE button on the sensor box.
2. Select the AXIAL field by clicking the RADIAL/AXIAL SELECT SWITCH on the sensor.
3. Return the sensor to its position next to the solenoid.
4. Start measuring data. The Signal Generator will start automatically.
5. Record the value of current from the Digits display into the Data section.
6. Insert the sensor rod into the center of the coil. Move the sensor around inside the coil to see if the radial position of the sensor changes the reading on the computer.
7. Record the reading for the axial component of the magnetic field inside the coil in the middle, away from either end of the coil. Record this value in the Data section.
8. Remove the Magnetic Field Sensor from the coil. Select the RADIAL field. Hold the sensor far away from any source of magnetic fields and re-zero the sensor by pushing the TARE button on the sensor box.
9. Insert the sensor rod into the center of the coil. Record the reading for the radial component of the magnetic field in the Data section.
10. Measure the length of the solenoid coil.

- Note: When measuring the coil, make sure that you only measure the length of the solenoid with the wrapped coil and not the entire solenoid.

Analyzing the Data

1. Calculate the theoretical value of the magnetic field inside the coil using the measured current, length, and number of turns for the coil (for the SE-8653 outer coil, the number of turns is 2920). Record this value.
2. Use you data to answer the questions in the Lab Report section.

Record your results in the Lab Report section.

Name ____________________ Class _____________ Date ________

Lab Report - Activity P58: Magnetic Field of a Solenoid

What do you think?

Solenoids are an important aspect of automated controls. Solenoids are used in common household appliances. Can you name a few? (Hint: Start with the washing machine.)

Data

Recorded Current = _______ amps

Length of Primary Coil = _______ cm

Theoretical Magnetic Field = _______ gauss

Measured Magnetic Fields (gauss)

Axial (gauss)	Radial (gauss)

Questions

1. Did the axial reading change when the sensor was moved radially outward from the center toward the windings on the coil?

2. Was the axial reading different from the reading in the middle of the coil when the sensor was inside but near the ends of the coil?

3. By comparing the axial and radial readings, what can you conclude about the direction of the magnetic field lines inside a solenoid?

4. Compare the theoretical value to the axial value using a percent difference. What are some factors that could account for this percent difference?

Name ____________________ Class _____________ Date _________

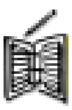
Activity P59: Magnetic Field of Helmholtz Coils (Magnetic Field Sensor, Power Amplifier, Rotary Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Magnetism	P59 Helmholtz Coils.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Magnetic Field Sensor (CI-6520)	1	**Lab Jack (SE-9374)**	2
Power Amplifier (CI-6552)	1	**Mass and Hanger Set (ME-9348)**	1
Rotary Motion Sensor (CI-6538)	1	Meter stick, wood	1
Base and Support Rod (ME-9355)	1	**Patch Cord (SE-9750)**	3
Helmholtz Coil (EM-6711)	2	**String (SE-8050)**	1 m

What Do You Think?

The purpose of this activity is to examine the magnetic field produced by the current in a pair of Helmholtz coils, and to measure the magnetic field strength between the coils and compare the measured value to the theoretical value. How does the strength of the magnetic field between the coils relate to the distance of separation between the Helmholtz coils?



Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

Helmholtz coils are a pair of coils that each has the same radius, R. The coils are usually placed parallel to each other a distance R apart and along the same axis.

The magnetic field along the axis at the midpoint between the two coils is then given by

$$B = \frac{8\mu_o NI}{\sqrt{125}R}$$

where $\mu_o = 4\pi \times 10^{-7}$ (tesla•meters)/amp, I is the current (amps) in one coil, R is the radius of the coil, and N is the number of turns of wire in one coil.

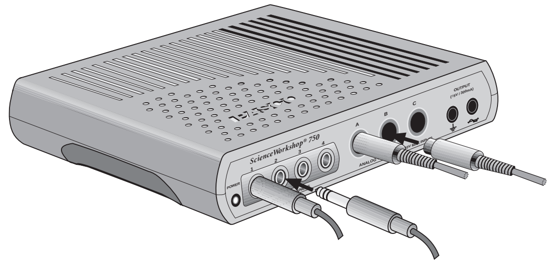
SAFETY REMINDER	
• Follow all safety instructions.	THINK SAFETY ACT SAFELY BE SAFE!

For You To Do

In this activity, use the Power Amplifier to supply the current through the Helmholtz coils. Use the Magnetic Field Sensor to measure the strength of the magnetic field between the coils. Use the Rotary Motion Sensor to measure the position of the Magnetic Field Sensor as you move it along the axis of the two coils.

Use *DataStudio* or *ScienceWorkshop* to control the Power Amplifier and measure and display the strength of the magnetic field and the position of the sensor. Compare the measured magnetic field strength to the theoretical magnetic field strength. Determine the relationship of the inter-coil strength of the magnetic field to the distance between the coils.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Rotary Motion Sensor phone plugs to Digital Channel 1 and 2.
3. Connect the Magnetic Field Sensor DIN plug to Analog Channel A on the interface.
4. Connect the Power Amplifier to Analog Channel B. Plug the power cord into the back of the Power Amplifier and connect the power cord to an appropriate electrical receptacle.
5. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P59 Helmholtz Coils.DS	(See end of activity)	(See end of activity)

- The *DataStudio* document opens with a Digits display of magnetic field strength and current and a Graph display of Field Strength vs. Position.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.
- The Signal Generator is set to output DC at 10.0 V. It is set to Auto so it will start and stop automatically when start and stop measuring data.

PART II: Sensor Calibration & Equipment Setup

- You do not need to calibrate the Magnetic Field Sensor or the Power Amplifier. The Magnetic Field Sensor produces a voltage that is directly proportional to the magnetic field strength as follows: 10 millvolts = 10 gauss (where 1000 gauss = 0.1 tesla). The sensor's range is ±2000 gauss.
- Note: Depending on the strength of the magnetic field around the coils, you may want to increase the sensitivity of the Magnetic Field Sensor.

Range Select switch: Use this switch to select one of the three input ranges for the sensor. The ranges are as follows:

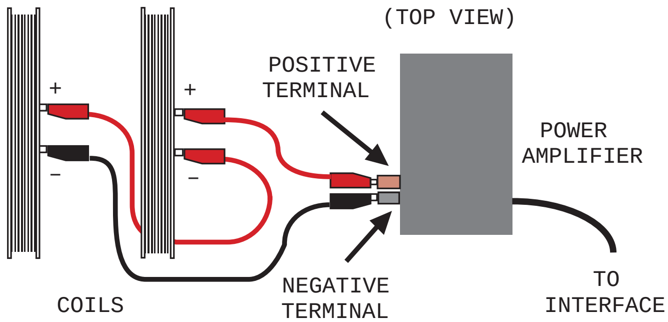
Gain	Range	Resolution	Accuracy
1X	±1000 gauss	0.5 gauss	100 gauss
10X	±100 gauss	0.05 gauss	10 gauss
100X	±10 gauss	0.005 gauss	1 gauss

- For this activity, begin with the Range Select switch on the 1X setting.

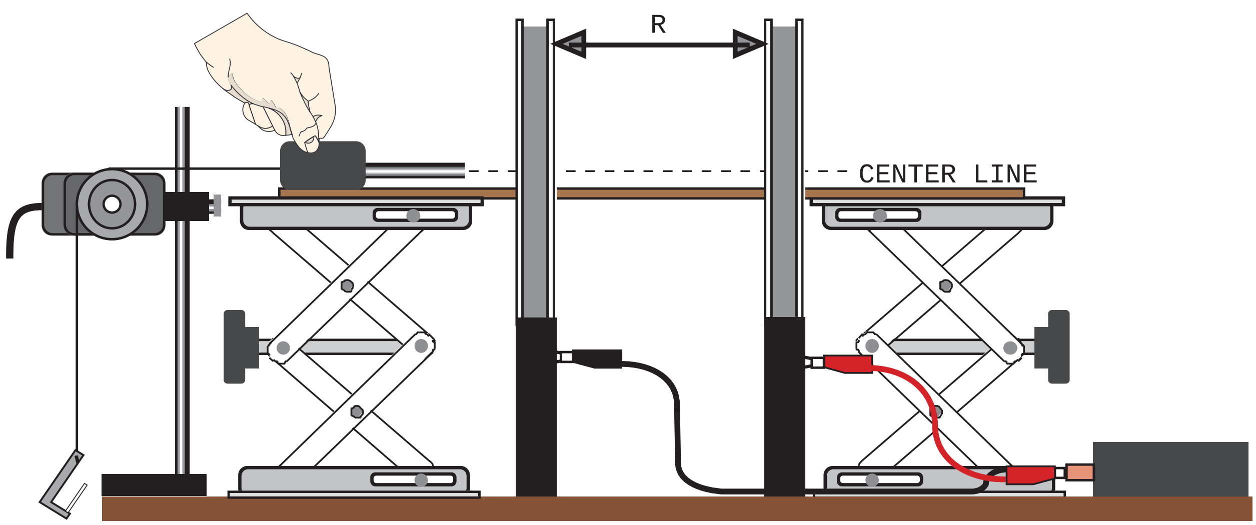
Name ____________________ Class ______________ Date _________

Equipment Setup

1. Connect the Helmholtz coils in series with the output from the Power Amplifier. Use one patch cord to connect the positive terminal of the Power Amplifier to the positive terminal on the first coil. Use a second patch cord to connect the negative terminal on the first coil to the positive terminal on the second coil. Use the third patch cord to connect the negative terminal on the second coil to the negative terminal on the Power Amplifier.

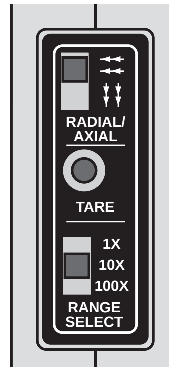


2. Measure the radius of a coil. Record the radius in the Data section. Position the two coils so they are one radius, R, apart and parallel to each other.
3. Construct a ‘track’ for the Magnetic Field Sensor in the following way: Place a laboratory jack on each side of the Helmholtz coils to support the meter stick. Place the meter stick through the Helmholtz coils as shown with the 50-cm mark of the meter stick at the midpoint between the coils.
4. Adjust the <u>position</u> of the laboratory jacks so they are at least 30 cm from the center of the coils.
5. Adjust the <u>height</u> of the laboratory jacks so the Magnetic Field Sensor can move along the center line (vertically) of the two coils when it rests on the meter stick. Make sure the meter stick is level.



6. Remove the ‘O’ ring from the three-step pulley on the Rotary Motion Sensor. Mount the Rotary Motion Sensor on a support rod near the Magnetic Field Sensor.
7. Attach one end of a string to the Magnetic Field Sensor and place the string on the pulley of the Rotary Motion Sensor. Attach a mass hanger to the other end of the string so the string stays on the pulley of the sensor.

PART III: Data Recording



1. Hold the Magnetic Field Sensor away from any magnetic field sources. Zero the sensor by clicking the TARE button on the top of the sensor bos.
2. Select the AXIAL field by clicking the AXIAL/RADIAL SELECT SWITCH on the top of the Magnetic Field Sensor.
3. Place the sensor box on top of the meter stick with the end of the sensor rod aligned with the 30-cm mark, facing toward the coils. Hold the sensor in place.
4. Turn on the power switch on the back of the Power Amplifier.

- Note: The red light-emitting diode (LED) on the front of the Power Amplifier may light up. This indicates that the Power Amplifier is providing maximum current.

5. Start measuring data. (Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*.)
6. Record the value shown in the Digits display for **Current** in the Data section.
7. Slowly and steadily move the Magnetic Field Sensor along the meter stick from the 30-cm mark to the 70-cm mark.

- Observe the field strength in the Digits display.

8. Stop measuring data when you reach the 70-cm mark.
9. Turn off the Power Amplifier.

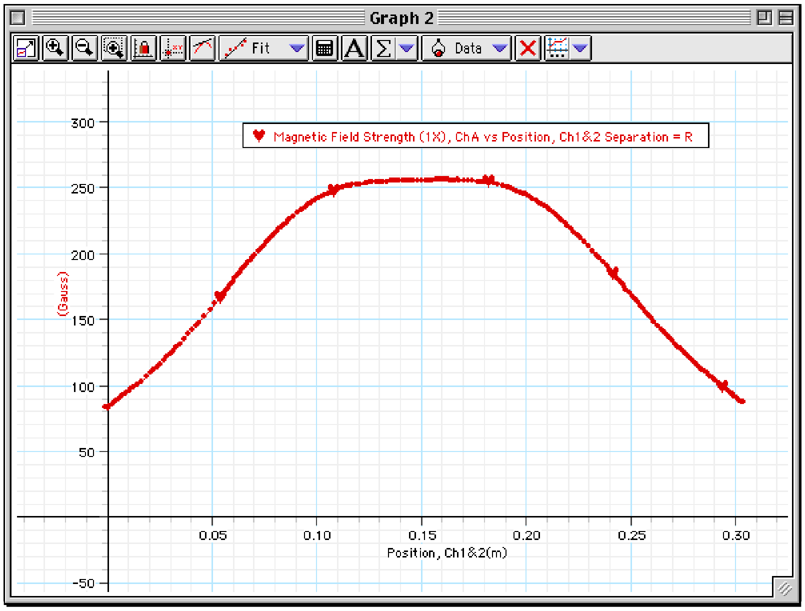
Optional

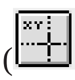
- Hold the Magnetic Field Sensor in your hand. Click MON to monitor data. Use the sensor to explore the entire volume between the two coils. Pay attention to how much variation there is in the field as the sensor is moved away from the center.
- If it is possible to change the separation between the coils, repeat the data measurement with the coils separated by 1.5 R instead of R. Change the separation again to 0.5 R and repeat the data measurement.

Name ____________________ Class _____________ Date _________

Analyzing the Data

1. Use the Graph display's built-in analysis tools to find the magnetic field strength midway between the coils.



- Hint: Use the 'Smart Tool' in *DataStudio* or the 'Smart Cursor' () in *ScienceWorkshop*.
- Record the magnetic field strength (Y-coordinate) for the midpoint between the coils.

2. Record the number of turns in one of the coils.
3. Calculate the theoretical value of the magnetic field at the midpoint between the Helmholtz coils using the measured current, radius, and number of turns for the coil.
4. Compare the theoretical value to the measured value at the midpoint using a percent difference.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P59: Magnetic Field of Helmholtz Coils

What do you think?

The purpose of this activity is to examine the magnetic field produced by the current in a pair of Helmholtz coils, and to measure the magnetic field strength between the coils and compare the measured value to the theoretical value. How does the strength of the magnetic field between the coils relate to the distance of separation between the Helmholtz coils?

Data

Item	Value
Radius of coil	
Number of turn	
Current	
Measured field strength	
Theoretical field strength	
Percent difference	

Questions

1. Based on your graph, over what distance along the axis can the magnetic field be considered a constant?

2. How did the measured value of magnetic field strength compare to the theoretical value? What factors may have caused the difference, if any?

Optional Questions

1. How uniform is the magnetic field between the coils as the sensor was moved radially outward from the center toward the windings of the coils?

2. If a different separation of the coils was used, how did that affect the answers to the first two questions?

Name ____________________ Class ______________ Date _________

Modify an existing *ScienceWorkshop* file.

Open the *ScienceWorkshop* File

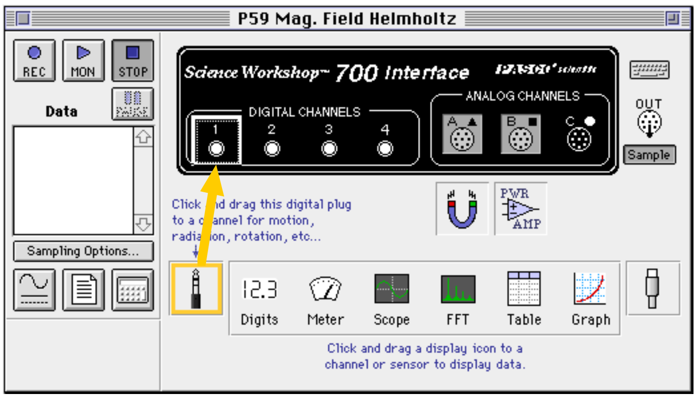
Open the file titled as shown:

ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P53 Mag. Field Helmholtz	P53_HELM.SWS

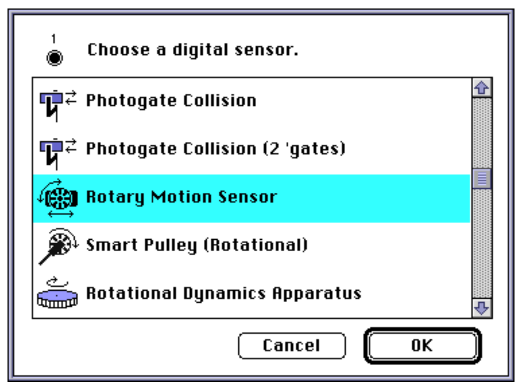
This activity uses the Rotary Motion Sensor to measure the position of the Magnetic Field Sensor as you move the Magnetic Field Sensor through the Helmholtz coils.

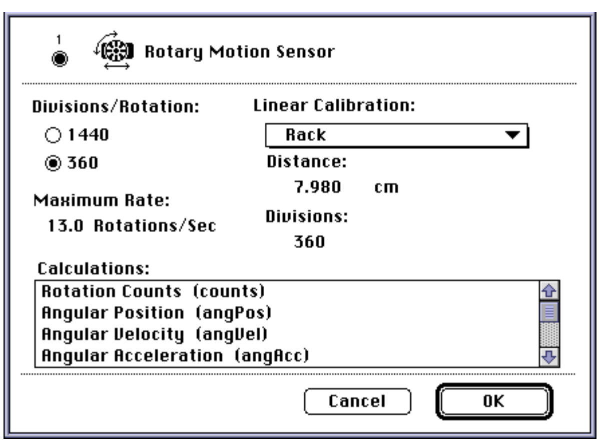
- Add the Rotary Motion Sensor to the Experiment Setup.
- Modify the Sampling Options.
- Change the Graph display to include 'Position' from the Rotary Motion Sensor.

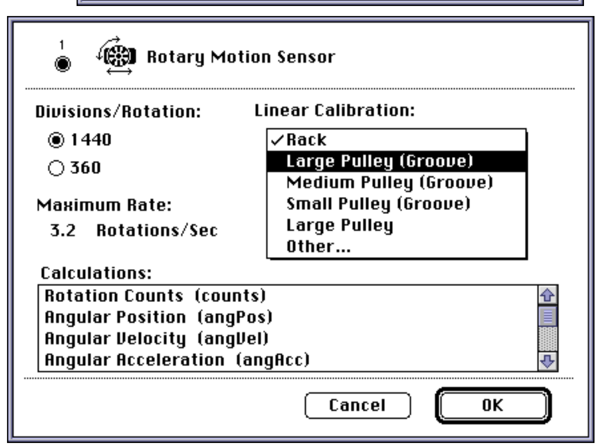
1. Click and drag the Digital Sensor Icon plug to Channel 1.

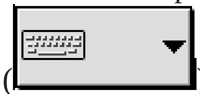


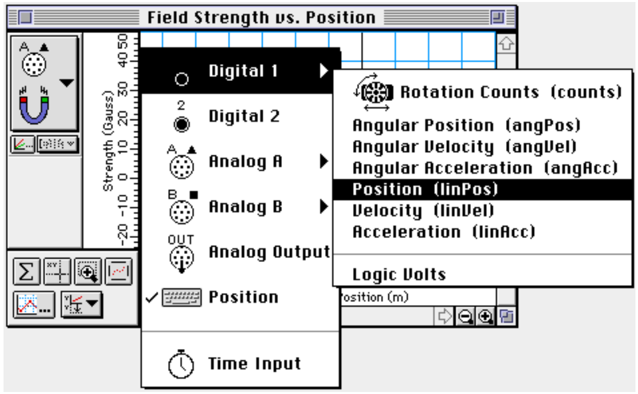
2. Select 'Rotary Motion Sensor' from the list of digital sensors.
3. In the Experiment Setup window, double-click on the Rotary Motion Sensor icon to open the Sensor Setup window.
4. Change the **Divisions/Rotation** from 360 to 1440. Click the **Linear Calibration** menu and select Large Pulley (Groove) from the menu. Click **OK** to return to the Experiment Setup window.







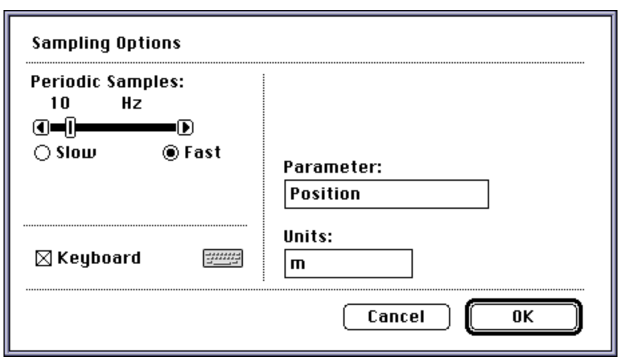
5. Click the Graph to make it active. Click the **Horizontal Axis Input Menu** button (). Select **Digital 1, Position (linPos)** from the Input Menu.

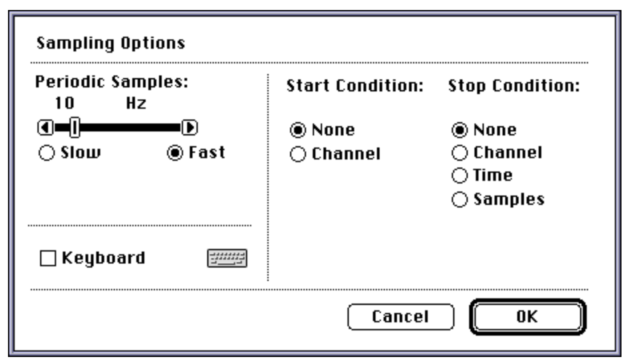


- The Graph will display Strength (gauss) along the vertical axis, and Position (m) along the horizontal axis.

6. Finally, change the Sampling Options so that the Keyboard Sampling window does not open when you start measuring data.

- Click the **Experiment** menu. Select **Sampling Options…** from the menu to open the **Sampling Options** window.
- The Sampling Options window shows that Keyboard is selected, and that the Parameter is Position and the Units are m.
- Click the check box in front of **Keyboard** to turn Keyboard Sampling off.





- Click **OK** to return to the Experiment Setup window.

7. Follow the procedure for measuring data as described before. Position the sensor on the meter stick as before. To collect data, click 'REC'. Begin moving the sensor slowly and steadily through the coils, stopping at the same end position as before. Click 'STOP' to stop collecting data.

Name ____________________ Class _____________ Date _________

Activity P60: Inverse Square Law – Nuclear (Nuclear Sensor, Rotary Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Radioactivity	P60 Nuclear Inv Sqr Law.DS	P60 Inverse Square	P60_INV2.SWS

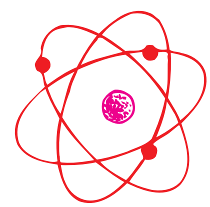
Equipment Needed	Qty	Equipment Needed	Qty
Nuclear Sensor (SN-7997)	1	Clamp, Three-finger (SE-9445)	1
Rotary Motion Sensor (CI-6538)	1	Linear Motion Accessory (CI-6688)	1
Base and Support Rod (ME-9355)	2	Radiation sources (SN-8110)	1 set
Clamp, Right angle (SE-9444)	1	Tape	1 roll

What Do You Think?

What is the relationship between the distance to a radioactive source and the measured activity from the source?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

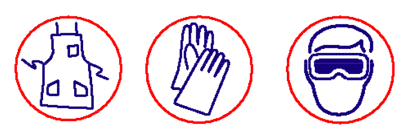
Background



One of the most common natural laws is the inverse square law. As one famous scientist put it, "the inverse square law is characteristic of anything which starts out from a point source and travels in straight lines without getting lost." Light and sound intensity both behave according to an inverse square law when they spread out from a point source. Your intuition says that as you move away from a point source of light like a light bulb, the light intensity becomes smaller as the distance from the bulb becomes larger. The same is true for sound intensity as you move away from a small radio speaker. What may not be as obvious is that if you move **twice** as far from either of these sources, the intensity becomes **one fourth** as great, not half as great. In a similar way, if you are at the back of an auditorium listening to music and you decide to move **three** times closer, the sound intensity becomes **nine** times greater. This is why the law is called the **inverse square** law.

Nuclear radiation behaves this way as well. If you measure the counts per second at a distance of 1 centimeter, the counts per second at 2 centimeters or at 4 centimeters should vary inversely as the square of the distance.

SAFETY REMINDERS



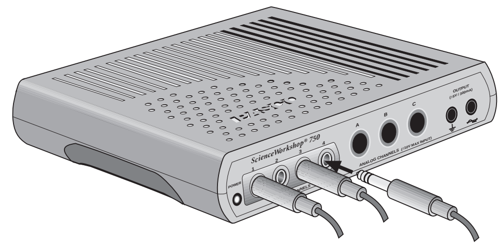
- Wear protective gear.
- Follow directions for using the equipment.
- Handle the radioactive sources properly.

For You To Do

Mount the radioactive source on the linear motion accessory of the Rotary Motion Sensor. Use the Nuclear Sensor to measure the radiation counts per time interval as you slowly move the radioactive source away from the sensor. Use the Rotary Motion Sensor to measure the position of the source relative to its starting position.

Use *DataStudio* or *ScienceWorkshop* to record and display the counts of radiation per interval of time, and the linear position of the source. Use the built-in data analysis tools to determine the mathematical formula that best fits the data in a plot of counts of radiation versus position.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Nuclear Sensor phone plug into Digital Channel 1 on the interface.
3. Connect the Rotary Motion Sensor stereo phone plugs into Digital Channels 3 and 4. Connect the plug with the yellow tape into Digital Channel 3.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P60 Nuclear Inv Sqr Law.DS	P60 Inverse Square	P60_INV2.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document opens with a Table display of Counts per Time Period. The Statistics area is open at the bottom of the Table.
- Data recording is set at one measurement per 2 seconds. In other words, each time period for the Nuclear Sensor is 2 seconds.

PART II: Sensor Calibration and Equipment Setup

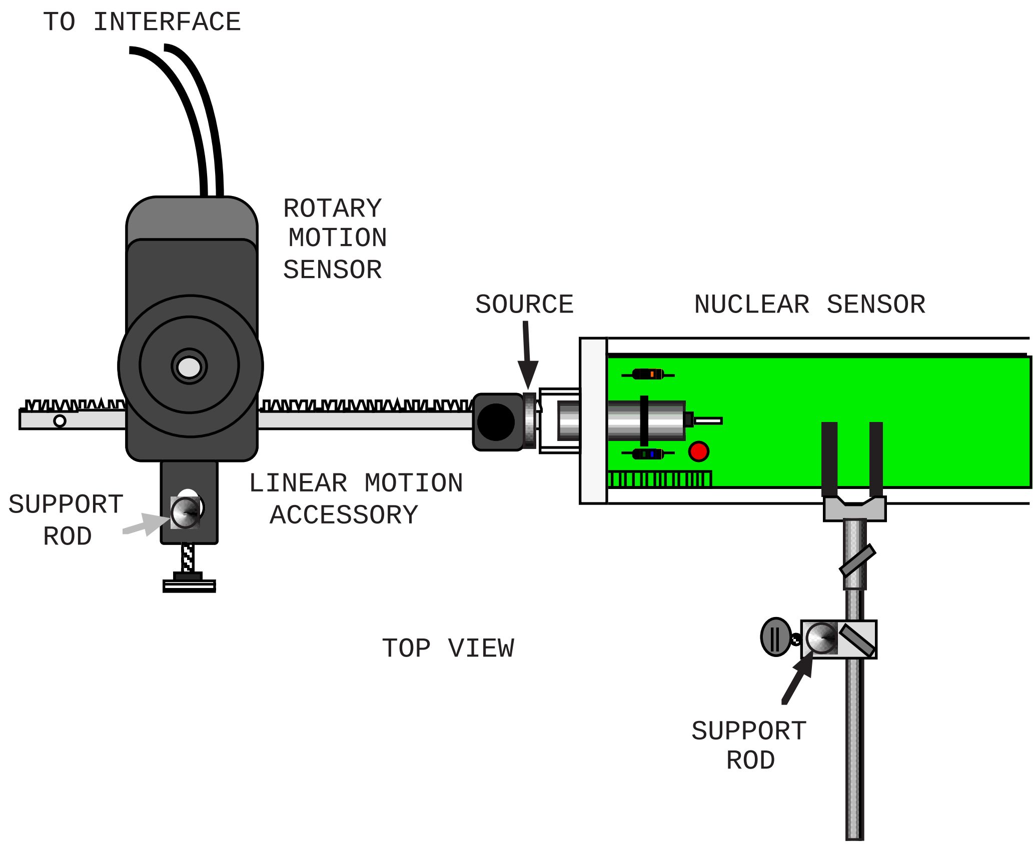
- You do not need to calibrate the Nuclear Sensor or the Rotary Motion Sensor.

1. Carefully remove the plastic protective cap from the end of the Nuclear Sensor. Use a base and support rod and clamps to mount the Nuclear Sensor so it is horizontal a few centimeters above the tabletop.
2. Use tape to mount an active beta source on the clamp at the end of the linear motion accessory.

- NOTE: Be very careful when handling any radioactive source as it may be harmful to your health. Avoid long-term exposure and always make sure that you wash your hands after handling any radioactive source.

3. Put the linear motion accessory into the slot on the Rotary Motion Sensor (RMS).
4. Use a base and support rod to mount the RMS so the linear motion accessory is horizontal and the radioactive source is at the same height as the end of the Nuclear Sensor.
5. Position the linear motion accessory so the source is as close to the end of the Nuclear Sensor as possible.

Name ____________________ Class _____________ Date _________



PART III: Data Recording

1. Move the Digits display so you can see it. Start measuring data. Watch the counts in the Digits display.
2. When the first counts are visible in the Digits display, begin to move the radioactive source away from the Nuclear Sensor VERY SLOWLY.

- The Nuclear Sensor records radiation counts for an interval of 2 seconds. Try to move the linear motion accessory in such a way that the source moves less than one centimeter per two seconds.

3. When the counts in the Digits display stop changing by more than one or two counts per interval, stop collecting data.

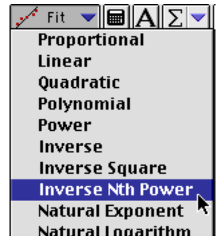
Optional

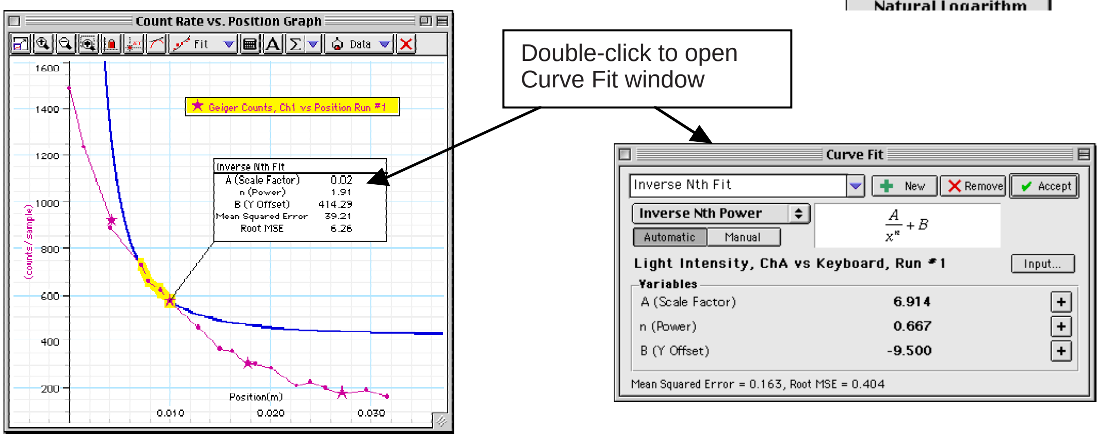
- If possible, repeat the procedure using an alpha source and then repeat the procedure using a gamma source.

Analyzing the Data

Use the Graph display's built-in analysis tools to fit your data to a mathematical formula.

- In *DataStudio*, click the 'Fit' menu button (). 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.





- Note: To see the mathematical formula and its parameters, double-click the curve fit text box in the Graph.

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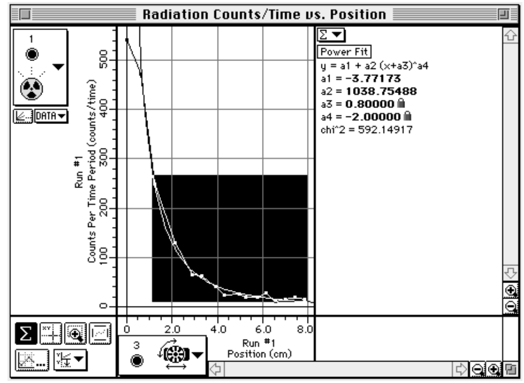
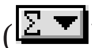
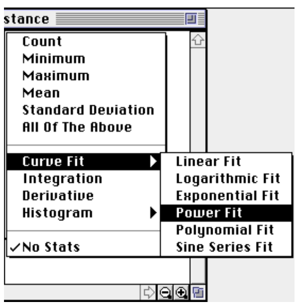
- In *ScienceWorkshop* click the 'Statistics' button to open the Statistics area on the right side of the Graph. Click the 'Autoscale' button to automatically rescale the Graph to fit the data.



- 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 raised to a power.

- 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. 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. You may need to enter values for the other parameters. For example, try a small number such as **1.0000** or **0.9000** for the value of the **a3** coefficient.

- 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.

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Lab Report - Activity P60: Inverse Square Law – Nuclear

What Do You Think?

What is the relationship between the distance to a radioactive source and the measured activity from the source?

Questions

1. Does nuclear radiation follow the inverse square law? Justify your answer.

2. What first action would be important to protect yourself from the radiation released from a broken container of radioactive material?

Optional Questions

1. Does alpha and gamma radiation have the same relationship to distance from the source as beta radiation?

2. How would the risk of exposure to radioactive substances be different if nuclear radiation followed an inverse cube law?